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Quinn, Jarus W.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The meeting dealt with the development and application of sources of coherent radiation from the extreme ultraviolet to the x-ray spectral region. Closely related areas of interest are multiphoton phenomena, soft x-ray optics, and laser produced plasmas. Topics covered included: short-wavelength lasers, free electron lasers and undulators, harmonic generation and frequency conversion, short wavelength optics and novel instrumentation, laser plasma radiation sources, multiphoton phenomena, ultrafast short-wavelength sources, applications in spectroscopy, microscopy, and microfabrication, phase coherent applications: holography and interferometry, and unique applications of short-wavelength sources.

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1988 SHORT WAVELENGTH
REGISTRATION LIST

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WAMPLER	FRED B	LOS ALAMOS NATL LAB		LOS ALAMOS, NM	87545	USA
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1988 SHORT WAVELENGTH
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TOTAL REGISTRATION = 165

SHORT WAVELENGTH COHERENT RADIATION: GENERATION AND APPLICATIONS

CONFERENCE EDITION

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Topical Meeting

September 26–29, 1988

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6:00 PM-9:00 PM REGISTRATION/RECEPTION

MONDAY, SEPTEMBER 26, 1988

NAUSET LOBBY

7:30 AM-5:15 PM REGISTRATION/SPEAKER CHECKIN

NAUSET III

8:15 AM-8:30 AM
OPENING REMARKS
R. W. Falcone, J. Kirz, *Meeting Cochairs*

8:30 AM-10:00 AM
MA, SESSION 1
Herschel S. Pilloff, *Office of Naval Research, Presider*

8:30 AM (Invited Paper)
MA1 The A. C. Stark Effect at Extremely High Intensities, R. R. Freeman, *AT&T Bell Laboratories.* Investigations of the A. C. Stark effect up to 10^{14} W/cm^2 in excited states of xenon demonstrate the role of ponderomotive forces on free electrons. (p. 2)

9:00 AM (Invited Paper)
MA2 Progress Toward a 44-Å X-Ray Laser, B. J. MacGowan, *Lawrence Berkeley Laboratory;* J. L. Bourgade, P. Combis, M.-Louis-Jacquet, D. Naccache, G. Thiell, *Centre de 'Etudes Limeil-Valenton, France;* C. J. Keane, Richard A. London, D. L. Matthews, S. Maxon, M. D. Rosen, D. A. Whelan, *Lawrence Livermore National Laboratory.* Since 1984 when soft x-ray amplification was convincingly demonstrated at XUV wavelengths near 200 Å, much effort has gone into obtaining soft x-ray gain at shorter wavelengths. One motivation is the possibility of using a high brightness source of amplified spontaneous emission to perform holography of live biological specimens over short time scales. (p. 3)

MONDAY, SEPTEMBER 26, 1988—*Continued*

9:30 AM (Invited Paper)
MA3 X-Ray Microscopy for the Life and Physical Sciences, D. T. Attwood, Y. Vladimirsky, S. Rothman, *Lawrence Berkeley Laboratory;* J. Kirz, N. Iskander, H. Ade, *SUNY-Stony Brook;* D. Kern, T. H. P. Chang, *IBM T. J. Watson Research Center;* W. Meyer-Ilse, P. Guttmann, *U. Gottingen, F.R. Germany;* H. Rarback, *Brookhaven National Laboratory.* Soft x-ray images of objects as diverse as unaltered biological components and microelectronic circuit patterns have been obtained with spatial resolution approaching 500 Å. (p. 5)

NAUSET LOBBY

10:00 AM-10:30 AM COFFEE BREAK

NAUSET III

10:30 AM-12:30 PM
MB, SESSION 2
Boris Stoicheff, *University of Toronto, Canada, Presider*

10:30 AM (Invited Paper)
MB1 Laser Spectroscopy of Autoionizing States, J. W. Hepburn, *U. Waterloo, Canada.* A molecular beam photoelectron spectrometer using coherent VUV generated by four-wave sum mixing has been used to study autoionization in NO and HI. (p. 8)

11:00 AM (Invited Paper)
MB2 Time-Resolved Study of Surface Recombination at Si(111) Surfaces, N. J. Halas, J. Bokor, *AT&T Bell Laboratories.* Picosecond time-resolved photoemission spectroscopy has been used to gain a complete picture of the microscopic surface dynamics which give rise to surface recombination. (p. 9)

11:30 AM (Invited Paper)
MB3 Recent Advances and Prospects of Bragg-Fresnel Optics, V. V. Aristov, *Institute of Microelectronics and Materials, USSR.* The paper considers the properties and applications of Bragg-Fresnel optics elements based on perfect single crystals and multilayer mirrors in the wavelength range 0.1-100 Å. (p. 11)

12:00 M (Invited Paper)
MB4 X-Ray Standing Waves: Achievements and Prospects, J. A. Golovchenko, *Harvard U.* X-ray standing wave optical methods have been developed and used in recent years in a number of challenging problems requiring atomic scale information from a relatively small number of atoms. We review some of the important advances and suggest areas where these x-ray interferometric methods may be expected to yield new insights into the atomic scale structure of matter. (p. 12)

12:30 PM-2:00 PM LUNCH BREAK

NAUSET III

2:00 PM–3:45 PM
MC, SESSION 3
Ryszard G..je..ski, *U.S. Department of Energy, Presider*

2:00 PM (Invited Paper)
MC1 Strong Field Processes in the Ultraviolet Region, K. Boyer, G. Gibson, H. Jara, T. S. Luk, I. A. McIntyre, A. McPherson, R. Rosman, C. K. Rhodes, *U. Illinois at Chicago;* J. C. Solem, *Los Alamos National Laboratory.* Research on strong field processes relevant x-ray laser development is discussed. (p. 14)

2:30 PM (Invited Paper)
MC2 Observation of Extreme Ultraviolet Amplification in 3—2 (42—46 Å), 4—3 (130.5 Å), and 5—4 (305 Å) Transitions in Laser-Produced Heliumlike Al Plasma, H. Kuroda, K. Muroo, K. Naito, Y. Tanaka, *U. Tokyo, Japan.* Enhancement of extreme ultraviolet radiation (42.4 Å) due to the stimulated emission process, emitted from heliumlike Al laser plasma, is observed by spectroscopic and line-focus measurements. (p. 15)

3:00 PM (Invited Paper)
MC3 96.9-nm Saturated Laser in Neutral Cesium, C. P. J. Barty, D. A. King, G. Y. Yin, K. H. Hahn, J. E. Field, J. F. Young, S. E. Harris, *Stanford U.* We report fully saturated laser action at 96.9 nm in cesium vapor. We believe this is the first laser in which the upper laser level is embedded in the continuum of the valence electron. (p. 17)

3:30 PM
MC4 X-Ray Laser Experiment with a Double-Pass Device and a Long Recombining-Plasma Column, P. Jaegle, A. Carillon, P. Dhez, B. Gauthe, F. Gadi, G. Jamelot, A. Klisnick, *U. Paris XI, France.* We present observations of a large experimental increase of intensity and directivity at 105.7 Å using a 60-mm long recombining-plasma column and a double-pass device with a spherical multilayered mirror. (p. 23)

NAUSET LOBBY

3:45 PM–4:15 PM COFFEE BREAK

MONDAY, SEPTEMBER 26, 1988—*Continued*

NAUSET III

4:15 PM–5:15 PM
MD, SESSION 4
Thomas J. McIlrath, *University of Maryland, Presider*

4:15 PM (Invited Paper)
MD1 Interaction of Intense Ultrashort Pulses with Gases, P. B. Corkum, N. H. Burnett, *National Research Council, Canada.* For high intensity linearly polarized light, above threshold ionization results from the time difference between ionization and the electric field maximum. Cold plasmas for XUV recombination lasers can be produced. (p. 26)

4:45 PM
MD2 Charge-Displacement Self-Channeling as a Method for Energy Concentration, K. Boyer, T. S. Luk, C. K. Rhodes, *U. Illinois at Chicago;* J. C. Solem, *Los Alamos National Laboratory.* A new mode of self-channeled propagation of high intensity radiation in highly ionized plasmas is described. (p. 28)

5:00 PM
MD3 Observation of the High Intensity Kapitza-Dirac Effect, D. W. Schumacher, M. Bashkansky, P. H. Bucksbaum, *AT&T Bell Laboratories.* Electrons have been scattered from an intense optical standing wave (the Kapitza-Dirac effect), producing momentum transfers of up to $\Delta p \approx 1000\hbar k$ at laser intensities of 10^{13} to 10^{14} W/cm^2. (p. 29)

TUESDAY, SEPTEMBER 27, 1988

NAUSET LOBBY

8:00 A* 12:00 M REGISTRATION/SPEAKER CHECKIN

NAUSET III

8:30 AM–10:00 AM
TuA, SESSION 5
Howard Schlossberg, *U.S. Air Force Office of Scientific Research, Presider*

8:30 AM (Invited Paper)
TuA1 Short Wavelength Lasers: Something Old, Something New, Peter L. Hagelstein, *Massachusetts Institute of Technology.* The first half of this presentation reviews theory and computation for short wavelength laser research as requested by the conference organizing committee. The second half reviews recent calculations and thoughts pertaining to collisional excitation lasers at modest pump laser intensities, and studies of whisper gallery mirrors. (p. 32)

9:00 AM (Invited Paper)
TuA2 Recent X-Ray Laser Related Experiments at Princeton, S. Suckewer, *Princeton U.* A short review of recent experiments with the soft x-ray laser, its use in microscopy, and the status of a system with the picosecond laser are presented. (p. 33)

9:30 AM (Invited Paper)
TuA3 Amplification of Na XI H_α, Mg XII H_α and Al XIII H_α Transitions, Y. Kato, M. Yamanaka, H. Daido, T. Tachi, H. Nishimura, H. Shiraga, E. Miura, P. R. Herman, H. Takabe, T. Jitsuno, M. Takagi, S. Nakai, C. Yamanaka, *Osaka U., Japan;* M. H. Key, G. Tallents, S. J. Rose, P. T. Rumsby, *Rutherford Appleton Laboratory, U.K.* Stripe, foil, and fiber targets were irradiated with high intensity line-focused laser light of 351-nm wavelength. Gain measurements of Na XI H_α at 54.19 Å, Mg XII H_α at 45.53 Å, and Al XIII H_α at 38.79 Å are reported. (p. 34)

NAUSET LOBBY

10:00 AM–10:30 AM COFFEE BREAK

TUESDAY, SEPTEMBER 27, 1988—*Continued*

NAUSET III

10:30 AM–12:00 M
TuB, SESSION 6
Jerry B. Hastings, *Brookhaven National Laboratory, Presider*

10:30 AM (Invited Paper)
TuB1 Coherent Nuclear Excitations in Crystals by Synchrotron Radiation Pulses, G. T. Trammell, *Rice U.* I discuss the theory of the super- and subradiant states excited in the crystal by the synchrotron pulses, the coherent increase and decrease of radiation widths, and the speeding up and slowing down of the decay rates of the coherently excited crystal. I also discuss the theory of the quantum beats observed. (p. 38)

11:00 AM (Invited Paper)
TuB2 Synchrotron Studies of Nuclear Bragg Scattering (tentative title), R. Ruffer, *U. Hamburg, F.R. Germany.* (p. 39)

11:30 AM (Invited Paper)
TuB3 Production of Long Coherence-Length Hard X Rays Using Nuclear Bragg Scattering of Synchrotron Radiation, D. P. Siddons, *Brookhaven National Laboratory.* Filtration of a synchrotron x-ray beam by scattering from nuclear Mossbauer resonance can produce beams with coherence lengths of several meters. The filtration techniques and potential uses are discussed. (p. 40)

12:00 M–8:00 PM AFTERNOON FREE

NOBSKA ROOM

8:00 PM–10:00 PM
TuC, SESSION 7: POSTER SESSION

TuC1 Collisionless X-Ray Generation from Picosecond Laser-Gas Interaction, P. H. Y. Lee, D. E. Casperson, G. T. Schappert, *Los Alamos National Laboratory.* Photon-counting experiments have been conducted to examine the conjecture of atomic inner-snell excitation by laser-driven coherent outer-shell oscillation. Results are presented. (p. 42)

TuC2 Population Inversion due to Charge Exchange Processes in Plasmas, Takako Kato, Kuniaki Masai, *Nagoya U., Japan;* Takashi Fujimoti, *Kyoto U., Japan.* Charge exchange processes associated with population inversion are studied for x-ray spectra from tokamaks with a collisional radiative model. (p. 44)

TuC3 Photoionization-Pumped Laser Geometry, M. H. Sher, S. J. Benerofe, J. F. Young, S. E. Harris, *Stanford U.* We discuss simple geometric scaling laws and their implications for improved efficiency and beam quality of laser-produced plasma pumped photoionization lasers. (p. 46)

TuC4 Amplification and Gain Measurement of Extreme Ultraviolet Radiation (42.4 Å), (45 Å), and (46 Å) in Heliumlike Al Laser Plasma, K. Muroo, Y. Tanaka, H. Kuroda, *U. Tokyo, Japan.* Gain coefficients of extreme ultraviolet amplification due to the stimulated emission of heliumlike Al 3—2 transitions (42.4 Å—46 Å) are estimated by a line-focused laser plasma experiment. (p. 47)

TuC5 Population Inversions Between n = 5, 4, 3, and 2 Levels of Heliumlike Al Plasma Observed by Spatially Resolved X-Ray Spectroscopy, H. Kuroda, M. Katsuragawa, K. Muroo, Y. Tanaka, *U. Tokyo, Japan.* Population inversions between n = 5, 4, and 3 excited levels are observed in a 100-ps laser-produced heliumlike Al plasma. Inversion between n = 3 and 2 was not confirmed. (p. 49)

TuC6 Multiple Harmonic Conversion of 1064-nm Radiation in Rare Gases, M. Ferray, A. L'Huillier, X. F. Li, L. A. Lompre, G. Mainfray, C. Manus, *Centre d'Etudes Nucleaires de Saclay, France.* Very high order harmonics of 1064-nm laser radiation are observed in Xe, Kr, Ar at 3×10^{13} W=cm^{-2}. The production rate decreases slowly with the order beyond 7. (p. 51)

TuC7 Probability of Soft X-Ray Radiation for the 3*p*—3*s* Transition in Neonlike Iron, Huimin Peng, Guoping Zhang, Jiatian Sheng, Yunfeng Shao, Yinchun Zhang, *Institute of Applied Physics & Computational Mathematics, China.* A laser-produced plasma condition is simulated using a non-LTE radiative hydrodynamic code. The values of population inversion and gain are calculated using steady rate equations. The probability for the 3*p*—3*s* transition in neonlike iron is shown. (p. 53)

TuC8 Harmonic Generation in Laser Free-Electron Scattering Reconsidered, Anna K. Puntajer, C.Leubner, *U. Innsbruck, Austria.* Conflicting published results are show to be partly incorrect by comparison with the exact classical cross section, of which a new measurable asymmetry is established and explained. (p. 54)

TuC9 Gain Guided X-Ray Beams, Ernst E. Fill, *Max Planck Institute for Quantum Optics, F.R. Germany.* It is shown that, with gain and index profiles of typical x-ray laser experiments, gain guiding dominates the weak defocusing effect caused by the index profile. (p. 55)

TuC10 CO_2 Laser Heated Plasmas for Collisionally Pumped [illegible] Laser Studies, G. D. Enright, N. H. Burnett, *National Research Council of Canada.* A kilojoule 10-μm ns laser pulse [illegible]ed to characterize plasmas produced by 10^{13} W cm^{-2} irradiation of thin foil targets with a line focus. (p. 57)

TuC11 Reflectance of Aluminum Reflectors in the Extreme Ultraviolet, Marion L. Scott, *Los Alamos National Laboratory.* The reflectance of an unoxidized aluminum film has been measured in the extreme ultraviolet wavelength range. This reflector could provide excellent retroreflectance over a wide XUV wavelength range. (p. 59)

TuC12 X-Ray Laser Gain Optimization and Spectroscopy Experiments in Plasmas Produced by 2ω and 3ω Laser Light, C. Keane, Richard A. London, D. L. Matthews, M. Rosen, *Lawrence Livermore National Laboratory;* J. L. Bourgade, P. Combis, M. Louis-Jacquet, D. Naccache, O. Peyrusse, G. Thiell, *Centre d'Etudes de Limeil Valenton, France;* B. J. MacGowan, *Lawrence Berkeley Laboratory.* We report results of recent spectroscopy and gain optimization experiments in the neonlike ions of Ge, Se, Sr, Mo, and Ag. Gain coefficients up to 5 cm^{-1} have been measured. (p. 61)

TuC13 Capillary Discharge Plasmas as Extreme Ultraviolet Laser Sources, J. J. Rocca, M. C. Marconi, D. Beethe, M. Villagran Muniz, *Colorado State U.* The possibility of XUV recombination laser action in plasmas from fast capillary discharges is analyzed. Capillary plasma XUV spectra and model calculations are discussed. (p. 63)

TuC14 High Power Short Pulse Ultraviolet Laser for the Development of a New X-Ray Laser, L. Meixler, C. H. Nam, J. Robinson, W. Tighe, K. Krushelnick, S. Suckewer, *Princeton U.;* J. Goldhar, *U. Maryland.* Experiments using a powerful picosecond laser system (at 248 nm) to examine prepulse effects are presented. A final KrF* amplifier has been introduced and is described. (p. 64)

TuC15 Measurement of the Quenching of Spontaneous Emission Coefficients in Laser-Produced Plasmas, Y. Chung, H. Hirose, S. Suckewer, *Princeton U.* The quenching of Einstein *A*-coefficients was observed by measuring the branching ratio of visible and VUV line intensities for C IV and C III ions. (p. 67)

TuC16 Contact Microscopy with a Soft X-Ray Laser, D. S. DiCicco, D. Kim, R. J. Rosser, C. H. Skinner, S. Suckewer, *Princeton U.;* A. P. Gupta, *Rutgers U.;* J. Hirschberg, *U. Miami.* A soft x-ray laser of output energy 1-3 mJ at 18.2 nm has been used to record high resolution contact images of biological specimens. (p. 69)

TuC17 Progress in Soft X-Ray Amplification at 154.7 Å and 129 Å in Lithiumlike Al XI and Si XII, D. Kim, C. H. Skinner, A. Wouters, E. Valeo, D. Voorhees, S. Suckewer, *Princeton U.* Gain length products of GL = 3-4 and GL = 1-2 have been observed in lithiumlike Al XI and Si XII, respectively, in a laser-produced magnetically confined recombining plasma. (p. 71)

TuC18 Calculation and Design of Nitrogenlike *W* Soft X-Ray Lasers, S. Maxon, S. Dalhed, B. MacGowan, Richard A. London, M. Rosen, *Lawrence Livermore National Laboratory;* P. Hagelstein, *Massachusetts Institute of Technology.* Calculations of *W* targets irradiated with 2-4 $\times$ 10^{14} W/cm^2 show gain on the leading 0—1 nitrogenlike transition at 43.11 Å. (p. 73)

TuC19 Characteristics of a Picosecond Laser Plasma, G. Gibson, R. Rosman, K. Boyer, H. Jara, T. S. Luk, I. A. McIntyre, A. McPherson, C. K. Rhodes, *U. Illinois at Chicago.* Vacuum ultraviolet spectra of highly ionized argon plasmas produced by high power subpicosecond laser irradiation are analyzed to determine the characteristics of the plasma. (p. 75)

TuC20 Quantum Mechanical Interference in Four-Wave Mixing, K. G. H. Baldwin, *Australian National U.* Constructive and destructive interference between two different quantum-mechanical pathways have been demonstrated in two-photon resonant four-wave mixing in sodium vapor. (p. 76)

TuC21 Soft X-Ray Lenses with 400-Å Outer Zone Width, V. Vladimirsky, D. T. Attwood, *Lawrence Berkeley Laboratory;* D. Kern, T. H. P. Chang, *IBM T. J. Watson Research Center;* W. Meyer-Ilse, P. Guttmann, B. Greinke, *U. Gottingen, F.R. Germany.* Fresnel zone plate lenses with outer zone widths of 400 Å have been fabricated and tested at soft x-ray wavelengths. Diffraction efficiency and spatial resolution are described. (p. 78)

TuC22 Soft X-Ray Spectroscopy of Laser-Produced Plasma, Shi-sheng Chen, Zhi-zhan Xu, Zheng-quan Zhang, *Shanghai Institute of Optics & Fine Mechanics, China.* We report recent progress in soft x-ray spectroscopy of laser-produced plasma measured by a transmission grating, grazing incidence spectrograph developed by our group. (p. 79)

TuC23 Transversely Optically Pumped S_2 Ultraviolet Laser in the 330–390-nm Range, Junhua Yu, Shangwen Sun, Chen Tang, Zuguang Ma, *Harbin Institute of Technology, China.* A series of six laser lines at 330–390 nm on the transition of $S_2(B^3\Sigma_u^- - X^3\Sigma_g^-)$ were first observed by transversely pumping with a XeCl laser (308.1 nm). (p. 80)

TuC24 Large Holographic Diffraction Gratings Made by a Multiple Exposure Technique, L. Wosinski, M. Breidne, *Institute of Optical Research, Sweden.* We present a technique that circumvents the limitations set by the mirrors and fabricate large holographic gratings, which thereafter are ion etched. Using the theory of M. Breidne and A. Roger, the profile of these gratings can be optimized. (p. 81)

TuC25 Spectra of Lead, Bismuth, Thorium, and Uranium Relevant to a Neodymiumlike Soft X-Ray Lasing Scheme, W. L. Hodge, *High Energy Laser Associates;* P. C. Filbert, D. A. Kohler, C. L. Navoda, J. D. Perez, *Lockheed Missile & Space Co.;* P. L. Hagelstein, *Massachusetts Institute of Technology;* S. Maxon, J. H. Scofield, *Lawrence Livermore National Laboratory;* J. M. Peek, *Los Alamos National Laboratory.* As a first step in the development of a neodymiumlike soft x-ray laser, survey spectra of high *Z* elements are presented. (p. 82)

TUESDAY, SEPTEMBER 27, 1988—*Continued*

TuC26 Soft X-Ray Lasing of Lithiumlike Ions in Laser-Produced Plasmas, Yim T. Lee, W. M. Howard, *Lawrence Livermore National Laboratory.* We discuss schemes which can be used to create population inversions in lithiumlike ions in a laser-produced plasma. These can give measurable gains for transitions in the sub 44 Å range. (p. 84)

TuC27 Time Development of Amplification of Na XI Hα-Line at 54.19 Å, H. Nishimura, H. Shirage, H. Daido, T. Tachi, P. R. Herman, E. Miura, H. Takabe, M. Yamanaka, Y. Kato, *Osaka U., Japan;* G. Tallents, M. H. Key, *Rutherford Appleton Laboratory, U.K.* Time development of the gain coefficient of the Na XI Hα transition at 54.19 Å is reported. (p. 86)

TuC28 Gain Measurement on a 18.2-nm Carbon Recombination Laser Produced by an Intense CO_2 Laser, H. Daido, E. Miura, Y. Kitagawa, K. Nishihara, Y. Kato, H. Nishimura, C. Yamanaka, S. Nakai, *Osaka U., Japan.* The properties of a cylindrical wall confined carbon recombination laser produced by a high power CO_2 laser are presented. A maximum gain length product of 2.4 was observed. (p. 88)

TuC29 Narrow Line X-Ray Transition Radiation in a Solid-State Superlattice: Material Selection, C. T. Law, A. E. Kaplan, *Johns Hopkins U.* We discuss the generation of narrow line-width radiation by selecting appropriate media constituting a superlattice. (p. 90)

TuC30 Effectiveness of Diffraction Gratings at Grazing Incidence as Harmonic Scrubbers, P. J. Wantuck, Q. D. Appert, *Los Alamos National Laboratory;* D. J. Pistoresi, K. Tong, *Boeing Aerospace Corp.* High power free-electron laser optical beams can contain substantial amounts of damaging UV and VUV harmonic wavelength components. We discuss the merits of using diffraction gratings at grazing incidence as harmonic scrubbers. (p. 91)

TuC31 VUV Amplification of Neonlike Titanium Ion, T. Hara, K. Ando, Y. Aoyagi, S. Namba, *Institute of Physical & Chemical Research, Japan;* H. Yashiro, T. Dote, *Saitama U., Japan.* Amplified spontaneous emission of *3s—3p* transition at 50.77 nm in neonlike titanium ion has been observed in a line-shaped plasma produced by a glass laser. (p. 92)

TuC32 Investigations of Multiphoton Excitation and Ionization in a Short Range Potential, Steven Cowley, Silvio Susskind, Ernest Valeo, *Princeton U.* Analytic and numerical results are presented for multiphoton excitation and ionization rates for a system containing a model confining potential consisting of a set of delta functions. (p. 94)

TuC33 Novel Grazing Incidence Optics for Synchrotron X-Ray Lithography, R. J. Rosser, P. M. J. H. Wormell, R. J. Speer, *Imperial College, U.K.;* M. Lampton, *UC-Berkeley.* We present the results of ray tracing, done at both IC and UCB, that show the saddle-toroid to be a satisfactory alternative to the scanning cylindrical mirror, while having similar manufacturing costs. Two-mirror designs are also considered, and show potential to improve on single mirrors in flux throughput and in having a horizontal beamline. (p. 95)

TuC34 X-Ray Lasers Research at Physics International, T. Nash, C. Deeney, J. Levine, M. Krishnan, *Physics International Co.* *Z*-pinch implosions onto coated targets and two separately controllable *Z*-pinches are being used to investigate recombination and photopumped x-ray laser schemes. (p. 96)

TuC35 Diffraction Contrast of the Bragg-Fresnel Lens in White and Monochromatic Radiation, V. V. Aristov, Yu. A. Basov, R. Frahm, W. Graeff, G. Materlik, A. A. Snigirev, *Institute of Microelectronics and Materials, USSR.* Studies have been made of imaging by a Bragg-Fresnel Lens (BEL) in the white and monochromatic spectrum of synchrotron radiation. A phase BEL has been experimentally realized. (p. 97)

TuC36 Fresnel Multilayer X-Ray Elements, V. V. Aristov, A. I. Erko, *Institute of Microelectronics and Materials, USSR.* A model of focusing elements for x-ray optics based on profiled multilayer reflection structures of x-ray optical elements exhibit the properties of volume holographic lattices. (p. 98)

TuC37 Fourier Transform Holographic Microscope, W. S. Haddad, D. Cullen, K. Boyer, C. K. Rhodes, J. C. Solem, *MCR Technology Corp.* A design for a Fourier transform holographic microscope to operate toward the lower end of the water window is presented. (p. 99)

TuC38 Amplified Spontaneous Emission and Superfluroescence in Hot Plasma X-Ray Lasers: a Possible Explanation for the Weak Lasing of the $(1/2,1/2)_0 \rightarrow (1/2,1/2)_1$ Lines, G. Hazak, A. Bar Shalom, D. Shvarts, L. A. Levin, *Nuclear Research Center, Israel.* The lasing process of $(1/2,1/2)_0 \rightarrow (1/2,1/2)_1$ lines in hot plasma x-ray laser experiments is studied. An explanation of the weak gain of these lines compared to theoretical predictions is suggested. (p. 100)

TuC39 Continuous Anti-Stokes Raman Laser Operation, A. Feitisch, B. Wellegchausen, *U. Hanover, F.R. Germany.* Investigations on cw anti-Stokes Raman laser schemes, allowing the conversion of infrared or visible laser radiation into the UV and VUV spectral range is reported. As active material argon ions, excited in a commercial argon ion laser are considered. Up to now, conversion of 648.3-nm radiation into 437.5-nm radiation has been achieved, with a conversion efficiency of more than 20% and a maximum output power of 150 mW. (p. 102)

TuC40 Proposed Method for the Measurement of the Spatial Coherence of Laboratory X-Ray Lasers, J. Trebes, T. Barbee, H. Nathel, A. Szoke, *Lawrence Livermore National Laboratory.* Measurement techniques for the determination of the spatial coherence of laboratory x-ray lasers are discussed. These techniques utilize the coherence dependent interference patterns from double slit and multiple slit arrays. The selenium x-ray laser with a wavelength of 208 Å used as an example. The x-ray optics necessary for this are discussed. Possible experiments on optical analog ASE sources such as dye laser amplifiers are also discussed. (p. 103)

WEDNESDAY, SEPTEMBER 28, 1988

NAUSET LOBBY

8:00 AM–5:00 PM REGISTRATION/SPEAKER CHECKIN

NAUSET III

8:30 AM–10:00 AM
WA, SESSION 8
Malcolm R. Howells, *Lawrence Berkeley Laboratory, Presider*

8:30 AM (Invited Paper)
WA1 Ultrahigh Peak Power Pulses Produced by Chirped Pulse Amplification, P. Maine, D. Strickland, B. Bado, G. Mourou, *U. Rochester.* Chirped pulse amplification allows the amplification of ultrashort pulses in solid-state media with very good energy storage capability such as Nd:glass, alexandrite, or Ti:sapphire. Pulses at the terawatt level have been produced with table top systems and pulses at the petawatt level will be produced on a large scale solid-state laser in the near future. (p. 106)

9:00 AM (Invited Paper)
WA2 Multiterawatt Excimer Laser System, S. Watanabe, A. Endoh, M. Watanabe, N. Sarukura, *U. Tokyo, Japan.* A subpicosecond multiterawatt excimer laser system has been developed. Peak powers were 1 TW in XeCl and 3-5 TW in KrF. Further improvement in KrF is anticipated. (p. 108)

9:30 AM
WA3 First Images from the Stanford Tabletop Scanning X-Ray Microscope, J. A. Trail, R. L. Byer, *Stanford U.* We present the first images taken with our tabletop scanning soft x-ray microscope. The microscope operates at a wavelength of 140 Å, uses a laser-produced plasma as the soft x-ray source, and uses normal incidence multilayer coated mirrors as the focusing optics. (p. 110)

9:45 AM
WA4 Progress in Optical Reconstruction of Submicron X-Ray Holograms, D. Joyeux, *Institute of Optics, France;* F. Polack, *U. Paris XI, France.* When reconstruction at low magnification is used (typically 2 or a few units), field and aperture aberrations need to be corrected when field and resolution are significant. A simple third-order correction, using a parallel face glass plate, allows working up to 0.5 N.A. over a 20 to 30 μm field. Experiments have been performed showing the efficiency of the method. We now investigate a higher order correction, to work at higher N.A. (p. 112)

NAUSET LOBBY

10:00 AM–10:30 AM COFFEE BREAK

NAUSET III

10:30 AM-12:00 M
WB, SESSION 9
Harvey M. Rarback, *Brookhaven National Laboratory, Presider*

10:30 AM (Invited Paper)
WB1 X-Ray Holographic Microscopy: Improved Images of Zymogen Granules, Chris Jacobsen, Malcolm R. Howells, *Lawrence Berkeley Laboratory;* Janos Kirz, *SUNY-Stony Brook;* Kenneth McQuaid, Stephen Rothman, *UC-San Francisco.* Soft x-ray holograms of rat pancreatic zymogen granules at sub 1000-Å image resolution are presented. A comparison of optical, electron, and x-ray images is made. (p. 116)

11:00 AM (Invited Paper)
WB2 Amplitude- and Phase-Contrast X-Ray Microscopy, G. Schmahl, *U. Gottingen, F.R. Germany.* X-ray microscopy experiments with the x-ray microscopes at the BESSY electron storage ring are described, especially phase-contrast x-ray microscopy experiments. (p. 118)

11:30 AM (Invited Paper)
WB3 X-Ray Holography: X-Ray Interactions and Their Effects, Richard A. London, James E. Trebes, Mordecai D. Rosen, *Lawrence Livermore National Laboratory.* We describe a theoretical study of the scattering and absorption of x rays by a biological sample during holography, and the implications on resolution and x-ray source design. (p. 119)

12:00 M-2:00 PM LUNCH BREAK

NAUSET III

2:00 PM-3:00 PM
WC, SESSION 10
Bob D. Guenther, *U.S. Army Research Office, Presider*

2:00 PM
WC1 Narrowband Tunable VUV/XUV Radiation Generated by Frequency Mixing of Pulsed and cw Laser Radiation, G. Hilber, A. Lago, R. Wallenstein, *U. Hanover, F.R. Germany.* A rigorous theoretical analysis of frequency mixing in gases provides new important information on the improvement of the conversion efficiency. With this improved efficiency, frequency mixing in gases becomes a simple reliable method for the generation of powerful tunable VUV/XUV radiation. (p. 122)

2:15 PM
WC2 Ultrahigh Resolution VUV/XUV Laser: Its Use in the Hyperfine Study of Krypton, A. H. Kung, T. Trickl, M. Vrakking, E. Cromwell, Y. T. Lee, *UC-Berkeley.* Spectroscopic measurements with precision better than 210 MHz in the XUV have been achieved. Hyperfine splittings, isotope shifts, and lifetimes of the three lowest nanosecond Rydberg states of Kr are determined. (p. 124)

WEDNESDAY, SEPTEMBER 28, 1988—*Continued*

2:30 PM
WC3 High Efficiency, Scalable, 130-nm Coherent Sources by Four-Wave Mixing in Hg Vapor, C. H. Muller III, D. D. Lowenthal, C. E. Hamilton, *Spectra Technology, Inc.;* A. V. Smith, *Sandia National Laboratories.* Coherent vacuum ultraviolet pulses with energy of 1.1 mJ, 2.2-ns pulse length (2 MW cm^{-2} unfocused), and measured bandwidth ≤ 0.1 cm^{-1} have been achieved at 130 nm with conversion efficiencies of 5% from two-photon-resonant four-wave mixing in mercury vapor. The experimental results and theoretical predictions are described. (p. 126)

2:45 PM
WC4 Intense Coherent Radiation in the VUV and XUV Region with Electron Beam Pumped Rare Gas Excimer Lasers, Wataru Sasaki, Kou Kurosawa, *U. Osaka Prefecture, Japan;* Peter R. Herman, Junio Yoshida, Yoshiaki Kato, *Osaka U., Japan.* High power rare gas excimer lasers in the ultraviolet region have been reviewed. An anti-Stokes Raman laser at 89 nm in photodissociated oxygen atoms pumped by an argon excimer laser is discussed. (p. 130)

NAUSET LOBBY

3:00 PM-3:30 PM COFFEE BREAK

NAUSET III

3:30 PM-5:15 PM
WD, SESSION 11
Wolfgang Eberhardt, *Exxon Research and Engineering Company, Presider*

3:30 PM (Invited Paper)
WD1 Multiphoton Spectroscopy of Multielectron Atoms and the Quest for Direct Two-Electron Ejection, P. Lambropoulos, *U. Southern California.* I present recent calculations on alkaline earths and on rare gases, which consider the multielectron character of these atoms, and attempt an interpretation of experimental data involving autoionizing and/or doubly excited states, two-electron transitions and transitions to excited ionic states. I also present an analysis of recent observations of the effect of internally generated harmonics on the multiphoton ionization process. (p. 134)

4:00 PM (Invited Paper)
WD2 Observation of Asymmetries in Above-Threshold Ionization, P. H. Bucksbaum, M. Bashkansky, D. W. Schumacher, *AT&T Bell Laboratories.* Recently observed angular asymmetries in above-threshold photoemission are not predicted by Keldysh-Reiss or perturbation theories. The experiments and possible explanations are discussed. (p. 135)

4:30 PM (Invited Paper)
WD3 Multiphoton Ionization with Femtosecond Laser Pulses, H. G. Muller, *FOM Institute, Amsterdam.* Multiphoton ionization of xenon at 620 nm with pulses of around 100-fs duration is studied by electron spectroscopy. (p. 137)

5:00 PM
WD4 High Order Harmonics in Light Scattering by Atomic Electrons Above Threshold, J. H. Eberly, O. Su, *U. Rochester;* J. Javanalnen, *U. Connecticut.* We report multiphoton ionization computer experiments at high laser intensity. We describe the scattered light spectrum accompanying the corresponding above-threshold ionization (ATI) electron spectrum from a given laser pulse in several different cases. (p. 138)

OCEANFRONT DINING ROOM

6:00 PM–8:00 PM CLAMBAKE

THURSDAY, SEPTEMBER 29, 1988

NAUSET LOBBY

8:00 AM–12:00 M ***REGISTRATION/SPEAKER CHECKIN***

NAUSET III

8:30 AM–10:15 AM
ThA, SESSION 12
E. Michael Campbell, *Lawrence Livermore National Laboratory, Presider*

8:30 AM (Invited Paper)
ThA1 X-Ray Emission Studies of Subpicosecond Laser-Produced Plasmas, M. M. Murnane, H. C. Kapteyn, R. W. Falcone, *UC-Berkeley.* X-ray pulsewidth and spectroscopy measurements of plasmas produced by intense subpicosecond laser pulses are described. (p. 140)

9:00 AM (Invited Paper)
ThA2 Non Reciprocity of Autoionizing Interferences, Lasers without Inversion, S. E. Harris, *Stanford U.* Interferences of autoionizing lines may reduce or eliminate absorption of lower level atoms. Stimulated emission shows no such interferences, thereby allowing laser gain without population inversion. (p. 141)

9:30 AM (Invited Paper)
ThA3 Studies of Hot Solid Materials Produced by an Ultrashort Pulse Laser, H. M. Milchberg, *U. Maryland;* R. R. Freeman, *AT&T Bell Laboratories.* Measurements of transport and radiation properties of some hot solid density materials prepared by a subpicosecond high power laser are presented, with discussions of relevant plasma/solid-state physics issues and soft x-ray source development. (p. 142)

10:00 AM
ThA4 Coplanar Vacuum Photodiode for Measurement of Short-Wavelength Picosecond Pulses, J. Bokor, A. M. Johnson, W. M. Simpson, R. H. Storz, *AT&T Bell Laboratories.* We have fabricated a vacuum photodiode in a coplanar stripline geometry. This device is capable of high quantum efficiency and picosecond response time. It may be particularly useful for diagnostics of picosecond soft x-rays from laser-produced plasmas. (p. 143)

NAUSET LOBBY

10:15 AM–10:45 AM COFFEE BREAK

NAUSET III

10:45 AM–12:15 PM
ThB, SESSION 13
Brian E. Kincaid, *Lawrence Berkeley Laboratory, Presider*

10:45 AM (Invited Paper)
ThB1 Observations of High Density Plasmas Produced with a Picosecond High Power KrF Laser, O. Willi, *Imperial College of Science & Technology, U.K.* The interaction of a single picosecond, high power KrF laser pulse with solid targets has been studied using time integrated and time resolved x-ray spectroscopy. Fully ionized aluminum plasmas with temperatures of about 400 eV and densities well above 10^{23} cm^{-3} were observed when the ASE prepulse was less than 10^{-5}. (p. 146)

11:15 AM
ThB2 X-Ray Optics Technologies for X-Ray Laser Research and Applications, N. M. Ceglio, *Lawrence Livermore National Laboratory.* A variety of new x-ray optical components is being implemented for the development of x-ray laser cavities, a soft x-ray interferometer, and a high intensity ($\gtrsim 10^{13}$ W/cm^2) laboratory x-ray laser. (p. 147)

11:45 AM (Invited Paper)
ThB3 Free-Electron Lasers in the Extreme Ultraviolet, Brian E. Newnam, *Los Alamos National Laboratory.* Continued development of accelerator, magnetic undulator, and resonator mirror technologies will enable free-electron lasers to operate below 100 nm in the next few years. (p. 148)

MONDAY, SEPTEMBER 26, 1988

NAUSET III

8:30 AM–10:00 AM

MA1–3

SESSION 1

Herschel S. Pilloff, Office of Naval Research,
Presider

The A. C. Stark Effect at Extremely High Intensities

R. R. Freeman

AT&T Bell Laboratories

Room 1E-338

Murray Hill, NJ 07974

Investigations of the A. C. Stark effect up to 10^{14} W/cm^2 in excited states of xenon demonstrate the role of ponderomotive forces on free electrons.

PROGRESS TOWARDS A 44 Å X-RAY LASER

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Since 1984 when soft x-ray amplification was convincingly demonstrated at XUV wavelengths near 200 Å,[1,2] much effort has been put into obtaining soft x-ray gain at shorter wavelengths. One motivation is the possibility of using a high brightness source of amplified spontaneous emission to perform holography of live biological specimens over short time scales.

Since 1984 developments have pushed the wavelengths of collisionally pumped Ne-like 3p-3s schemes down to 106 Å while the analogous Ni-like 4d-4p schemes have also shown small amounts of amplification (a gain of 1.2 cm^{-1}) at 50 Å.[3] Recombination schemes have reported gain at wavelengths as low as 81 Å in H-like Fluorine.[4]

This paper will look at recent results obtained in attempts to extrapolate Ni-like schemes to ~44 Å. Problems and limitations on the gain achievable with realistic drivers will be discussed, as well as some ideas for increasing the gain in these and other schemes.

Recent results of experiments with neon like and recombination systems will also be described. A more complete discussion of these latter topics will be presented in the poster paper by C.J. Keane et al.

Acknowledgments

This work was sponsored in part by the U.S. Department of Energy, Lawrence Livermore National Laboratory under contract No. W-7405-ENG, and by the Air Force Office of Scientific Research under contract F49620-87-K-0001, through the U.S. Department of Energy, Lawrence Berkeley Laboratory, under contract DE-AC03-76SF00098. We also gratefully acknowledge the support of the Centre d'Etudes de Limeil, Limeil - Valenton, France.

References

1. D.L. Matthews et al., Phys. Rev. Lett. 54, 110 (1985).
2. S. Suckewer et al., Phys. Rev. Lett. 55, 1753 (1985).
3. B.J. MacGowan et al., J. Opt. Soc. Am. B (to be published).
4. C.L.S. Lewis et al., Plasma Phys. Controlled Fusion 30, 35 (1988).

X-RAY MICROSCOPY FOR THE LIFE AND PHYSICAL SCIENCES

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Summary

Soft x-rays in the 30-45 Å spectral region have been used with both scanning[1] and imaging x-ray microscopes[2] to form images of interest to the biological and microelectronic communities. For the life sciences, unaltered biological components--vesicles for the intra-cellular transport of digestive enzymes--have been imaged in an aqueous environment without recourse to sectioning, fixing or staining. Of interest for future developments in the microelectronics industry, various nanostructures and patterns associated with experimental 0.1 micron electronic circuits have been imaged. High resolution Fresnel zone-plate lenses were used, with outer zone widths as small as 400 Å. Spatial resolution approaching 500 Å has been obtained.

1. H. Rarback et al., Rev. Sci. Inst. 59, 52 (Jan. 1988).

2. D. Rudolph, B. Niemann, G. Schmahl, and O. Christ, in X-ray Microscopy (Springer-Verlag, Berlin, 1984), p. 192.

NOTES

MONDAY, SEPTEMBER 26, 1988

NAUSET III

10:30 AM–12:30 PM

MB1–4

SESSION 2

Boris Stoicheff, University of Toronto, *Presider*

LASER SPECTROSCOPY OF AUTOIONIZING STATES

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One of the important applications of tunable coherent radiation in the vacuum ultraviolet and extreme ultraviolet spectral ranges is for the study of highly excited states of atoms and small molecules. These include discrete states above the lowest ionization threshold, which can decay through interactions with ionization continua, giving rise to sharp resonances in the photoionization spectrum. These autoionizing states have mostly been investigated using synchrotron light sources in recent years, but the superior performance of coherent VUV sources make them far better choices for these studies.

In this paper, these advantages will be illustrated by reference to recent experimental work done in our laboratory, in which autoionizing states in HI and NO have been probed by coherent VUV generated by four wave sum mixing in mercury vapour. These experiments have been carried out on a new apparatus which has been designed to take advantage of the characteristics of the tunable coherent light. In this machine, molecules are cooled by supersonic expansion, and the resulting molecular beam is intersected in a very low density region by the collimated VUV. This intersection volume is contained inside the extraction optics of a time-of-flight photoelectron spectrometer, and the photoelectrons produced by the coherent VUV are energy analyzed, or extracted for total cross section measurements.

The experiments done on HI investigated spin-orbit autoionization, a process associated with rare gas photoionization. In HI, the nature of the spin-orbit autoionization was dramatically effected by rotational excitation in the HI. For NO, the final states of the NO^+ formed as a result of vibrational autoionization have been measured by photoelectron spectroscopy. These results probe "propensity rules" for vibrational autoionization.

Time-resolved study of surface recombination at Si(111) surfaces

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At present, the technologically important phenomenon of nonradiative surface recombination at semiconductor surfaces and interfaces is very poorly understood. Since the phenomenon was initially described by Shockley, Bardeen, and others over 30 years ago, knowledge of the basic physics has progressed surprisingly little. We have endeavored to obtain a complete microscopic understanding of surface recombination at a semiconductor surface, including knowledge of the surface-state electronic structure and the detailed kinetics of the bulk-surface transfer of charge carriers. The Si(111) cleaved surface is an excellent model system for this study since the surface electronic structure is extremely well known experimentally and theoretically. There is a single intrinsic mid-gap state at 0.45 eV above the bulk valence band maximum (vbm) which is labelled π^*. Previously, infrared radiation was used[1] to selectively excite the π^* state without exciting the bulk and the details of its decay kinetics were measured. We have now directly observed the role played by this state in surface recombination of bulk electrons and holes.

Using 50 psec laser pulses at 532 nm, a bulk electron-hole plasma was excited. The time dependence of the bulk conduction electron density near the surface as well as the population arising in the π^* surface state due to surface recombination of the bulk carriers were monitored using time-resolved photoemission spectroscopy.[1] All of the relevant bulk-surface scattering rates have now been obtained.

The key parameter which is normally used to describe surface recombination is the phenomenological surface recombination velocity, S. We have derived a value for S using a modification of the Stevenson-Keyes model[2] and our measured scattering rates. We then obtained a value of S for this surface by fitting the time dependence of the bulk conduction electron density to a solution[3] of the one-dimensional diffusion equation subject to the appropriate boundary condition which involves S. The agreement is excellent. We have thus obtained a complete picture of the microscopic surface dynamics which give rise to surface recombination.

REFERENCES

1. J. Bokor, R. Storz, R. R. Freeman, and P. H. Bucksbaum, Phys. Rev. Lett. **57,** 881(1986).

2. D. T. Stevenson and R. J. Keyes, Physica **20,** 1041(1954).

3. M. S. Tyagi, J. F. Nijs, and R. J. Van Overstraeten, Solid-State Electron. **25,** 441(1982).

Recent Advances and Prospects of Bragg-Fresnel Optics

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USSR

The paper considers the properties and applications of Bragg-Fresnel optics elements based on perfect single crystals and multilayer mirrors in the wavelength range 0.1-100 A.

X-Ray Standing Waves - Achievements and Prospects

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and
Division of Applied Science
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Cambridge, MA 02138

ABSTRACT

X-Ray standing wave optical methods have been developed and applied in recent years to a number of challenging problems requiring atomic scale information from a relatively small number of atoms. This talk will review some of the important advances in this field and suggest new areas where these x-ray interferometric methods may be expected to yield new insights into the atomic scale structure of matter.

MONDAY, SEPTEMBER 26, 1988

NAUSET III

2:00 PM–3:45 PM

MC1–4

SESSION 3

Ryszard Gajewski, Department of Energy, *Presider*

STRONG FIELD PROCESSES IN THE ULTRAVIOLET REGION

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and

J. C. Solem
Physics Division, MS-B210, Los Alamos National Laboratory
Los Alamos, New Mexico 87545

SUMMARY

Amplification in the x-ray range requires prodigious energy deposition rates spatially organized in a high-aspect-ratio volume of material. Operation in the high field regime ($E >> e/a_0^2$) appears to offer a new means for the creation of these necessary conditions. The three basic elements involved are (1) a new extremely high-peak-power ultraviolet laser technology, (2) energy deposition stemming from high-order multiphoton processes, and (3) a mode of channeled propagation that arises in the strong field regime. The compatibility of these three independent considerations and their scaling relationships will be discussed.

Observation of Extreme Ultraviolet Amplification in 3-2 (42~46Å), 4-3(130.5Å) and 5-4(305Å) Transitions in Laser Produced He-like Al Plasma

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To demonstrate the XUV stimulated emission process in plasma produced by 100ps glass-laser pulse, close to the water window region, XUV and X-ray spectroscopic measurements are done by adopting He-like Al 3-2, 4-3 or 5-4 transition scheme. This scheme is simple and predictable by the spectroscopic analysis, and suitable to demonstrate the induced emission of the shorter wavelength than any other transition ever attained.

First, intensities of 2p-1s, 3p-1s, 4p-1s and 5p-1s transitions of He-like Al in X-ray region, and those of 3-2, 4-3 and 5-4 transitions in XUV region were measured, at various laser energy. Enhancements of XUV intensities of 3-2(42.4 ~ 46Å), 4-3(130.5Å) and 5-4(305Å) transitions were seen compared to intensities of 3-1, 4-1 and 5-1 transitions as the laser energy was increased. These enhancements were probably due to the induced emission process.

Next, intensities of 3-2 transition were measured at various line-focus length, keeping the laser energy density as constant. Intensities of He-like 3d-2p, 3p-2s and 3s-2p transitions grew exponentially compared to the linear growth of transitions of lower ionized Al. These exponential growth are found to be due to the induced emission process. Gain coefficients are estimated as $4\sim10cm^{-1}$.

96.9nm Saturated Laser in Neutral Cesium

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Summary

We present what we believe is the first laser with its upper level embedded in the continuum of the valence electron. The laser employs a traveling-wave geometry which creates a ~20ps long pulse of laser-produced soft x-rays traveling synchronously with the generated 96.9nm radiation. We measure a small-signal gain of $4.9 cm^{-1}$ uniformly over a length of 17cm, or a total extrapolated small-signal gain of about exp(83). After about 4cm of length, the output energy grows linearly with length, indicating the laser transition is fully saturated.

Figure 1 shows a partial energy level diagram for the neutral Cs system. We believe that the upper and lower levels of the 96.9nm laser transition are 5p5 5d 6s $^4D_{1/2}$, located at $117702 cm^{-1}$, and 5p6 5d $^2D_{3/2}$, at $14496 cm^{-1}$, respectively. The designations are based on comparisons of the RCN/RCG atomic physics code[1] with absorption and ejected electron spectra by Connerade[2] and Pejcev[3] respectively.

The existence of levels above the first ionization potential which live for longer than 100ps has been well documented in neutral Rb.[4] These levels generally have very poor branching ratios to radiation as compared to autoionization. Thus, it should be very difficult to observe spontaneous emission from a transition of this type, and laser action is possible only if levels are excited rapidly enough to produce sufficient gain so that the stimulated emission rate exceeds the autoionizing rate. In our experiments this very rapid excitation is provided by the combination of a 20ps pumping pulse and a synchronous traveling-wave geometry.

Figure 2 shows the experimental geometry. A 3J, 20ps pulse at 1064nm is incident upon a cylindrical lens at 65 deg from normal and is focussed onto a Cs coated stainless steel target parallel to the lens.[5] The target is surrounded by Cs vapor at a pressure of 4 torr. The large angle of incidence expands the length of the line focus by l/cos65 = 2.36, producing a 17 cm long plasma. Our 20ps, 1064nm pulse is generated by grating compression of an amplified chirped pulse. By adjusting the final grating of our compressor to be 2.3 deg from parallel with respect to the first grating, we are able to produce a plasma which sweeps along the target at the speed of light. Such corrections are essential to the observation of high gains.

Figure 3 shows the 96.9nm output energy as a function of pumped length. The length was varied by masking the input laser beam. The total output energy for the 17 cm of active length is at least 2μJ.

Variations of gain with respect to pump pulse length and degree of pumping synchronization, together with spontaneous emission studies of the laser level vs emission from various ion stages support the hypothesis that this transition is from an autoionizing level in neutral Cs.

1. Robert D. Cowan, *The Theory of Atomic Structure and Spectra* (University of California Press, Berkeley, California, 1981) Secs. 8-1, 16-1, and 18-7.
2. J.P. Connerade, Astrophysical Journal, **159**, 685 (1970)

3. V. Pejcev and K.J. Ross, J. Phys. B, **10**, 2935 (1977)
4. J.K. Spong, J.D. Kmetec, S.C. Wallace, J.F. Young, and S.E. Harris, Phys. Rev. Lett., **58**, 2631 (1987)
5. M.H. Sher, J.J. Macklin, J.F. Young, and S.E. Harris. Opt. Lett., **12**, 891 (1987)

Figures

Figure 1. Partial Cesium Energy Level Diagram

Figure 2. Experimental Setup

Figure 3. Saturated 96.9nm Laser Output

96.9nm Cs Laser

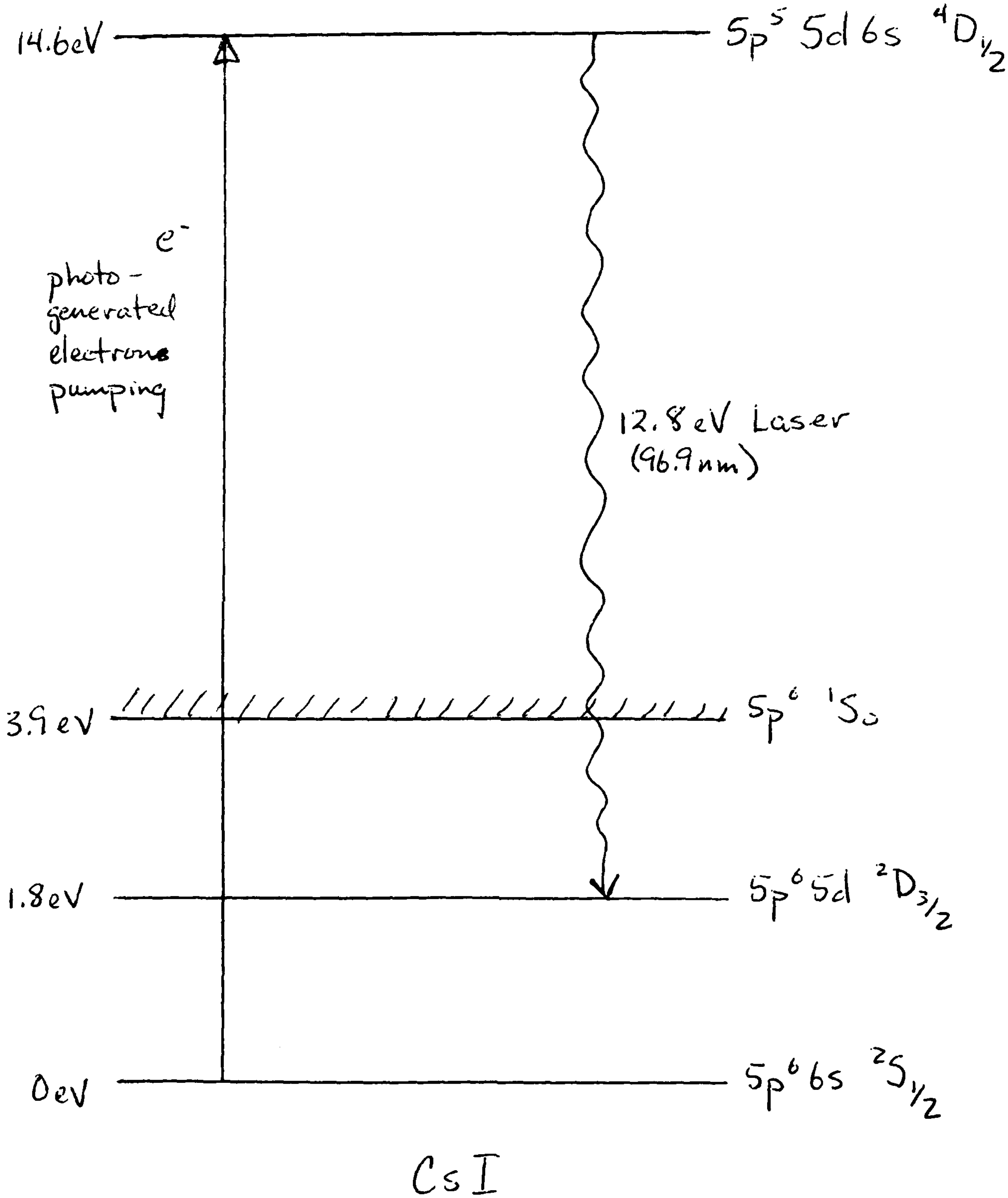

Figure 1. Partial Cesium Energy Level Diagram

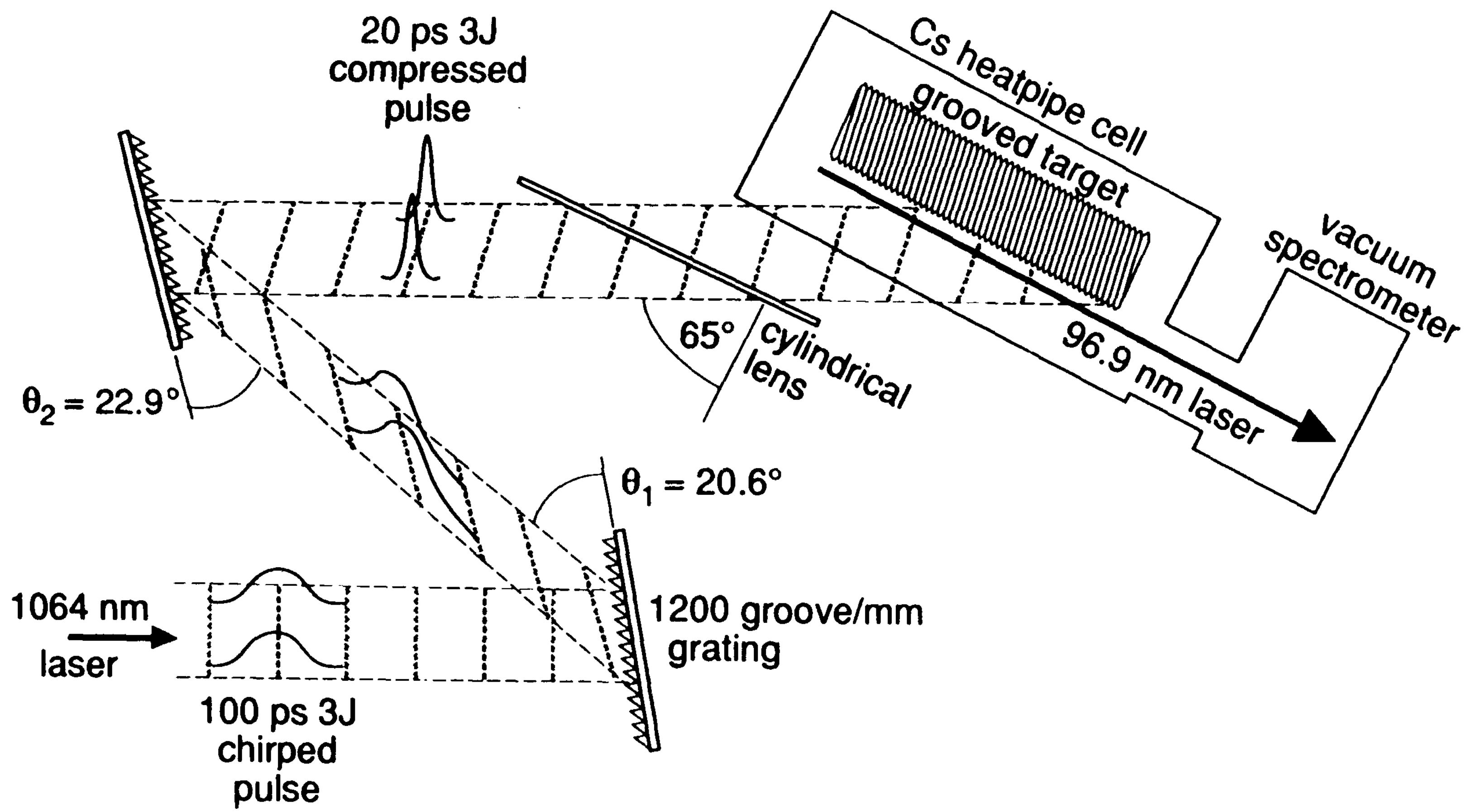

Figure 2. Experimental Setup

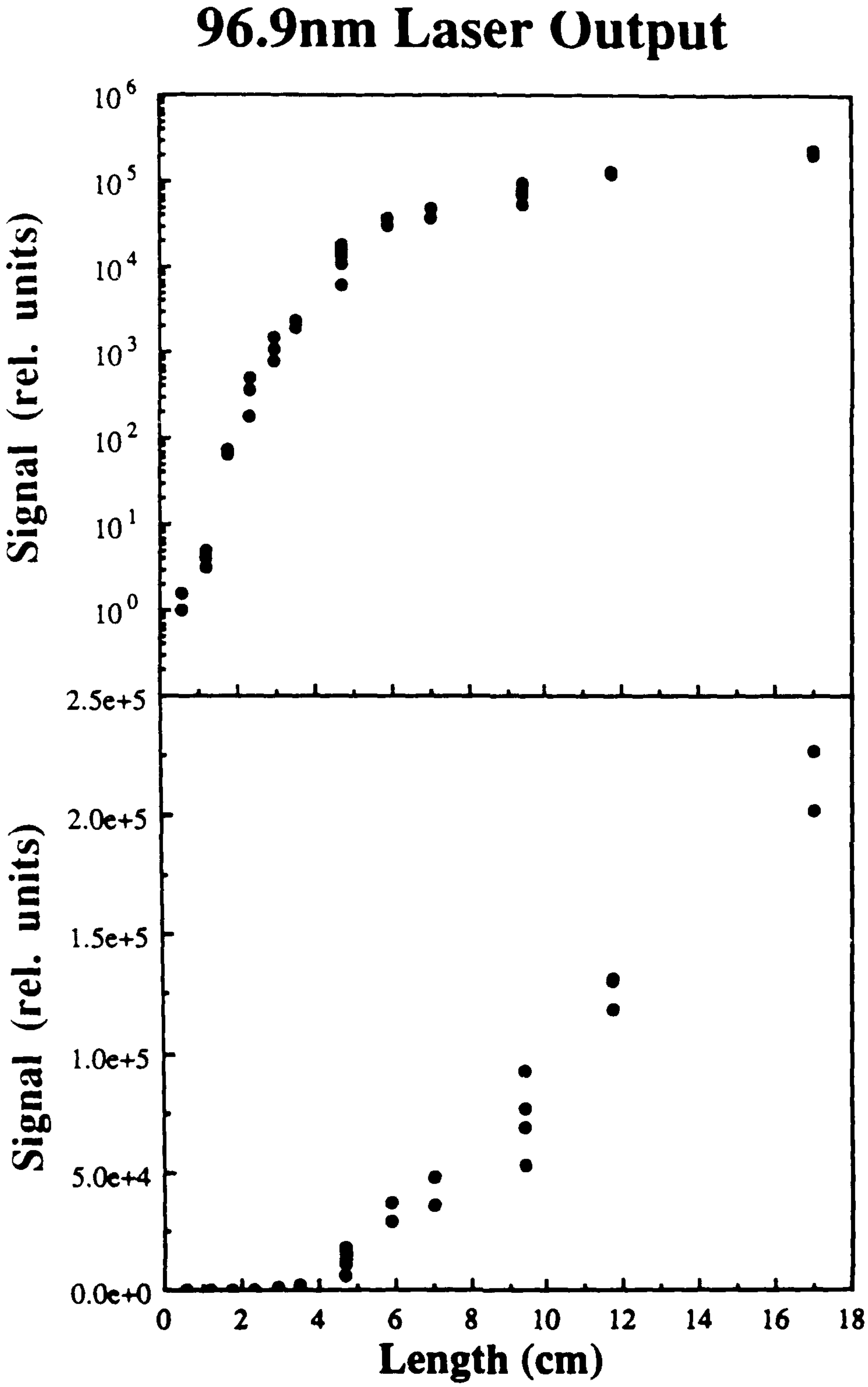

Figure 3. Saturated 96.9nm Laser Output

X-RAY LASER EXPERIMENT WITH DOUBLE-PASS DEVICE AND LONG-RECOMBINING-PLASMA COLUMN

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Amplification of spontaneous emission for 3d-5f lithium-like transition in recombining laser-plasma was previously reported (1). Plasma recombinaison scheme used in such experiment have been already demonstrated up to 65A (2). It leads to smaller gain coefficients than Ne-like ions pumped by plasma free-electron collisions (3) but needs comparatively moderate power requirements and presently has given longer amplification life-time.

In the presently reported experiment, soft X-ray lasing properties has been observed for a 60mm long aluminium plasma column produced by a five beams 1.06μ wavelength neodymium laser. The 2ns pulse duration and 100J per beam focused on a 200μ line give a $2x10^{12}$ W/cm^2 power density at the target surface which leads to the needed population inversion in Al^{+10}. Some percent of the 105.7A line intensity can be returned through the plasma by using a spherical W/C normal incidence multilayered mirror set at the rear of the column. A shutter opens or closes the path from plasma to mirror.

A new grazing incidence concave grating spectrometer has been designed to select emission having a strong directivity in axial direction. Detection was achieved by scintillator and Optical Multichannel Analyser set on the focal circle.

Compared to the spectra obtained without mirror, the double-pass obtained by setting the mirror is shown to increase largely the intensity and the directivity of the beam at 105.7A. According to this result a six-pass cavity with realistically improved reflexion coefficient and a gain coefficient about 0.7 will suffice to reach the laser saturation threshold.

(1) P. JAEGLE et al. Journal de Physique, C6-31, Vol.47 (1986).
(2) A. CARILLON et al. Journal de Physique, C9-375, Vol.48 (1987).
(3) D. MATTHEWS et al. JOSA B4, 575 (1987).

NOTES

MONDAY, SEPTEMBER 26, 1988

NAUSET III

4:15 PM–5:15 PM

MD1–3

SESSION 4

Thomas J. McIlrath, University of Maryland,
Presider

The Interaction of Intense Ultrashort Pulses with Gases

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Study of the interaction of relatively intense, ultrashort pulses with gases has confirmed the approximate validity of Keldysh-Reiss theories of multiphoton ionization.

Keldysh-Reiss theories dress the outgoing wavefunction of the electron for its oscillatory motion in the external field. If the external field is strong ($U_{osc} >> h\nu$), however, the electron can be dressed classically. Quantum mechanics is essential only while the electron is under the primary influence of the atomic field.

We assume that the tunneling probability is given by the instantaneous field of the laser according to well developed DC theories. Tunneling produces electrons with little residual energy. We assume velocity = 0 as initial conditions for classical equation of motion. The final electron energy is, therefore, determined by the classical interaction with the laser field.

The Interaction of Intense..., P.B. Corkum and N. H. Burnett

The electron velocity distribution which is calculated using this prescription agrees with that implicit in Keldysh theory [1] and agrees approximately with the distribution calculated from Reiss [2]. Many of the features of ATI can be understood in this simple manner.

We will show that linearly-polarized ultrashort-pulse 0.3 μm light produces low electron temperature plasmas that are of considerable interest for recombination lasers.

1. L.V. Keldysh, JETP 20, 1307 (1965).
2. H.R. Reiss, Phys. Rev. A 22, 1786 (1980).

CHARGE-DISPLACEMENT SELF-CHANNELING AS A METHOD FOR ENERGY CONCENTRATION

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and

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SUMMARY

We develop an analytic theory of charge-displacement self-channeling: a mechanism by which a laser beam can be dynamically trapped by the refractive index gradient produced in the ponderomotive expulsion of free electrons. The phenomenon should be observable with ultrashort-pulse high-energy ultraviolet lasers in the 10^{19} – 10^{20} W/cm^2 range. We show that the power density in the channel very greatly exceeds that required for strong amplifications in the kilovolt range.

Observation of the High Intensity Kapitza-Dirac Effect

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Murray Hill, NJ 07974
(201) 582-3793

The Kapitza-Dirac (K-D) effect is the wave-particle dual of Bragg scattering, in which a particle beam scatters from an optical standing wave due to stimulated Thomson backscattering.[1] At low intensities, the scattering rate Γ is simply calculated by perturbation theory:

$$\Gamma = \frac{U_0^2}{\hbar^2 \Delta\nu},$$

where U_0 and $\Delta\nu$ are the ponderomotive potential and bandwidth of either laser beam.

At high intensities this formula breaks down, and the scattering becomes position dependent:

$$\Gamma(z)_{1 \rightarrow 2} = \frac{2U_0}{\hbar}\sin(2kz),$$

where this is the *net* scattering rate of photons from beam 1 to beam 2.

To observe this limit, we have investigated the scattering of above-threshold ionization (ATI) photoelectrons from optical standing waves with intensities of 10^{13} to 10^{14} W/cm^2.[2] We find high momentum transfer between the standing wave "lattice" and the electrons, indicating scattering rates comparable to the optical frequency.

The high intensity standing waves were made by colliding two focused laser pulses in a vacuum chamber seeded with xenon or krypton (figure 1a). ATI photoelectrons were collected on an intensified detection screen. Figure 1b is a histogram of 9-12 eV ATI electrons from a *single* linear polarized beam (no standing wave). Figure 1c shows the K-D scattering along θ when the focus contains a standing wave. The change in emission angle between 1b and 1c indicates $\Delta p \approx 1000\hbar k$. Figures 1d-1f show the effects of polarization and relative laser intensity on K-D scattering.

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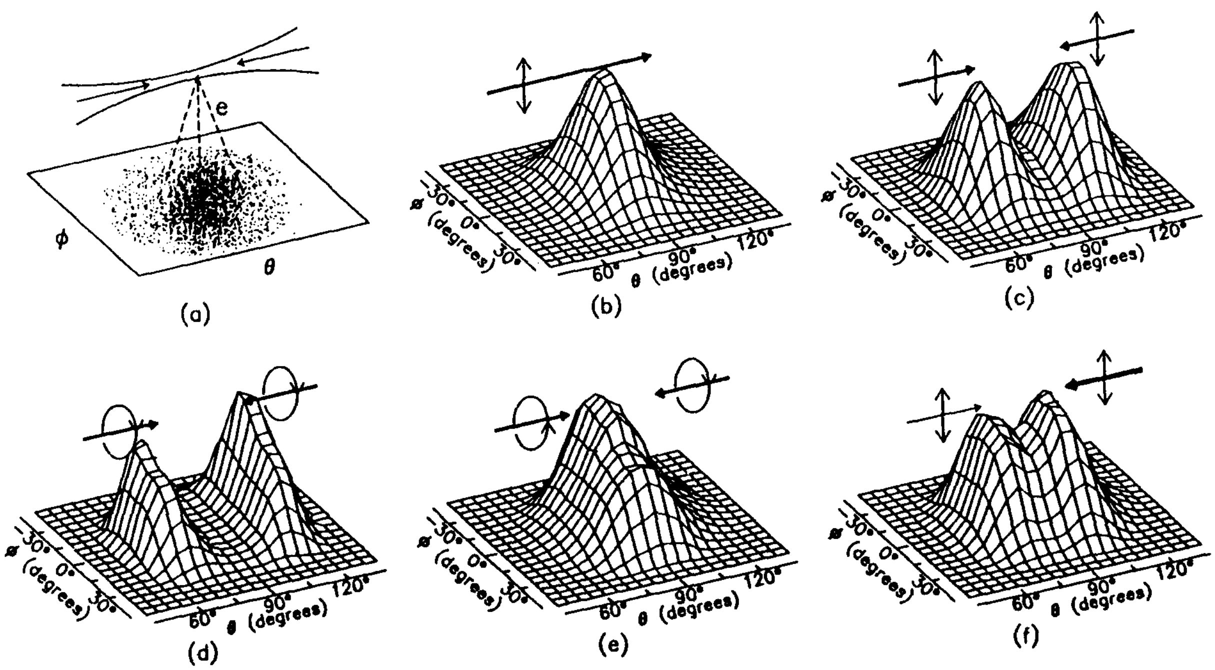

TUESDAY, SEPTEMBER 27, 1988

NAUSET III

8:30 AM–10:00 AM

TuA1–3

SESSION 5

Howard Schlossberg, Air Force Office of Scientific Research, ***Presider***

Short Wavelength Lasers:

Something Old, Something New

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Massachusetts Institute of Technology

Cambridge, MA 02139

The first half of this presentation reviews theory and computation for short wavelength laser research as requested by the conference organizing committee. The second half reviews recent calculations and thoughts pertaining to collisional excitation lasers at modest pump laser intensities, and studies of whisper gallery mirrors.

Invited Talk For
Short Wavelength Coherent Radiation September 26-29, 1988

"RECENT X-RAY LASER RELATED EXPERIMENTS AT PRINCETON"

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Summary

Recent experiments with the goals of increasing the output energy of the Soft X-Ray Laser (SXL) at 18.2 nm in CVI and increasing the gain at 15.4 nm in AlXI and 12.9 nm in SiXII, will be presented. Application of the SXL for X-ray microscopy with emphasis on biological cell microscopy will be illustrated with recently obtained data.

Work on the construction of a new system using the Powerful Picosecond Laser (PP-Laser) for the development of an X-ray laser significantly below 10 nm will be presented. The spectra in the XUV region obtained with the PP-Laser and the effect of pre-pulse on the spectra will be discussed. The difficulties with intensity calibration of XUV spectrometers for X-ray laser experiments will also be discussed.

The talk will end with a presentation of the theoretical effort to model multiphoton processes in a strong EM field.

Amplification of Na XI Hα, Mg XII Hα and Al XIII Hα Transitions

Y. Kato, M. Yamanaka, H. Daido, T. Tachi, H. Nishimura, H. Shiraga, E. Miura, P. R. Herman, H. Takabe, T. Jitsuno, M. Takagi, S. Nakai and C. Yamanaka

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and

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Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, OX11, UK
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Summary

This paper will describe extension of recombining plasma laser with Hα transition in hydrogen-like ions to shorter wavelengths.
In particular, gain measurements of Na XI Hα at 54.19 Å , Mg X11 Hα at 45.53 Å and Al X111 Hα at 38.79 Å are reported.

Amplification of Hα transitions of C VI at 182.2 Å, O VIII at 102.4 Å, and F IX at 80.9 Å have been reported.[1∼4] According to the isoelectronic scaling of recombining plasma lasers,[5] extension of Hα laser to shorter wavelengths could be limited by high electron temperature required for obtaining fully-stripped ions of high-Z atoms. Target irradiation with short wavelength, high power laser is expected to reduce this difficulty since the initial plasma is created at a higher density

which is advantageous for attaining larger population inversion density.

Using the GEKKO XII glass laser facility at ILE, either a stripe, a foil or a fiber target was irradiated with one or two laser beams of 351-nm wavelength, each having 150-J energy at a 130 ps pulse width. Each laser beam was focused to a line of 30-μm width and 7-mm length.

The XUV radiation emitted along and transverse to the line focus were analyzed with the axial and transverse spectrographs, respectively. Data were taken either with X-ray films for time-integrated measurement or with X-ray streak cameras for time-resolved measurement. The gain coefficient was determined from the axial-to-transverse line intensity ratio. The relative sensitivities of the two spectorgraphs were calibrated over a broad spectral range from careful cross-calibration shots.

The gain-length product GL thus obtained reflect target irradiation conditions and target structures. The GL values are GL=1.3 for Na Xl Hα and GL=1.0 for Mg X11 Hα corresponding to G=2.2 cm^{-1} and 1.7 cm^{-1} respectively. Also positive gain is observed for the Al X111 Hα line. Note that these gain values are tentative, since careful data analyses involving deconvolution of overlapping lines are required for accurate gain determination.

The results that have been obtained are very encouraging for developing a soft X-ray laser in the water window.

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NOTES

TUESDAY, SEPTEMBER 27, 1988

NAUSET III

10:30 AM–12:00 M

TuB1–3

SESSION 6

Jerry B. Hastings, Brookhaven National Laboratory,
Presider

Coherent Nuclear Excitations in Crystals by Synchrotron Radiation Pulses

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Recently two groups have succeeded in filtering synchrotron radiation in the hard X-ray region using nuclear Bragg scattering[1,2]. The filtered beams using Fe^{57} crystal Bragg scattering have a spectral width $\Delta E \sim 10^{-8}$ ev @ 14.4 kev, and thus a longitudinal coherence length ℓ_c - 30 meters @ $\lambda \sim 1$Å.

I shall discuss the theory[3] of the super- and subradiant states excited in the crystal by the synchrotron pulses, the coherent increase and decrease of radiation widths, the speeding up and slowing down of the decay rates of the coherently excited crystal. Also, I shall discuss the theory[3] of the quantum beats observed[1] which result from the interference of waves of different frequencies emitted by different atoms coherently excited by an incident synchrotron pulse.

References

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Nuclear Bragg Diffraction using Synchrotron Radiation

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Nuclear Bragg diffraction in combination with synchrotron radiation will become a powerful new X-ray source in the Å-region. This new source exceeds already Mossbauer sources in brilliance giving Mossbauer scattering experiments further impetus. With the planned dedicated storage rings synchrotron radiation, filtered by measures of the Mossbauer effect, will not only allow new types of Mossbauer experiments but offers also a new X-ray source for μeV resolution and long coherence length X-ray optics.

The first experiments[1] had shown that there is a resonance in the diffraction spectra and even that the diffracted X-rays are highly monochromatic ($\Delta E/E \sim 10^{-12}$). Although these experiments had shown the expected time behavior, an improved fast detector revealed the complete time spectra in all details[2].

These experiments point out the basic phenomena connected with the nuclear Bragg diffraction of γ-quanta:

speedup (coherent enhancement), quantum beats, and
polarization mixing (Faraday rotation, etc.).

The speedup in the time spectra - a dynamical effect of the diffraction, depends on the angle of incidence and is most pronounced at the beginning of the time spectra. This is clearly and very easily seen in the measurements of the antiferromagnetic $^{57}FeBO_3$.

In the quantum beats the hyperfine splitting of the nuclear levels and/or the resonance shifts between different nuclear sites in the crystal are expressed. The observation of quantum beats allows a sensitive and direct determination of the hyperfine interaction parameters.

Due to the fact that the nuclear Bragg diffraction is sensitive to the internal hyperfine fields, a strong polarization mixing of the scattering amplitudes may occur. Especially in the case of yttrium scattering iron garnet crystals, the spectra show a strong mixing depending on the directions between the $\vec{B}$-field and the $\vec{k}$-vector of the incident γ-ray.

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U. van Burck, R. L. Mobbauer, E. Gerdau, R. Ruffer, R. Hollatz, G. V. Smirnov, J. P. Hannon, Phys. Rev. Lett., 59, 355, 1987.

The production of long coherence-length hard x-rays using nuclear Bragg scattering of synchrotron radiation.

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Summary

Recently, several experimenters have successfully observed nuclear Bragg scattering from crystals containing ^{57}Fe. By coherently exciting the 14.4keV resonance at the Bragg condition, almost pure beams of extremely monochromatic radiation can be generated. Although the intensities observed are so far quite low, the brightness produced by these techniques exceeds that available from radioactive sources. Instrumental improvements will soon make possible interesting new experiments. Several properties of the nuclear Bragg reflection process are interesting in themselves. These include the observation of beating in the time domain among hyperfine split resonance lines, and polarization mixing produced by scattering from oriented circularly polarized oscillators. Some speculations on the potential applications of this new source of long coherence-length radiation will be presented.

TUESDAY, SEPTEMBER 27, 1988

NOBSKA ROOM

8:00 PM–10:00 PM

TuC1–40

SESSION 7: POSTER SESSION

COLLISIONLESS X-RAY GENERATION FROM PICOSECOND LASER-GAS INTERACTION

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SUMMARY

Recent experiments[1] on multiphoton ionization of atoms by intense, short wavelength, picosecond laser pulses have shown effects of unsually strong nonlinear coupling of the laser energy to the atoms. On this basis it has been conjectured[2] that atomic inner-shell excitation can be induced by laser-driven coherent oscillation of the outer-shell electrons, provided that the laser irradiance is sufficiently high that the associated electric field is comparable to or greater than an atomic unit.

It is thought that laser-driven coherent outer-shell oscillations will provide the possibility of achieving collisionless nuclear excitation by an indirect process;[3] indeed, experiments are in progress[4] to test this idea by searching for the 73 eV isomeric level of coherently excited ^{235}U atoms.

At the Los Alamos Bright Source we are conducting photon counting experiments to search for x rays characteristic of inner-shell radiation in order to test the above mentioned conjecture. Picosecond KrF laser pulses are focused onto low density noble gases at an irradiance of 10^{17} W/cm^2, and x rays generated from this interaction are measured by a photon counting system consisting of a high gain microchannel-plate/ phosphor/photomultiplier detector assembly. A fiducial at "zero time" is established by measuring the prompt x rays from a solid target irradiated by the KrF laser pulse. A multichannel analyzer with 1-ns resolution provides temporal discrimination between prompt (< 1 ns delay) inner-shell radiation and delayed x rays. Spectral discrimination is provided by a set of carefully designed filters. Counting statistics are obtained over many (> 2000) shots.

Preliminary results show no evidence of prompt inner-shell x rays. Delayed x-ray signals most likely due to recombination processes, however, have been measured. Models for the experimental results will be presented and discussed.

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Population Inversion due to Charge Exchange Processes in Plasmas

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The charge exchange process,

$$Ar^{17+}(1s) + H(n_i) \rightarrow Ar^{16+}(n\ell) + H^+ \qquad (1)$$

was found to affect the line intensities of 1snp - $1s^2$ in X-ray spectra of Ar^{16+} observed from tokamaks[1,2]. Strong intensities at n = 9 and 10 arise from the process (1) with hydrogen atom in the ground state (n_i=1). A shoulder at n = 18 and a peak at n = 27 are due to n_i = 2 and n_i = 3, respectively[2]. Observed spectra are analysed with a collisional radiative model, where all sublevels up to n = 40 of He-like ions are taken into account.

In the process (1), n-ℓ distribution in highly excited states significantly affects the intensity ratios associated with the lower levels, w ($1s^2\ ^1S$ - 1s2p ^1P), x,y ($1s^2\ ^1S$ - 1s2p ^3P) and z ($1s^2\ ^1S$ - 1s2s ^3S). Thus the ℓ-distribution in highly excited states can be estimated from the observed spectra of n = 2 as demonstrated in Fig.1. Here ℓ-distribution is assumed to follow the statistical weights. The upper part shows the spectra for n = 2 (w, x, y and z) and the lower part for n $\geq$ 7. Fig. 2 shows the case that all the electrons captured are distributed in only ℓ = 1 (np state). The intensity of z is enhanced compared to that in Fig.1.

References

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Fig. 1

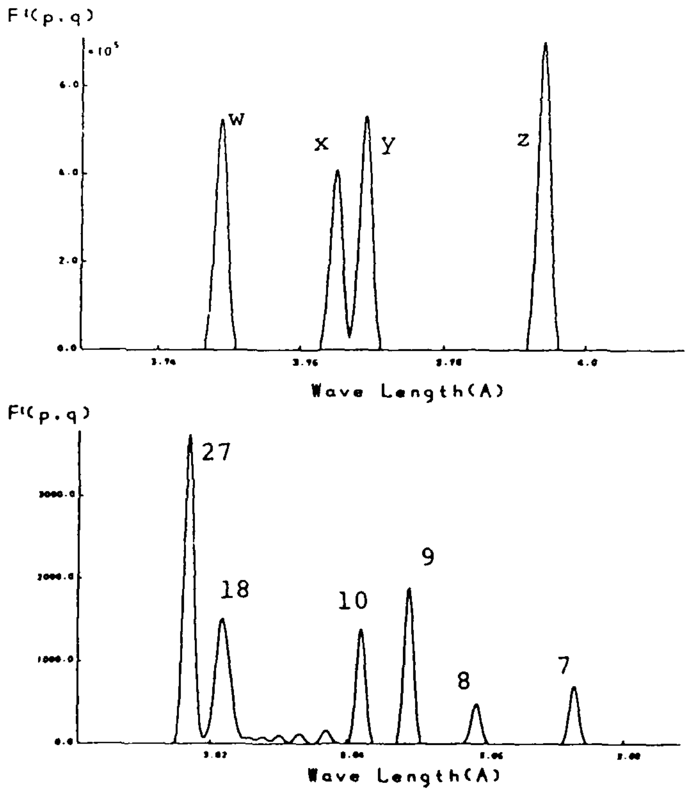
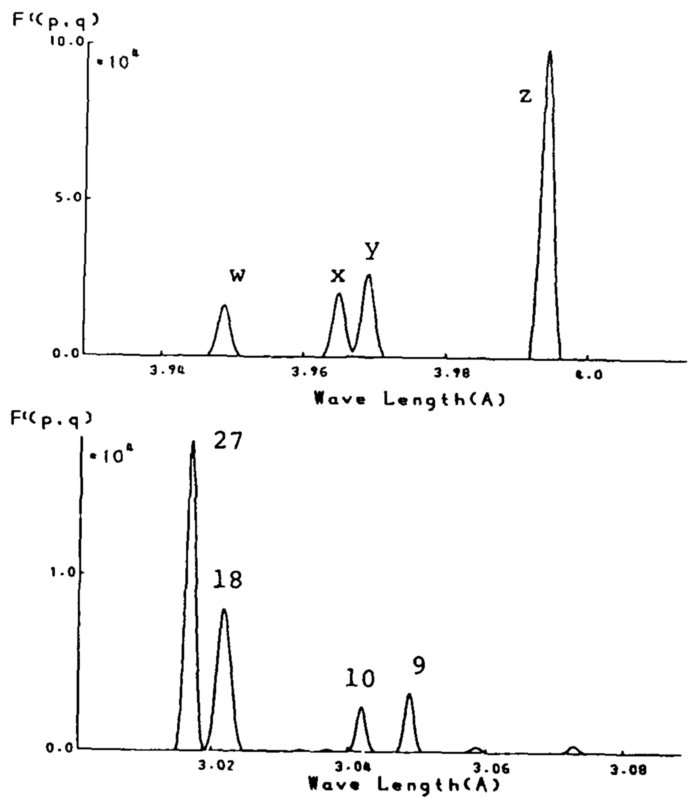


Fig. 2



Photoionization-Pumped Laser Geometry

M. H. Sher, S. J. Benerofe, J. F. Young, and S. E. Harris

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The recently reported saturation[1] of the 109-nm Auger laser in xenon III[2] utilized a newly developed, oblique incidence, traveling wave, laser-produced plasma geometry. This geometry allows excitation of a variable gain length while maintaining constant pump laser intensity on target and soft-x-ray conversion efficiency. Distribution of the soft-x-ray pump flux over an increased length is desirable in photoionization-pumped lasers because of the pump flux, density, and gain limitations imposed by the free electrons created in the pumping process. The assumption that the gain will be highest at some optimum pump flux leads to simple scaling laws for the total small signal gain and transverse dimensions of the laser as its length is changed. The gain per unit pump energy, the brightness of the output beam, and the fresnel number of the laser should all improve with increased length.

We will discuss experiments to verify these scaling laws, where we increase the length of the laser simply by increasing the angle of incidence of the pump beam. In addition, we expect to discuss the effects of varying intensity, wavelength, pulse length, and a pre-pulse on soft-x-ray conversion efficiency and laser operation. These studies will lead to a better understanding of the factors important in the design of useful photoionization lasers.

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Amplification and Gain Measurement of Extreme Ultraviolet Radiation (42.4Å, 45Å and 46Å) in He-like Al Laser Plasma

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Concerning the extreme ultraviolet lasing in the laser-produced plasma, He-like Al scheme is atractive because the wavewlength of He-like 3-2 transitions are shorter than any other transition ever done, and very close to the water window. This scheme is expected to give a large population inversion caused by the rapid decaying of the n=2 level, and the great feed to the n=3 levels by the cascade radiative transitions and two electron transitions through the autoionized states.

A 100ps glass-laser pulse was line-focused on the solid Al target, and intensities of He-like 3-2 transitions were measured at various plasma length, keeping the laser input energy density as constant. Intensities of 3d-2p(45Å), 3s-2p(46Å) and $3p\,^1P_0$-$2s\,^1S$(42.4Å) grew exponentially and saturated, as the plasma length was increased. This exponential growth is due to the stimulated emission process, and saturation is due to the escape of the XUV light from the line-shape-plasma axis caused by bending of XUV light in a density-graded plasma. Gain coefficients are estimated as $9.8cm^{-1}$, $7cm^{-1}$ and $4.4cm^{-1}$ for He-like Al 3d-2p, 3s-2p and 3p1PO-2s1S transitions respectively.

Population Inversions between n=5, 4, 3 and 2 levels of He-like Al Plasma Observed by Spatially Resolved X-ray Spectroscopy

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Population inversions between N=5, 4 and 3 levels are observed in a 100ps Laser-produced plasma. As a results, XUV of 42Å~46Å, 130Å and 305Å corresponding to 3-2, 4-3 and 5-4 transitions are observed experimentally. Relative population densities are determined by measuring the intensities of spatially resolved X-ray line spectra of 6.635Å, 6.314Å and 6.18Å corresponding to the 3-1, 4-1 and 5- 1 transitions, which are normalized by their oscillation strengths. Careful absorption was paid to rule out the effect of reabsorption. Populations were inverted at the region located 50~100μm from the target surface. Laser light was focused into 50 μm diameter and amount of inversion was clearly increased when laser intensities was increased. As to the 5-4 and 4-3 inversion, similar result was observed in silicon target, however inversion between n=3 and 2 was not confirmed at these laser intensities. XUV gains are very promising especially as to 5-4 and 4-3 transitions in both target.

MULTIPLE HARMONIC CONVERSION OF 1064 NM RADIATION IN RARE GASES

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SUMMARY

Generation of very high order odd harmonics (up to the 33^{th} in Ar) is observed when a rare gas is exposed to a 36 ps, 1064 nm Nd-YAG laser[1]. A pulsed gas jet provides a non linear medium of 1 mm length and 15 torr pressure[2]. The use of a well collimated gas jet considerably minimizes the re-absorption of the generated XUV radiation. This emission is spectrally analyzed along the laser axis by a grating monochromator. Taking into account the spectral efficiencies of the grating and the detector, we have determined the absolute intensity of each harmonic in Xe, Kr, Ar. Fig.1 gives a typical result obtained in Ar. The shortest wavelength observed is 32.3 nm at $3x10^{13}$ Wcm^{-2}.

The harmonics intensity decreases very slowly with the order between 7 and 27. Note that the 13^{th} harmonic is missing probably due to its re-absorption. The energy conversion rate is $5x10^{-10}$ for the third harmonic. Laser intensity dependences for some harmonics will also be presented.

The primary wavelength appears to play an important role, since the shortest wavelength induced here in Ar for an intensity of $3x10^{13}Wcm^{-2}$ is very close to that obtained by a 248 nm laser at much higher intensity ($>10^{15}$ Wcm^{-2}) by McPherson et al[3].

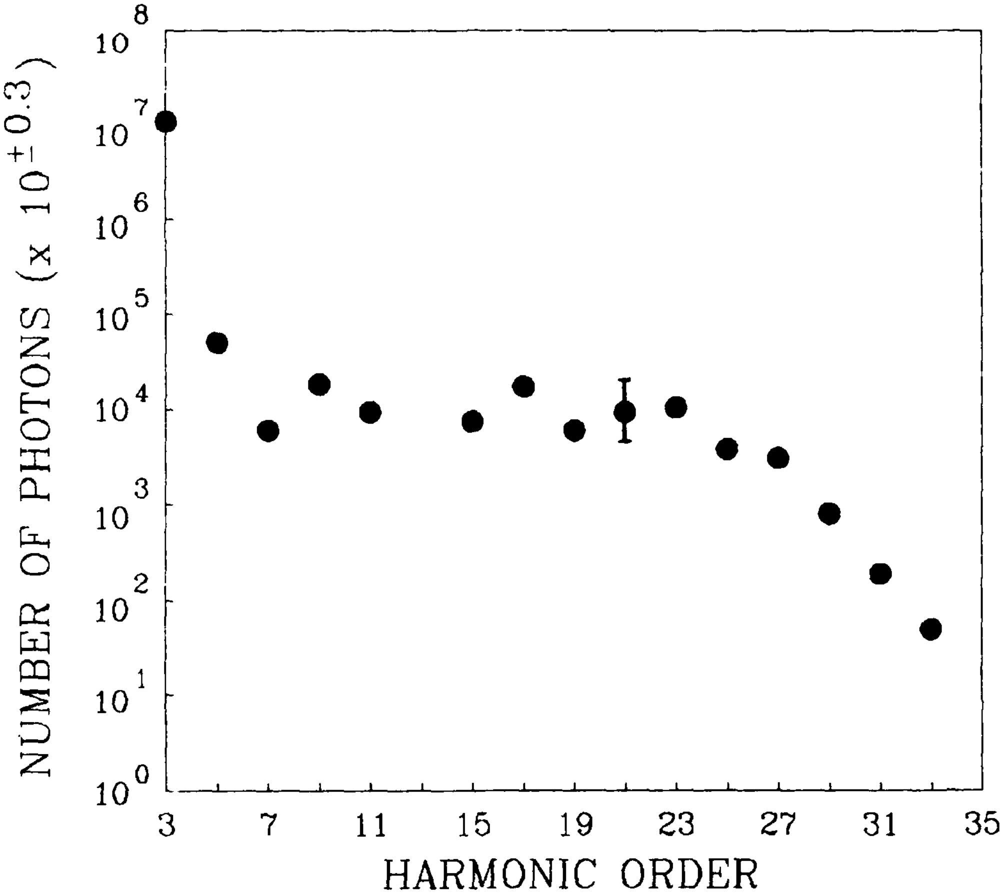

Fig.1 Absolute intensity of the harmonics generated in Ar at $3x10^{13}Wcm^{-2}$ (λ=1064 nm).

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Probability of Soft x-ray Radiation for 3p-3s Transition in Neon-like Iron

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Summary

The computational simulation of soft x-ray lasers has been done for some years at Institute of Applied Physics and Computational Mathematics. Some probabilities for 3p-3s transition in Neon-like ions have been obatined.

Laser-produced plasma condition is calculated using one dimensional non local thermodynamic equilibrium radiative hydrodynamic code JB-19. In this code, the bremsstrahlung effect, radiative ionizations and recombinations, collisional ionizations by electrons, three-body recombinations, collisional excitions and de-excitations, radiative line transitions and Compton scattering are considered. The multigroup flux-limited diffusion approximations is used in the radiative transport equations. Laser absorption via inverse bremsstrahlung is considered to be the most important in our computational simulations. The calculated plasma parameters then form the input to the steady rate equations code, which sloves for the populations in the some levels of the ions.

We simulated the interactions of double frequency neodymium-glass laser beam, which is focussed into a line onto target, with thin foils. At first we made the computational results of neon-like Se to be agreed with the experemental results of LLNL, then we calculated the plasma conditions for CH-Fe foil with different power densities and different pulse widths of laser beams. The populations and gain for 3p-3s transition in Ne-like Fe are calculated. Some computational results are shown.

HARMONIC GENERATION IN LASER–FREE ELECTRON SCATTERING RECONSIDERED

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The classical cross section for zero electron drift velocity by Vachaspati[1] deviates strongly from a semi–classical one by Ehlotzky[2] and from an unpublished quantum electrodynamical cross section by Jafarpour. Therefore, the cross section is recalculated within classical electrodynamics, which suffices for the experimental configurations in question, as was recently confirmed again by Dobiasch et al.[3] in the context of the compton laser. This classical cross section, derivable more simply and with fewer approximations than the semi–classical one, is perfectly equivalent in the non–relativistic case and it also incorporates relativistic Thomson scattering as envisaged by McDonald[4].

For second harmonic scattering, Fig. 1 shows fair agreement between the classical cross sections. The semi–classical one deviates substantially owing to an error in Ref. 2, but, after correction, can be made to agree with the present result for all harmonics.

Even for zero electron drift velocity as in Fig. 1, the cross section exhibits a marked forward–backward asymmetry, not mentioned in the literature before. It is explained as an interference between the fields produced by the linear and nonlinear components of the electron motion, and it renders Englert and Rinehart's[5] direction of observation most unfavorable for observing second harmonic photons.

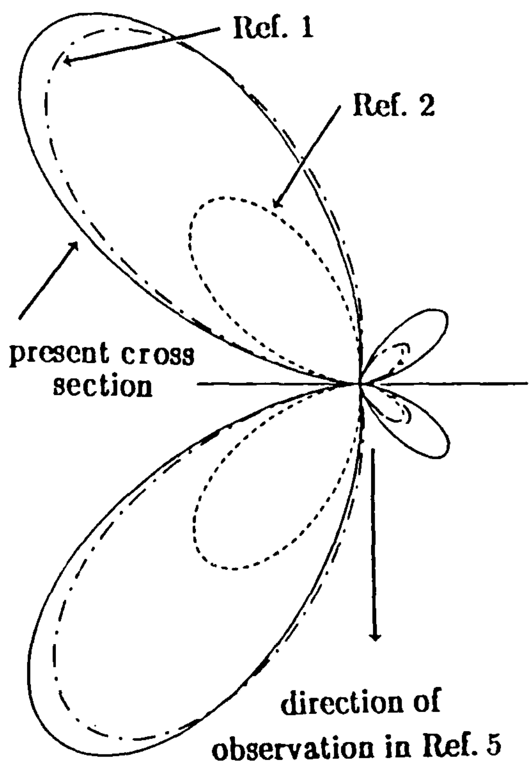

Fig. 1

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GAIN GUIDED X-RAY BEAMS

by

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In typical laser plasma x-ray laser experiments strong electron density gradients transverse to the direction of propagation of the x-ray beam exist. There is concern [1,2] that the associated refractive index gradient may deflect the x-ray laser beam out of the high gain region, thus limiting the maximum achievable effective gain length. Numerical analysis by ray tracing [3] indeed seems to indicate beam losses due to the refractive index gradient.

In x-ray laser experiments, however, there is not only a refractive index gradient but also a strong gain distribution transverse to the beam propagation direction. Approximating the gain and index profiles by quadratic functions, analytic formulae for the propagation of Gaussian beams in such media may be found [4,5]. The analysis is possible even for non-coincident symmetry axes of the gain and index distributions. The application of this theory to x-ray laser experiments shows that under most conditions the beam parameters are determined by the gain profile and that beam spreading due to the refractive index profile does not occur.

An arbitary beam injected into the medium is quickly transformed into a 'matching beam', propagating without change. The effective gain of the matching beam is somewhat lower than the gain at the maximum of the gain distribution.

The theory has been extended to a situation in which the gain or index distribution (or both) leads the beam along a curved path. The original motivation for considering this case was the hope that an x-ray laser resonator could be realized by guiding the beam around a full circle, thus eliminating the need for high reflectivity x-ray mirrors. Unfortunately the losses in this geometry were found too high to make such an x-ray ring laser feasible, except for rather exotic conditions. The theory may, however, be useful to assess the losses of x-ray laser beams in a medium in which the gain and index distributions exhibit a small curvature in the direction of beam propagation. Unexpectedly small gains observed experimentally may possibly be explained by soft bends of the gain medium caused by inhomogeneities along the line focus.

This work was supported in part by the Commision of the European Communities in the framework of the Association Euratom/IPP.

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CO_2 Laser Heated Plasmas for Collisionally Pumped XUV Laser Studies

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The possibility of using CO_2 laser-generated hot electrons to produce a 3p-3s inversion in Ne-like Cu was first proposed a number of years ago[1]. In the past few years several laboratories have reported gain in electron collisionally pumped 3p-3s transitions in Ne-like ions with Z in the range 29-42. These gains were observed in plasmas produced by visible[2,3] and 1 μm[4] lasers. Several important differences exist when attempting to produce inversion in plasmas produced with CO_2 lasers. For the collisionally pumped schemes it is desirable to produce plasmas with electron densities $>10^{20}$ cm^{-3} which is above the critical density for the 10 μm irradiation. In addition at the intensities required to produce the plasmas the absorption of the 10 μm light will be dominated by collective processes which will generate hot electrons. The fact the plasma will be overdense potentially allows the use of a longer heating pulse and lower average density which should result in lower ion temperatures and reduced doppler widths. The hot electrons will undoubtedly enhance lateral energy loss, particularly with a line focus, but these electrons may also directly pump the 3p-3s transitions through alternative collisional processes.

The NRC kilojoule CO_2 laser system was used to irradiate foils at moderate intensities ($\sim10^{13}$ W cm^{-2}) with a line focus (7 mm X 150 μm) to produce an extended plasma of interest for XUV laser studies. X-ray line and continuum diagnostics of layered targets have been used to infer a 300 eV heat front that penetrates to depths of ~20 μgm cm^{-2} in Al. Electron densities of $\sim10^{20}$ cm^{-3} have also been inferred with these diagnostics. With Cu targets we have observed L-shell x-ray transitions in Ne-like and F-like ions which reveal a similar ionization distribution to that observed in 1μm laser-produced plasmas at in which gain has been observed.

We are currently studying n=3-3 x-ray transitions from Ne-like Cu in the region of the expected 3p-3s inversion[4]. For these experiments we are using free standing thin Cu foils and we have modified our focussing system to obtain a line focus up to 14 mm in length.

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Reflectance of Aluminum Reflectors in the Extreme Ultraviolet

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The reflectance of unoxidized aluminum films at non-normal incidence has been measured in our ultra-high vacuum (UHV) deposition and analysis chamber. We find that a multi-facet reflector coated with an unoxidized aluminum film can provide a broad spectrum retroreflector in the extreme ultraviolet (XUV). Our reflectivity measurements have been accomplished with an in situ reflectometer consisting of a capillary discharge source, a grating monochromator and a microchannel plate detector in our UHV chamber.[1]

The silicon substrate is coated with aluminum with the UHV chamber at a base pressure of 5 x 10(-10) Torr to avoid any oxidation from water vapor or oxygen. Our measurements indicate that the formation of a single monolayer of aluminum oxide on the surface of this aluminum film is sufficient to appreciably reduce the XUV reflectance of the sample. Reflector lifetime has been measured in our UHV system and these measurements indicate that the reflector is not appreciably degraded in our system when held at a vacuum level of ~2 x 10(-9) Torr [mostly helium from our windowless source] for one month.

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X-ray Laser Gain Optimization and Spectroscopy Experiments in Plasmas Produced by 2ω and 3ω Laser Light

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We report on recent Ne-like ion spectroscopy and gain optimization measurements in Ge, Se, Sr, Mo, and Ag plasmas. There were two primary objectives in this series of experiments. The first was to attempt to optimize gain in various Ne-like systems as a function of laser wavelength, target thickness, and irradiation intensity. In addition, several experiments were done to attempt to explain the lower than expected gain[1] on the J=0-1 transitions in Ne-like ions.

Gain optimization experiments using 2ω light produced gain coefficients as high as 4.7 cm^{-1} in Ne-like Se (this compares with the nominal 4 cm^{-1} obtained in earlier work[2]). Ne-like Sr was studied for both gain optimization and J=0 physics; gain coefficients of up to 5 cm^{-1} were measured on the J=2-1 transitions. Soft x-ray amplification was also observed in Ne-like Ge and Mo.

The Ne-like ions of Se, Mo, and Ag were also investigated with 3ω laser light. For Se, the intensity ratios of J=2-1 to J=0-1 lines were observed to be similar to that measured previously for 2ω laser light. In Mo, however, differences in these ratios with respect to those obtained with 2ω irradiation[3] were seen.

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CAPILLARY DISCHARGE PLASMAS AS EXTREME ULTRAVIOLET LASER SOURCES

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We propose the use of capillary discharge plasmas for the development of compact VUV, XUV and soft X-ray recombination laser sources. The capillary advantages relate to the generation of a dense highly ionized plasma, as well as its subsequent rapid cooling due to the high electron heat conduction to the capillary walls. Both conditions are necessary to achieve large recombination rates, and significant gain at short wavelengths. In addition, the capillary geometry limits the plasma radius helping to avoid self-absorption of the lower level radiation.

Time dependent collisional-radiative and transport calculations show that in hot capillary plasmas, electron heat conduction can be significantly greater than radiation cooling. These mechanisms act together to cause rapid cooling of the plasma. Calculations done for the 18.2 nm CVI transition in capillaries 50 to 100 μm in diameter predicts gains of the order of 5 cm^{-1}. Populations invertions are also expected to occur in the 3-2 transitions of other hydrogenic ions, as well as in some non-hydrogenic transitions.

The evolution of the plasma parameters in these discharges was studied using time resolved emission spectroscopy in helium, lithium and carbon discharges with length-to-diameter ratio ≃100. The XUV spectrum of a lithium discharge [figure 1] shows the 72.91 nm 3-2 transition of hydrogenic lithium and oxygen impurity lines dominating the spectrum: illustrating that highly ionized plasmas are obtained with modest excitation. The proposed laser excitation scheme is expected to be applicable with elements up to Z=6.

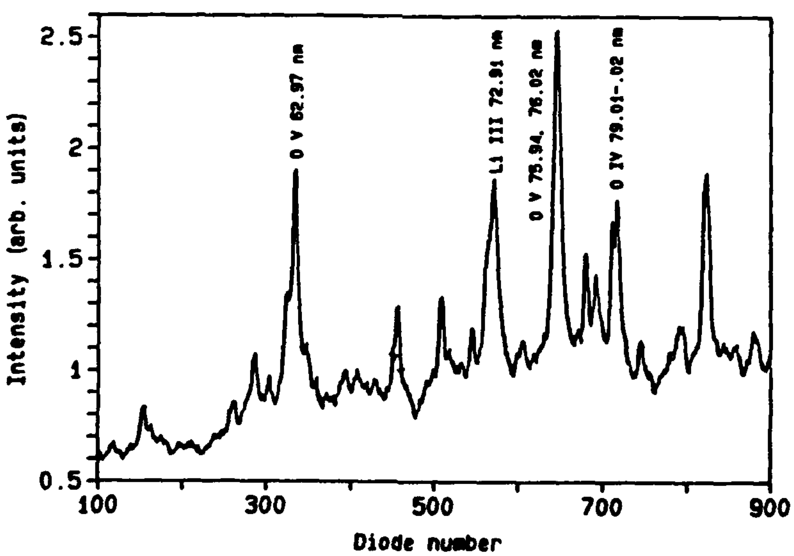

Figure 1- Time integrated spectrum (53 nm-93 nm) of a 500 μ diameter, 38 mm long LiH capillary excited by discharging a 40 KV, 6.6 nF capacitor bank by a 50 ns pulse.

HIGH POWER, SHORT PULSE, ULTRA-VIOLET LASER FOR THE DEVELOPMENT OF A NEW X-RAY LASER

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Summary

The first stage of a powerful picosecond laser (PP-laser) system has been developed. A 248 nm seed pulse is generated by frequency converting the output of a dye oscillator/amplifier. This pulse is then amplified in a series of excimer (KrF) amplifiers. The first stage provides ~20-30 mJ in ~1psec and is focussable to ~10^{16} W/cm^2. By adjusting the injection timing of the seed pulse, the level of pre-pulse energy was varied and the effect on the laser-plasma interaction was studied by observing XUV spectra, in particular, lines from highly ionized species were analyzed. Results indicate that the hottest plasma is formed with minimal pre-pulse energy. To increase the power output of the system to ~ 1 TW the pulse width has been shortened[1] and a third, final amplifier has been added. The final amplifier is a uv-preionized KrF discharge unit with a 5 cm by 10 cm cross-section and a length of 100 cm. The beam is double passed through the amplifier and directed onto the target. The energy delivered from the

final amplifier is expected to be in the range of 0.5 Joule with a pulsewidth less than 0.5 ps. We will also present a system for the development of a new type of X-ray laser. This system consists of the PP-laser, a 1 kJ CO_2 laser, 150 kG magnet, spectroscopic diagnostics and synchronization electronics.

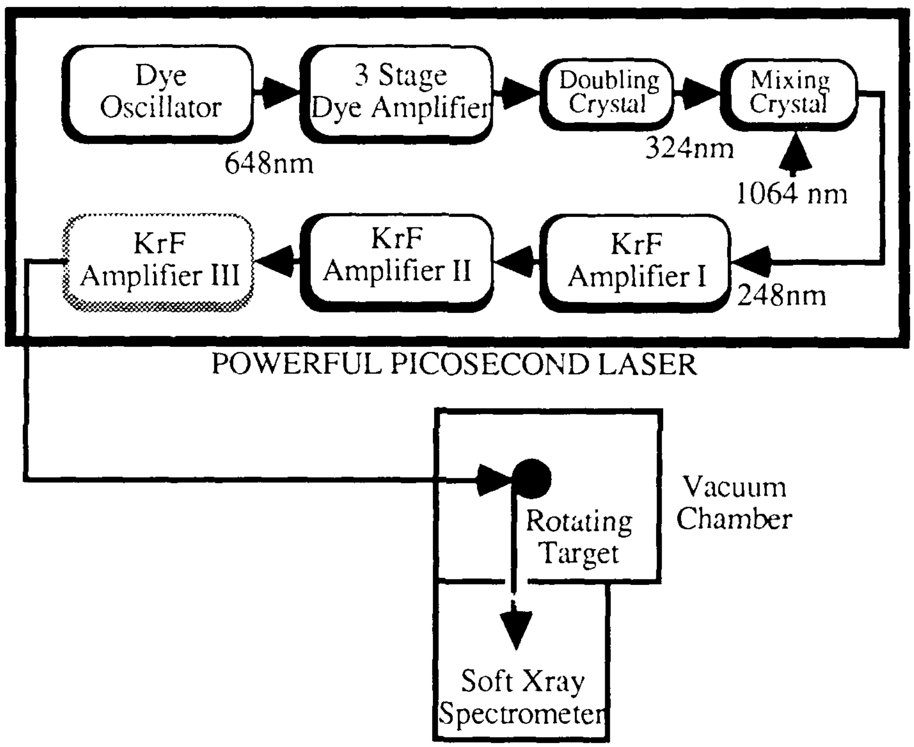

Figure 1
Block Diagram:
Set-up for Laser-Target Experiments

[1] This work performed in conjunction with J. Fujimoto, M.I.T.

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MEASUREMENT OF THE QUENCHING OF SPONTANEOUS EMISSION COEFFICIENTS IN LASER-PRODUCED PLASMAS

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Summary

The branching ratio, defined as the intensity ratio of two spectral lines originating from the same upper energy level, is for optically thin plasmas the same as the ratio of the coefficients of the spontaneous emission, known as Einstein A-coefficients, which are believed to be constants in most cases unless accompanied by significant line shifts.

A surprising decrease of the branching ratio of the visible to the VUV line intensities emitted by laser-produced plasmas with increasing plasma density was observed using a novel VUV-visible duo-multichannel spectrometer. The plasma was created by interaction of a pulsed CO_2 laser (10J/pulse, 150 ns) or a ruby laser (5J/pulse, 15 ns) with a solid carbon target, and spatially resolved measurements of the line emission as a function of distance from the target surface were made.

The experiment with a CO_2 laser[1] showed an order of magnitude decrease of the branching ratio between CIV 5801-5812 Å and CIV 312.41-312.46 Å transitions from the ratio at low density, with significant broadening but no observable shift of the lines. More recent results from the higher density plasmas produced by a ruby laser showed an even larger decrease.

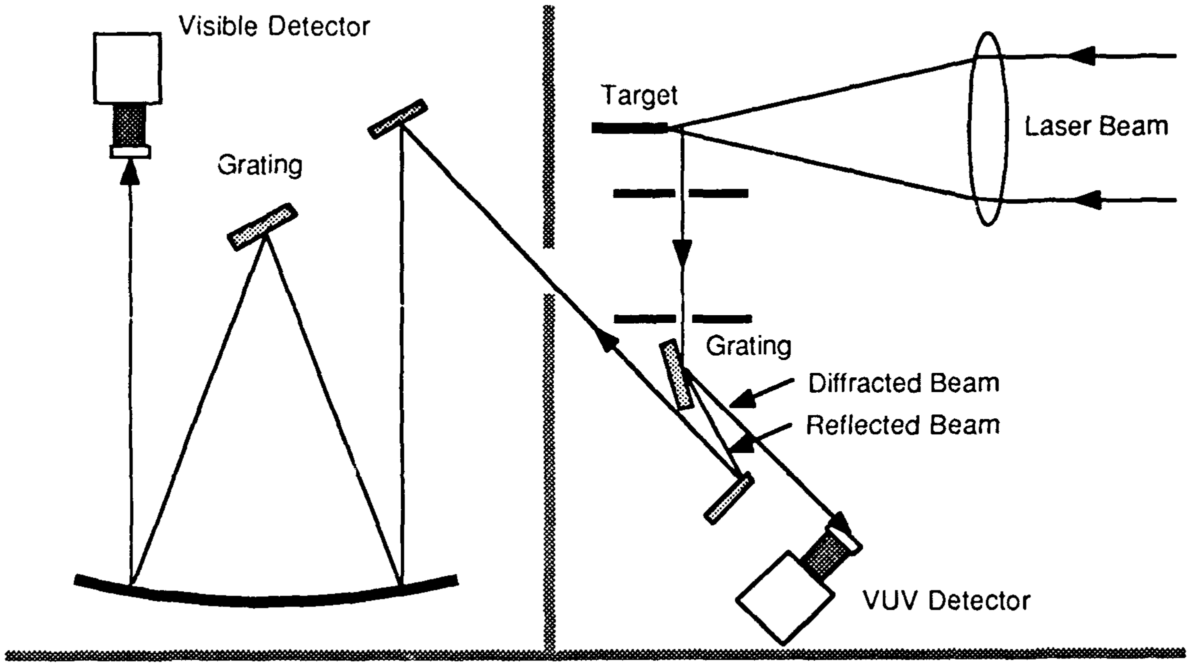

Fig. 1 : Experimental Setup

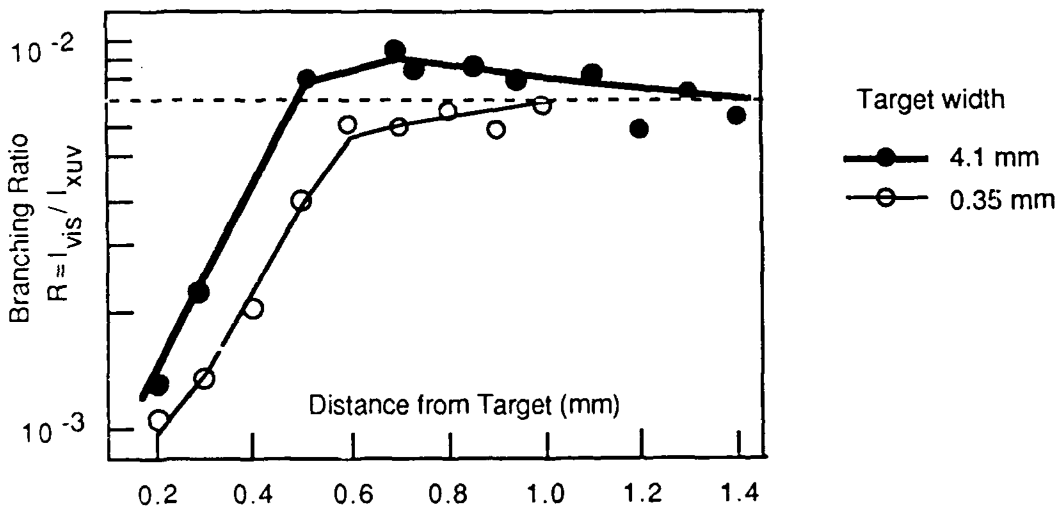

Fig. 2 : Branching ratio curve for CIV 5801-5812Å and 312Å as a function of the distance from the target.

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CONTACT MICROSCOPY WITH A SOFT X-RAY LASER

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Summary

Soft X-ray microscopy offers the exciting prospect of imaging live cells at high resolution, thereby bridging the gap between electron microscope images of non-live cells that have undergone extensive specimen preparation and low resolution but high fidelity images of live cells recorded with light microscopes.

The Princeton soft X-ray laser[1] has been applied to high resolution contact microscopy. The laser provides a 1-3 mJ output pulse of 10-30 nsec duration at 18.2 nm which is used to illuminate a biological specimen in a Composite Optical X-ray Laser Microscope of novel design dubbed "COXRALM" (see fig 1). COXRALM is designed to permit the biologist to observe, select, and manipulate a living cell immediately before exposure. A 1000 Å thick silicon nitride window is used to separate the laser vacuum chamber from the cell. The shadow of the specimen is recorded in photo-resist which is later viewed in an electron microscope.

We have begun a study of the immune system of the German cockroach *Blattella Germanica* using these techniques and initial images of blood cells obtained in vacuum appear to show identifiable features in active immune cells.

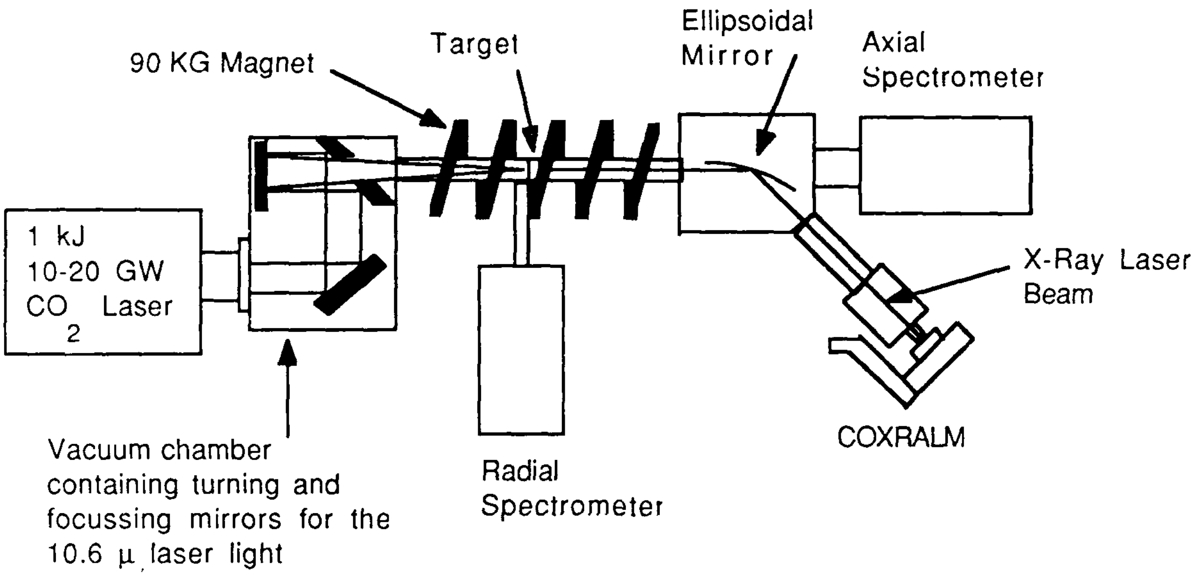

Fig. 1. Schematic of the experimental arrangement at PPPL.

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PROGRESS IN SOFT X-RAY AMPLIFICATION AT 154.7Å AND 129 Å IN LI-LIKE AL XI AND SI XII

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Summary

We have investigated the possibility of lasing action at 154.7Å in Li-like Al XI and 129Å in Li-like Si XII in a magnetically confined recombining plasma. A ~ 1 kJ CO_2 laser was focused onto an aluminum or silicon target assembly and the resulting plasma confined in a solenoidal magnet. A strong magnetic field of up to 90 kG was used to keep the electron density high (~5 x 10^{18} cm^{-3}) and

impurities such as iron or titanium were introduced to enhance the plasma cooling in the recombination phase so that favorable conditions for the fast three body recombination and collisional cascade processes would be met.

To better understand the behavior of the magnetically confined, laser-produced plasma, a one-dimensional hydrodynamic code along with an atomic physics code for Li-like ions has been developed to simulate the experiment. From the computer code, relevant line intensities were time-integrated to produce theoretical spectra which were compared with those experimentally observed. The theoretical predictions of gain agree well with the observations. The advantage of the Li-like ions as a gain medium over the H-like ions is the lower ionization potential energy for approximately the same wavelength of the potential lasing line. The gain characteristics in Li-like Mg X, Al XI, and Si XII will be discussed.

Work on the development of soft x-ray laser amplifier will also be presented.

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Calculation and Design of Ni-Like W Soft X-Ray Lasers†

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SUMMARY

Gain on 0-1 transitions has now been demonstrated in Ni-like Eu[1,2] and Yb[3] using targets between 60 and 100 μg/cm^2. The intensities of the input laser were 7×10^{13} W/cm^2 (Eu) and 1.4×10^{14} W/cm^2 (Yb). The measured gain coefficient on the 71Å (Eu) and the 50.3Å line (Yb) was 1 cm^{-1}. Using a modified version of the Lagrangian hydrodynamics code LASNEX together with the kinetics code XRASER, the calculated gains are in reasonable agreement with experiment.[2]

In Ni-like W, the leading 0-1 transition has the wavelength 43.11Å. 1D calculations for 90 μg/cm^2 targets irradiated by a 3ω Gaussian pulse show an increase in the gain coefficient from 1 to 2.6 cm^{-1} as the intensity is increased from 2.2×10^{14} to 2.6×10^{14} W/cm^2. The electron temperature, at the peak of the input pulse, increases from 0.8 to 0.95 keV.

A more dramatic effect is seen by using square pulses (3ω). The gain coefficient increases from 2 to 6 cm^{-1} when the intensity

is increased from 1.8×10^{14} to 2.2×10^{14} W/cm^2. The electron density for the square pulse is a factor 2.5-3.0 times larger than the gaussian pulse.

The modified version of LASNEX which was used to run these problems radiates more energy producing lower temperatures in the plasma.

†Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

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CHARACTERISTICS OF A PICOSECOND LASER PLASMA

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SUMMARY

Unusual states of highly ionized plasmas can be generated over a wide range of electron density with the use of high-power subpicosecond ultraviolet lasers. Plasmas created by such means should have characteristics quite different from those produced by traditional techniques involving current-pinches or laser radiation in the much longer nanosecond time regime. Generally the conventional approaches involve electron collisions over a considerable period (e.g. $\gtrsim 10^{-9}$ sec) as the main mechanism producing the higher charge states. Consequently, this process often can be well described in thermodynamic terms. In contrast, plasmas produced by multiphoton ionization on a subpicosecond time-scale can involve a high level of ionization, low electron heating, negligible ion heating, and insignificant heavy body hydrodynamic motion. Under these circumstances the energy is deposited rapidly, generally in a time shorter than the radiative lifetimes of a large class states radiating in the vacuum ultraviolet (VUV) and soft x-ray regions.

This work presents VUV spectra of argon plasmas produced by a high power subpicosecond ultraviolet laser over a wide range of laser intensity (10^{16} – 10^{19} W/cm^2) and electron density (up to 2×10^{20} cm^{-3}). Ionization of the L shell from Ar^{8+} has been demonstrated, and under certain conditions recombination rates and electron temperatures can be deduced.

Quantum mechanical interference in four wave mixing.

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When a process can take place via two or more different quantum-mechanical pathways, constructive and destructive interference effects can follow. Here we report the demonstration of these effects in four wave mixing in sodium vapour. The two different four wave mixing pathways were enhanced by different two-photon resonances. By varying the wavelengths of the lasers involved, the phase of the interference could be varied.

Two pulsed dye lasers (25 ns pulses) of wavelengths λ_1 = 602.2 nm (600 kWcm^{-2}) and λ_2 = 557.0 nm (1.4 MWcm^{-2}), excited a sodium vapour of atomic density 3 x 10^{14} cm^{-3}. Two photons of wavelength λ_1 combined with a photon of wavelength λ_2 to produce radiation at the sum frequency ($\nu_{uv} = 2\nu_1 + \nu_2$), with wavelength λ_{uv} = 195.5 nm. The four wave mixing was enhanced by two-photon resonance with either the $5s$ state or the $4d$ state (see Fig. 1).

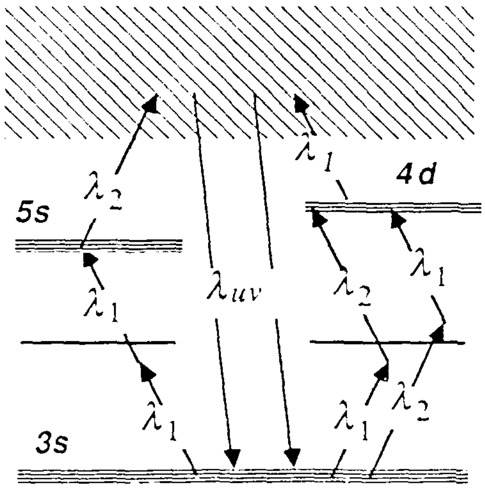

FIG. 1. Sodium energy level diagram showing the two-photon resonances which enhanced the four wave mixing.

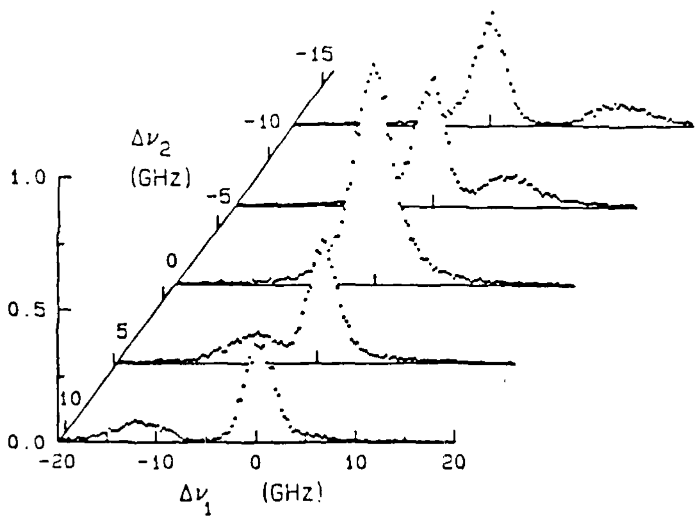

FIG. 2. Three-dimensional plot of four wave mixing signal recorded (in arbitrary units) as a function of both laser detunings.

Fig. 2 shows the four wave mixing signal recorded as λ_1 was scanned, for different values of λ_2. When λ_2 was suitably chosen, the two peaks in the signal, due to the two different two-photon resonances, merged. The resulting signal was larger than the sum of its individual components, demonstrating constructive interference. Destructive interference was also demonstrated, under different conditions. A simple theoretical model, involving the third-order nonlinear susceptibility $\chi^{(3)}$, gives a good description of the phenomena observed.

SOFT X-RAY LENSES WITH 400 Å OUTER ZONE WIDTH

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Summary

Fresnel zone plate lenses for focussing and imaging radiation in the 10-50 Å wavelength region have been fabricated with outer zone widths as small as 400 Å. The zone plates were fabricated by electron beam lithography using a high resolution vector scan system designed specifically for nanometer pattern writing. A special circular pattern generation technique, utilizing high speed polar/cartesian conversion was utilized. Field size was calibrated for squareness and orthogonality using electron beam lithography calibration marks and laser interferometry. Patterns were written in a 180-200 nm thick PMMA resist on a 30 nm gold electroplating base. The substrate was a 100 nm silicon nitride film. The pattern received a dose of 250 $\mu C/cm^2$ at 25 KeV. Special patterns requiring a thick central stop region, received a doubled dose, followed by a double development/double plating technique.

A method utilizing the phenomenon of form birefringence was used for monitoring the development of the fine features. In the optical microscope with polarized light and crossed analyzer, a distinct change of the reflected intensity is observed during the final stages of development.

Text patterns imaged at 45 Å wavelength demonstrate a spatial resolution approaching 500 Å. Measurements of zone plate efficiency are also described.

Soft X-Ray Spectroscopy of Laser-Produced Plasma

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Laser-produced plasmas emit intense X radiation primarily at sub-KeV Photon energies. Spectra in the sub-KeV region were measured with a pinhole transmission grating and grazing incidence spectrographs respectively. The transmission grating spectrometer with two pinholes of 25 µm and 50 µm in diameter is consisted of free-standing gold bars (1000 Lines/mm, bar thickness 0.45 µm). The wavelength resolution achieved in the spectrometer was 10Å. The grazing incidence spectrograph is composed of a toroidal mirror and a concave grating. It is designed to cover the spectral range of 10~450 Å in the first difraction order. The angles of incidence on both mirror and grating are 87~87.5° in order to maintain good efficiency down to 20 Å. The spectrograph of 998.8 mm radius and 2400 grooves/mm, the brazing angle being 2°.

The plasmas were produced by an asperical lens with f=60mm focusing a high power Nd^{3+} glass laser beam with pulseduration of ~200ps and energy of ~10 J on flat targets with different atomic number Z.

The main results include identification and classification of spectra of XUV emission soft X-ray population inversion, and interpreting pinhole transmission grating spectra of low, intermediate, and high Z targets.

* Also with China Center of Advanced Science and Technology (World Lab.), Beijing.

Transversely Optically pumped S_2 Ultraviolet Laser in the Range of 330-390nm

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An ultraviolet laser oscillation of six lines is first achieved on the $B^3\Sigma_u^- \rightarrow X^3\Sigma_g^-$ transition in S_2. S_2 molecules are generated in a T-shaped quartz cell with two controlled heating zones. The transitions $v'=4 \leftarrow v''=1$ and $v'=5 \leftarrow v''=2$ occured in S_2 transversly pumped with a XeCl laser(3081A). A cavity is composed of R=90% and R=50% mirrors. Except observed blue--green laser lines, a series of ultraviolet lines from 330nm to 390nm are observed. The peak wavelengths are 3309.2A, 3377.3A, 3401.8A, 3448.1A, 3531.6, and 3804.2A. The origins of above described lasing are discussed. By the way, the absorption and small signal gain coefficients are measured. The mean gain is near $0.30cm^{-1}$, which agrees with the result of classical gain calculations. As we know, the UV sulfur dimer lasings from 330nm to 390nm as we reported here, are much shorter than the previously achieved. The S_2 lasing range observed by S.R.Leone and J.P.Girardeau-Mont is 365~570nm and 370~490nm, respectively.

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LARGE HOLOGRAPHIC DIFFRACTION GRATINGS MADE BY A MULTIPLE EXPOSURE TECHNIQUE.

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Abstract

EUV and soft X-ray sources often requires grazing incidence optics in order to obtain high throughm-put. Therefore gratings (and mirrors) in monochromators and spectrometers have to have large dimensions. The maximum size of a holographic grating that can be manufactured in a specific set-up is, in principle, limited by the size of the collimating optics (mirrors) in this set-up.

In our contribution we woud like to present a technique which permits to circumvent the limitation set by the mirrors and fabricate large holographic gratings,which thereafter have been ion-etched. Using the theory of Ref.1 the profile of these gratings can be optimized.

The idea is very simple. On a large substrate, gratings are exposed sequentially and in phase with the help of a reference grating. To be able to do this, it is necessary to control the phase of the exposing interference pattern. By using the same technique as the one described in Ref 1 we have succesfully added grating structures, in phase, on the same substrate. In principle, this technique can be used to make very large gratings.

The accuracy to which two subsequent grating patterns can be positioned is better than $\lambda/20$ (see Fig 1).

In our contribution we will describe the idea and the exposure system used to manufacture the "large" gratings. Some theoretical aspects of the problem, such as the limit of the accuracy, will be discussed together with a presentation of experimental results and evaluation of the quality of the diffracted wavefront.

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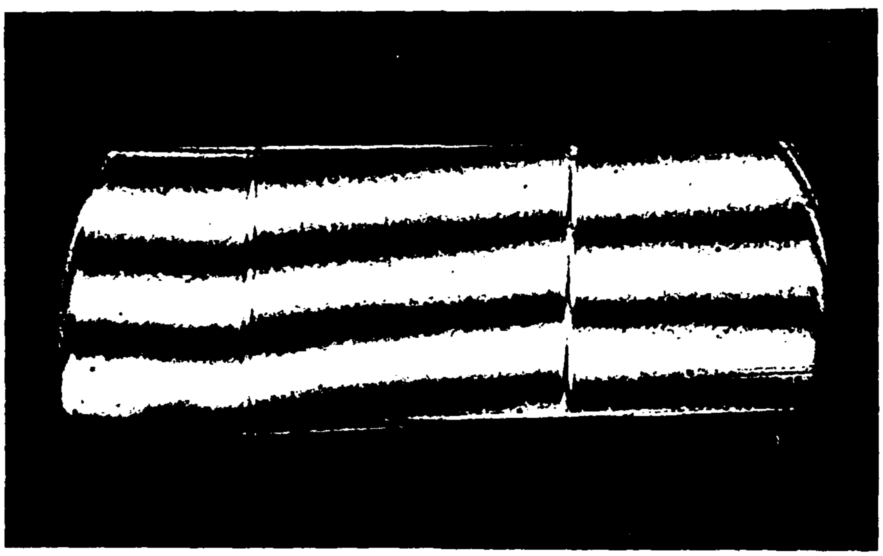

Fig 1. Interferogram of two boundaries between three subsequent gratings.

Spectra of Lead, Bismuth, Thorium and Uranium Relevent To A Neodymium-Like Soft X-ray Lasing Scheme, W.L. Hodge, High Energy Laser Associates, 6114 LaSalle Ave Oakland, Ca. 94611 Phone: (415) 658-8586, P.C. Filbert, D.A. Kohler, C.L. Navoda, and J.D. Perez, Applied Physics Laboratory, Palo Alto Research Laboratory, Lockheed Missile and Space Company, Palo Alto, Ca. 94304 Phone:(415) 424-2022, work supported by the Lockheed Independent Research Program, P.L. Hagelstein, Research Laboratory of Electronics, Massachusetts Institute of Technology Cambridge, Ma. 02139 Phone: (617) 253-0899, work supported by the Vinton-Hayes Foundation, S. Maxon, and J.H. Scofield, Lawrence Livermore National Laboratory, Livermore, Ca. 94550, Phone:(415) 447-8162, J.M. Peek, Los Alamos National Laboratory, Los Alamos, NM 87545, Phone: (505) 665-0542.

The Nd-like isoelectronic sequence (60 electrons) of high Z elements could provide the basis for a soft x-ray laser(1). Gain may be possible at approximately 70 A for the 5f-5d transition in Nd-like Uranium. The potential advantage is that a medium power Nd:glass laser (10E12 to 10E13 watts/cm2) is sufficient to create a soft x-ray laser. As a first step in this development, soft x-ray spectra from Pb, Bi, Th and U were taken. These results will be presented along with three different atomic structure computer calculations of transition energies.

The spectra were produced with 10E11 to 10E14 watt/cm2 of laser power from the Lockheed Pulsed Laser Facility. Time integrated and theoretical spectra of Uranium are displayed in figure 1. The data is dominated by broad unresolved transition arrays (UTAs) from 5-5 and 6-5 transitions. The theoretical spectrum was created using calculated gf values and wavelengths for the Nd-, Pm- and Sm-like isoelectronic sequences. This comparison partially explains the gross features of the experimental data. Transitions from a large number of other ionization states will help form the broad UTAs.

1. P.L. Hagelstein and S. Dalhed, Phy. Rev. A,37,1358 (1988).

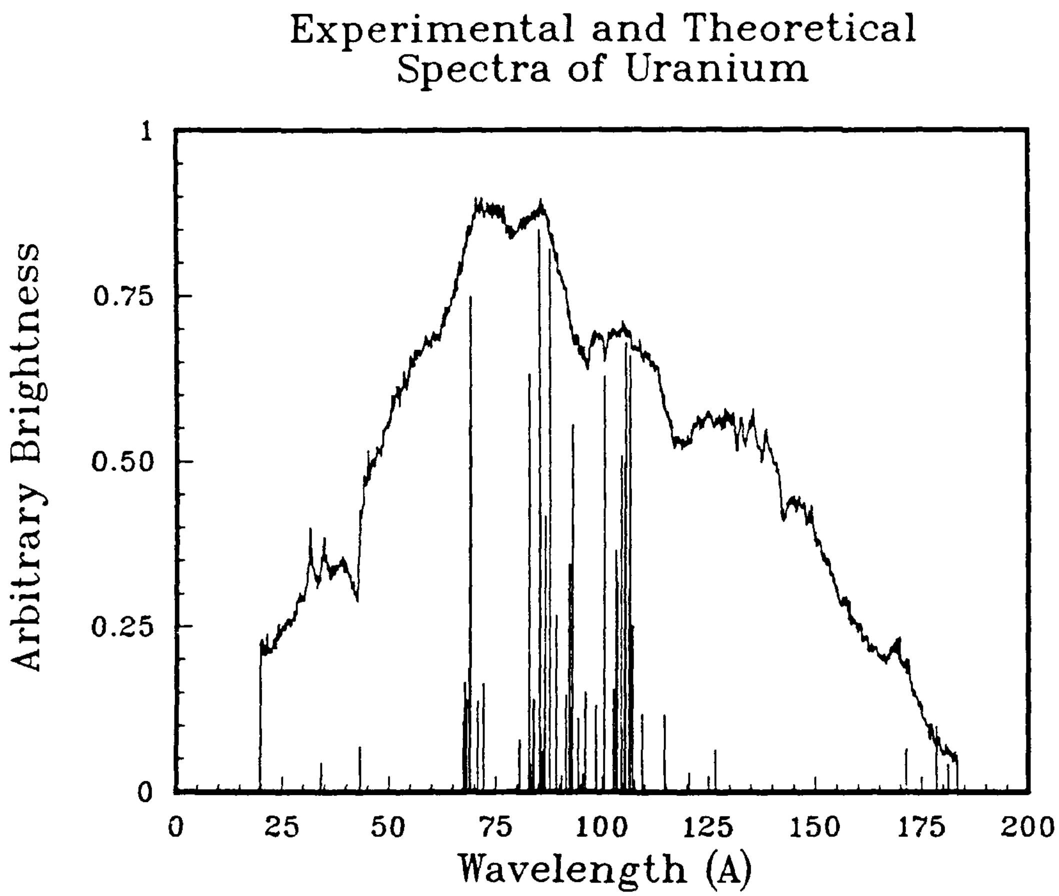
Experimental and Theoretical
Spectra of Uranium
Arbitrary Brightness
1
0.75
0.50
0.25
0
0
25
50
75
100
125
150
175
200
Wavelength (A)

Figure 1

Soft X-Ray Lasing of Li-like Ions in Laser-Produced Plasmas*

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Livermore, CA 94550

Several demonstrations of lasing in the extreme-ultraviolet (XUV) wavelength region have been successfully achieved using either collision or recombination pumping. The first successful demonstration was reported for the 3p-3s transitions in Ne-like selenium ions. Laser transitions at shorter wavelengths have also been achieved by using the 4d-4p transitions in Ni-like ions. These schemes are based on collisional excitation pumping, while in other successful schemes the upper lasing levels are populated directly by recombination processes.

However, lasing using resonant photo-pumping in the XUV wavelength region has not yet been demonstrated. In resonant photo-pumping, the emission from one ion is used to pump a transition in the ion of a different element. A successful resonance scheme requires a close overlap between the wavelengths of these transitions. This concept for achieving population inversions of ions in plasmas was first proposed by Vinogradove et al. and by Norton and Peacock. Although several schemes for achieving laser amplification in the sub 100 Å wavelength region have been proposed, the shortest wavelength at which significant gain has been measured by using photo-pumping is 2163 Å.

Recently, we propose a new laser scheme based on resonant photo-pumping of Li-like ions using Kα radiation. In particular, we consider the lasing plasma to be a thin iron foil and the pump radiation source to be an aluminum slab. Both of these targets are assumed to be irradiated by a high-power optical laser. The radiation from the $2p_{3/2}$-$1s_{1/2}$ transition of H-like aluminum ions in the source is used to pump the $5p_{1/2}$ and $5p_{3/2}$ levels of Li-like iron ions in the lasing plasma. Pumping of the 5p levels results in gains for the transitions between the n=5 and n=4 levels at the wavelengths of 70 Å.

In this paper we explore the possibility of designing a lasing medium in which population inversions between the n=5 and n=3 levels will occur in addition to that between the n=5 and n=4 levels. In our scheme, such transitions are between the 5f and 3d levels, giving the wavelengths at approximately 23 Å. A source with this wavelength which lies inside the "water window" is needed for biological holography. Our calculation shows that population inversions between the 5f and 3d levels will occur if the lasing plasma after being ionized to Li-like state can be rapidly cooled down to a lower temperature. This results from the decrease in the collisional excitation contribution to the 3d level populations and from the increase in the 5f level populations by direct recombination. Rapid cooling of the lasing plasma will, in addition, enhance the gains for the n=5 to n=4 transitions. We will discuss experimental designs which can be used to demonstrate laser amplifications in these transitions.

In this paper we also present other resonance line pairs which can be applied to resonantly photo-excite Li-like ion of different elements other than iron. Discussion on the possibility of achieving laser amplification in some of these schemes by using laser-produced plasmas as a lasing medium will be presented.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Time Development of Amplification of Na XI Hα line at 54.19Å

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Summary

Time-development of the gain coefficient of the Na XI Balmer-α (Hα) transition at 54.19Å is reported.

The XUV emissions along and transverse to the x-ray laser axis were analyzed with grazing incidence spectrographs which were coupled to x-ray streak cameras[1]. An example of the time-resolved spectrum of a NaF stripe target observed along the x-ray laser axis is shown in Fig.1. The Na XI Hα line is blended with Na IX $4p\,^2P^0$-$2s\,^2S$ and F IX $5d\,^2D$-$2p\,^2P^0$ lines. These blended lines were deconvolved using the time variations of the other lines belonging to the same atomic species.

The time-variation of the gain value of the Na XI Hα was deduced by two different methods. First the ratio of the Hα intensities along and transverse to the x-ray laser axis, and second the dependence of the Hα intensity on the target length were analyzed.

The experimental results will be compared with a numerical simulation in which an non-LTE average ion model is coupled with a hydrodynamic code.

References

1. Detailed irradiation conditions are reported by Y.Kato, et al., in another talk at this meeting.

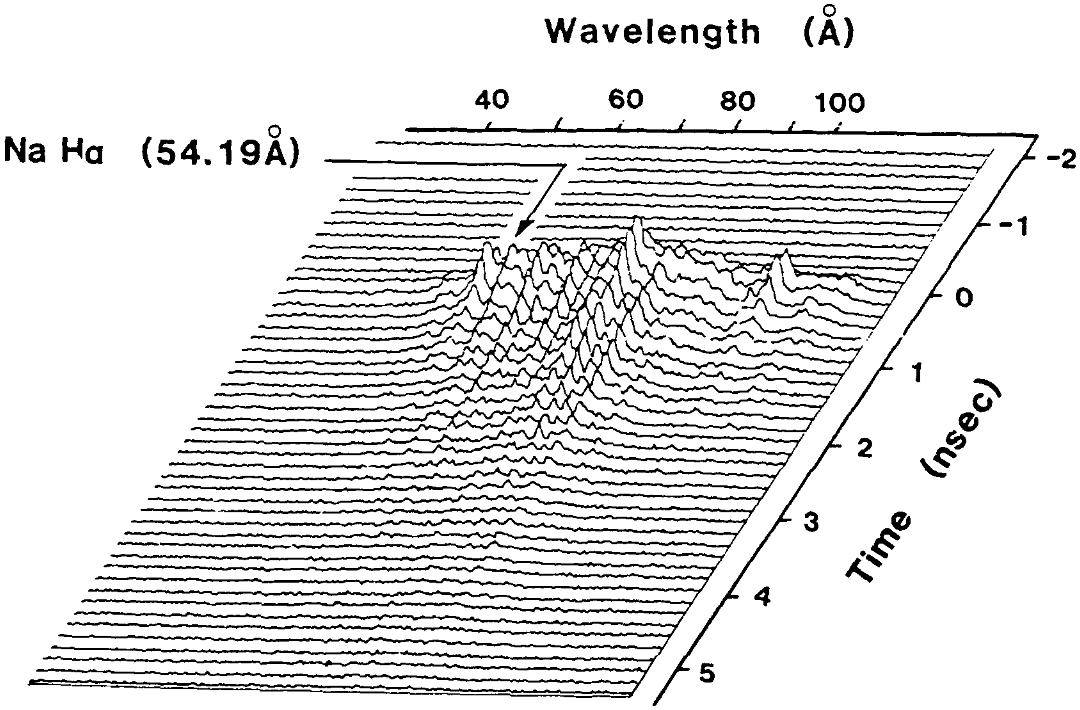

Fig. 1 Time-resolved spectrum of a NaF stripe target observed along the laser axis.

Gain Measurement on a 18.2nm Carbon Recombination Laser Produced by an Intense CO_2 Laser

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We present the gain measurement on recombination pumped XUV lasers. Figure 1 shows the target, the illumination geometry and the observation system. We used a cylinder-type target made of 30-μm thick parylene (C_8H_8) whose diameter is 3mm and the length is 3mm~12mm. The laser irradiates the 2500-A thick parylene foil attached to the end of the cylinder.The fully ablated plasma expands in the cylinder and is confined. The plasma generated at the cylinder wall by the scattered light is also confined in the cylinder, producing an almost uniform plasma without magnetic field[1]. The plasma length of more than 1cm was observed with x-ray pinhole camera. Then the almost fully ionized plasma is cooled by heat transport from the hot plasma to the wall.

The 400J in 50-ns CO_2 laser was focused with a spherical mirror (f/10) giving peak intensity of 3×10^{12} W/cm^2 on the target. We observed XUV spectra with a grazing incidence spectrometers in the axial and transverse directions of the lasing medium. A typical XUV spectra are shown in Fig.2. CVI 3d-2p line is enhanced in axial direction compared with CVI 6d-2p and 5d-2p lines. The maximum gain length product is calculated to be 2.4 at cylinder length of 12mm.

1. S. Suckewr et al., Phys. Rev. Lett.55,1753(1985).

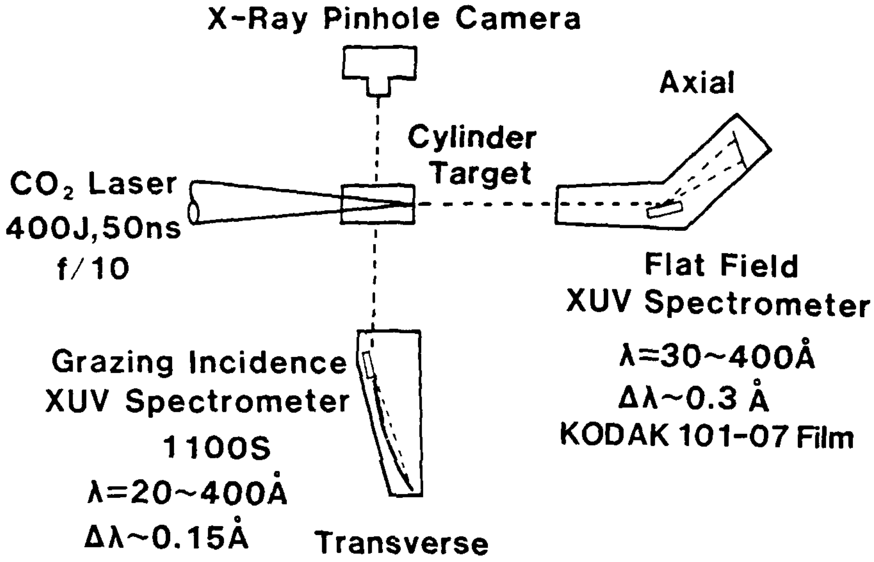
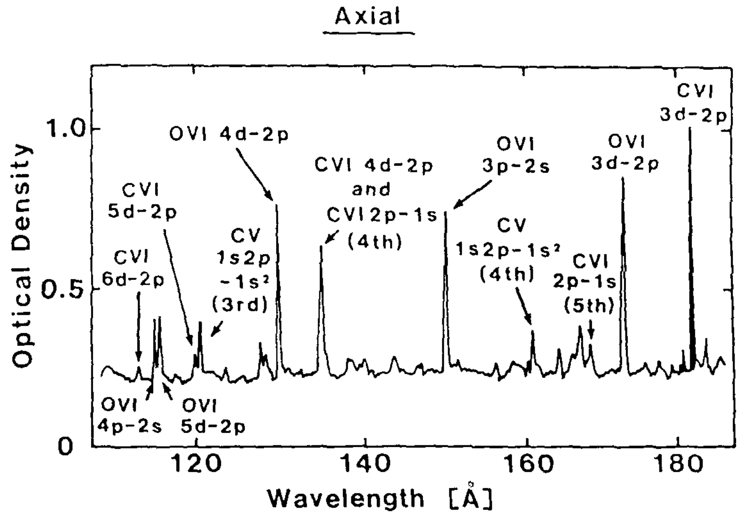


Fig.1 Schematic diagram of the target, the illumination geometry and the observation system.



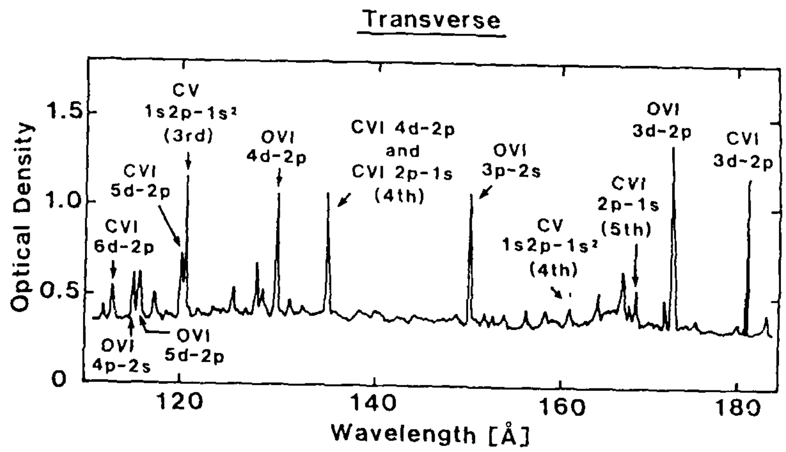


Fig.2 Observed axial and transverse XUV spectra. CVI 3d-2p line is enhanced in axial direction compared with CVI 5d-2p, 6d-2p lines.

Narrow Line X-Ray Transition Radiation in a Solid-State Superlattice: Material Selection

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The so called transition radiation is generated during electrons traverse the interface of two media with different dielectric constants. In an x-ray source based on superlattice [1] with many interfaces, the radiation is greatly enhenced around certain angle and spectral range. The spectral width of radiation can be further narrowed due to the narrow resonance of dielectric constants in the vicinity of atomic absorption edges of the constituting media for the superlattice. From the data available for all the elements in the periodic table, we can construct systems [2] with these elements which radiate at a wavelength between 10 Å to 100 Å with narrow line, i.e. in the vicinity of K, L, and M edges of these elements. Since the radiation power is proportional to the difference of dielectric constants, the alternating layers of the superlattice should be chosen in such a way that one of the media ("radiator") has its resonant frequency (i.e. frequency of one of its absorption edges) in the vicinity of the desired frequency whereas the other medium ("spacer") should be nonresonant in the same frequency range. Based on this consideration and the limitation of the length of the superlattice imposed by electron scattering and photoabsorption, we propose a material selection criterion for system consisting e.g. of 100 to 1000 alternating layers of C (as a spacer) and Ce (as a radiator) with the spatial period $\sim$ 50Å to 500Å and radiating narrow lines at wavelengths 10Å - 100Å using an electron beam energy $\sim$200 kev to a few Mev. This research is supported by AFOSR.

1. A. E. Kaplan and S. Datta, Appl. Phys. Lett. 41, 661 (1984).
2. C. T. Law and A. E. Kaplan, Opt. Lett. 12, 900 (1987).

TuC30-1

The Effectiveness of Diffraction Gratings at Grazing Incidence as Harmonic Scrubbers

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High power free electron lasers (FEL) produce significant amounts of radiation that are harmonics of the fundamental. For a device operating at 632.8 nm, harmonic production will occur at both UV and VUV wavelengths. Such energetic harmonic components present a substantial damage threat to optical coatings, and thus they need to be removed or at least substantially minimized. Current designs for FEL ring resonators use grazing incidence hyperboloids to handle the high power optical beams. Diffraction gratings could conceivably be placed in the surface of these grazers such that the harmonic wavelengths are dispersed and the fundamental remains virtually unperturbed. In this paper, we examine the merit of using grazing incidence gratings as harmonic scrubbers. Several grating designs are considered and their theoretical diffraction efficiencies calculated. In addition, the harmonic wavelength dispersive qualities of a grating rhomb, which is to be used as an outcoupler and sideband component filter in an FEL resonator currently under construction by the Boeing Aerospace Corporation, will be presented.

VUV Amplification of Neon-like Titanium Ion

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Hirosawa 2-1, Wako, Saitama 351-01, Japan. 0484-62-1111

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In short wavelength region, lasing of neon-like ion by the electron collisional excitation was already reported in short pulse experiment.[1,2] However, this pumping scheme is essentially a continuous excitation. And so longer pulse laser was used for this experiment. We observed amplified spontaneous emission of 3s-3p neon-like titanium ion at 50.77 nm in longer pulse experiment compared with others. We used titanium slab as a target and the glass laser was focused on a target as a line shape of 18 mm length and about 50 μm width. The power of laser needs to be 50 J in order to produce the neon-like ion of titanium. We measured the intensity of the line spectra of 3s-3p j=1-2 transition at 50.77 nm along the length direction by using a Seya-Namioka type monochromator which has a resolution of 0.2 nm. When the observed length of the plasma increased, the intensity of 50.77 nm grew up well, but the intensity of another wavelength near 50.77 nm did not change. We can conclude from this measurement that the spontaneous emission was amplified along a length direction. Cavity experiment can apply for this plasma to get high output power, because our glass laser has long pulse duration.

1) D. L. Mattews et al., Phys. Rev. Lett., 54, 110(1985).

2) T. N. Lee et al., Phys. Rev. Lett., 59, 1185(1987).

Investigations of Multiphoton Excitation and Ionization in a Short Range Potential

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Princeton, New Jersey 08544, U.S.A.

A proximate sequence of delta function confining potentials can be viewed as an approximation to a continuous potential. Indeed, a single delta function has been extensively investigated as a prototypical model of short range potentials in investigations of multiphoton ionization. We extend previous work to the systematic analysis and numerical evaluation of the time evolution of the state of a single charged particle in a system consisting of a multiple delta function confining potential and a finite strength, nearly periodic externally imposed electric field. The potential is constructed so as to allow several bound states in addition to continuum states in the absence of external preturbations. For a single bound state, we compare our results for the ionizaton rate with those of Keldysh and others. In the case of two bound states, we calculate both excitation and ionization rates for few and for many photon processes. In the limit of large minimum number of photons required for excitation or ionization, we apply techniques asymptotic in the large photon number to investigate the time evolution.

NOVEL GRAZING INCIDENCE OPTICS FOR SYNCHROTRON X-RAY LITHOGRAPY.

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± SAG, UCB, Berkeley

By replacing the scanning mirror in a synchrotron lithography beamline with a fixed saddle-toroidal mirror, wafer-size fields can be exposed without any moving parts in the high vacuum section of the beamline or the need to move the electron beam in the storage ring.

The saddle-toroid - a toroid with concave minor radius and convex major radius - does not appear to have been used in optical design before, possibly because it appears difficult to make. Bending sections of tubular glass has been shown to be a satisfactory and inexpensive way of making toroidal mirrors [1], and provides an easy means of producing saddle-toroids.

We will present the results of ray tracing, done both at IC and UCB that shows the saddle-toroid to be a satisfactory alternate to the scanning cylindrical mirror, as used in beamlines like the IBM U-6 line at the NSLS [2], while having similar manufacturing costs. The great advantage is not having the worry of a moving part in a high vacuum section, which could result in costly downtime in a commercial exposure beamline.

Two-mirror designs are also considered, and show potential to improve on single mirrors in flux throughput and in having an horizontal beamline.

References.

1. M. Faldon et al, Applied Optics,July 15th 1988.
2. J. Warlaumont, Nuc.Inst. and Meth. in Physics Res A246(1986) 687-694

X-Ray Lasers Research at Physics International

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San Leandro, CA 94577

Z-pinch implosion onto coated targets and two separately contollable Z-pinches are being used to investigate recombination and photo-pumped X-ray laser schemes.

Diffraction Contrast of the Bragg-Fresnel Lens in White and Monochromatic Radiation

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G. Materlik, A. A. Snigirev
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USSR Academy of Sciences
142432 Chernogolovka, Moscow
USSR

Studies have been made of imaging by a Bragg-Fresnel Lens (BFL) in the white and monochromatic spectrum of synchrotron radiation. A phase BFL has been experimentally realized.

Fresnel Multilayer X-Ray Elements

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Institute of Microelectronics and Materials

USSR Academy of Sciences

142432 Chernogolovka, Moscow

USSR

A model of focusing elements for x-ray optics based on profiled multilayer reflection structures of x-ray optical elements exhibit the properties of volume holographic lattices.

Fourier–Transform Holographic Microscope

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MCR Technology Corporation

P.O. Box 10084, Chicago, Illinois 60610–0084

(312) 326–5007

SUMMARY

In the arrangement considered, the x–ray beam illuminates both the reference scatterer and the specimen, which can be simultaneously dropped into the path of the beam or statically mounted on a very thin foil. Charge–coupled devices are used for recording, their output being digitized and linked directly to a computer.

A critical element of this design is the reference scatterer, which is a grazing incidence reflecting sphere. A survey of the periodic table shows that nickel is the optimum reflector near the carbon K–edge while osmium is optimum near the nitrogen K–edge. Both elements are sufficiently reflective to make this form of microholography feasible. It has been found that nickel spheres in the 2–10 μm range can be fabricated to a very high degree of surface smoothness and roundness, sufficient for this application.

A computer algorithm for reconstructing Fourier–transform holograms, including corrections to the phase shift and the amplitude for reflection from the spherical scatterer, is described. The results of a numerical experiment demonstrate the efficacy of this algorithm and clearly indicate that the extension to practical x–ray holography is feasible.

AMPLIFIED SPONTANEOUS EMISSION AND SUPERFLUORESCENCE IN HOT PLASMA X-RAY LASERS - A POSSIBLE EXPLANATION TO THE WEAK LASING OF THE $(1/2,1/2)_0 \rightarrow (1/2,1/2)_1$ LINES

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Summary

The basic conditions for Amplified Spontaneous Emission (ASE) and Superfluorescence (SF) in hot plasma X-Ray laser experiments(1) are examined on the basis of the well-known Schuurmans-Polder(2) and Arecchi-Courtens(3) criteria. It is shown that in the experiments performed at LLNL(1) the lasing lines $(1/2,1/2)_0 \rightarrow (1/2,1/2)_1$ in Neon-like ions fulfill the condition for SF. This is due to collisional narrowing and lack of dephasing collisions for these lines(4) . The steady state of ASE ,in which spontaneous emission from single atoms is amplified as it propagates down the long dimension of the system, is not established . Instead ,the system breaks into hundreds of small cooperation volumes of size $l = c\tau_R' \equiv$ **450 μm**. Each of which superfluoresces into random directions in many short and intense pulses of duration $\tau_R' \equiv 1.5$ psec with random delay times around a mean value of $\tau_D' = 76$ psec. A simple estimate shows that although the integrated output intensity emitted in all directions is high ,the forward emission is weaker than the value expected on the basis of ASE calculations. Moreover, the intensity does not grow exponentially with the length of the system . This result may explain the yet unresolved puzzle of the very weak gain as compared to the theoretical predictions for these transitions in the LLNL experiments.

References

1) a)D. L. Matthews et. al. Phys. Rev. Letters 54 ,110 (1985)

2)M. F. H. Schuurmans and D. Polder, Physics Letters 72A 306 (1979)

3) P. T. Arecchi and E. Courtens, Phys. Rev. A 2 1730 (1970)

4)H. R. Griem Phys. Rev. A 33 ,3580 (1986)

Continuous Anti-Stokes Raman Laser Operation

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Investigations on cw anti-Stokes Raman laser schemes, allowing the conversion of infrared or visible laser radiation into the UV and VUV spectral range is reported. As active material argon ions, excited in a commercial argon ion laser are considered. Up to now, conversion of 648.3-nm radiation into 437.5-nm radiation has been achieved, with a conversion efficiency of more than 20% and a maximum output power of 150 mW. Details of the process and some future developments will be discussed.

PROPOSED METHOD FOR THE MEASUREMENT OF THE SPATIAL COHERENCE OF LABORATORY X-RAY LASERS*

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University of California
Livermore, CA 94550

Measurement techniques for the determination of the spatial coherence of laboratory x-ray lasers are discussed. These techniques utilize the coherence dependent interference patterns from double slit and multiple slit arrays. The selenium x-ray laser with a wavelength of 208 Å used as an example. The x-ray optics necessary for this are discussed. Possible experiments on optical analog ASE sources such as dye laser amplifiers are also discussed.
*This work was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

NOTES

WEDNESDAY, SEPTEMBER 28, 1988

NAUSET III

8:30 AM–10:00 AM

WA1–4

SESSION 8

Malcolm R. Howells, Lawrence Berkeley Laboratory,
Presider

ULTRAHIGH PEAK POWER PULSES PRODUCED BY CHIRPED PULSE AMPLIFICATION

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Chirped Pulse Amplification (CPA)[1] allows the amplification of short laser pulses in amplifying media with good storage properties (low transition cross section) like Nd:glass[1,2] or Alexandrite.[3-4] In these media, straight amplification cannot be performed well, because of the large input flux necessary to reach efficient energy extraction. This condition leads to unacceptable peak powers. To minimize the intensity effects, the pulse is stretched, amplified, and recompressed. This technique allows an efficient energy extraction while maintaining a good beam quality. The intensity is kept below the onset level of small-scale focusing, occurring when values of the B integral are larger than three. We recall that the B integral is given by the expression.

$$B = \frac{2\pi}{\lambda} \int_{o}^{L} n_2 \, I(z) dz.$$

where λ is the laser wavelength, n_2 the nonlinear index of refraction, I(z) the laser intensity, and L the optical element lengths.

Using this technique, we have been able to amplify single picosecond pulses to the joule level using a table-top system. The beam divergence has been measured to be two times the diffraction limit at the output of the system.

A 50 ps pulse is produced by a cw mode-locked YLF laser. The pulses are coupled into a single mode optical fiber and are spectrally broadened by self-phase modulation and stretched by group velocity dispersion. Additional stretching up to a nanosecond can be obtained by using a pair of gratings between the focal points of telescope.[5-6] The pulses are then injected into a regenerative amplifier, which brings their energy from the nanojoule to the millijoule level. The regenerative amplifier output is successively amplified to 100 mJ and 1 J by two Nd:glass amplifiers of 9 mm and 16 mm diameters respectively. After amplification, the pulses are recompressed to 1 ps by a double-pass grating-pair compression system. At this point the laser energy 0.6 J.

We have shown that amplification over nine orders of magnitude can be achieved with this technique. Presently, we are exploring the possibility of scaling up the pulse energy with Nd:glass systems to the 1 kJ level, while maintaining the pulse duration of 1 ps. Also, we will describe current efforts based on CPA to produce ultrahigh peak power pulses in the picosecond domain with material such as Ti:sapphire or Alexandrite.

ACKNOWLEDGMENT

These authors wish to thank Lawrence Livermore Laboratory for the loan of the Nd:YLF laser and the diffraction gratings, ENSTA/Ecole Polytechnique for the loan of the Nd:Glass amplifier head, and Corning Glass Works for the single mode optical fiber.

This work was supported by by the United States Air Force Office of Scientific Research under contract F49620-87-C-0016 to the Ultrafast Optical Electronics Center at the Laboratory for Laser Energetics of the University of Rochester; by SDIO/IST and managed by ARO under contract #DAAL03-86-K0152; and by the Laser Fusion Feasibility Project at the Laboratory for Laser Energetics which has the following sponsors: Empire State Electric Energy Research Corporation, New York State Energy Research and Development Authority, Ontario Hydro, and the University of Rochester. Such support does not imply endorsement of the content by any of the above parties.

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4. M. Pessot, J. Squier, P. Bado, G. Mourou, and D. Harter, submitted to IEEE J. Quant. Electron.
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Multiterawatt Excimer Laser System

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Summary

A multiterawatt excimer laser system has been almost completed in our institute. This system consists of an oscillator stage, the front end stage with two high repetition rate lasers, two wide aperture ($7x7cm^2$) discharge amplifiers, and an electron beam-pumped amplifier with a cross section of $23x23cm^2$. Recently peak powers of 1 TW and 3~5TW have been achieved in XeCl and KrF respectively.

As an oscillator stage, the synchronously pumped dye laser was operated at 616nm for XeCl, and at 745nm for KrF respectively. The pump source was a cw mode-locked YAG laser with a fiber-grating compressor. A single pulse among the pulse train was amplified in a four-stage dye amplifier chain, which was pumped by a 5.5-ns, 75-mJ XeCl laser. Amplified subpicosecond pulses were frequency converted to the XeCl and KrF wavelengths. UV pulses were amplified by the two lasers with an aperture of $2x1.5cm^2$. At this stage, the pulse width of XeCl was measured to be 310fs. The pulse width of KrF was measured by a newly devised method which used three-photon fluorescence of the XeF C-

A transition. The shortest pulse width was 220fs, while the typical pulse width was 300fs. In XeCl, two wide aperture ($7x7cm^2$) amplifiers were employed to scale up a peak power to 1TW. The Amplified Spontaneous Emission (ASE) was carefully suppressed by using an appropriate spatial filter between amplifiers and relatively low gain operation of 4.8%/cm. The output energy was 300mJ with an ASE level of 3%. The resulting peak power is 1TW with the pulse width of 310fs.

In KrF, one $7x7cm^2$ amplifier and an electron beam-pumped amplifier were employed in the double pass configuration. The experiment is now under progress. Until now the output energy of 1.5J was obtained with an ASE content of 1.8%. We used a 250mm-diameter CaF_2 as an output window because two photon absorption is considerable in a fused quartz. In the KrF experiment, linear dispersion and self phase modulation should be taken into account to estimate the final pulse width. We tentatively estimate the pulse width of 300~500fs. Then, the present peak power corresponds to 3~5TW. The process of pulse width broadening will be analyzed by a single shot measurement with the three-photon fluorescence method. The further improvement in a peak power and the limiting factors will be reported in the meeting.

First Images From the Stanford Tabletop Scanning X-ray Microscope

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Summary

We have constructed a scanning soft x-ray microscope which uses a laser-produced plasma as the soft x-ray source and normal incidence multilayer coated mirrors in a Schwarzschild configuration as the focusing optics. The microscope is very compact with the complete system, including the laser, fitting entirely on a single optical table. The microscope is shown schematically in Figure 1 and a photograph of the system is shown in Figure 2.

The present operating wavelength is 140Å, determined by the bandpass of the multilayer coatings used in the x-ray focusing optics. Our present mirrors are coated with Molybdenum/Silicon multilayers and have a measured peak reflectance per mirror of over 50% at 140Å with a 7Å bandwidth. The Schwarzschild objective produces an image of the source aperture demagnified by a factor of 100. Using a 30μ pinhole source aperture we have measured a microscope resolution of under 1μ.

The laser used to form the plasma x-ray source is a commercial Quanta Ray Nd:YAG laser which operates at 10Hz with a pulse length of 8 ns and pulse energies of up to 800mJ at 1.06μ. With only 200 milliwatts of average laser power, and again using the 30μ pinhole source aperture, we obtain an average x-ray flux through the focus of the microscope of 10^5 photons per second.

We will describe the significant features of the microscope and present initial test results, including images of artificial microstructures.

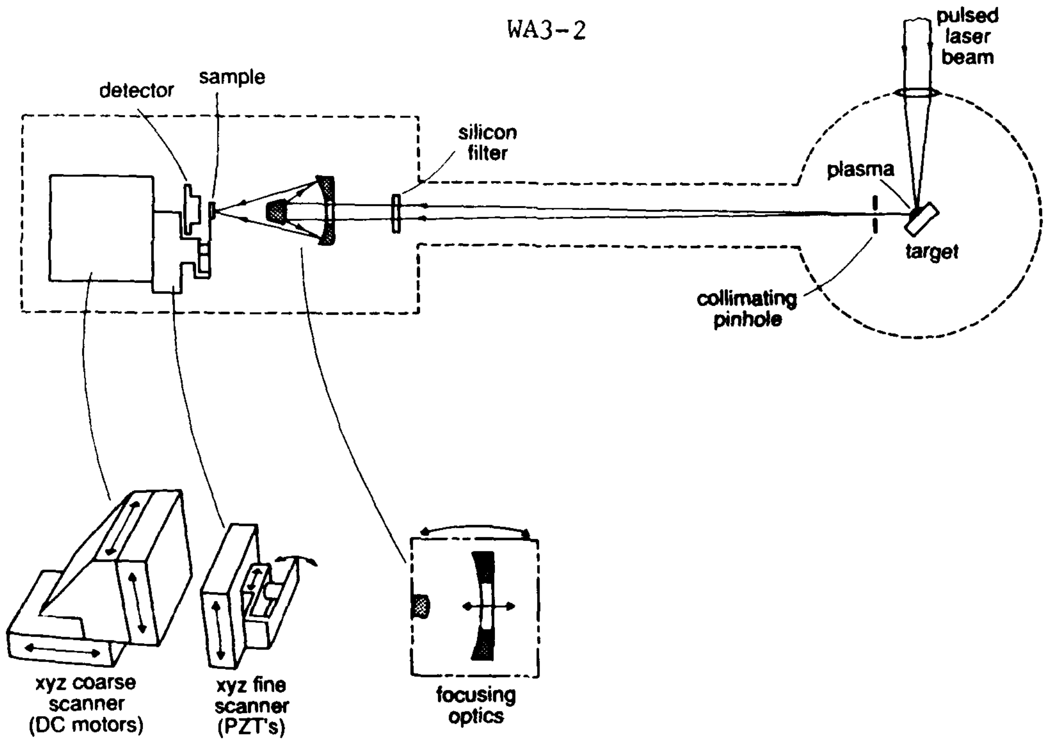

Figure 1 A schematic showing the arrangement of the microscope components

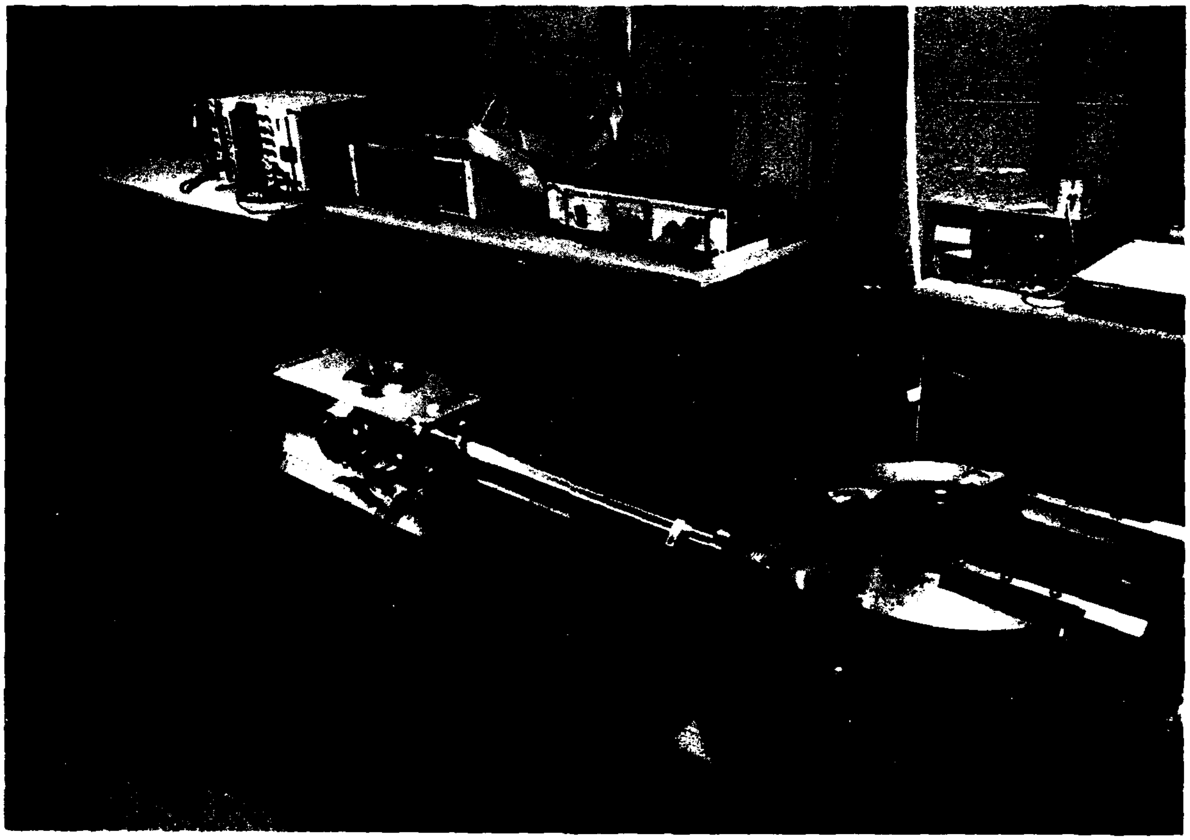

Figure 2 A photograph showing the complete microscope. The target chamber for the laser-produced plasma is in the lower right corner. The laser is just visible at the top left of the optical table. The boxcar integrator, alignment and stage control electronics, and MCP power supply sit on the instrumentation tables above the optical table.

Progress in Optical Reconstruction of Submicron X-Ray Holograms

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The most direct way to decode photographically recorded holograms (e.g., on resists) is the optical reconstruction process, which presents two main advantages: 1) there is no intermediate (noise generating) step between recording and reconstruction; 2) from the user's point of view the process is very simple.

However, optical reconstruction is submitted to some limitations. The first one is fundamental; the resolution cannot be better than $1_c/2$ (1_c: reconstruction wavelength). Therefore, to reach high resolution, one must use shorter wavelengths, which are limited to 200 nm if in-air optical techniques are used. a second limitation arises from the coherent diffusion noise by optical surfaces. To our opinion, it can be significantly reduced by using specially prepared lenses (coating and cleanness), and working in a dust free environment. The third limitation is set by the holographic process itself, through holographic aberrations. Analysis of the different reconstruction geometry indicates two possible strategies, both including correction methods.

Reconstruction with high primary magnification allows direct image observation through low resolution devices (e.g., camera). In such a case, the desired object resolution is obtained from the reconstruction wavefront numerical aperture, which should be high when object resolution is close to the $1_c/2$ limit.

When reconstruction at low magnification is used (typically 2 or a few units), the necessary aperture is split between the reconstruction wavefront generation and the image observation system, making optics easier to produce.

In both cases, field and aperture aberrations need to be corrected when field and resolution are significant. A simple third order correction, using a parallel face glass plate, allows working up to .5 NA over a 20 to 30 um field. Experiments were performed which showed the efficiency of the method. We now investigate a high order correction, in order to work at high NA. (In principle, a parabolic correction should provide a quasi perfect correction, but can not be implemented at NA aperture greater than .7.) In fact computing and making a special lens working on axis, at one wavelength down to 200 nm should not be more difficult than producing a classical high power microscope objective.

Finally, extension of these results to the vacuum UV range was examined. In this wavelength range, mirror objective should be used, instead of refractive ones. Since diffraction limited quality is needed, only on-axis systems are possible, which means that a central obturation occurs. Well corrected optical formulae do exist, but they do not work at high aperture. In that context, the low magnification reconstruction geometry could be interesting. For instance at l_e=125 nm, resolution close to 100 nm can be obtained with only a .3 NA. This is not an academic possibility: a diffraction limited, Schwartzschild objective (.25 NA), working at this wavelength, has been produced at the Institut d'Optique (for other purposes).

Using even lower wavelength is a technological problem. In particular, the shape accuracy of optical surfaces, which is related to the wavelength, becomes very difficult to obtain.

NOTES

WEDNESDAY, SEPTEMBER 28, 1988

NAUSET III

10:30 AM–12:00 M

WB1–3

SESSION 9

Harvey M. Rarback, Brookhaven National Laboratory, *Presider*

X-ray holographic microscopy: improved images of zymogen granules

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Summary

Gabor holograms recorded on photoresist using soft x-rays from an undulator have demonstrated the technique's possibilities for recording high resolution information [1,2]. However, our previous reconstructed images have been of low quality [3]. We have now obtained higher quality reconstructed images of air-dried rat pancreatic zymogen granules which exhibit sub-1000 Angstrom resolution, which are similar to other soft x-ray micrographs of granules, and which yield information not available in 100 KeV electron or optical images of similarly prepared specimens.

Recorded holograms are "developed" to convert the incident x-ray exposure into a surface relief pattern. The metal-shadowed hologram is then enlarged using a transmission electron microscope, and the resulting film negative is digitized with a microdensitometer. The digitized hologram is reconstructed by an algorithm that mimics the optical reconstruction process; the numerical reconstruction route opens up the possibility of using non-linear reconstruction schemes in the future. The technique offers a technologically achievable route to obtaining high resolution images of hydrated biological specimens; usable resolution and image quality are ultimately limited by the low visibility of high spatial frequency hologram fringes.

1. M. Howells, C. Jacobsen, J. Kirz, R. Feder, K. McQuaid, and S. Rothman, "X-ray holograms at improved resolution: a study of zymogen granules", Science **238**, 514-517 (1987).

2. D. Joyeux, S. Lowenthal, F. Polack, and A. Bernstein, "X-ray microscopy by holography at LURE", in D. Sayre, M. Howells, J. Kirz, and H. Rarback, eds., **X-ray Microscopy II** (to be published by Springer-Verlag, Berlin, 1988).

3. C. Jacobsen, J. Kirz, M. Howells, K. McQuaid, S. Rothman, R. Feder, and D. Sayre, "Progress in high-resolution x-ray holographic microscopy", in D. Sayre, M. Howells, J. Kirz, and H. Rarback, eds., **X-ray Microscopy II** (to be published by Springer-Verlag, Berlin, 1988).

Amplitude- and Phase-Contrast X-Ray Microscopy

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Summary

X-ray photons in the wavelength range of about 0.5 - 5 nm are best suited for x-ray microscopy. In the wavelength range $\lambda \geqslant 2.5$ nm the absorption cross sections are about one order of magnitude smaller than the cross sections for electrons in the energy range in which electron microscopy is performed. These absorption cross sections for soft x-rays are appropriate for high resolution investigation of biological specimens in their natural state having a thickness of up to about 10 micrometer. Especially interesting is the wavelength range between the K absorption edges of oxygen (λ = 2.34 nm) and carbon (λ = 4.38 nm) because in this wavelength range the radiation is weakly absorbed by water but strongly absorbed by organic matter resulting in a rather good amplitude contrast of wet specimens.
For many elements and wavelengths phase shift is the dominating process and not photoelectric absorption. That means that phase-contrast x-ray microscopy can be performed with the following advantages compared to x-ray microscopy modes using amplitude contrast: For wavelengths larger than the carbon K-edge, the amplitude contrast of organic material surrounded by water is very low. To the contrary, for wavelengths slightly larger than CK_{α} the phase contrast of such an object is high. Even in the wavelength range between the K-edges of carbon and oxygen (water window) wavelengths are found for which imaging in phase contrast is better concerning contrast and dosage compared to amplitude contrast imaging.
In addition, imaging with phase contrast can be extended to wavelengths of about 0.5 nm with a dosage comparable to that necessary for imaging with amplitude contrast in the water window. The last point may be of practical importance in future work because with shorter wavelengths thicker specimens can be investigated than up to now.
X-ray microscopy experiments performed in amplitude- and phase-contrast at the electron storage ring BESSY in Berlin will be discussed.

References:

1. X-Ray Microscopy, eds. G. Schmahl and D. Rudolph, Springer Series in Optical Sciences Vol. 43, Springer Verlag (1984)
2. X-Ray Microscopy - Instrumentation and Biological Applications, eds. P.C. Cheng and G.J. Jan, Springer Verlag (1987)
3. X-Ray Microscopy II, eds. D. Sayre, M. Howells, J. Kirz and H. Rarback, Springer Series in Optical Sciences, Springer Verlag (1988), in press

X-Ray Holography: X-Ray Interactions and Their Effects

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We summarize a theoretical study of the interactions of x rays with a biological sample during the creation of a hologram. We have reexamined the primary process of x-ray scattering by objects within an aqueous environment. Based on optical scattering theory, we report apparently accurate and simple formulae for cross-sections, in terms of the x-ray index of refraction of the matter. For the case of a protein sphere in water, we present the x-ray penetrability, the incident fluence to scatter a desired number of photons, and the associated dose absorbed by the sample. Based on this information, the choice of an optimal wavelength for x-ray holography is discussed.

The problem of the motion resulting from the energy absorbed during a short exposure is described. We explore the thermalization of x-ray energy, and the equation of state and hydrodynamics of the heated material. The possibility of using very short exposures in order to capture the image before motion can compromise the resolution is explored.

The impact of these calculations on the question of the feasibility of using an x-ray laser for holography of biological structures is discussed.

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

NOTES

WEDNESDAY, SEPTEMBER 28, 1988

NAUSET III

2:00 PM–3:00 PM

WC1–4

SESSION 10

Bob D. Guenther, Army Research Office, *Presider*

Narrowband Tunable VUV/XUV Radiation Generated by Frequency Mixing of Pulsed and CW Laserradiation

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Four- and six-wave mixing of pulsed and cw laser radiation in gases generates coherent radiation in the spectral region of the VUV/XUV at 60 - 200 nm.[1] Recently considerable experimental progress has been achieved towards the development of powerful coherent VUV/XUV light sources based on these nonlinear optical methods.

The third-order resonant sum- and difference frequency mixing in Kr, for example, generates broadly tunable VUV/XUV radiation at wavelengths in the region of 70 - 200 nm. Because of the high efficiency, the reliability, and the experimental simplicity the conversion in Kr has the potential to become a standard method for the generation of frequency tunable VUV/XUV light.[2]

The frequency mixing of cw laser radiation produces frequency stable VUV radiation (at 140-200 nm) of narrow spectral width ($\Delta E<3\cdot 10^{-5}cm^{-1}$).

In contrast to the extensive experimental investigations the theoretical treatment of frequency mixing in gases was restricted mostly to special conditions (like homogeneous medium, equal confocal parameters, focii of the laser beams located at the same position, etc.)[3].
Using the integral method to solve the inhomogeneous Maxwell equation we were able to perform a rigorous theoretical analysis of the frequency mixing in gases.[3] This analysis provides a general description of optical frequency mixing of n different laser beams in gases of arbitrary density distribution. Besides the conversion in pulsed gas jets, the frequency mixing using Gaussian laser beams with different confocal parameters and the

frequency conversion of crossed beams have been analyzed in detail. These results provide new, important information for the optimization of the conversion efficiency. Possible improvements indicated by theory exceed one order of magnitude. First experiments confirm these predictions.

Because of the enhanced efficiency frequency mixing of pulsed radiation generated with laboratory-size laser systems will produce tunable VUV light of narrow spectral width ($E<10^{-2}cm^{-1}$) and pulse powers of at least 10-50 KW.

1 R. Hilbig, G. Hilber, A. Lago, B. Wolff, and R. Wallenstein Comments At.Mol.Phys. part D18, 157 (1986), and references therein

2 G. Hilber, A. Lago and R. Wallenstein, JOSA B4, 1753 (1987)

3 A. Lago, G. Hilber, and R. Wallenstein, Phys.Rev.A 36, 3827 (1987), and references therein.

ULTRAHIGH RESOLUTION VUV-XUV LASER:
APPLICATION TO THE HYPERFINE STUDY OF KRYPTON

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and
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We have developed a near-transform-limited intense laser spectrometer that is broadly tunable from 74nm to >150nm for ultrahigh resolution studies in this region. Construction of the source is based on a pulse-amplified single-mode dye laser system. The vuv bandwidth is measured to be 210 MHz. This laser source combines the versatility of a synchrotron source, the simplicity of a "table-top" system and the spectral and temporal purity of a laser light source.

Utility of this source has been demonstrated in a high-resolution study of the 4p-5s[3/2], -5s'[1/2], -6s[3/2], -6s'[1/2] and -7s[3/2] J=1 transitions of Kr spanning the spectral region from 123.6nm to 94.5nm. The ns states (n=5,6,7) were studied using the 1 + 1 resonant multiphoton ionization technique where the ns states form the resonant intermediate. Calibrations using known I_2 frequencies yield an improved absolute calibration of the ^{86}Kr 4p-ns transition frequencies by more than an order of magnitude. The hyperfine parameters for the 5s[3/2] level are in very good agreement with those measured using interferometric techniques. This is the first time that determination of hyperfine parameters for the other levels are possible. From these parameters we find that for n=5 the jj quantum numbers are good to 99.63 $\pm$ 0.06% while for n>5 the jj quantum numbers are good to at least 99.99%.

Isotope shifts of ~30 MHz/amu for the most abundant isotopes were obtained. These shifts can be explained by the simple Bohr shift and the specific mass effect. Lifetimes for the n=6 and 7 states which are longer than the duration of our laser pulse can also be measured. Our lifetime results differ substantially from calculations reported in the literature. These results should form a basis for the atomic theorists to obtain an improved set of wavefunctions for Kr.

The laser source used in this study should be applicable to ultrahigh-resolution studies of other atomic and molecular systems.

This work is supported by the Chemical Sciences Division, Office of Basic Energy Sciences of the U.S. Department of Energy.

High Efficiency, Scalable, 130 nm Coherent Source by Four-Wave-Mixing in Hg Vapor.

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and

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Recent experimental results[1] and calculations[2-4] have shown that two-photon-resonant sum-frequency mixing in Hg vapor is an efficient process for the production of coherent vacuum ultraviolet radiation at 130 nm. Efficient conversion is possible with relatively low input intensities (5-10 MW cm^{-2}) and collimated (non-focused) beams. The collimated geometry is very important because it allows tractable modeling, area scaling of the processes to higher energies per pulse and high optical quality of the output wave. Using the collimated geometry we have demonstrated 5 percent conversion efficiencies with VUV output energies at 130 nm of 1.1 mJ in 2.2 ns pulses.

The energy level diagram for 130 nm generation in mercury is shown in Fig. 1. The input frequencies are determined by the requirements that the process be index matched in pure Hg vapor and also be two-photon resonant with the 7^1S state. For the process shown in Fig. 1, the nonlinear susceptibility is quite large,[4] leading to efficient conversion using relatively low input intensities and a 1 meter cell containing a few torr of Hg. The efficiency is limited by various processes. For exact two-photon resonance these include modification of the two-photon resonant 7^1S level by intense light generated by amplified spontaneous emission from the 7^1S level to the 6^1P levels, and by a quantum mechanical interference effect arising from the two alternate pathways from the ground state to the two-photon resonant state[4]. For small detuning from the two-photon resonance, nonlinear refractive indexes and hyper-Raman gain appear to be the dominant efficiency limiting processes. A quantitative model of the mixing process based on steady state nonlinear response of the Hg atoms and numerical integration of Maxwell's equations leads to predicted efficiencies of about 5% for exact resonance and slightly higher efficiencies for a slight detuning from two-photon resonance.

Ring dye lasers operating at 765, 810, and 777 nm followed by several stages of pulsed dye and solid state Titanium Sapphire laser amplifiers are used to produce the fundamentals of the wavelengths used in the four-wave-mixing process. The 255 nm beam shown in Fig. 1 is the third harmonic of 765 nm while the 405 nm beam is the second harmonic of the 810 nm beam.

Measurements of mixing efficiency, beam quality, and bandwidth have been obtained and will be presented along with theoretical predictions.

References

1. C.H. Muller, III, D.D. Lowenthal, M.A. DeFaccio, and A.V. Smith, "High efficiency, energy scalable, coherent 130 nm source by four-wave-mixing in Hg vapor," to be published in Optics Letters.

2. A.V. Smith, G.R. Hadley, P. Esherick, and W.J. Alford, Opt. Lett. 12, 708 (1987).

3. A.V. Smith and W.J. Alford, "A practical guide for 7S resonant frequency mixing in Hg: Generation of light in the 230-185 and 140-120 nm ranges," J. Opt. Soc. Am. B., Vol. 4, p. 1765, 1987.

4. A.V. Smith, W.J. Alford, and G.R. Hadley, "Optimization of two-photon resonant four-wave mixing: Application to 130.2 nm generation in Hg vapor," to be published in J. Opt. Soc. Am. B.

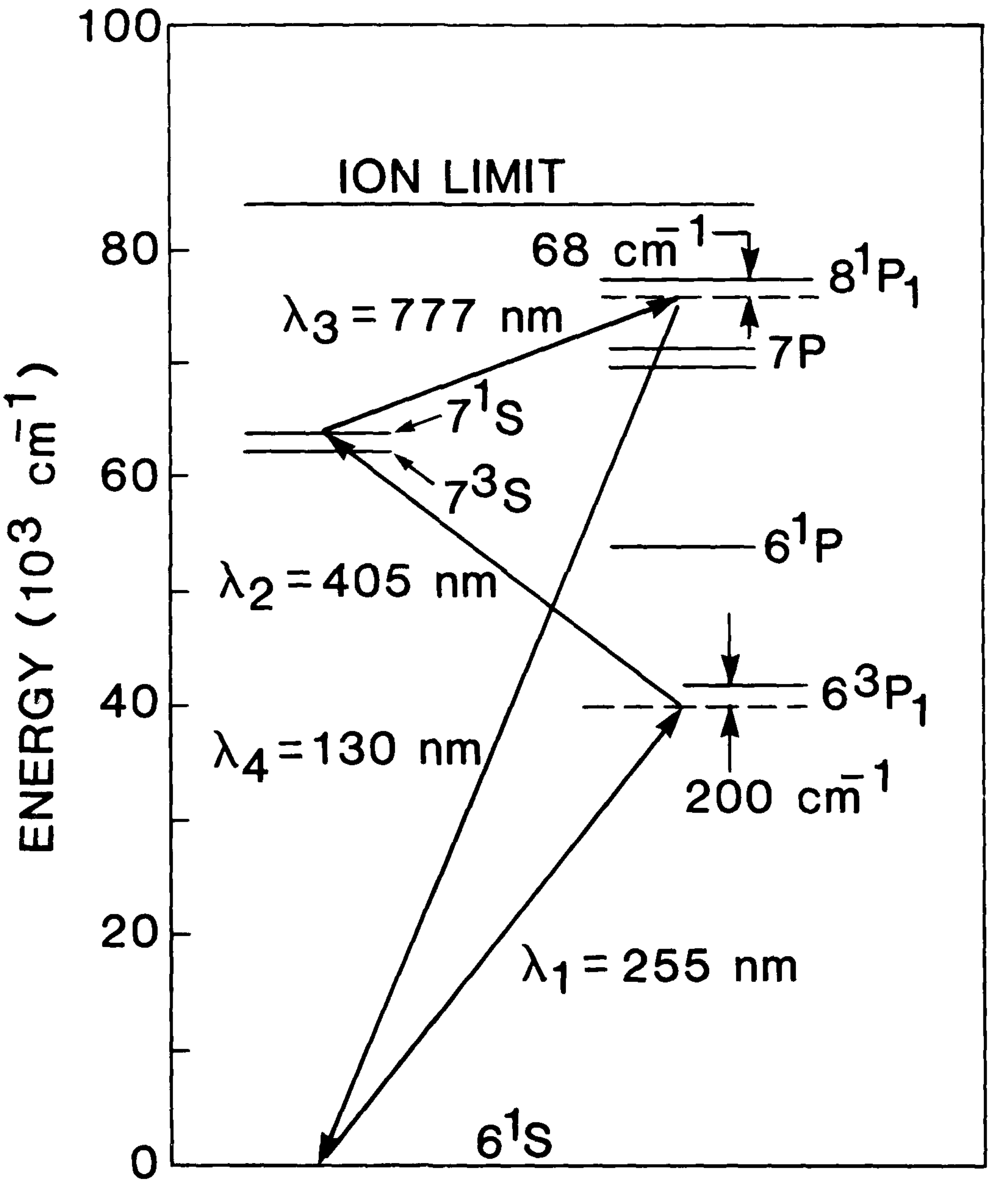

Fig. 1. Simplified energy level diagram for Hg showing mixing scheme for the production of 130 nm radiation.

Intense Coherent Radiation in the VUV and XUV Region with Electron Beam Pumped Rare Gas Excimer Lasers

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Electron beam pumped rare gas excimer lasers have been developed to generate high power coherent radiation in the VUV spectral region. For this purpose various materials, such as a SiO_2 plate, a single crystal Si, a single crystal Mo, a SiC film and a MgF_2 plate, were tested as cavity mirrors which were high resistant to an optical damage against intense VUV radiation in the laser cavity. The maximum high power output was achieved with 16MW at 126nm for an Ar excimer[1] laser and 7MW at 146nm for a Kr excimer laser[2], respectively, when the SiC back mirror for Ar excimer laser and the Si back mirror for Kr one, together with the MgF_2 output mirror, were used as a cavity. An extension of wavelength of the excimer laser radiation was performed by using a stimulated Raman scattering in hydrogen molecules with high conversion efficiency of about 50% at a maximum value for the first Stokes line. In addition to the first Stokes line, the second Stokes and the third Stokes lines were obtained for both the Ar and Kr excimer lasers, and moreover the first anti-Stokes line was appeared for the Kr excimer laser.

An interesting approach for generating intense coherent radiation in the XUV spectral region is the anti-Stokes Raman laser (ASRL). White[3] initially proposed the idea of using the group VI elements as a Raman medium. For XUV generation, N_2O gas is first dissociated by Ar excimer laser radiation as follows:

$$N_2O + h\nu\ (127\text{nm}) \longrightarrow O(^1S_o) + N_2$$

The quantum yield for the metastable state ^1S_o is approximately 0.8[4], resulting in a population inversion with the ground, $^3P_{0,1,2}$. If the intensity of the Ar excimer radiation is sufficient to fully dissociate the N_2O gas, the remaining excimer radiation can pump the singlet metastable oxygen to generate stimulated anti-Stokes Raman scattering at 89nm by the reaction

$$O(^1S_0) + h\nu(124.8\text{nm}) \longrightarrow O(^3P_{0,1,2}) + 89\text{nm}.$$

The photon energy of Ar excimer laser is very close to the energy difference between the level $O(^1S_0)$ and the autoionization level $3s''\,^3P_1$, thereby providing a strong resonance effect to enhance the conversion efficiency.

[1]W.Sasaki, K.Kurosawa, P.R.Herman, E.Fujiwara and Y.Kato: To be published in the Proc. of the International Symposium on Short Wavelength Lasers, Nov.11, 1987, at ILE Osaka, Japan.

[2]K.Kurosawa, W.Sasaki, E.Fujiwara and Y.Kato: To be published in IEEE J. Quantum Electron. QE-24, No.9, (1988).

[3]J.C.White: Opt. Lett. 9, 38 (1984).

[4]G.Black, R.L.Sharpless, T.G.Slanger and D.C.Lorents: J. Chem. Phys. 62, 4266 (1975).

NOTES

WEDNESDAY, SEPTEMBER 28, 1988

NAUSET III

3:30 PM–5:15 PM

WD1–4

SESSION 11

Wolfgang Eberhardt, Exxon Research and Engineering Company, *Presider*

Multiphoton Spectroscopy of Multielectron Atoms and the Quest for Direct Two-Electron Ejection

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I present recent calculations on alkaline earths and on rare gases which take into consideration the multielectron character of these atoms and attempt an interpretation of experimental data involving autoionizing and/or doubly excited states, two-electron transitions as well as transitions to excited ionic states. The discussion includes the dependence of these processes on laser intensity and frequency.

In the second part of the paper, I present an analysis of recent observations of the effect of internally generated harmonics on the process of multiphoton ionization.

Supported by the National Science Foundation Grant Number PHY-8609966 and the U.S. Department of Energy Grant Number DE-FG0387ER60504.

Observation of Asymmetries in Above-Threshold Ionization

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Electron angular distributions from above-threshold ionization of rare gases by intense, elliptically polarized light are not symmetric with respect to reflection about the principal polarization axes.[1] Neither nonresonant multiphoton perturbation theory, nor nonperturbative Keldysh-type theories such as the one proposed by Reiss,[2] predict this behavior. The asymmetries have been observed in helium, krypton, and xenon ATI spectra, and depend on the laser intensity and polarization, and the electron energy.

Figure 1 displays the azimuthal angular distribution for 19 photon ionization of krypton by 1064 nm light of 150 psec duration, focused to approximately $2\mathrm{x}10^{13}\mathrm{W/cm}^2$, and elliptically polarized with helicity $h=-0.82$. The dashed line is prediction for a Keldysh-Reiss theory. The obvious discrepancy is the strong asymmetry with respect to reflection about either the major or minor axes. Simultaneous reflection $\hat{x}\rightarrow-\hat{x}$, $\hat{y}\rightarrow-\hat{y}$ is symmetric, as required by spatial isotropy.

The magnitude of the asymmetries as a function of laser intensity and helicity are shown in figure 2. "Low" and "High" intensities refer to $I_{peak}=2\times10^{13}\mathrm{W/cm}^2$ and $4\times10^{13}\mathrm{W/cm}^2$, respectively.

Although we lack a theory for this new intense field phenomenon, there is a semi-classical argument that suggest a physical principle responsible for the broken symmetry, and provides a qualitative explanation. An electron that ionizes by absorbing many elliptically polarized photons carries off several units of angular momentum. The electron-ion system must therefore have a classical impact parameter. During the escape of the electron from the ion's coulomb field, the electron executes a hyperbolic trajectory. The asymptotic momentum therefore deviates from the momentum at the point of closest approach, leading to asymmetric distributions.

1. M. Bashkansky, P. H. Bucksbaum, and D. W. Schumacher, Phys. Rev. Lett., in press.
2. H. R. Reiss, Phys. Rev. A *22*, 1786 (1980).

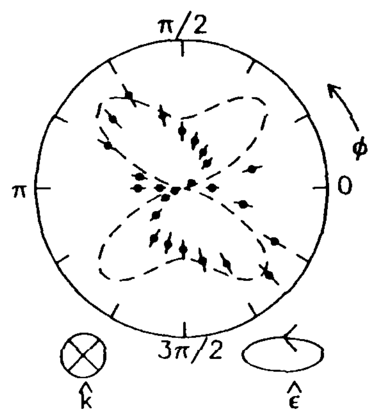

Figure 1

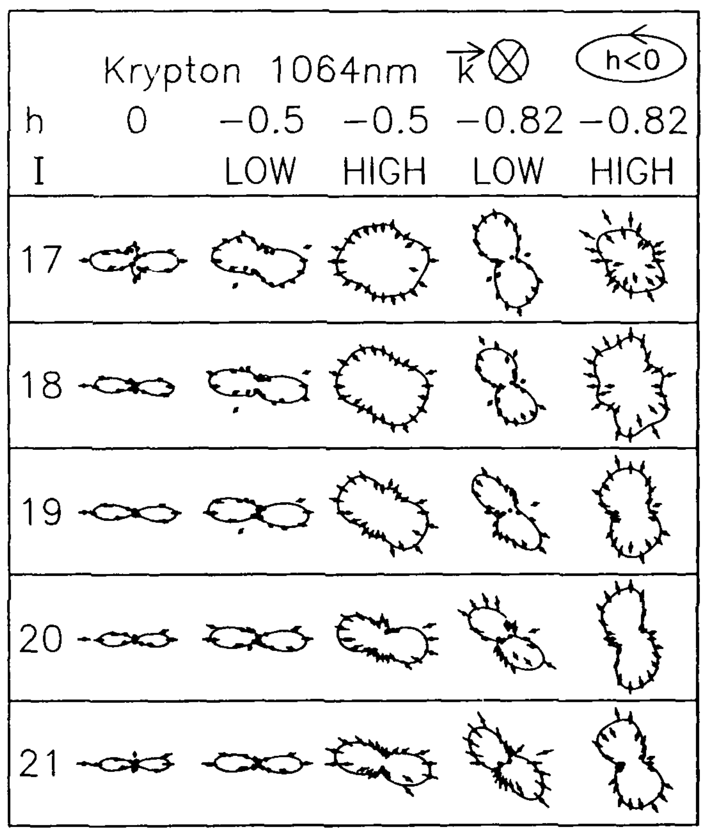

Figure 2

Multiphoton Ionization with Femtosecond Laser Pulses

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There are a number of reasons to use subpicosecond pulses in multiphoton ionization experiments. Pulses with shorter risetimes make it possible to study processes with higher rates before one runs into the problem of depletion of target atoms. Furthermore the momentum of the electron does not change between the point of ionization and the detector if the pulse expires before the electron has time to sample the spatial inhomogeneity of the light intensity. This makes it possible to identify the intensity at which an electron was formed from the energy with which it reaches the detector.

Yet another advantage is the fact that the primary ionization products are subject to the ionizing radiation for only a short amount of time, thus reducing the probability of sequential ionization as compared to direct processes. In this paper the experimental results on the multiphoton ionization of xenon with pulses of 100 fs, that were obtained during the preceding year at ENSTA, Palaiseau, will be presented.

High Order Harmonics in Light Scattering by Atomic Electrons above Threshold

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We report multiphoton ionization computer experiments at high laser intensity. We describe the scattered light spectrum accompanying the corresponding above-threshold ionization electron spectrum from a given laser pulse in several different cases

THURSDAY, SEPTEMBER 29, 1988

NAUSET III

8:30 AM–10:15 AM

ThA1–4

SESSION 12

E. Michael Campbell, Lawrence Livermore National Laboratory, *Presider*

X-Ray Emission Studies of Sub-Picosecond Laser Produced Plasmas

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We report experimental studies of high-temperature, high-density plasmas under intense sub-picosecond laser illumination. Ultrafast laser pulses are used to produce an impulse excitation of the solid so that absorption of the laser light and plasma X-ray emmision occur at densities higher than those encountered in a conventional plasma. This can lead to the production of X-ray pulses of rapid rise and fall times[1,2].

We will discuss the experimental evidence we have obtained for laser absorption and X-ray emission at densities higher than critical. Self-reflectivity measurements have demonstrated metal-like reflectivity under short pulse illumination, indicating laser absorption in the solid before any plasma expansion occurs. X-ray streak camera measurements have been performed with camera limited time resolution showing the presence of a short X-ray pulse under sub-picosecond laser illumination both in the soft X-ray and keV region of the spectrum. The characteristic X-ray decay time is faster than for conventional critical-density plasmas. Finally we report on X-ray spectroscopy studies which demonstrate the presence of a high-density rapidly-recombining plasma.

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2) R.W. Falcone and M.M. Murnane, "Proposal for a Femtosecond X-Ray Ligth Source" *Short Wavelength Coherent Radiation: Generation and Applications,* D.T. Attwood and J. Bokor, eds. (AIP, New York, 1985).

Nonreciprocity of Autoionizing Interferences, Lasers without Inversions

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Interferences of autoionizing lines may reduce or eliminate absorption of lower level atoms. Stimulated emission shows no such interferences, thereby allowing laser gain without population inversion.

Studies of Hot, Solid Materials Produced by an Ultrashort Pulse Laser

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We have performed a series of experiments with an ultrashort UV laser which illustrate electron transport and radiation properties of strongly heated materials at near-solid density. In aluminum, a Drude metal at the laser wavelength, the resistivity has been determined by observing the change in the material's reflectivity with the electron temperature ranging over four orders of magnitude, from room temperature to the hot plasma regime. A maximum in the resistivity is seen, which is consistent with classical minimum mean free path arguments.[1] Experiments have also been performed with insulators, and a metal, copper, with band absorption in the UV. The copper results indicate the presence of these 3d band absorptions well into the strong heating regime ($kT_e \sim 50eV$). The broadband soft x-ray yield from hot solid aluminum shows a scaling with electron temperature which is different from that of a long-range collision dominated Maxwellian plasma, and suggests the presence of short range interactions. Fitting model cross sections to the measured collision frequencies further supports this view.

In the context of using ultra-short laser-produced plasmas as a source of ultrashort pulse soft x-rays, evidence is presented that hot solid material temperature loss mechanisms at the temperatures of our experiments may not be sufficiently rapid to result in subpicosecond soft x-ray bursts.

[1] H. M. Milchberg, R. R. Freeman, S. C. Davey, and R. M. More submitted for publication

Coplanar vacuum photodiode for measurement of short-wavelength picosecond pulses

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A vacuum photodiode is the most elementary photoelectric detector. Such a device is sensitive to photon energies which exceed the photocathode work function in accord with the classical photoelectric effect. For vacuum ultraviolet and soft X-ray radiation, photoelectric quantum yields in excess of 50% can be reached.[1] With a carefully designed external circuit, the response time of such a detector is limited by the diode capacitance. The present state-of-the-art risetime in a commercial biplanar vacuum photodiode[2] is 60 psec.

Recent studies[3] have demonstrated the utility of the coplanar transmission line geometry with lateral dimensions of several micrometers for the generation and propagation of picosecond electrical pulses. We have realized an ultrafast vacuum photodiode detector by taking advantage of a microfabricated coplanar stripline geometry. Two parallel stripline electrodes themselves serve as the photocathode and collection anode. A representation of our initial devices is shown in Figure 1. In the application primarily envisioned for this device, namely the measurement of short soft X-ray pulses radiated by picosecond laser plasma sources, the photodiode is optimized to give high sensitivity for soft X-rays, while a small portion of the pump laser pulse used to create the plasma is also used to trigger a conventional photoconductive sampler in order to read out the photodiode pulse.

The device has been tested using 266 nm ultraviolet (UV) laser pulses of ~500 fsec duration derived from a compressed, mode-locked Nd:YAG laser. The results are shown in Figure 2. With 60 V applied bias, we obtained a 4 psec rise time and a 12 psec fall time. It was not possible to apply a higher bias voltage to this device due to avalanche breakdown of the silicon between the lines. By improving the device processing to eliminate the silicon between the striplines, higher bias voltage and hence higher speed should be obtained.

REFERENCES

1. J. A. R. Samson, *Techniques of Vacuum Ultraviolet Spectroscopy,* (Pied Publications, Lincoln, Nebraska, 1967).

2. e.g. Hamamatsu Corp., Middlesex, NJ. model R1328U.

3. M. B. Ketchen, et al., Appl. Phys. Lett. **48**, 751(1986).

Fig. 1: Coplanar vacuum photodiode and conventional sidegap photoconductive sampler.

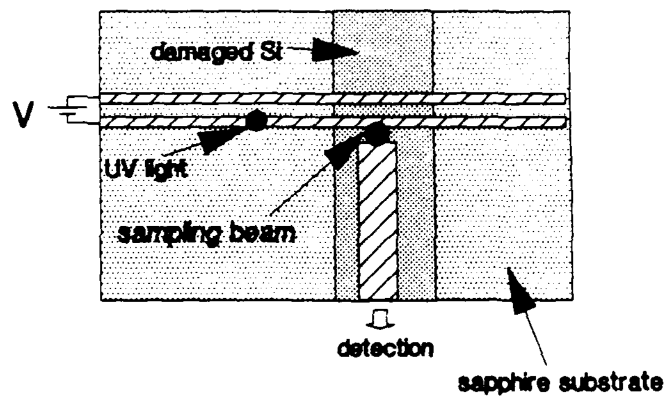
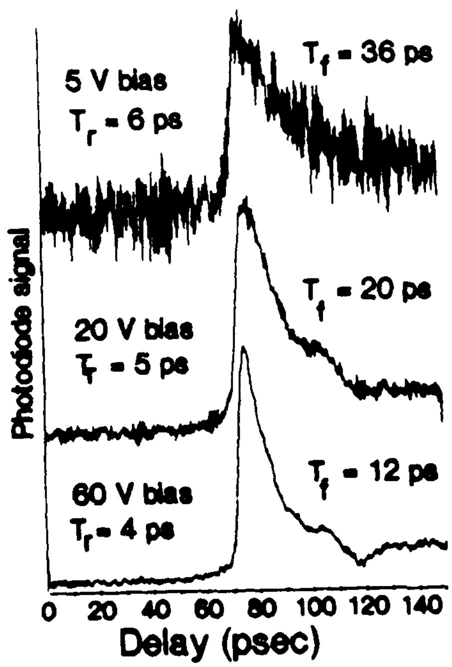


Fig. 2: Response of device to 500 fsec UV laser pulses at various applied bias voltages. The sidegap sampler was independently measured to have 2 psec response time.



THURSDAY, SEPTEMBER 29, 1988

NAUSET III

10:45 AM–12:15 PM

ThB1–3

SESSION 13

Brian E. Kincaid, Lawrence Berkeley Laboratory,
Presider

Observations of High Density Plasmas Produced with a Picosecond High Power KrF Laser

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The high power KrF laser system at the SERC Central Laser Facility has been used to irradiate solid targets with laser energies up to 1 joule in 3 picoseconds. Single shot irradiances up to 10^{17} Wcm^{-2} were achieved at the target surface. A number of diagnostics were used to investigate the plasmas produced. These included time integrated and time resolved X-ray and VUV spectroscopy.

Fully ionized aluminum plasmas were observed with temperatures of about 400 eV and densities well above 10^{23} cm^{-3} when the ASE prepulse was less than 10^{-5}. The temperature and density were inferred from X-ray line ratios and from observations of Stark broadening and continuum lowering. In contrast, when the prepulse level was large, the X-ray spectra indicated an electron density of about 3×10^{22} cm^{-3}. The production of suprathermal electrons above 4.5 keV was studied on bare and plastic coated titanium targets by observing TiK_α emission. From the intensity of the K_α signal, it was found that about 20% of the incident laser energy was deposited in hot electrons.

The experimental results were simulated using a 1D hydrocode and a 2D Fokker-Planck code. Good agreement was obtained with the experimental observations. Both the experimental results and the simulations will be discussed in the presentation.

X-ray Optics Technologies for X-ray Laser Research and Applications*

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Summary

Newly developed techniques in high precision thin film deposition and submicron lithography now make possible the fabrication of efficient, normal incidence x-ray mirrors and beamsplitters as well as low f/number x-ray lenses, and synthetically generated x-ray reflection holograms. These capabilities have been utilized in x-ray laser cavity experiments, which have produced a 400-fold increase in the brightness of laboratory sources of amplified spontaneous emission (ASE).

These new x-ray optical components are also being implemented in the development of the first soft x-ray interferometer, and a high intensity ($\geq 10^{13}$ watt/cm^2) soft x-ray laser source. The soft x-ray interferometer, in addition to its metrological applications, would extend by three orders of magnitude current capabilities for probing high density, long scale length plasmas. The high intensity x-ray laser source would allow the laboratory investigation of non-linear properties of materials at soft x-ray wavelengths, perhaps launching a new field of Nonlinear X-ray Optics.

*This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Current Prospects for Free-Electron Lasers in the Extreme Ultraviolet*

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In the last few years, free-electron laser (FEL) oscillators and amplifiers have produced coherent radiation over a broad spectral range extending from 463 nm in the visible to millimeter wavelengths as summarized graphically in Fig. 1. These successful demonstrations have encouraged a number of research centers to boldly consider extension of this electron-accelerator-based technology to the extreme ultraviolet (XUV) below 100 nm where no powerful, tunable, coherent-radiation source presently exists. Here, the peak- and average-power output of FEL oscillators and amplifiers should surpass the capabilities of any existing, continuously tunable photon sources by many orders of magnitude.

Extending FELs to ever shorter wavelengths, however, is inherently difficult since the gain decreases monotonically with the square-root of the wavelength, and below 100 nm the available mirrors for resonators have comparatively low reflectance, generally ≤50%. With such mirrors, the small-signal power gain for a single pass through the magnetic undulator must exceed 400% just to reach the threshold for oscillation. Increased gain can be attained with long undulators comprising several hundred periods and peak current of ≥100 A. However, long undulators have reduced homogeneous gain bandwidth equal to 1/4N, where N is the number of periods. Since the gain is decreased by transverse beam emittance and longitudinal energy spread, it is essential that the accelerators deliver very bright electron beams. Storage rings and rf-linear accelerators, as indicated in Fig. 2, appear to be the only sources of electron beams with brightness adequate for XUV FELs.

The proposed FEL schemes include oscillators using optical resonators, single-pass amplifiers based on self-amplification of spontaneous emission (SASE), multiple-pass regenerative amplifiers, and optical klystrons in which electrons bunched by external lasers radiate coherent harmonics. We review the features and output parameters of several of these active or proposed programs and the technological challenges that must be met to guarantee their successful operation.

* This work was supported by the Division of Advanced Energy Projects of the U. S. Dept. of Energy Office of Basic Energy Sciences and by Los Alamos National Laboratory (ISR&D).

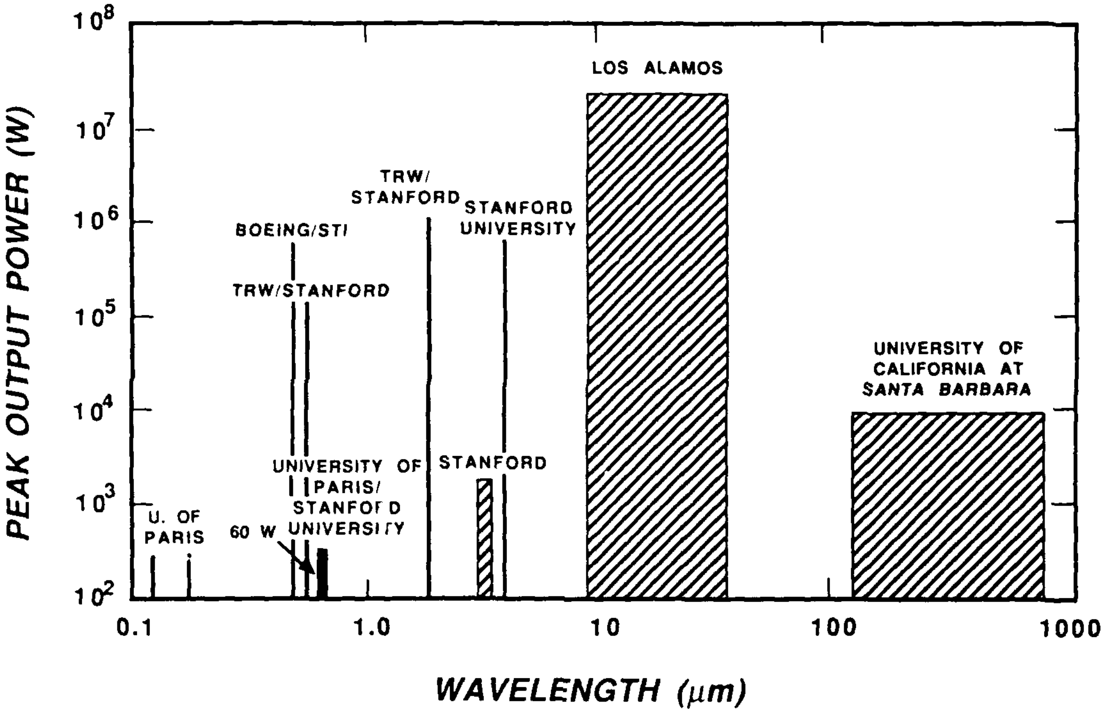

Figure 1. FEL oscillators presently span a broad wavelength range from the visible to the far-ir. Devices to operate in the 10 - 100 nm range have been designed for demonstration experiments.

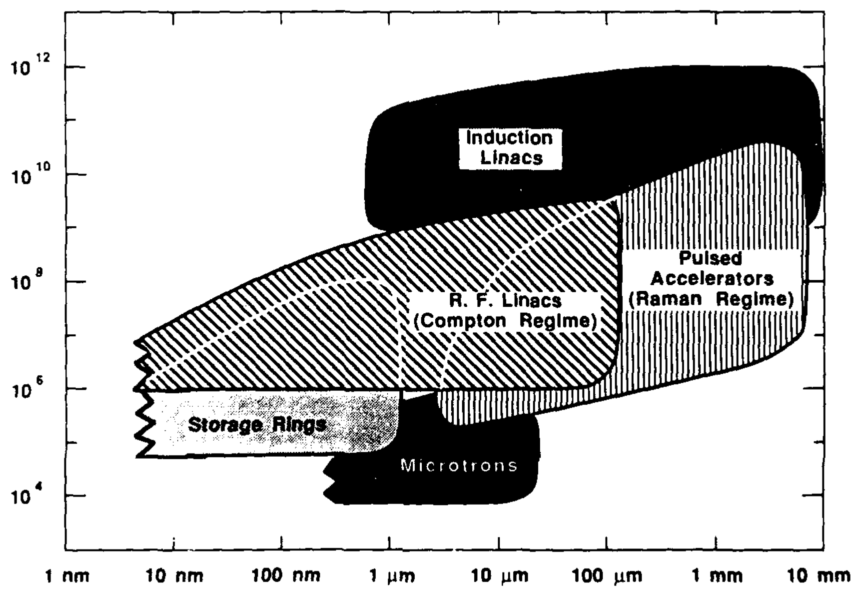

Figure 2. FELs for different wavelength regimes use different accelerator technologies. The FEL resonance equation states that wavelength depends inversely as the square of the electron energy. Thus, low-voltage machines such as diode pulsers and electrostatic accelerators are generally used for the far-infrared and millimeter wave regions. To reach shorter wavelengths, higher electron energy with high beam brightness is required. Storage rings and rf linacs with advanced injectors appear capable of extending FEL operation to 100 nm and below.

NOTES

KEY TO AUTHORS, PRESIDERS, AND PAPERS

KEY TO AUTHORS, PRESIDERS, AND PAPERS—*Continued*

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KEY TO AUTHORS, PRESIDERS, AND PAPERS—*Continued*

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