Efficient e-beam sustained Ar:Xe laser

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ABSTRACT

An efficient atomic Xe laser pumped by a combination of an e-beam and an electric discharge has been made. In the present study we investigated the laser operation as a function of gas pressure. The best results were obtained at a pressure of 7-8 bar under optimized excitation conditions. The specific output energy reached 10 J/l and the specific laser power 12 MW/l. The efficiency is about 2%. When both e-beam and sustainer current are present simultaneously the efficiency can rise to 7-9% in a 0.25 μs interval.

1. EXPERIMENTAL CONFIGURATION

In an e-beam sustained discharge laser the e-beam is used to ionize the gas medium and to stabilize the discharge. If we consider the laser as a four level system with the metastable 6s state of Xe as the ground state the discharge electrons on its turn ionize the Xe (6s) atoms. This technique has already been applied to the atomic Xe laser[1,2,3]. In figure 1 a schematic overview of our setup is given. With a Marx generator a high voltage pulse is made which produces an electron beam (e-beam) by field emission in the diode. The e-beam enters a 5x55 cm^2 cross section of the active volume through a 25 μm titanium foil.
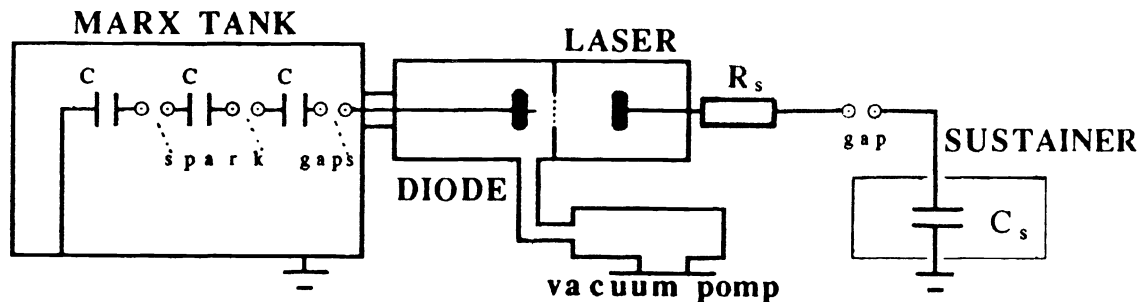

Fig. 1 Schematic overview of the setup.

In our experiments the sustainer supply consisted of a charged capacitor C_s connected to the discharge electrode or "sustainer electrode" in the laser volume. Connected in series is a resistor R_s consisting of a sodium-chloride solution. By changing the salt concentration R_s can be varied and in this way also the discharge conditions. The sustainer capacitor was switched to the sustainer electrode by two spark gaps in parallel. Insertion of the sparkgaps allowed charging voltages of the sustainer capacitor above the breakdown voltage of the medium and consequently a higher power deposition. To reduce the selfinductance of the discharge circuit two spark gaps in parallel are used. In this way a short risetime of the sustainer current is realized to make the overlap between e-beam current and discharge current as large as possible. The spark gaps are triggered by a mini-marx, a small coaxial marx generator designed to deliver a 100 kV voltage pulse with a nanosecond risetime.

The short risetime of the 100 kV voltage pulse insures triggering of both spark gaps simultaneously. In this way the selfinductance of the discharge circuit is kept low at a value of 240 nH.

In figure 2 a cross section of the laser head is shown. The sustainer electrode is a an Ernst profile[4]. The insolating material between the profile and the back plate is PVDF which has good electric insolation properties.

1 — e—beam entrance
2 — sustainer electrode
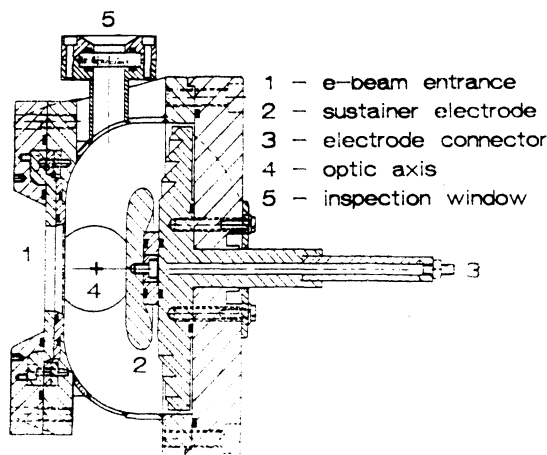3 — electrode connector
4 — optic axis
5 — inspection window

Fig. 2 Cross section of the laser head.

The active volume of the laser is 0.33 liter which can be filled with gas mixtures at pressures up till 8 bar. Since it was found that the output energy has a broad maximum around 0.4% Xe in Ar all studies were carried out with this mixture.

The distance between the e-beam entrance foil and the sustainer electrode is 2 cm. The laser cavity consists of one total reflecting gold mirror with a radius of curvature of 2 meter and a flat ZnSe output coupler with 50% reflectance. The aperture of the laser is 5.9 cm^2.

The sustainer voltage, sustainer current and laser power waveforms are measured with Philips PM 3350 and PM 3355 digitizers. The laser waveform is detected by an uncooled InSb ORP-10 photodiode with 100 ns risetime and a 1-7 μm wavelength range. The total laser energy is measured with an ED 500 Gentec Joule meter. By comparing the integrated ORP-10 output to the Gentec reading the ORP-10 signal can be calibrated in Watt.

2. DESCRIPTION OF THE EXPERIMENTS

Typical waveforms of the sustainer voltage, sustainer current, electrical power and laser power are given in figures 3a-d for a 90 keV e-beam. The discharge conditions are: 4 bar gas pressure, R_s = 1.0 Ω and C_s = 5.4 μF for several charging voltages of the sustainer capacitor C_s. The sustainer electrode voltage is more or less constant during the e-beam current. The corresponding electrical field strength given by E/p is found as 0.2 V cm^{-1} torr^{-1}. It is also seen that during the e-beam current the output power is higher than after its termination.
After the e-beam has ended the laser power follows the sustainer current at a reduced level. Laser action is most efficient when both e-beam and discharge current are present simultaneously.
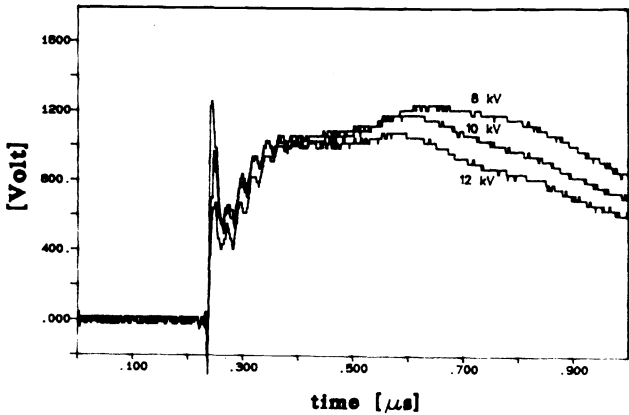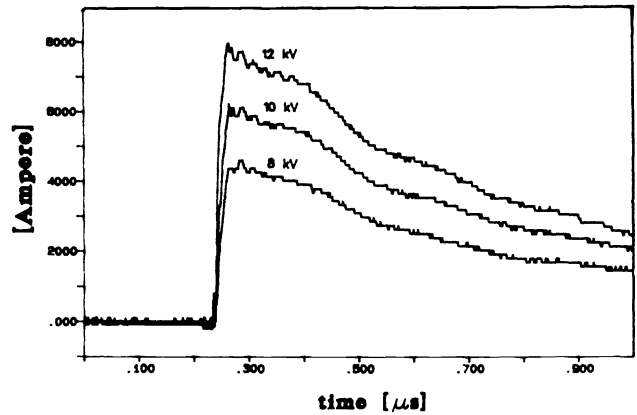
Fig. 3a Sustainer voltage.
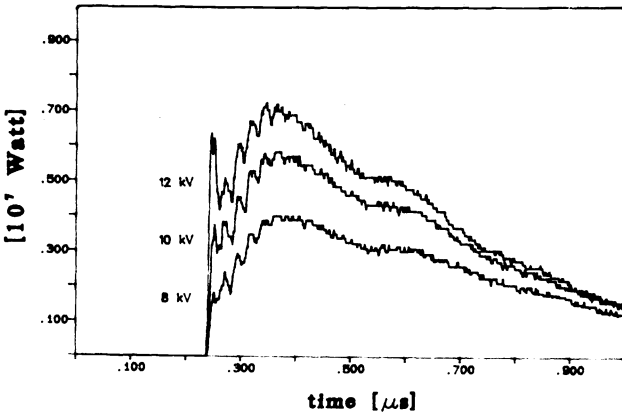

Fig. 3b Sustainer current.
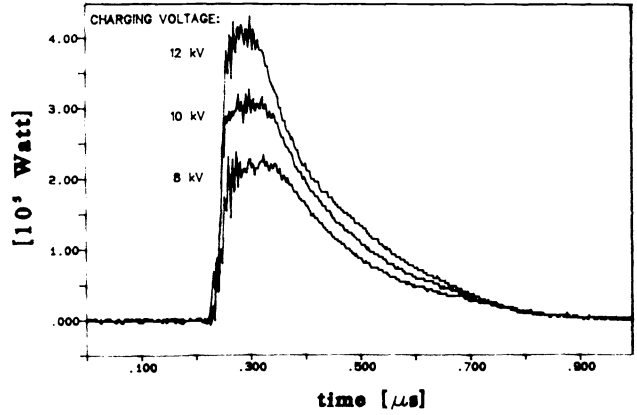

Fig. 3c Electrical power.

Fig. 3d Laser power.

In figure 4 the output energy for two discharge conditions is plotted for a 180 keV e-beam and 8 bar gas pressure. At zero charging voltage of C_s the output energy is produced only by the e-beam. With increasing charging voltage of C_s the output energy increases showing that discharge electrons contribute to the laser excitation. A maximum specific output energy of 10 J/l is reached with $R_s = 0.1\ \Omega$, $C_s = 5.4\ \mu F$ and 12 kV charging voltage at 8 bar pressure. The enhancement of the output energy by the discharge is about 15 times. At higher charging voltages and consequently higher discharge currents the coupling between the lasing 5d and 6p levels by the discharge electrons (electron collision mixing: ECM) reduces the laser action by destroying the population inversion[5].

In a separate paper a study is described which shows that there is a critical power deposition, due to electron collisional mixing effects, which is pressure dependent. Also is shown in this paper that the efficiency can be as high as 9% in an interval of 0,25 μs where the discharge has optimized parameters and is almost in a steady state[6].

The output energy is about 1-2% of the energy stored in the sustainer capacitor. This efficiency can be improved further by eliminating the dissipation in resistor R_s (f.e. by using a pulse forming network) and by matching the duration of the e-beam and the discharge current.
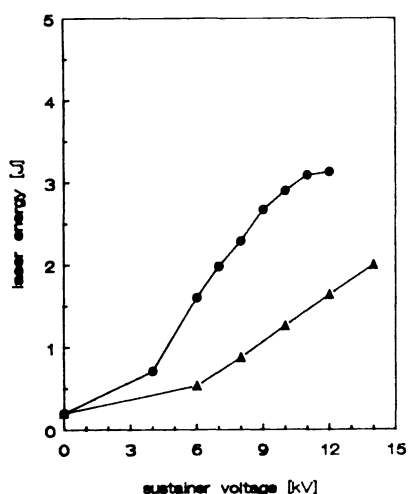
Fig. 4 Laser energy as a function of the sustainer voltage
(p = 8 bar; R_s = 0,1 Ω; c = 1,8 μF; C = 5,4 μF).

3. CONCLUSIONS

In the experiments Xe laser action has been investigated in a pressure range of 1-8 bar for a 0.4% Xe in Ar mixture using 90 keV and 180 keV e-beams. By changing R_s and/or C_s the discharge conditions could be varied. Below 3 bar strong electron collision mixing resulted in poor laser action. At 4 bar the 90 keV e-beam was sufficient to condition the discharge. On the contrary, at 8 bar 180 keV electrons were necessary resulting in the highest reported output energy of 10 J/l. The efficiency is about 2% but in a 0.25 μs interval when e-beam and discharge current are both present simultaneously an efficiency of 8-9% was found.

4. ACKNOWLEDGEMENTS

5. REFERENCES

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