A Technique for Studying the Absorption Characteristics of Electron Beam Excited Gas Plasmas by Organic Dye Vapors

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Abstract—A new method for determining the absorption spectra of electron beam pumped rare gases is described. The excited gas may be conveniently probed by the fluorescence radiation from organic dye vapors. Preliminary results for argon absorption in the range 375 to 395 nm are reported.

ELECTRON beam pumped gas lasers such as rare gas and rare gas-halide lasers have proven to be highly efficient sources of coherent radiation [1]. Scaling such laser system for high power operation seems to be limited by several quenching processes such as a bound-bound absorption from low lying excited atomic and molecular states in the rare gases. In particular, a broad continuous absorption in argon and xenon is present throughout the visible that has uncertain origin [2]-[4]. In order to both analyze and overcome problems associated with this newly identified loss mechanism, precise knowledge of the magnitude and spectral position of the absorption characteristics is necessary. The most direct approach to this problem has been to use the radiation from tunable pulsed laser sources to probe the absorption [5], [6]. However, this technique requires careful pulse synchronization and application of various laser systems to obtain reliable results.

In this paper, we describe a novel and alternative technique for convenient probing of the rare gas absorption behavior over a broad spectral range that uses the fluorescence or amplified spontaneous emission of a suitable dye vapor added as a background radiation source. As an experimental test of this technique, the electron beam produced plasma absorption of argon was examined using the fluorescence background of a small amount of vapor from the dye POPOP (p-phenylene-bis-(5, 7-phenyl-2 oxazole) added to the rare gas. In gain studies of electron beam excited POPOP dye vapor [8], [9] mixtures, it was established that POPOP vapor can be considered as a background source of radiation provided its vapor pressure is kept low (typically <0.1 torr) and the buffer gas pressure exceeds a minimum pressure required for complete dye vapor excitation (~1 atm argon). For argon pressures greater than 1 atm, the transmission of the internally generated dye fluorescence is essentially governed by the absorption of the buffer gas.

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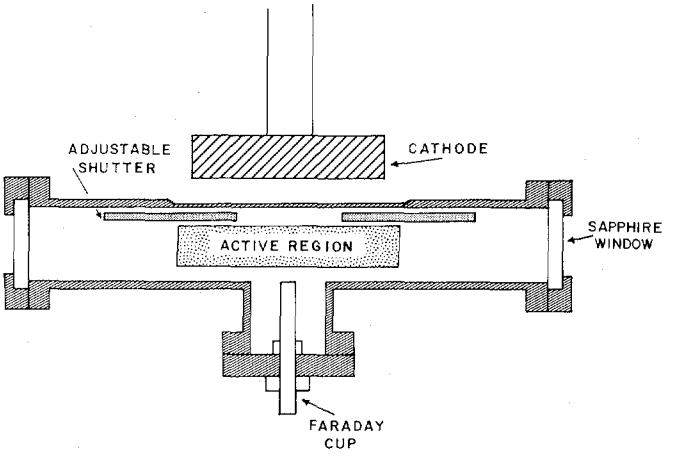

Fig. 1. Dye vapor cell with magnetically driven shutter system for optical absorption measurements of rare gases.

Since a convenient cell design capable of high pressure and high temperature operation for electron beam excitation of rare gases and dye vapors has been described in detail elsewhere [9], we limit our description of Fig. 1 to only those aspects that pertain to the absorption measurement. A magnetically positioned shutter system can be used inside the cell to block one half (3 cm) of the incident electron-beam pump flux that penetrates through a thin titanium anode window. In case of small absorption, a magnetically positioned mirror may be used instead of the shutter to probe twice the active length for absorption. If I_1 and I_2 denote the photodiode signals for half and total active length (L = 6 cm) for a diode positioned at a distance d from the center of the active region such that $L/d \ll 1$, the net unsaturated gain efficient α and absorptivity β is given by the relation [10]

$$\alpha - \beta = \frac{2}{L} \ln\left(\frac{I_2}{I_1} - 1\right). \tag{1}$$

The absorptivity β includes both the dye and rare gas absorption. For small dye vapor pressures (<0.1 torr) most dyes exhibit no measurable gain coefficient, and the dye absorption can be determined experimentally in the absence of any rare gas absorption. Equation (1) holds only for small differences which can easily be fulfilled by an appropriate choice of the dye vapor pressure.

The observed absorption of the full POPOP dye vapor fluorescence band of about 20 nm centered at 385 nm for increasing argon buffer gas pressures is shown in Fig. 2. An effective increase of the argon absorption of 25 percent upon increasing the argon pressure from 1 to 4 atm for an electron-

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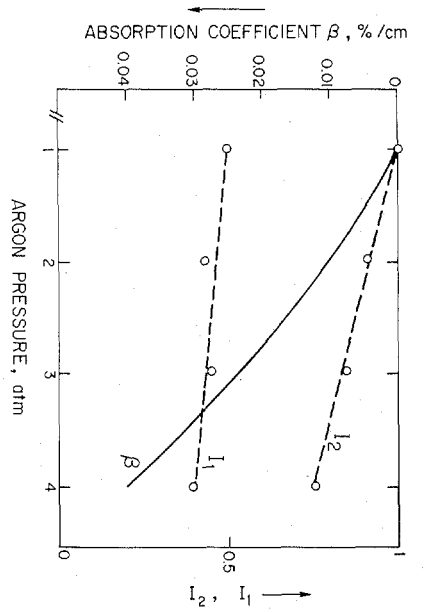

Fig. 2. Dependence of dye vapor fluorescence intensities I_1 (3 cm probing lengths) and I_2 (6 cm probing length) upon argon buffer gas pressure together with calculated absorption data from I_1 and I_2. The data were obtained with 0.25 torr of POPOP dye vapor.

beam irradiated length of 6 cm was observed. This nonlinear absorption can be attributed to the various pressure dependent processes associated with the formation of ionic and molecular species [2]-[4]. The spectral resolution of the absorption measurements using this new technique is limited to about 20 nm, which is the bandwidth of the probing POPOP dye vapor emission. The method can be conveniently extended to higher spectral resolution of 1 nm or less by using an appropriate filter system, such as a monochromator. Furthermore, this method can be utilized to probe a broad spectral range of rare gas absorption in the UV and visible. Fig. 3 summarizes the fluorescence spectra of various optically excited dye vapors that cover the entire range from 300 to 650 nm. These vapors appear to be interesting candidates (at typical operating temperatures of 200 to 300°C) for probing the absorption of electron beam irradiated rare gas or rare gas halide systems. This measurement technique is limited to probing rare gas kinetics that occur in a nanosecond time scale due to the typical decay times of several nanoseconds of the first excited singlet state of most organic dyes in the vapor phase [11]. Contamination of the *e*-beam pumped reaction cell by an unwanted residue of dye is avoided by a pump out procedure. Furthermore, reliability of this absorption method requires uniform electron beam current distribution along the length of the anode foil.

In summary, we have described a novel technique for probing the absorption behavior of electron beam excited rare gas systems, such as argon, neon, or xenon, by the addition of dye

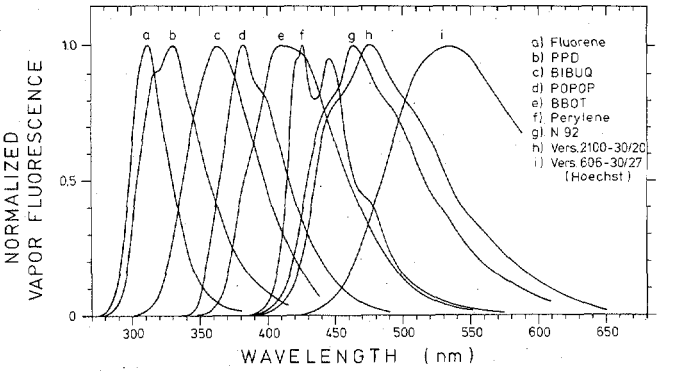

Fig. 3. Normalized vapor phase fluorescence spectra of various organic dyes to indicate available spectral coverage from 300 to 650 nm.

vapor. The dye vapor fluorescence can then serve as a radiation source to probe plasma absorption with high spectral resolution and broad range. Measurements performed with POPOP dye vapor indicate an absorption of 25 percent for argon at 4 atm in the spectral range 375 to 395 nm.

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