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The objective of this research investigation is to determine, experimentally and analytically, the physical mechanisms that determine the behavior of continuous and quasi-continuous, laser sustained plasmas (LSP). The principal questions involve the effects of a forced convection environment, optical geometry and pulse format on the stability, fractional power absorption, plasma structure, and fluid mixing. The future application of this technology to space propulsion rests on the availability of lasers with powers in the megawatt range. It now appears likely that lasers of this size will be free electron lasers (FEL) that produce power as a series of pulses, rather than continuously. Transient argon plasmas were created using the 20 ns pulse from an excimer laser at a wavelength of 307 nm. These plasmas were self initiated from optical breakdown, requiring no auxiliary means for initiation as in the case for cw sustained plasmas. The decay of these plasmas were monitored using an optical multichannel analyzer (OMA), and it was found that the plasmas decayed with microsecond time scales. This time is considerably longer than the 46 ns interpulse time for the free electron laser (FEL)

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Section 19 (continued): at Los Alamos National Laboratory, and it was anticipated that quasi-steady plasmas would be sustained with the FEL. Experiments at Los Alamos confirmed that the RF Linac FEL would sustain self-initiated, quasi-steady plasmas in argon at a variety of pressures and flowrates, but it was not possible to obtain self-initiation of plasmas in either nitrogen or hydrogen under the same conditions.

WORK STATEMENT

Objective

The principal objective of this research is to determine the effects of different optical beam modes and pulse format on the plasmas sustained in a forced convection flow using continuous carbon dioxide and pulsed RF Linac free electron lasers.

Approach

Detailed experimental measurements of the plasma temperature field are obtained from continuum emission images of the continuous plasmas which are obtained using a digital image acquisition system. These measured temperature fields can then be used to analyze the spatially resolved energy and momentum balance within the LSP. The detailed spatial analysis is performed with the aid of a new transform based method for the Abel inversion and a new computational model for the LSP that were developed at UTSI.

Free electron lasers produce their power as a series of short pulses, and to study the effects of the pulses on the plasma, time resolved spectra will be obtained using an optical multichannel analyzer (OMA). The transient spatial development of the plasma will be determined from images obtained using a high-speed framing and streak camera. The spectra will be analyzed to determine the state of equilibrium in the plasma and the rate of interpulse plasma relaxation.

Status of the research

A new flow chamber was designed and constructed for the experiments with the free electron laser (FEL) at Los Alamos National Laboratory (LANL). This chamber was constructed with zinc selenide windows on both ends so that laser absorption measurements could be made directly. The flow tube where the plasma is sustained has a diameter of 1 cm to provide higher incident flow velocities at reasonable mass flow rates, and an annular flow was provided at the surface of the window for cooling. A 127 mm focal length lens was used to focus the laser beam into the chamber which provides an approximately f/4 focusing system. Continuous plasmas were initiated and sustained in this chamber using the UTSI continuous carbon dioxide laser prior to its use at LANL. Operation of the diagnostic instrumentation was verified, but no quantitative measurements were attempted.

Transient argon plasmas were studied in our laboratory prior to the LANL experiments to determine the characteristic relaxation time. Plasmas were self-initiated by optical breakdown at pressures of one and two atmospheres of argon in a separate closed test cell having no flow. Emission spectra were obtained from the decaying plasma using an EG&G OMA III optical multichannel analyzer (OMA). The OMA gate was set to 10 ns width and scanned using a variable delay to observe approximately 4 microseconds after plasma initiation. The spectra initially consisted primarily of continuum emission, but as the plasma decayed the spectrum shifted to emission from the argon ion AII and then to emission from the neutral atom AI. This decay occurred over several microseconds and indicated that the plasma would not extinguish during the 46ns interpulse time characteristic of the Los Alamos FEL, and it should be possible to sustain a quasi-steady plasma using the 80 microsecond bursts from the FEL. Experiments performed at one and two atmospheres produced similar results, both in spectral characteristics and decay time.

Arrangements were made to obtain the use of the RF Linac FEL at Los Alamos for the first week in August, 1988. This laser operates at tunable wavelengths near 10 micrometers, and for our experiments was tuned to 10.6 micrometers for direct comparison with the carbon dioxide laser. The laser output consists of a TEM_{oo} gaussian beam with a burst of micropulses lasting for 80 microseconds. The bursts are repeated at 1 s intervals with a total burst energy of approximately 300 mJ, giving an average power of 3.75 kW during the burst. Each burst consists of approximately 1730 micropulses that have a duration of approximately 10 ps and are spaced 46 ns apart to provide a peak power of approximately 17 MW.

A variety of diagnostic measurements were made during the experiments. A Hadland image converter camera was interfaced to a CID camera to provide digital images that were acquired using a Matrox framegrabber housed in a Masscomp computer. This provided high-speed images of the transient plasma formation and decay at a framing rate of 100,000 frames/s. Time resolved spectra of the plasma were obtained using the OMAIII in a manner similar to that used for the excimer generated plasmas. The OMA gate time was 10 ns and spectral scans were taken over 60 ns to insure that the scan would cover the entire interpulse delay time. Spectra were obtained at 20 microsecond intervals throughout the 80 microsecond burst. The plasmas were also observed using the CID camera and continuum bandpass filter previously for the diagnostic measurements of continuous laser sustained argon plasmas.

Data were obtained for FEL sustained argon plasmas at pressures from 1 to 3 atmospheres over a range of incident flow velocities. Plasmas were easily initiated at all pressures with nearly complete absorption of the incident laser beam. Preliminary evaluation of the spectral data indicates that a quasi-steady plasma was established, with little variation in the spectra on either the nanosecond or the microsecond time scales. Attempts were made to obtain self-initiated plasmas in both nitrogen and hydrogen under the same conditions as used for argon, but these attempts failed. The observed threshold for breakdown in argon was approximately 20 mJ in the 80 microsecond burst, but the molecular gases failed to self initiate at an energy of 250-300 mJ. Unpublished calculations by S. D. Rockwood at LANL indicate that the breakdown threshold for hydrogen and air should be within a factor of 2 of that for argon at a wavelength of 10.6 micrometers and pulse widths of 10 ps. These new results indicate that further theoretical analysis will be required for complete understanding of plasma breakdown for these short pulse conditions.

Publications

1. S.-M. Jeng, D. R. Keefer, R. Welle and C. E. Peters, "Laser-Sustained Plasmas in Forced Convective Argon Flow, Part II: Comparison of Numerical Model with Experiment," AIAA J., Vol. 25, No. 9, pp. 1224-1230, September 1987.

2. L. Montgomery Smith, Dennis R. Keefer and S. I. Sudharsanan, "Abel Inversion Using Transform Techniques," J. Quant. Spectrosc. Radiat. Transfer, Vol. 39, No. 5, pp. 367-373, 1988.

3. S.-M. Jeng and D. Keefer, "A Theoretical Evaluation of Laser Sustained Plasma Thruster Performance," accepted for publication in J. of Propulsion and Power, 1988.

Professional Personnel

1. Dr. Dennis Keefer, Professor of Engineering Science and Mechanics.

2. Dr. San-Mou Jeng, Assistant Professor of Aerospace and Mechanical Engineering.

3. Mrs. Quan Zhang, Graduate Research Assistant.

Interactions

Dr. Keefer attended the Laser Propulsion Workshop held at The University of Illinois during February, 1988, and made a presentation on the current status of the UTSI research on laser sustained plasmas.

There has been a continuing role as advisors and consultants between Drs. Keefer and Jeng with the Laser Propulsion project at NASA Marshall Space Flight Center. This interaction involves the diagnostics, ignition, and data analysis for experiments in laser sustained hydrogen plasmas and the design of a 30 kW thruster for their experimental program. The project director at NASA/MSFC is Mr. Lee Jones.

There has also been a continuing exchange of information and visits between Dr. Keefer, Dr. Jon Cross and Dr. David Cremers of Los Alamos National Laboratory. Dr. Cross uses the LSP as a source of high velocity oxygen atoms for the study of materials interactions at orbital velocities, and Dr. Cremers uses the LSP for analytical spectroscopy.

Inventions

None