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Short Note

Output Characteristics of a KrF Laser Dependent on the F_2 Absorption in Inactive Regions

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Dependence of the output power of a discharge-pumped KrF laser on the F_2 absorption in inactive regions has been studied. The F_2 absorption cross section at 248 nm was experimentally determined to be 1.6×10^{-20} cm^2. A greater than 15% increase in the output was obtained by filling the inactive regions on the optical path with a rare-gas mixture.

KEYWORDS: KrF, excimer laser, F_2 photoabsorption, rare-gas filling

Discharge-pumped KrF excimer lasers have been intensively developed of use in optical microlithography.[1] These lasers are designed to be of compact size with a small length of active region for saving the footprint and relatively large inactive regions which are necessary for sealing shutters or gate valves for frequent window maintenance. These inactive regions of the medium contain F_2, which causes a loss of output power due to photoabsorption.[2-4] This paper reports the dependence of the output power on the F_2 absorption in the inactive regions of a compact discharge-pumped KrF laser. The loss in laser mixtures under static conditions is attributed solely to the F_2 absorption from the loss measurement experiment. Influence of the F_2 absorption in inactive regions on the laser output has been examined using a technique of rare-gas filling. The output power was increased by more than 15% with the contribution of the rare-gas filling over the range of repetition rate from 25 to 400 Hz.

A laser with a 40-cm length and a 2-cm gap of active region was prepared. The capacitor-transfer circuit involves a 16-nF storage capacitor and a 14-nF peaking capacitor. For the present experiments we covered the inactive regions, over 21.4 cm each, with ceramic tubes, gate valves and window manifolds, as illustrated in Fig. 1. The tubular parts of the inactive regions occupy 43% of the optical path in the vessel. Rare-gas charging ports are connected to the tubular inactive regions at the sites adjacent to the windows. A rare-gas mixture of Ne and He is introduced through the ports into the inactive regions. Additionally, a F_2-mixture diluted with Kr, Ne, and He is injected into the vessel through another port distant from the windows. The gas charging rate at each port is adjusted by mass-flow controllers in case the gas constituents differ from those of an initially filled mixture. During the experiments total gas pressure was maintained at a constant value. In order to allow high-repetition-rate operation, the laser is equipped with a cross-flow fan which clears the gases between the discharge electrodes after every discharge pulse. The maximum velocity of the gas flow through the region between the discharge electrodes is about 20 ms^{-1}. This value is large enough to mix the injected gases uniformly as soon as the gases flow out of the tubular inactive regions and halogen charging port.

The absorption loss at the laser line (248 nm) in various mixtures containing F_2 under static conditions, without pumping discharge, has been measured by observing the attenuation of the other KrF laser beam passed through the mixture. The output-to-input ratio was measured using Molectron JD-50HR energy detectors. The measured absorption coefficients for various gas mixtures are shown in Fig. 2. Since the absorption coefficients are substantially independent of the Kr concentration, the F_2 absorption is the dominant cause of loss in the mixture. The F_2 absorption cross section was thus determined to be 1.6×10^{-20} cm^2, which agrees well with the values obtained previously.[2,3]

Transmittance of a typical gas mixture involving 5.6-mbar F_2 and 113-mbar Kr under static conditions without lasing was also measured as a function of the rare-gas charging rate, as shown in Fig. 3. The measured transmittance under no rare-gas charging is 79%, in good agreement with the value of 80.4% which was calculated using the measured absorption coefficient $\alpha=2.2\times10^{-3}$ cm^{-1} for 5.6-mbar F_2. On introduction of a rare-gas mixture into the inactive regions, the transmittance increases with increasing charging rate and is saturated around 84% at the charging rate of more than 2 l/min. The 4% increase

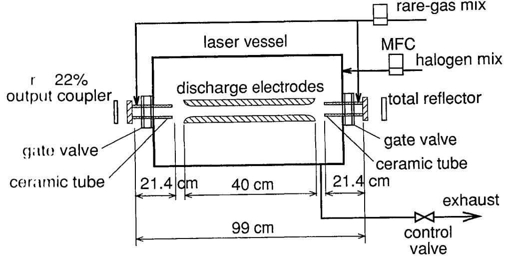

Fig. 1. Experimental setup of the laser with tubular inactive regions, into which a rare-gas mixture is charged at a constant charging rate regulated by mass-flow controllers.

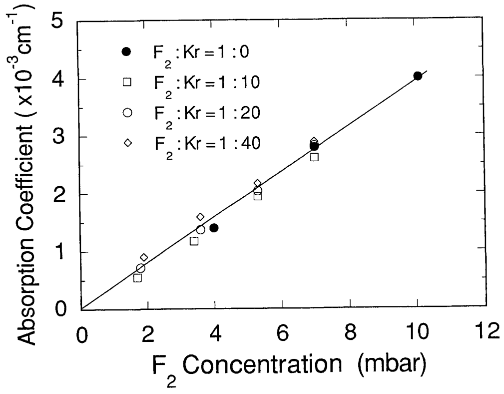

Fig. 2. Measured absorption coefficients of F_2 at 248 nm as functions of the partial pressure of F_2 for various fractions of Kr.

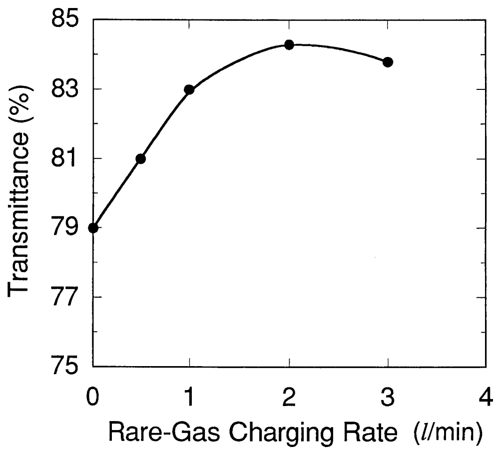

Fig. 3. Measured transmittance of a static laser mixture as a function of the rare-gas charging rate.

at the maximum means that the single-pass loss in the laser mixture was reduced by 4%. From the experimental data of the F_2 absorption coefficient, a transmittance of 88.4% was calculated under the assumption of complete rare-gas filling of the tubular inactive regions. This value gives the upper limit of the transmittance and is slightly larger than the measured saturation value of 84%. A possible cause for the discrepancy is the existence of heterogeneous regions of the gases at the apertures of the tubes, where the laser mixture is not replaced completely by the rare-gas.

The output characteristics of the laser with and without rare-gas filling have been examined for repetition rates from 25 to 400 Hz at a constant charging voltage of 26 kV. The laser mixture is composed of 5.6-mbar F_2, 113-mbar Kr, 424-mbar Ne, and 1257-mbar He. The optical resonator consists of a total reflector and a 22% reflector as an output coupler. The output power was monitored with a Scientech 38-0203 calorimeter.

Figure 4 shows the laser performance as a function of the repetition rate for various rates of the rare-gas charging. By rare-gas filling with a rate of more than 1 *l*/min, the output is increased by 10 to 20% over the range of repetition rate from 25 to 400 Hz.

In summary, it was confirmed that the F_2 absorption is the dominant cause of optical loss in the inactive regions under static conditions without lasing. The rare-gas filling reduced the single-pass loss through the vessel by 4%. The output power of the KrF laser was increased using a technique of rare-gas filling of the inactive regions on the

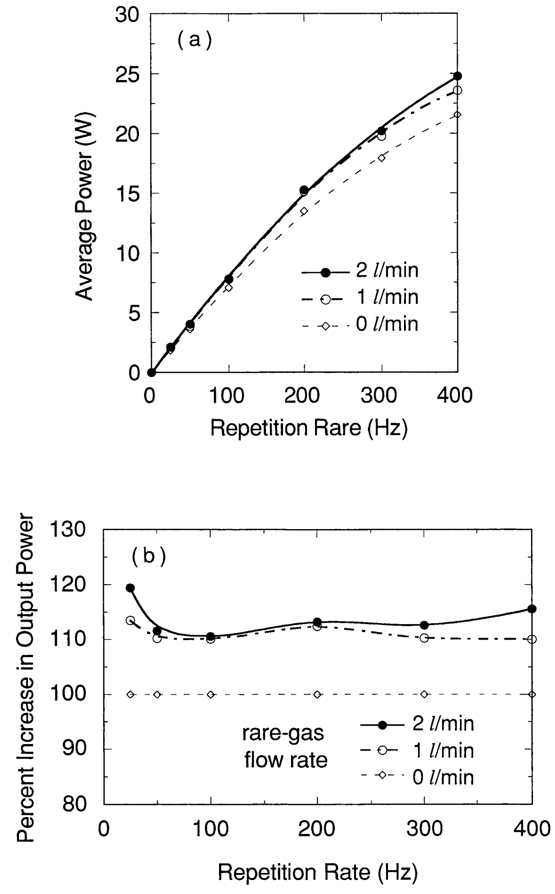

Fig. 4. Laser performance as a function of the repetition rate for various rare-gas charging rates: (a) average power and (b) normalized power.

optical path. A greater than 15% increase in the average power was observed for repetition rates from 25 to 400 Hz when the rare-gas charging rate into the inactive regions was more than 1 *l*/min.

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