HIGH ENERGY EXTRACTION OF ELECTRON BEAM PUMPED KrF LASERS AT MULTI ATMOSPHERES

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Received 12 December 1983

The construction is described of a simple and compact KrF laser with electron beam excitation. The electron beam is generated in a coaxial vacuum diode, driven directly by a ten-stage coaxial Marx generator. A flat MgF_2 outcoupler and a suprasil roof prism, protected by an MgF_2 window, proved to be resistant against optically and chemically induced damage. A gas mixture of 4.5 bar Ar, 150 mbar Kr and 10 mbar F_2 gives an energy output of 0.46 J from a 16 cm^3 volume in 40 ns pulses or 0.72 MW/cm^3.

1. Introduction

This paper deals with the pressure dependency of the energy extraction for an electron-beam pumped KrF laser. Electron-beam pumping is very well suited to generating high power densities during the pulsed excitation. Using this excitation technique, the coaxial e-beam configuration has proven to be an efficient design for generating high laser output energies. However, with this configuration a great deal of the e-beam energy is absorbed by the foil of the anode tube. The fraction of e-beam energy transferred to the gas can be increased by increasing the gas density, however the quenching and radiation absorption processes increase strongly with the gas density. Therefore the question arises what are, for a given current density of the e-beam, the optimum densities of the gas components. A theoretical analysis of the problem [1,2] predicts that especially at current densities above 100 A/cm^2 it is advantageous to increase the densities of the gas components. This prediction is investigated experimentally in the present work.

We report on experimental studies of energy extraction at argon pressures up to 7 bar. We find that the produced power density increases with pressure up to 4.5 bar. The experiments have been performed with a compact system having an active volume of only 16 cm^3.

2. Description of the laser system

The laser system consists of a coaxial vacuum diode [3,4] driven directly by a low-inductance ten-stage Marx generator [5] as shown in fig. 1. The spark gaps are UV-triggered, except for the first gap, which is triggered externally. Each stage is formed by eight pairs of $BaTiO_3$ capacitors of 1.8 nF each. The total capacitance per stage is 7.2 nF. The UV-radiation of each firing gap can reach the next gap. In this way a fast, low jitter Marx generator is obtained.

The generator is enclosed in a cylindrical vessel of one meter height and 0.25 m diameter, filled with 4 bar SF_6 to prevent flash-over. This compact arrangement provides a low inductance and a fast rise-time. The charging and ground-return resistors consist of two columns of silicon rubber tubing, filled with copper-sulphate solution; they are branched off at each stage. The resistance per stage is about 1 kΩ, so that the internal discharge circuit of a firing gap has a time constant of about 7 μs. These resistors are capable of high power dissipations and are flexible enough to suit the electrical stressing requirements of the generator. The Marx generator is capable of producing 100 J at a maximum voltage of 600 kV. The sparking gaps are flowed with dry air.

The voltage is monitored by means of a differentiating voltage sensor [6,7] and the current is recorded

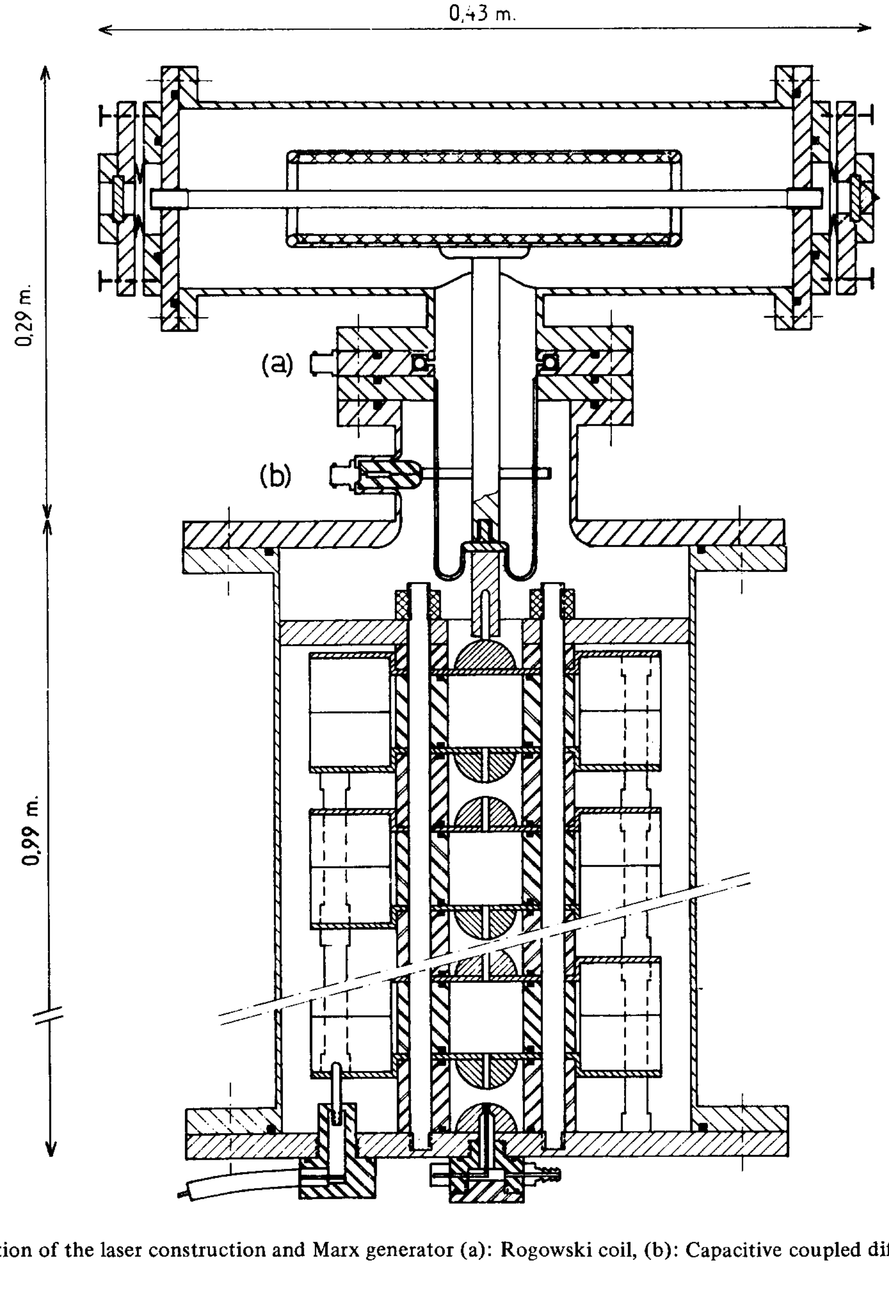

Fig. 1. Cross-section of the laser construction and Marx generator (a): Rogowski coil, (b): Capacitive coupled differentiating voltage sensor.

via a self-integrating Rogowski coil [8], both fitted near the diode as shown in fig. 1. Both signals can be displayed simultaneously on two transient digitizers.

The cathode consists of a 20 cm long cylinder of 5 cm diameter, with rounded ends to prevent field emission or flash-over to the vacuum chamber walls. Inside this cylinder, two graphite felt strips of 20 $\times$ 0.7 cm^2 are mounted parallel to the axis [9], giving a two-sided transversal excitation in a radial symmetric electric field.

The cylindrical anode laser tube was made of 25 μm titanium foil with a single electric weld along the axis.

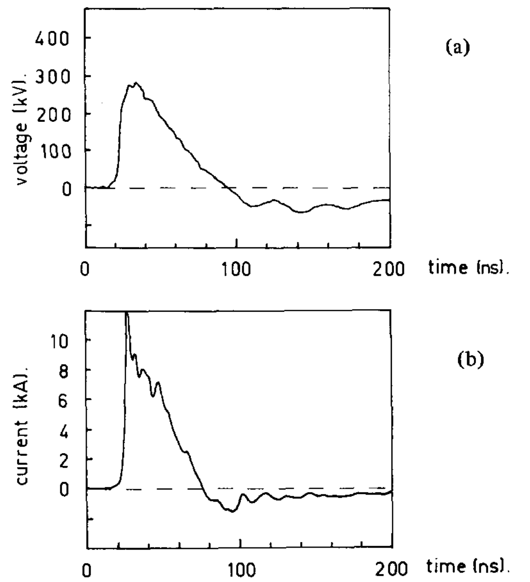

Fig. 2. (a) Voltage pulse and (b) current pulse at vacuum diode as a function of time for a generator charging voltage of 60 kV.

The diameter is 1 cm and the active volume is 16 cm^3. Ti endpieces were laser welded to this tube, after which heat treatment at 700°C was used to remove internal strains. This ensured reliable operation of the anode tube. The tube is tested for gas pressures up to 10 bar. This cathode configuration gives a good impedance matching. The corresponding voltage and current waveforms are illustrated in figs. 2a and b, respectively. We see that the current pulse-width is about 50 ns and that the current increases with the charging of the diode capacitance, which is estimated to be 25 pF. From photographic observations of phosphorescence of Torr Seal on a perspex tube we found uniform excitation along the laser tube.

3. Experiments

It was observed that the fluorine and its compounds produced in the discharge together with the laser radiation causes severe damage to most mirrors. As a total reflector we tried a MgF_2 coated Al mirror, a suprasil roof prism, and a MgF_2 plate with Al coating on its backside. As outcouplers we investigated coated suprasil reflectors, and planeparallel suprasil and MgF_2 windows. Of all components investigated we found the MgF_2 windows to be sufficiently resistant against fluorine and its compounds.

It was also seen that damaged components had suffered by the combination of the refractive gas and light: outside the beam the suprasil was less affected. Hence we made our total reflector from a suprasil roof prism mounted directly onto a plane parallel MgF_2 plate in such a way that the gas is only in contact with the MgF_2 plate. As an outcoupler we used a plane parallel MgF_2 plate without coatings.

All experiments have been done after first thoroughly passivating the system. Before a series of measurements was made, the laser cavity was repeatedly filled, until the output energy of the first shot of each consecutive gas filling remained constant.

The experiments have been done at charging voltages of 40, 50 and 60 kV for the Marx generator, resulting in a total observed current of 4.6, 6.2 and 7.5 kA respectively. From this we estimate the current densities as approximately 230, 310 and 375 A/cm^2. Measurements have been done at argon pressures from 2 to 7 bar, while varying the F_2 pressure from 2.5 to 25 mbar. The Kr pressure was kept at a constant value of 150 mbar, as the output energy depends only very little on the concentration under these conditions. The output energy was measured by reflecting 8% of the beam off an uncoated quartz flat into a Gen Tec ED-500 calorimeter. A maximum output energy of 0.46 J was obtained at a current density of 375 A/cm^2 with a mixture of 4.5 bar Ar, 150 mbar Kr and ~9 mbar F_2. The resulting yield of 29 J/ℓ compares favourably with that of other coaxial e-beam pumped systems [10,11]. For lower excitation current densities, the optimum output was reached at slightly lower F_2 pressures. In fig. 3 we have plotted the output energy at 375 A/cm^2 as a function of the F_2 concentration (up till 15 mbar) for 150 mbar Kr and 2.5, 4.5 and 6 bar Ar pressure respectively. The plotted values are the averaged results of several measurements, reproducible to within a few percent.

It is seen that around 9 mbar F_2 the output energy has a broad maximum as a function of the F_2 pressure. Lowering the F_2 concentration resulted in a strong decrease in output energy; however for pressures from 9–25 mbar, the energy was less dependent on the F_2 concentration. In fig. 4 we plotted the observed output as a function of the Ar pressure at several current densities, for 150 mbar Kr and 10 mbar F_2 (not at optimum). Pressure jump measurements show-

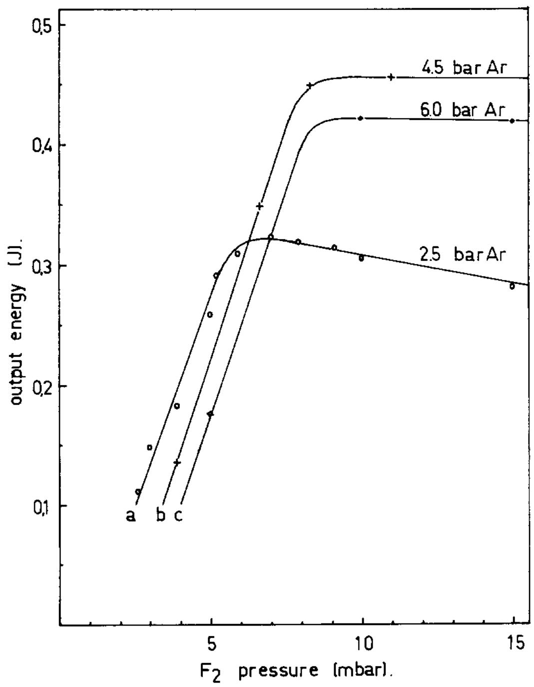

Fig. 3. Output energy as a function of the F_2 pressure at argon pressures of 2.5 bar (a), 4.5 bar (b) and 6 bar (c). Krypton pressure 150 mbar, current density 375 A/cm^2.

ed that, under our conditions, the energy deposited in the laser gas is proportional to the excitation current density. From our output energy measurements we can infer that the ratio of maximum output energy

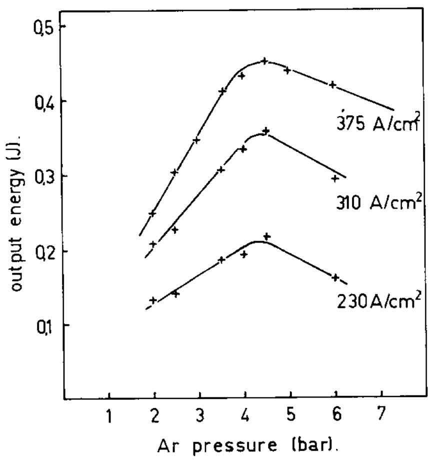

Fig. 4. Dependence of output energy on argon pressure. F_2 pressure: 10 mbar, Kr pressure: 150 mbar. Current densities: 230, 310 and 375 A/cm^2.

and current density increases with the current density: for current densities of 230, 310 and 375 A/cm^2 we found ratios of 0.96, 1.16 and 1.21 respectively. So we may conclude that the efficiency of the system increases with the energy deposited in the gas. This result is in accordance with theoretical predictions [1,2].

4. Conclusions

This laser system demonstrates that it is possible to construct a small and simple e-beam pumped excimer laser system, with a high specific output power of approximately 0.72 mW/cm^2. The efficiency of the system increases with the excitation energy. Laser and electric welded 25 μm Ti foil cylinders, pressurized at 7 atm, and fluorine resistant mirrors withstood more than 600 shots.

Acknowledgement

The authors wish to thank P.J.M. Peters for helpful discussions and H.T.M. Prins for his technical assistance.

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