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Improved Performance of the Microwave-Pumped XeCl Laser

P.J.K. WISOFF, A. J. MENDELSOHN, S. E. HARRIS, AND J. F. YOUNG

Abstract–**Significant improvements in pulse length (200 ns), output power (500 W), and repetition rate (400 Hz) of the microwave-pumped XeCl laser are reported. Efficient coupling of microwave power into Ne at pressures up to 17 atm has been demonstrated.**

MICROWAVE pumping is a simple and practical excitation technique for high pressure, rare gas halide (RGH) lasers which avoids the instabilities and consequent short pulse lengths of conventional avalanche discharge systems. Other methods which have been used to achieve long excimer laser pulse lengths include resistively stabilized discharges [1], X-ray preionized discharges [2], *e*-beam controlled discharges [3], and *e*-beam excitation [4]. The first microwave device was described by Mendelsohn *et al.* [5], and in this letter we report significant improvements in pulse length, power, and repetition rate, based on increased microwave power, new coupling geometries, and an improved gas handling system. The effects of a small microwave absorption skin depth are discussed, and preliminary results of very high pressure experiments are presented.

The first set of experiments used the same cell as [5], but with a higher capacity recirculating pump, cleaner gas manifold system, higher microwave power, and improved mechanical mounting of the cell and mirrors. The basic experimental configuration, as shown in Fig. 1 and described in [5], consisted of two sections of WR-90 waveguide coupled together by a series of "Riblet Tee" slots [6]. These slots were spaced to transfer RF power uniformly from the primary to secondary waveguide along a 40 cm active region. A Metal Bellows MB-602 recirculating pump maintained a longitudinal flow of the RGH mixture through a 3 mm i.d. quartz tube located in the secondary guide. The optimum RGH mixture consisted of 0.3 percent Xe, 0.05 percent HCl, and 99.6 percent Ne at an absolute pressure of 2–3 atm which was limited by the recirculating pump. The RF power was generated by a Varian SFD-303 coaxial magnetron and line type pulser which provided 600 kW, 2 μs long pulses at 9.375 GHz.

The design provided 150 full-width half-maximum (FWHM) laser pulses, approximately 20 percent round trip gain, and output powers of 500 W centered at 308 nm using 5 percent output coupling. While this pulse length is ten times longer than those of typical discharge systems, it is surprisingly short relative to the observed fluorescence, which lasted over 500 ns FWHM. The normal repetition rate was 10 Hz, although rates over 400 Hz were possible with reduced performance because of the low longitudinal flow rate. At 400 Hz, an average power of 1 mW was observed.

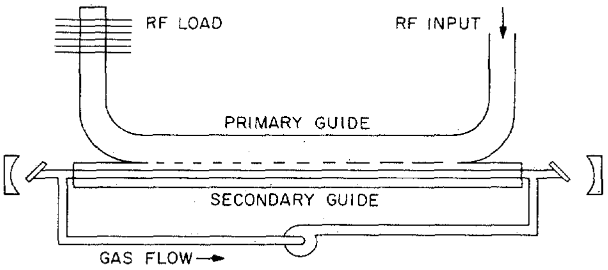

Fig. 1. Schematic of the microwave-pumped XeCl laser. The Brewster windows are CaF$_2$, and the cavity consists of 2 m radius mirrors 1 m apart.

In a second set of experiments, a new SFD 303B magnetron, which could provide up to 1.4 MW, 3.5 μs long pulses, was used in conjunction with a new cell design. The secondary guide area was reduced by decreasing the waveguide height to about 6 mm, the plasma tube outside diameter. Since the longitudinal absorption length is inversely proportional to the fractional area of the guide filled with plasma, decreasing the area of the secondary guide shortens the longitudinal absorption length. To further optimize microwave power deposition, an exchangeable coupling plate was used between the primary and secondary guides. Best results were obtained with a "Riblet Tee" structure over the input half of the discharge length, followed by a completely open region between the two guides. As shown in Fig. 2, the microwave power was completely absorbed for the first 500 ns of the input microwave pulse. The reflected power was negligible throughout the pulse. Laser action occurred at the time of maximum fluorescence, which coincided with the drop in microwave absorption. Compared to the earlier cell, we observed longer pulses, ~200 ns, but reduced peak powers, ~250 W. The net gain was higher than before, ~40 percent per round trip, so that larger output coupling may give improved powers and efficiency. This cell was normally operated at 20 Hz with a maximum repetition rate of 190 Hz.

The deposition of microwave power into the plasma was in part limited by a small skin depth which became evident as a ring of bright fluorescence at the circumference of the plasma tube. For a uniform plasma, the absorption skin depth is proportional to $(\nu_c/\omega n_e)^{1/2}$ where ν_c is the collision frequency, n_e is the electron density, and ω is the microwave frequency. This indicates that one can reduce the skin depth problem by working at high pressures provided ν_c increases more rapidly than n_e.

A new smaller volume cell has been designed, shown in

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The authors are with the Edward L. Ginzton Laboratory, Stanford University, Stanford CA 94305.

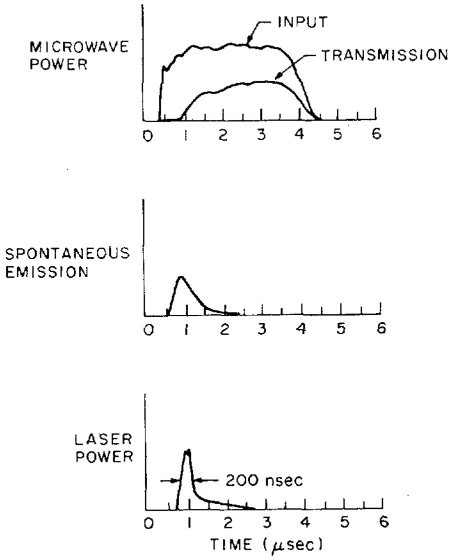

Fig. 2. Relative time behavior of the microwave input and transmitted power, XeCl spontaneous emission, and laser output pulses. Negligible microwave power was reflected.

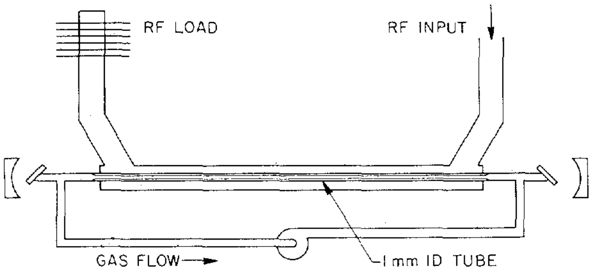

Fig. 3. Schematic of the small volume, direct coupled, microwave-pumped cell.

Fig. 3, with a 1 mm i.d., 25 cm long tube placed directly in the primary guide. A 50 cm confocal resonator having a mode which nearly fills the tube was used. Preliminary results indicate that the skin depth is sufficiently large to uniformly excite the small bore tube. In addition, because of the smaller active volume, the microwave power required to reach XeCl laser threshold has been reduced to ~100 kW. One disadvantage of the direct coupling, however, is the relatively high microwave reflection, ~30 percent.

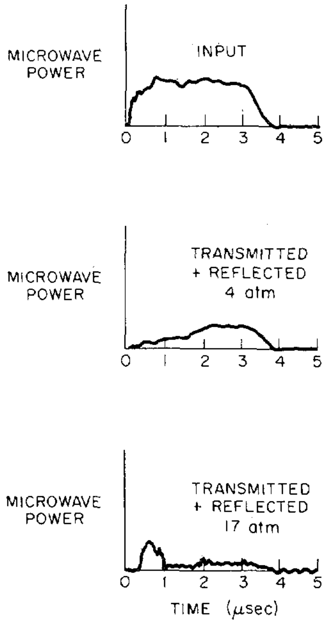

Fig. 4. Relative time behavior of the microwave input and transmitted + reflected power for the cell of Fig. 3.

We have also used this cell design, but with a 3 mm i.d. tube, to test the ability of microwaves to couple effectively into very high pressure gases. The tube was statically filled with pure Ne up to pressures of 17 atm and measurements of incident, reflected, and transmitted microwave power were made. An external Xe flashlamp directed through a small window in the side of the waveguide provided the small amount of UV preionization required for breakdown at these pressures. For pressures of less than 8 atm, the microwave absorption is nearly 100 percent early in the pulse but decreases to ~50 percent later in the pulse. Typical time behavior for 4 atm is shown in Fig. 4. Presumably, the electron density is rising faster than the collision frequency, causing the microwaves to be shielded out of the plasma. From 8–17 atm, the microwave absorption during the latter half of the pulse increases until at ~17 atm, the absorption is ~100 percent over the complete pulse length following breakdown. This indicates that microwave pumping may offer a simple technique for investigating high pressure laser systems which are impractical using typical electric discharges.

With these cell designs, we have improved the peak laser powers by 25 times that reported earlier. The pulse lengths have been increased by a factor of 2, and the repetition rate has been extended to 400 Hz from the previously reported 10 Hz. Preliminary studies have also demonstrated that microwave pumping may have unique application to the high pressure excimers such as Xe_2, Xe_2Cl, and other dimer or triatomic species.

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