Strategies for High Efficiency Operation of the E-Beam Excited Atomic Xenon Laser Using High-Power and High-Energy Loading

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ABSTRACT

E-beam excitation of the atomic xenon laser is theoretically and experimentally investigated using short-pulse high-power deposition (> MW/cm^3-atm) and low-power high-energy loading ($\leq$ 1 kJ/ℓ-atm). Scaling laws are derived to maximize laser power and energy efficiency.

SUMMARY

The e-beam excited atomic xenon laser operates in the near infrared on transitions ranging from 1.73 μm to 3.65 μm. The laser is operated in gas mixtures consisting of less than a few percent of xenon and rare gas buffers at pressures of 0.5-10 atm. The highest efficiencies have been obtained in Ar/Xe mixtures. In this paper we report on an investigation of short-pulse high-power and low-power high-energy loading of the atomic xenon laser. Results from a model for the Xe laser [1] are compared to experiments to derive scaling laws for these pumping schemes. Experiments on high-power-deposition (1-10 MW/cm^3-atm) pumping of Ar/Xe mixtures were performed using a short pulse (30 ns) coaxial electron beam [2]. High-energy deposition ($\leq$ 1 kJ/ℓ-atm) was obtained using a long pulse (1 ms) λ-type e-beam source at power depositions of $\leq$ 1 KW/cm^3-atm. [3, 4].

When pumping for long periods (> 10's μs), gas heating may result in convection. To accurately model the Xe laser under these conditions, hydrodynamics effects must be considered. The kinetics and optical time scales (<100's ns), however, are small compared to the convective time scale. We therefore separately integrated the hydrodynamic conservation equations to obtain the gas density and temperature as a function of $(\vec{r}, t)$. We then assumed that the local intrinsic laser power efficiency is a function of the local fractional ionization and gas temperature for a given gas density and mixture. The laser efficiency can then be separately calculated as a function of these parameters using the kinetics model described in Ref. 1.

Due to the large oscillator strengths of the atomic transitions of interest ($5d \rightarrow 6p$), electron collision mixing and quenching (ECMQ) of the laser levels are important. There is a critical electron density, n_c, above which ECMQ dominates and oscillation cannot be sustained, n_c corresponds to a fractional ionization, f_I, of 0.8 - 1.0 x 10^{-5} [1]. Maximum laser power efficiency is obtained at f_I = 2-3 x 10^{-6}. High-power deposition may result in high electron densities which exceed n_c during the current pulse. High-energy loading, even

at low-power deposition, can also eventually quench laser oscillation, because the electron density generally increases with increasing gas temperature as experienced with high-energy loading.

Using high-power deposition (> MW's/cm^3-atm), laser oscillation was not observed during the current pulse. A delay of up to 100's of ns passed before oscillation began. These results, reproduced by the model, are explained by the electron density during the current pulse exceeding n_c. Oscillation occurred in the afterglow when the electron density decayed below n_c. For short e-beam pulses, much of the deposited energy still resides in ions and in excited states at the onset of oscillation. Therefore, a reasonable energy efficiency may be recouped. When pumping with high-energy loading ($\leq$ 1 kJ/ℓ), the laser pulse terminated prior to the end of the current pulse. These results, also reproduced by our model, are explained by an increase in f_I above n_c during the pulse, a consequence of increasing gas temperature and convective rarification.

In order to improve laser efficiency at high-energy loading, gas mixtures must be used which have a higher heat capacity but which do not significantly interfere with the kinetic pathways leading to the upper laser level. He/Ar/Xe and Ne/Ar/Xe mixtures meeting these requirements have been experimentally [4] and theoretically characterized. In both cases, the laser efficiency remains close to that which is obtained in Ar/Xe mixtures; however, there may be a change in the laser spectrum.

References

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