XV. GASEOUS ELECTRONICS*

Academic and Research Staff

Prof. E V. George
Prof. G. Bekefi
Prof. S. C. Brown
J. J. McCarthy
W. J. Mulligan

Graduate Students

J. Golden
G. J. Raff

RESEARCH OBJECTIVES

Our general objectives are concerned with the study of atomic and molecular processes and with the transport of charged particles in weakly ionized collision-dominated plasmas. We are devoting our efforts to those problems in gaseous electronics that are relevant to the physics of gas lasers. These devices have numerous applications.

We are expanding our studies of gas lasers to the development of techniques for measuring gas-discharge parameters such as collision cross sections as a function of energy, by using the lasing mechanism as a probe. In particular, we are investigating the observed time delay between the beginning of the excitation current and the output laser pulse. It is thought that this delay is a measure of the excitation cross section. These delays have been seen in both ion and He-Ne lasers.

We have recently developed a theory for extending the useful range of microwave cavities for obtaining electron densities by cavity frequency shifts. This technique is being used in the studies of ion lasers both in the pulsed and cw regimes.

With the advent of the high-pressure CO_2 laser our attention has been focused on studying the plasma formation. At present, the power output of these lasers is limited because the plasma is extremely nonuniform; only a few per cent of the gas medium is actually excited.

We are also looking into problems of striations, sound propagation, and mode locking, which have practical applications in producing better and more stable gas laser devices.

E. V. George

A. TIME-DEPENDENT CHARACTERISTICS OF PULSED ION LASERS

The phenomenon of current-controlled time delays in the laser output of pulsed Argon and Xenon ion lasers has been previously reported.[1,2] Briefly, several particular laser transitions occur only after delay times of ~10-40 μs from initiation of the excitation current pulse. The value of the delay time depends upon the strength of the pulse current, with shorter delays corresponding to higher currents. This phenomenon is observed for typical gas pressures in the range 20-100 mTorr and at discharge currents from 5-30 A in a 2-mm I. D. bore discharge tube.

In order to develop the theory of the time-delay characteristics, the spontaneous

*This work was supported by the Joint Services Electronics Programs (U.S. Army, U.S. Navy, and U.S. Air Force) under Contract DA 28-043-AMC-02536(E).

emission of several of the relevant transitions were observed. Figure XV-1 gives a partial energy level diagram for singly ionized Argon. Both transitions 5145 Å and

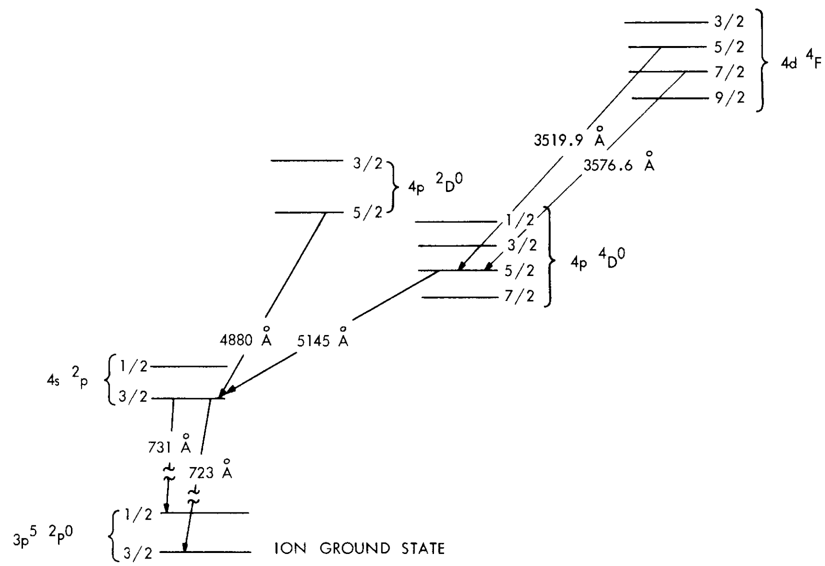

Fig. XV-1. Partial energy level diagram of Ar II.

4880 Å, which terminate on the 4s $^2P_{3/2}$ level, display time-delay behavior. The intensities of the spontaneous emissions for the transitions 5145 Å, 4880 Å, 3576 Å, and 3520 Å were measured as a function of the peak value of the discharge current pulse. The photomultiplier output of the 4880 Å spontaneous emission for three values of pulse current is illustrated in Fig. XV-2. In all of the measured Argon transitions, the spontaneous emission intensity was found to be proportional to the square of the pulse current.

Consider the rate of population of the j^{th} excited level in a singly ionized gas. The rate equation may be expressed[3]:

$$\frac{dN_j}{dt} = (-A_j+d_jn_-)N_j + S_{oj}N_on_- + S_{Ij}n_-^2,$$

where N_j is the density of excited ions, N_o is the neutral atom density, and n_- is the electron density. The density of singly ionized particles is assumed to be equal to the electron density. S_{oj} and S_{Ij} are the production rate coefficients for the state j by electron collision with neutral atoms and with singly ionized particles, respectively. A_j is the effective radiative decay rate of the j state, and d_j is the destruction rate coefficient of the state by electron collision.

The differential equation has the solution

$$N_j(t) = \left(\frac{n_- N_o S_{oj} + n_-^2 S_{Ij}}{A_j + d_j n_-}\right)\left[1 - e^{-(A_j+d_j n_-)t}\right]. \tag{1}$$

If the destructive collision rate is negligible compared with the spontaneous emission rate, $A_j \gg d_j n_-$, and the excitation of neutral atoms to the j ion state (one-step excitation process) dominates over the formation of ions from neutrals with subsequent excitation of the ions (two-step process), the solution reduces to

$$N_j(t) = \frac{n_-^2 S_{Ij}}{A_j}\left(1 - e^{-(A_j+d_j n_-)t}\right). \tag{2}$$

Note that to the order of approximation which may justify neglecting $d_j n_-$ in the denominator of the first factor, the destructive rate coefficient cannot be dropped from the exponential.

If it is further assumed that the electron density is proportional to the discharge current (this seems to be the case based on preliminary results of electron density measurements reported in Sec. XV-B), the measured quadratic dependence of spontaneous emission upon current conforms to Eq. 2.

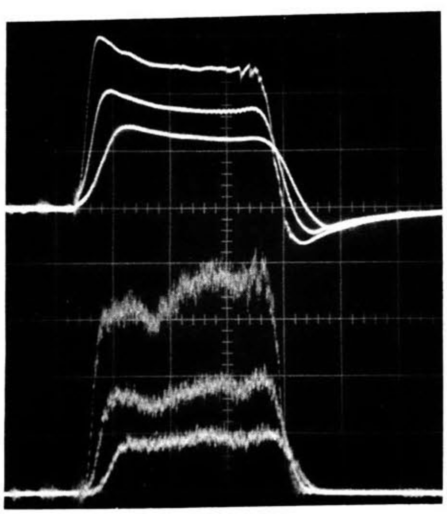

Fig. XV-2. Upper trace: current pulses, 4 A/div. Lower trace: spontaneous emission of the 4880 Å Ar II line at 30 mTorr pressure, 20 mV/div. The order of the emission traces corresponds to the order of the current traces. Time base: 10 μs per major division.

Figure XV-2 also shows that there is no delay time between the current pulse and spontaneous emission independent of the amount of current. This was the case for all Ar II transitions measured and was a somewhat surprising result. This evidence indicates that for the rate coefficients $(A_j+d_j n_-)$ in the exponential of Eq. 2 the $d_j n_-$ term is negligible compared with A_j; this implies a vast dominance of radiative transitions over destructive collisions. Previously reported measurements of the 4954 Å, Xe III transition, which show laser time-delay characteristics indicate that the spontaneous emission is also subject to current-dependent time delays, analogous to the laser output.[2] Thus the Xenon transition data suggest the possibility of electron destruction of the upper laser ion level as a significant mechanism in time-delay behavior. The Argon measurements, however, raise serious doubts concerning the efficacy of destructive collisions in explaining the time-delay characteristics and, perhaps, favor the theory of gradual freeing of trapped ion resonance radiation on account of ion temperature increases within a current pulse.[4]

G. J. Raff

References

1. E. V. George and S. F. Fulghum, Jr., "Time-Dependent Threshold Characteristics of a Pulsed Xenon Laser," Quarterly Progress Report No. 96, Research Laboratory of Electronics, M.I.T., January 15, 1970, pp. 113-115.

2. G. J. Raff, S. F. Fulghum, Jr., and E. V. George, "Time-Dependent Threshold Characteristics of Pulsed Nobel Ion Lasers," Quarterly Progress Report No. 98, Research Laboratory of Electronics, M.I.T., July 15, 1970, pp. 71-73.

3. T. Cottrell, IEEE J. Quant. Electronics, Vol. QE-4, p. 435, 1968.

4. M. B. Klein, Appl. Phys. Letters 17, 29 (1970).

B. ELECTRON DENSITY MEASUREMENTS IN PULSED ARGON ION LASERS

A program of measurements of the electron densities in pulsed ion lasers, by means of microwave cavity techniques has begun. The density is calculated from observed shifts in the TE_{011} cavity resonance that are due to the presence of the plasma. The extension of microwave diagnostics to high-density laser plasmas has been reported previously.[1]

The measurements are being conducted on a laser tube of 42-cm discharge length and 2.0 mm bore diameter. The current is pulsed at a repetition rate of 30 per second, with peak currents of up to 25 A. Figure XV-3 is a block diagram of the experimental apparatus. As the microwave generator is slowly swept through the frequency range of the expected shift (5470-5500 MHz), its output is gated on for a duration of 1 μs at a rate synchronized to the laser pulse rate. A variable time delay τ between the initiation of the laser pulse and the gate pulse allows the microwave sampling of the plasma at any time within the pulse, or in the afterglow region. The pulsed microwave cavity output is then fed to a synchronous detector slaved to the pulse repetition rate where the samples are integrated to yield a continuous signal of the cavity

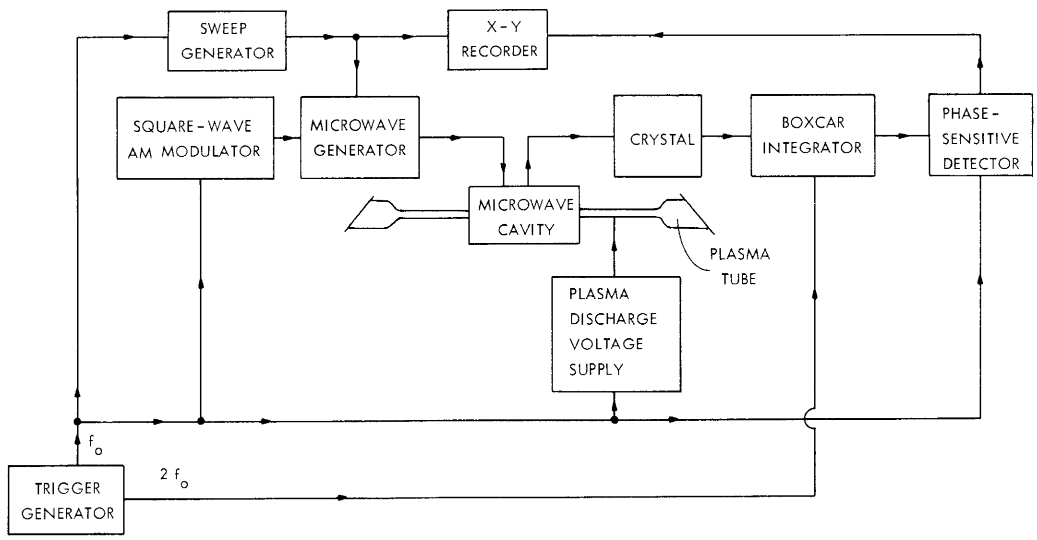

Fig. XV-3. Apparatus used in measurement of the pulsed plasma discharge.

output power. This power level is input to the vertical axis of the chart recorder while the microwave generator sweep voltage that is proportional to the microwave frequency is fed to the horizontal axis. Wavemeters are used as frequency calibrators. The frequency shift of the cavity resonance for given plasma conditions is measured from that of the resonance without the plasma discharge, and the electron density is thereby computed.

Preliminary density measurements are reported here.

1. Density-Current Relationship

Figure XV-4 shows the sampling gate superimposed upon a discharge current pulse of 6 A. The 37-μs duration of the pulse is typical of all discharges, and the gate delay τ was held fixed at 20 μs. Figure XV-5 shows the results of density measurements for Argon as a function of pulse current for 4 values of filling pressure. We hope that recent improvements in the experimental techniques will reduce the scatter in data points. It is fairly obvious from Fig. XV-5, however, that the electron density is linear, with pulse current over substantially the total current range investigated. The measurements indicate considerably higher values of density than would be expected on the basis of extrapolating similar measurements performed on Argon ion cw discharges in the same plasma geometry. The present pulsed data tentatively indicate a density scaling law of

$$n \approx 70 \times 10^{11} Jp \ (\text{cm}^{-3}),$$

where n is electron density, J is the discharge current density in A/cm^2, and p is

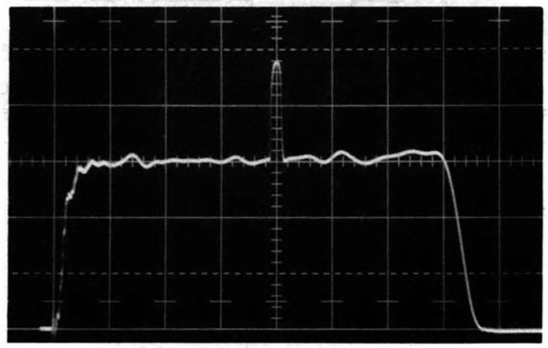

Fig. XV-4. Discharge current pulse for 66 mTorr Argon with gate pulse superimposed. Vertical: 2 A/div. Horizontal: 5 μs/div.

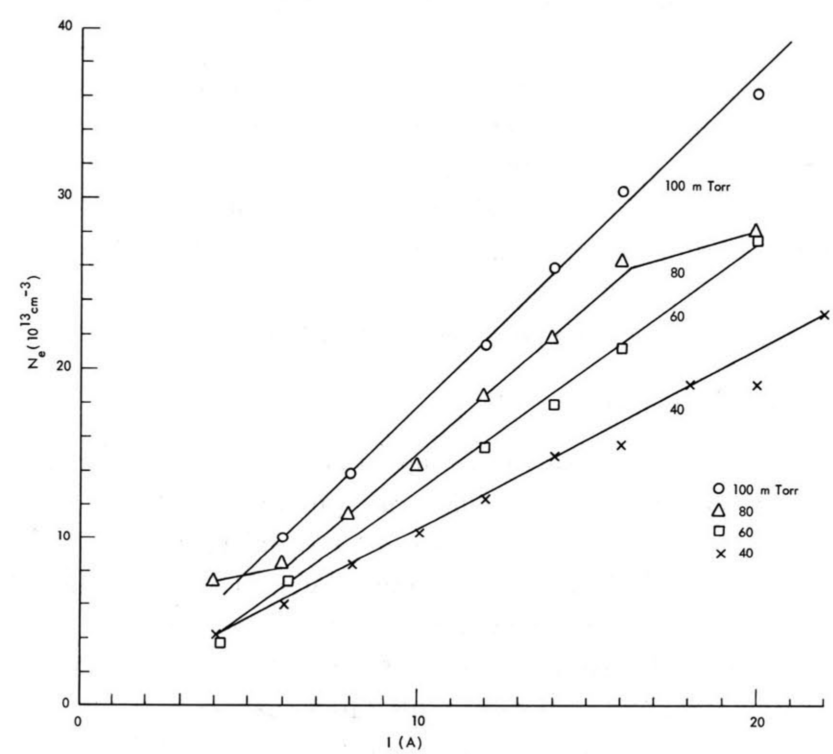

Fig. XV-5. Electron density as a function of pulsed discharge current for 40, 60, 80 and 100 mTorr pressures of Argon.

pressure in Torr. The proportionality coefficient is approximately a factor of 35 higher than that obtained from cw measurements.[2] Differences in other plasma parameters between the two cases, such as field strength, particle temperatures, and wall temperature are being investigated in order to explain the scaling defect.

2. Density-Time Relationship

The time behavior of electron density within the discharge pulse has also been observed. For this measurement, the discharge current was held constant at 20 A, while the sampling gate delay was varied from 5 μs to 50 μs from the turn-on of the pulse. Measurements in times less than 5 μs from turn-on could not be accomplished because of the transient ringing of the microwave cavity within this period. For a pressure of 66 mTorr of Argon, we found that the electron density maintained a value of 2.6×10^{14} cm^{-3}, with less than 7% measurement variation, for the entire measurable duration of the current pulse.

G. J. Raff, E. V. George

References

1. L. D. Pleasance and E. V. George, "Microwave Diagnostics of High-Density Laser Plasmas," Quarterly Progress Report No. 98, Research Laboratory of Electronics, M.I.T., July 15, 1970, pp. 73-78.

2. L. D. Pleasance and E. V. George, "Microwave Density Measurements in Ion Laser Plasmas," Twenty-third Annual Gaseous Electronics Conference, Hartford, Connecticut, October 20-23, 1970.