High Temperature Studies of Electron-Beam Pumped Argon–Nitrogen Laser Characteristics

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Abstract—**Gain and laser output power of an electron beam pumped Ar–N_2 mixture were measured over the temperature range 25 to 350°C. The gain is about 0.6 cm^{-1} at room temperature, and increases to almost 1 cm^{-1} at 250°C. The laser performance at elevated temperatures was determined using a specially designed high temperature resonator. The fluorescence yield and laser output are found to decrease monotonically with temperature.**

Introduction

During studies of various kinetic processes involving electron-beam excited laser media, especially organic dye vapors [1], [2], we found that argon-nitrogen mixtures provided a convenient method for characterizing new measurement techniques. In particular, we used the laser performance of Ar-N_2 [3], [4] as a critical test for the high temperature capability of a newly developed optical quartz resonator. As a result of these tests, we observed certain properties of the Ar-N_2 system which have not been previously reported. Specifically, the fluorescence yield, gain, and laser output power from this system were monitored over a range of temperature from 25 to above 300°C.

The Experiment

Our basic apparatus consisted of a stainless steel cell, designed to operate at high temperature and pressures, mounted directly to the field emission diode of a Physics International Pulserad 110 electron beam accelerator. The cell was thermally isolated from the machine and enclosed in an oven which permitted heating of the entire experimental region to above 400°C. Two ports, one on each end of the cell, permitted observation through high-pressure sapphire or quartz windows of the optically active region along an axis transverse to that of the electron beam. A port at the rear of the cell allowed access for such diagnostic probes as a Faraday cup or a thermistor calorimeter. Details on cell construction and system performance are discussed in [5].

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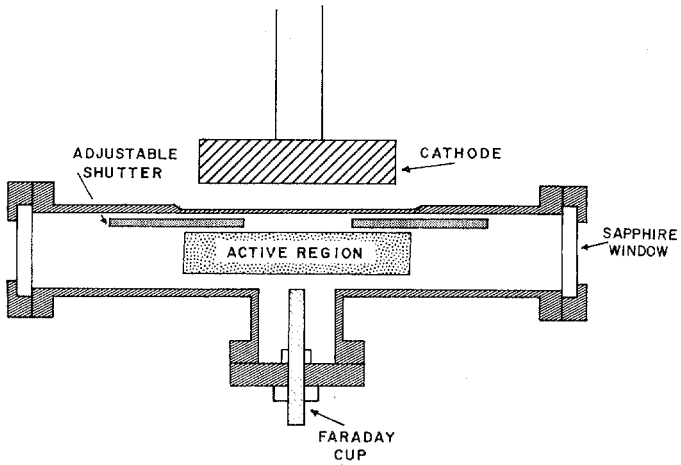

Fig. 1. Diagram of the stainless steel experimental cell. The electron beam enters cell via a titanium foil separating the cathode from the active region. The adjustable shutters slide back and forth with the aid of magnetic coupling through the cell wall.

In order to measure the fluorescence output from the argon-nitrogen mixture, as well as to determine its gain, a method adapted from [6], [7] was used. Two sliding aluminum shutters were placed inside the cell. These shutters would block portions of the incoming electron beam, and permit pumping of only a specified region. A diagram of the cell, together with its shutters, is shown in Fig. 1. An ITT FW114 photodiode was mounted about 65 cm away from the center of the cell to monitor the fluorescence yield.

In our first experiment, performed at room temperature, the shutters were progressively opened wider and wider while the increase in fluorescence output was observed. A plot of the intensity as a function of shutter width is shown in Fig. 2. Adopting the analysis of [7] to our case, we may express the output I, as a function of aperture width x, as:

$$I = \frac{I_0}{\alpha}\,(e^{\alpha x} - 1)$$

where I_0 is a constant proportional to the fluorescence output per unit length from the gas, and α is the effective net gain of the medium in cm^{-1}. This expression does not take into account saturation effects or absorption in the unpumped region by unexcited nitrogen or other species, and may only be applied in the small-signal approximation. The expression also assumes that the detector is located far away from the cell.

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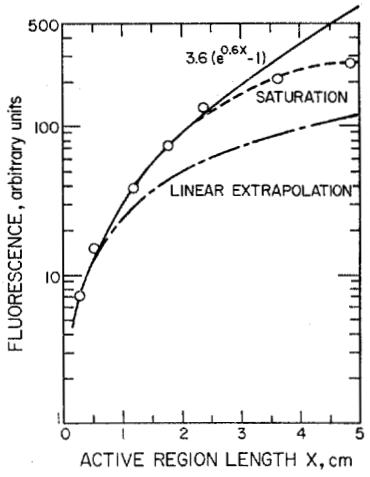

Fig. 2. Fluorescence output from 10 percent N_2 in Ar mixture as a function of the width of the pumped region. The solid line is a mathematical fit to the data with the expression $I = I_1/\alpha(e^{0.6} - 1)$. The dotted line shows where saturation effects begin to occur. The dot-dashed line indicates a linear increase in fluorescence output as a function of pump width.

The solid line in Fig. 2 represents a best fit to the data, using $I_0/\alpha = 3.6$ and $\alpha = 0.6$ cm^{-1}. It is interesting to note that this value of α is quite close to that predicted by Bhaumik [8], although in his work a gain of only one-half this value is reported. The dot-dashed line indicates the behavior which would be observed from a strictly linear system, (i.e., no loss, no gain, the output being just proportional to the length of the pumped region). The dotted line indicates where the actual output from the cell begins to deviate from the small expression due to saturation effects. In these experiments, a 4 atm commercially mixed 10 percent nitrogen in argon mixture was pumped with a current density of around 500 A/cm^2 and an electron beam energy of 1 MeV. The total saturated output from one window of the cell into 6×10^{-4} saturation was about 1 W for a 5 cm long active region.

In order to measure gain at elevated temperatures, it was necessary to change the experimental apparatus slightly. Technical problems made moving both shutters with good accuracy difficult. Thus, we adopted the procedure of simply changing the length of the pumped region from 1 to 2 cm. This was accomplished through the use of one fixed shutter and a second shutter which opened and closed with the aid of a pair of samarium-cobalt magnets. One magnet was mounted on the shutter, while the second was attached to a handle on the outside of the cell. Suitable stops on the movable shutter ensured that we could achieve exactly 1 and 2 cm openings by simply sliding the shutter all the way to one side or the other. The two arrows on Fig. 2 indicate the two widths which were used. These points were chosen to be within the nonsaturated region of the argon-nitrogen gain. Homogeneity of the pumping electron beam was checked by monitoring the fluorescence product by various positions of a small aperture which was moved across the active region. Very little variation was observed. We measured the fluorescence output over a temperature range from 25 to 225°C as shown in Fig. 3. We may conveniently take the ratio of the 2 cm long fluorescence to the 1 cm long fluorescence region and calculate the small-signal gain α. If the

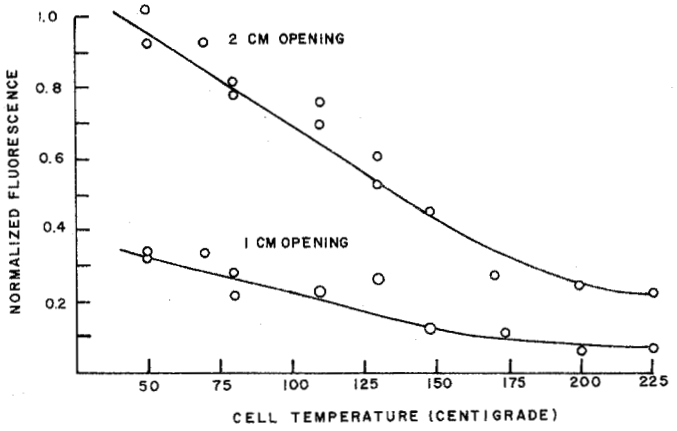

Fig. 3. Normalized fluorescence output from Ar-N_2 as a function of cell temperature for both a 1 and 2 cm pumped region.

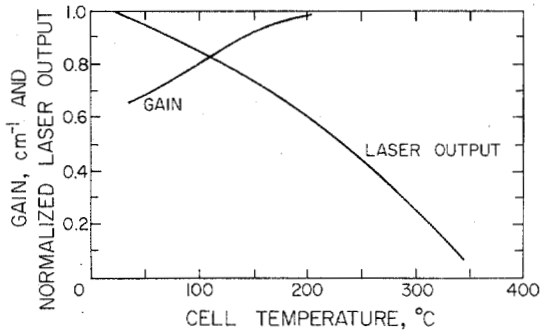

Fig. 4. Gain and normalized laser output power for Ar-N_2 as a function of temperature. The gain is in cm^{-1}, while the laser output is normalized to the 25°C output.

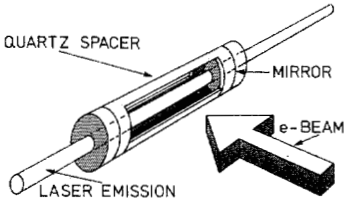

Fig. 5. Schematic of the high temperature resonator. The electron beam enters the active region through one of the side openings. The laser beam exits through the dielectric coated quartz mirrors which are sintered onto a quartz spacer.

output for the 2 cm opening is called I_2, and that for the 1 cm opening I_1, then the gain α is given by the expression

$$\alpha = \ln\left(\frac{I_2}{I_1} - 1\right).$$

The values which are obtained for α from our data are then plotted in Fig. 4. Although the fluorescence output from the argon-nitrogen mixture decreased with increasing temperature, the small-signal gain α remained in the 0.6-1 cm^{-1} range. We were unable to take data beyond 250° because of the poor signal-to-noise ratio of the very low fluorescence output.

We also investigated the laser output power from this system as a function of temperature. A prealigned, optical quartz resonator, as shown in Fig. 5, was developed consisting of a

quartz spacer with ends polished parallel and flat to within $\lambda/10$. Two flat quartz substrates, with high temperature resistant reflective coatings, were attached directly to the quartz spacer by a sintering technique described in [5]. The mirrors were developed for organic dye vapor laser studies, and therefore were not optimally coated for the Ar-N_2 laser. They had a reflectivity of about 90 percent at the 380 nm line, and a 60 percent reflectivity at the 358 nm line. Two symmetrical openings, one on each side of the spacer, provided access for the electron beam. Faraday cup measurements of the current density along the optic axis with and without the resonator indicated essentially no change in the energy deposition in the active region. Fig. 4 also shows a plot of the normalized laser output power as a function of temperature up to 350°C. The room temperature output power was about 100 kW with a 10 kA pump pulse at 1 MeV for our particular experimental arrangement. The laser output follows the decreasing fluorescence yield as a function of temperature while the gain of the system remained high. Although it would appear that the effective population inversion is unaffected by an increase in temperature, the energy transfer from the electron beam to the nitrogen species decreases as the cell gets hotter. One of the most likely explanations of this situation is a temperature dependent competition from reaction channels which leads to dissipation of the energy imparted to the system. One such candidate would be the endoergic reaction between Ar^+ and N_2^+, which would compete with the termolecular association of Ar^+ into Ar_2^+. This latter reaction is at the head of the main sequence leading to population inversion, and would be expected to have an inverse temperature dependence. Thus, energy is routed into loss channels via the N_2^+ reaction early in the kinetic chain, resulting in a decreased output but not a decrease in the relative inversion of the excited N_2 species.

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