Technical Notes

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Laser Absorption and Gain by Ar^+-Ion States in a Supersonic Expansion

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Introduction

THE extremely short lifetimes of the Ar^+-ion laser transitions ($\sim 10^{-9}$ sec) would seem to deplete the plasma entering a supersonic channel of excited Ar^+-ion laser levels. The time-dependent behavior of the Ar^+-ion laser under pulsed excitation, however, provides a mechanism by which a continuous flux of excited Ar^+-ions can be achieved in a supersonic channel.

When a static Ar discharge is excited with high current pulses of a few microseconds or longer duration, a small initial laser pulse frequently is observed, followed by a quenched region, and then by another stronger pulse of laser oscillations.[1-5] This second laser pulse lags behind the initiation of the excitation current by time periods comparable to the flow time characteristic of a plasma tunnel system ($\sim 10^{-4}$ sec). This time lag between the excitation current initiation and the delayed laser pulse provides the mechanism by which a continuously flowing plasma with excited Ar^+-ion states can be achieved.

Population inversion measurements have been reported by Leonard et al.[6] in the argon exhaust of a magnetic annular arc powered by an energy-storage capacitor bank operating for a 10 msec pulse. Gain measurements were made in the freestream of the ionized jet using a pulsed 2 w Ar^+-ion laser. Initial measurements indicated an apparent gain of approximately 10% per meter, comparable to the gain in a conventional pulsed Ar^+-ion laser operating at similar gas density, 10^{13} particles per cm^3. However, the arc developed marked instabilities in electrode potential and a stable operating regime could not be found with their particular experimental configuration. Therefore, no definite conclusions could be obtained regarding Ar^+-ion laser excitation in the plasma downstream of the arc discharge.[7]

This Note describes results of laser probe measurements conducted in a supersonic Ar plasma to conclusively determine if Ar^+-ion electronic states involved in the dominant Ar^+-ion laser transitions can be achieved in a supersonic flow which is a finite distance downstream of the excitation region and if a population inversion can be obtained.

Apparatus and Instrumentation

Argon excitation was achieved with a magnetically rotated electric arc, rotating at high speeds transverse to the gas flow.[8] Direct current was supplied to the electric arc and magnetic field by an SCR 1.5 mw power supply. Effectively, a "disk" of arc exists through which the argon flows. Under the appropriate conditions, the excitation mechanisms occurring during rapid passage of the flowing argon through the high power arc-discharge may be similar to those existing in pulsed and quasi-cw conventional static gas Ar^+-ion lasers.[1-5]

The range of operating conditions was: MHD arc current, 100–1000 amp, MHD arc stagnation chamber pressure, 3.5–200 torr, Ar mass flow rate, 0.4–9.1 g/sec. The magnetic coils were connected in series with the arc current, with 1 amp of coil current producing 9 g of magnetic field strength in the arc chamber.

Supersonic expansion was achieved with a stainless steel slit orifice (1.2 mm throat height, 8.8 cm width). The expansion region consisted of a 6.4 mm height by 8.8 cm width by 33.6 cm length stainless steel channel with 9 equally spaced 14.3 mm diam optical ports. Laser probe measurements were performed through the first optical port, 1 cm from the slit orifice and 19.7 cm from the magnetically rotated electric arc. A 50 mW Ar^+-ion laser beam was passed transversely across the width of the supersonic expansion. The diagnostic laser was a model 52B Coherent Radiation 4 w Ar^+-ion laser with a long-term power stability better than 0.1% rms. Brewster windows were used in the first optical port and extended externally 16.5 cm from the expansion chamber wall to minimize contamination of the windows.

The power of the probing laser beam of known wavelength incident on the supersonic flow was measured by a temperature compensated photocell contained in the diagnostic laser. The power of the probing beam after passage through the supersonic flow was measured by reflecting 1.0% of the beam with a lens to a second temperature compensated photocell. Both photocells had an accuracy greater than 0.1%. The change in laser power due to passage through the plasma (ΔI) was continuously recorded on an xy recorder. The power of the probe beam incident to the supersonic plasma was also continuously recorded on an xy recorder to verify the amplitude stability of the diagnostic laser during data acquisition.

For correlation of the laser measurements with the MHD arc parameters, an eight channel Sanborn recorder was used. The following were simultaneously recorded: MHD arc current and voltage, ΔI, arc chamber pressure, and exit water temperature from the arc generator anode and magnetic coils. The sensitivity of the Sanborn recorder to a change in ΔI was much less than that of the xy recorder; however, it was adequate for correlation purposes.

Results and Discussion

Sustained excitation of the $4s^2P_{1/2}$ state (4765Å Ar^+-ion lower laser level) and $4s^2P_{3/2}$ state (5145 and 4880Å Ar^+-ion lower laser level) was achieved in the supersonic expansion at a time several orders of magnitude greater than their ionic lifetimes after initial excitation in the MHD arc. The existence of $4s^2P_{1/2}$ and $4s^2P_{3/2}$ Ar^+-ion states in the supersonic jet was indicated by the absorption of the diagnostic laser beam at a wavelength of 4765Å and 5145Å, respectively. The data obtained with the 5145Å beam were confirmed with measurements obtained with a 4880Å beam.

Sustained generation of excited Ar^+-ions was correlated with a stagnation chamber MHD arc mode consisting of a very diffuse Lorentz rotating positive column. When the desired arc

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mode was obtained, the arc voltage abruptly dropped slightly in magnitude and achieved voltage stability. As the arc current was increased, the voltage increased and the arc chamber pressure either decreased slightly or remained constant. The pressure behavior was a definite indication of coupling of the energy supplied to the MHD arc to the ionization and excitation of the Ar plasma. With loss of the desired arc mode, indicated by a sudden drop in arc voltage and increase in pressure, generation of the laser states in the supersonic expansion ceased.

The magnitude of the arc current required for excitation of the electronic states depended on the electronic state. At an MHD arc chamber pressure of 50 torr, the threshold current required for generation of the $4s^2P_{1/2}$ energy level in the supersonic expansion was 340–380 amp, whereas the threshold current for the $4s^2P_{3/2}$ energy level was 420–500 amp.

The absorption measurements indicate positive existence only of the $4s^2P_{1/2}$ and $4s^2P_{3/2}$ lower laser levels of the Ar^+-ion. However, because of the existence in the supersonic expansion of these lower laser levels, the upper laser levels $4p^2P^0_{3/2}$, $4p^2D^0_{5/2}$, and $4p^4D^0_{5/2}$ of the 4765, 4880, and 5145Å transitions also are expected to be present. In the two-step excitation process by electron impact through the ground state $3s^23p^5\ {}^2P^0$ of the singly charged Ar^+-ion, one would expect, based on parity considerations, that excitation to the lower $4s$ levels should be more favorable than excitation to the upper $4p$ levels.[2] However, the theoretical calculations of Beigman et al.[9] suggest that the total excitation cross sections for the $4p$ and the $4s$ levels may well be of the same magnitude. In fact, according to their numerical results, excitation to the $4p$ configuration is favoured at high electron temperature. Through appropriate choice of the independent variables affecting the excitation parameters, one thus should be able to directly obtain population inversion of the Ar^+-ion states in the supersonic expansion.

Through variation of the Ar mass flow rate, sustained laser gain at 5145Å was obtained. Figure 1 is a typical representation of the obtained laser gain. The stagnation pressure was first increased to 130 torr, resulting in laser absorption. The arc voltage is very noisy until the arc current is increased. With increase in arc current laser gain commences and continues over a wide range of arc current. For the conditions of Fig. 1 a laser gain of 1.7% per meter was achieved.

The laser gain is most sensitive to the stagnation pressure and mass flow rate of Ar. The only essential differences in the conditions for which absorption occurred and for which gain occurred are the stagnation pressure and the mass flow rate of Ar. For example, with the same arc current, absorption would occur at a mass flow rate of 3.8 g/sec while gain would occur at a mass flow rate of 4.8 g/sec. With either increase or decrease of the mass flow rate from 4.8 the gain in Fig. 1 disappeared. This critical dependence of the laser gain on the mass flow rate is being investigated further.

The statement by Smith et al. for the observed delayed threshold laser oscillation for a pulsed static discharge tube applies equally well for the supersonic expansion, "It is difficult to envisage such excitation processes, cascades from the more highly ionized Ar states, or any plasma effect providing lifetimes as long as this."[5]

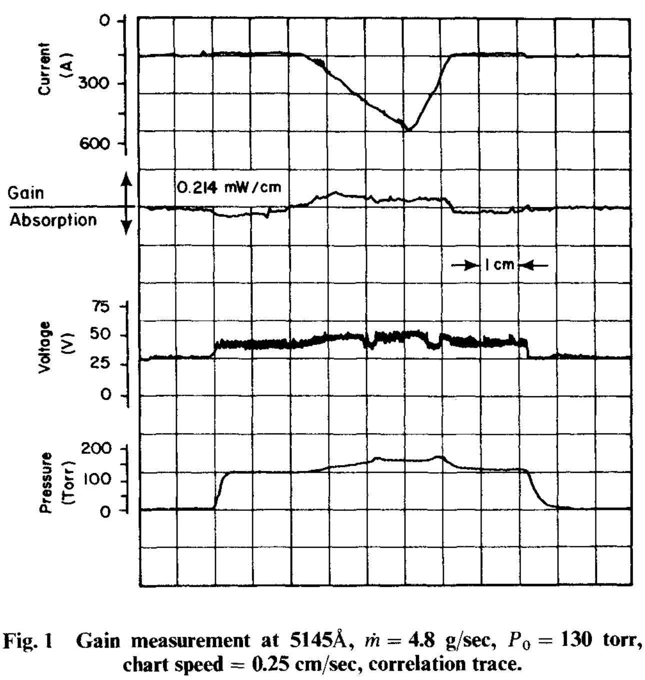

Fig. 1 Gain measurement at 5145Å, $\dot{m} = 4.8$ g/sec, $P_0 = 130$ torr, chart speed = 0.25 cm/sec, correlation trace.

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Method for Determining the Effect of Added Stores on Aeroelastic Systems

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In this Note, a method is presented for determining the effect of an added store on the stability of a given aeroelastic system. It is assumed that the addition of the store affects only the mass characteristics of the system, with the aerodynamic and elastic properties remaining unchanged. The mass of the added store, together with its c.g. and radius of gyration, is treated as an auxiliary variable in the flutter equation. The

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