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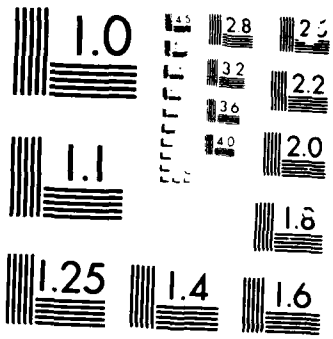
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Large coupling coefficient (>10 cm^{-1}) photorefractive crystals have been developed. The infrared response and the temperature dependence of these crystals have been studied. The applications of these crystals such as image subtraction, wavefront conversion and bistabie oscillations have been developed. The ultimate bandwidth limitations of the self-pumped phase conjugate mirror have been investigated. High speed detectors for use at the 1.3 μm region have been developed.

During this reporting period we have been conducting research on properties of photorefractive crystals and their applications, and the phase conjugation of picosecond light pulses.

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PHASE CONJUGATE OPTICS AND PICOSECOND OPTOELECTRONICS

Final Report

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BRIEF OUTLINE OF RESEARCH FINDINGS:

Large coupling coefficient (>10 cm^{-1}) photorefractive crystals have been developed. The infrared response and the temperature dependence of these crystals have been studied. New applications of these crystals such as image subtraction, wavefront conversion and bistable oscillations have been developed. The ultimate bandwidth limitations of the self-pumped phase conjugate mirror have been investigated. High speed detectors for use at the 1.3 μm region have been developed.

During this reporting period we have been conducting research on properties of photorefractive crystals and their applications, and the phase conjugation of picosecond light pulses

Studies of Photorefractive Crystals

Since the last reporting period research in the field of photorefractive crystals have led to several interesting and new discoveries.[1] Among them are the following:

1. Infrared photorefractive response in barium titanate and strontium barium niobate. Coupling coefficients greater than 1 cm^{-1} were observed at GaAs semiconductor laser wavelength. This opens up new possibilities for applying these crystals to GaAs laser phase locking and control.
2. The growth of optically excellent cerium-doped strontium barium niobate crystals with photorefractive properties comparable with the best materials today. At argon-ion wavelengths, coupling coefficients greater than 10 cm^{-1} were observed with response times of 50 msec at $1W/cm^2$ irradiance.

3. Investigation of the temperature dependence of the photorefractive effect in $BaTiO_3$ and $Sr_xBa_{1-x}Nb_2O_6$. This study showed that while the photorefractive effect in the latter material remains virtually temperature independent, it can be significantly increased in $BaTiO_3$ by reducing the temperature of the crystal.

Applications of Photorefractive Crystals

Three new applications based on the photorefractive effect and phase conjugation have been developed:

1. We demonstrted real time image subtraction intensity inversion and differentiation using a Michelson type interferometer with the two conventional retro-reflecting mirrors replaced by a single self-pumped phase conjugate mirror.[2]
2. An optical one-way, real time wavefront cleanup by means of photorefractive pumped oscillators is demonstrated. A factor of 4,000 increase in beam brightness has been achieved.[3]
3. Optical bistable oscillations with a self-pumped phase conjugate mirror are observed. An explanation of the experimental results based on the threshold of oscillation was developed. This effect can be used as a thresholding element in optical image processing systems.[4]

Phase Conjugation of Picosecond Light Pulses

In an extension of our recently published work on phase conjugation of picosecond light pulses,[5] we are investigating the ultimate bandwidth limitations of the passive phase conjugate mirror (PPCM). A preliminary analysis indicates that pumping of the PPCM with narrow pulses results in a phase conjugator with increased

bandwidth; however, there is also a subsequent drop in the overall reflectivity of the PPCM. Thus, much narrower pulses may possibly be phase conjugated with little distortion due to bandwidth limitations. In order to experimentally investigate this realm, we are constructing a pulse compression system to produce ~100 fs pulses from our modelocked dye laser. The system will also provide high bandwidth chirped pulses of ~1 ps duration for comparison with the transform limited pulses.

We have also been developing high speed detectors for use at the wavelength of 1.3 μm. In particular, we have fabricated p-i-n photodiodes in InGaAsP with a few novel features resulting in very high frequency response. This detector uses a polyimide bonding pad permitting a much smaller detector area and subsequently a reduced parasitic capacitance. Also, the p-layer (being the upper layer) is made with a very shallow diffusion which results in a built-in electric field. The consequence of this field is that carriers created outside the depletion region are now driven toward, instead of just diffusing to the depletion region thus reducing the detrimental effects of diffusion tails. These detectors have shown a temporal impulse response of 28 ps and their frequency response is 3 dB flat-out to 18 GHz.

References:

1. G. Rakuljic, A. Yariv and R. Neurgaonkar, "Undoped, Ce-doped, and Fe-doped $Sr_{0.6}Ba_{0.4}Nb_2O_6$ for Phase Conjugate Optics," to be published in Opt. Eng.
2. S-K. Kwong, G. Rakuljic, and A. Yariv, A, "Real Time Image Subtraction and 'Exclusive or' Operation Using a Self-Pumped Phase Conjugate Mirror," Appl. Phys. Lett. 48, 201 (1986).
3. S-K. Kwong and A. Yariv, Appl. Phys. Lett. "One-Way, Real Time Wavefront Converters," 48, 564 (1986).
4. S-K. Kwong and A. Yariv, "Bistable Oscillations With a Self-Pumped Phase Conjugate Mirror," to be published in Opt. Lett.
5. M. Cronin-Golomb, J. Paslaski and A. Yariv, "Vibration Resistance, Short Coherence Length Operation and Mode-Locked Pumping in Passive Phase Conjugate Mirrors," Appl. Phys. Lett. 47, 1131 (1985).

ASTRACTS OF PAPERS SUBMITTED FOR PUBLICATION UNDER THIS CONTRACT:

Undoped, Ce-doped, and Fe-doped $Sr_{0.6}Ba_{0.4}Nb_2O_6$ for Phase Conjugate Optics

G. Rakuljic, A. Yariv

We present the results of our theoretical and experimental studies of the photorefractive effect in single crystal SBN:60, SBN:Ce, and SBN:Fe. The two-beam coupling coefficients, response times, and absorption coefficients of these materials are given.

Optical Self-Focusing in Photorefractive Crystals and Its Compensation by a Self-Pumped Phase Conjugator

G. A. Rakuljic, S-K. Kwong, M. Cronin-Golomb, A. Yariv

Optical self-focusing and self-phase modulation effects were observed in photorefractive crystals. We demonstrated that such aberrations can be compensated to a high degree with a passive phase conjugate mirror. This compensation was possible since the thermal conductivity of the photorefractive crystals was large enough to prevent high frequency thermal gratings from forming.

Bistable Oscillations with a Self-Pumped Phase Conjugate Mirror

S. Kwong, A. Yariv

Optical bistable oscillation beams with a self-pumped phase-conjugate mirror are reported. The results of an experimental demonstration are given, and an explanation based on the threshold of oscillation is presented.

Effect of Temperature Variation in Photorefractive Devices

M. Cronin-Golomb, G. Rakuljic, A. Yariv

The steady state coupling constant of photorefractive $BaTiO_3$ can be significantly enhanced by cooling it towards its tetragonal to orthorhombic phase transition at 5°C. This enhances the operation of devices such as passive and externally pumped passive phase conjugate mirrors and photorefractive optical limiters.

Nonlinear Vectorial Two Beam Coupling and Forward Four-Wave Mixing in Photorefractive Materials

B. Fischer, J. White, M. Cronin-Golomb, A. Yariv

We present an exact solution of a nonlinear vector analysis of two beam coupling and forward four-wave mixing in photorefractive media.

Plane Wave Theory of Nondegenerate Oscillation in the Linear Photorefractive Passive Phase Conjugate Mirror

M. Cronin-Golomb, A. Yariv

We present a plane wave theory of nondegenerate oscillation in the linear passive (self-pumped) phase conjugate mirror (PPCM). The circumstances under which the plane wave theory allows spontaneous nondegenerate oscillation in this and other PPCM's are discussed.

One-Way, Real Time Wave Front Converters

S-K. Kwong, A. Yariv

Optical one-way, real time wavefront cleanup by means of photorefractively pumped oscillators is reported. A factor of 4000 increase in beam brightness has been achieved.

ABSTRACTS OF PAPERS PUBLISHED UNDER THIS CONTRACT:

Phase of Phase Conjugation and Its Effect in the Double Phase Conjugate Resonator

S-K. Kwong, A. Yariv, M. Cronin-Golomb, B. Fischer

Expressions for the phase of reflection from a photorefractive phase-conjugate mirror are obtained as a function of the intensity and phase of the pump and the probe beams. The phase is independent of these parameters in common photorefractive conditions in which the index grating is spatially shifted 90° with respect to the light-interference pattern. Multiple solutions exist for the phase and intensity of the reflection at large coupling strength. Oscillation conditions involving frequency detuning are obtained for the double phase-conjugate resonator (resonator formed with two phase-conjugate mirrors).

One-Way, Real Time Wave Front Converters

S-K. Kwong, A. Yariv

Optical one-way, real time wave front cleanup by means of photorefractively pumped oscillators is reported. A factor of 4000 increase in beam brightness has been achieved.

Real-Time Image Subtraction and "Exclusive or" Operation Using a Self-Pumped Phase Conjugate Mirror

S-K. Kwong, G. A. Rakuljic, A. Yariv

Real time "exclusive or" operation with an interferometer using a self-pumped phase conjugate mirror is reported. Also, results of image subtraction and intensity inversion are shown.

Vibration Resistance, Short Coherence Length Operation, and Mode-Locked Pumping in Passive Phase Conjugate Mirrors

M. Cronin-Golomb, J. Paslaski, A. Yariv

Because the ring and semilinear passive phase conjugate mirrors use dynamic transmission holograms, they are insensitive to vibration and may be pumped with light of short coherence length or with picosecond mode-locked laser light. Experimental demonstrations of these modes of operation are described.

Theory of Laser Oscillation in Resonators with Photorefractive Gain

A. Yariv, S-K. Kwong

A Theory for oscillation in an optical resonator with photorefractive gain was formulated. The threshold conditions for the oscillation were also obtained. The result, applicable to a whole class of new devices, is a prediction for an oscillation frequency different from that of the pump beam.

Conversion of Optical Path Length to Frequency by an Interferometer Using Photorefractive Oscillation

S-K. Kwong, A. Yariv, M. Cronin-Golomb, I. Ury

Frequency detuning effects in photorefractive oscillators are used in a new type of (passive) interferometry which converts optical path length changes to frequency shifts. Such an interferometer is potentially more accurate than conventional interferometers which convert optical path length changes to phase or intensity changes.

Lateral Coupled Cavity Semiconductor Laser

J. Salzman, R. Lang, A. Yariv

We report the fabrication and operation of a lateral coupled cavity semiconductor laser that consists of two phase-locked parallel lasers of different lengths and with separate electrical contacts. Mode selectivity that results from the interaction between the two supermodes is investigated experimentally. Frequency selectivity and tunability are obtained by controlling the current to each laser separately. Highly stable single mode operation is also demonstrated

Experimental Studies of Phase Conjugation with Depleted Pumps in Photorefractive Media

S-K. Kwong, Y-H. Chung, M. Cronin-Golomb, A. Yariv

We describe the experimental measurement of phase-conjugate reflectivity versus various ratios of input-beam intensities in photorefractive barium titanate and strontium barium niobate crystals. The experimental results are compared with the theoretical prediction from the coupled-wave theory. Three different methods to measure the nonlinear coupling constant of the crystal are also presented and compared.

Fundamental Mode Oscillation of a Buried Ridge Waveguide Laser Array

S. Mukai, C. Lindsey, J. Katz, E. Kapon,
Z. Rav-Noy, S. Margalit, A. Yariv

An eight-element phase-locked array of index-guided separate confinement ridge AlGaAs diode lasers is fabricated. In this array the absorption of light in the region between lasers is negligible and the gain profile across the array is nearly uniform. Unlike most other arrays, this array oscillates in its fundamental mode. Stable radiation patterns of near diffraction-limited single narrow beam with 1.6° width are obtained. The beam width approaches the theoretical limit for the present array structure.

Photorefractive Crystals as Optical Devices, Elements and Processors

J. White, A. Yariv

The physics of the photorefractive effect and the unique nonlinear optical properties of photorefractive crystals are described. A survey of the optical applications of the photorefractive effect follows. We include the use of photorefractive crystals as holographic storage elements, optical image amplifiers, phase conjugate mirrors, correction elements for intracavity laser distortions, phase conjugate windows for field transmission through inhomogeneous media, and coherent image processors.

High-Speed Schottky Photodiode on Semi-Insulating GaAs

Z. Rav-Noy, C. Harder, U. Schreter, S. Margalit, A. Yariv

A high-speed GaAs photodiode has been fabricated on a GaAs semi-insulating substrate. The photodiode has an active area of 8 μm x 15 μm and a bandwidth in excess of 9 GHz. This Schottky photodiode is suitable for monolithic integration with other optoelectronic components.

Tilted-Mirror Semiconductor Lasers

J. Salzman, R. Lang, S. Margalit, A. Yariv

Broad-area GaAs heterostructure lasers with a tilted mirror were demonstrated for the first time, with the tilted mirror fabricated by etching. These lasers operate in a smooth and stable single lateral mode with a high degree of spatial coherence. The suppression of filamentation manifests itself in a high degree of reproducibility in the near-field pattern.

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