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XeCl Laser Excitation by High Power Microwave Pulses*

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Abstract. Considerable progress of microwave pumping of excimer laser gas mixtures has been achieved. The present measurable best values for the pulse energy lie in the mJ range. A microwave pulse compression technique is applied using a resonantly charged microwave cavity. The stored energy is extracted by igniting a high density plasma in a quartz tube which acts as a switch and as a laser amplifier yielding a high energy laser pulse.

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High pressure rare-gas halide or excimer lasers require a high power fast switching circuitry as an electrical energy supply. One possibility to pump such a gas mixture resulting in a high efficient laser pulse energy can be performed by electron beam pumping. This is a rather complicated technique since the high pressure discharge chamber has to be separated by a thin electron transparent foil material from the evacuated electron accelerator part. *E*-beam excitation is able to pump large discharge volumes. The low repetitive operating *e*-beam driven lasers are well suited for applications requiring an extremely high laser pulse energy, i.e., inertial confinement fusion (ICF) experiments.

Many applications require high average power excimer lasers. In material processing laboratories the higher powers of these lasers result in higher processing speeds and throughputs. For instance, in semiconductor manufacturing the race of technology demands ever faster wafer processing speeds. This can be fulfilled with TEA-discharge pumped lasers. This technique is used by commercial high pressure gas discharge lasers. However, impedance matching of the energy storage capacitance to the nonlinear time varying plasma load is difficult to achieve. Additionally, the halogen contents of the gas mixture interact with the metallic electrodes and may cause streamers in the discharge.

For these reasons the microwave pumped discharge is an alternative technique. It is a metall-free discharge and therefore less gas degradation can be expected. The electrodeless coupling of the microwave energy into a quartz or ceramic tube is performed by displacement currents. A more homogeneous and stable discharge can be expected without any preionization techniques. High power microwave excitation techniques were reported in [1–7]. With a discharge pressure of 1–3 bar XeCl laser pulses with powers of 250 W and a pulse duration of 200 ns were measured using an *X*-band (9.375 GHz) magnetron with a pulse power of 1.4 MW [1]. The highest XeCl laser pulse energy of 28 mJ was reported from a system pumped by a relativistic *S*-band (3 GHz) magnetron. The pulsed microwave power was 500 MW and the pulse duration 16 ns [3, 4]. The first successful operation of a 4.5 MW *L*-band pumped XeCl laser without preionization resulting in a laser of 1.3 mJ pulse energy and a pulse duration of 16 ns was reported in [5]. The same system showed an improved performance of up to 2.7 mJ of pulse energy [6]. Using a 3 MW *S*-band magnetron with a pulse duration of 4 μs, a XeCl laser pulse energy up to 2 mJ with a pulse length of 7 ns was reported [7].

Microwave Design Features

The experiments were carried out with a *L*-band klystron transmitter with a maximum pulsed power of 10 MW, a variable pulse duration from 500 to 6000 ns, and a repetition frequency of up to 430 Hz. The microwave power was fed into a WR 650 rectangular waveguide utilized to pump a double ridge coupling structure which housed a quartz discharge tube. The dimensions were 6 mm × 8 mm, i.e., inner and outer diameter. The microwave excited discharge length was 438 mm. This resulted

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in an actively pumped volume of 12 cm^3. The substantial layout dimensions were optimized applying the computer code URMEL-T [8] as described earlier [9]. The data reported in [9] for the excimer laser performance were obtained with a magnetron generator as microwave source which had a power of 2.5 MW and a slow rising (rise time 220 ns) 4 μs long pulse. When the klystron transmitter was used as the source generator the first experiments were focussed on the influence of fast rising microwave pulses on the discharge. The rise time of the klystron pulse was 20 ns. This was possible by driving the transmitter with a new oscillator subsystem based on a dielectric resonance oscillator which was modulated by a pin diode switch [10]. The operation frequency of the klystron was adjusted to 1355 MHz. To prevent arcing, the waveguide which kept the discharge geometry had to be pressurized with sulfur hexafluoride (SF_6) up to 5 bar when a microwave power of 4 MW and more was applied to the system. These power levels required a better electrical contact of the ridges to the waveguide walls. The improved coupling together with the fast rising klystron pulse led to a new feature known from microwave pulse-compression cavities [11]. This facilitated a operating mode called "resonant energy storage mode" (RES mode). The investigated cavity is shown in Fig. 1 consisting of the discharge structure with the short circuit plate, the connecting waveguide together with the coupling aperture of the impedance matcher.

Results

For the experiments the klystron transmitter was set to a power of 4.8 MW and a pulse duration of 600 ns. The pulse repetition frequency was variied from 10 to 20 Hz. The transmitted and reflected microwave power was measured with two Hewlett-Packard diodes (HP model 423) and displayed on a oscilloscope (HP model 54112D). The rare-gas halide mixture for XeCl consisted of He/Xe/HCl = 1000/10/2 at a total pressure of up to 2 bar. The laser pulse energy was measured with a Gentec joule meter (model ED-200). The laser pulse duration was monitored with a fast vacuum photodiode (ITL model TF 1850).

Figure 2 depicts a typical result of the incident and reflected microwave power (curves 1 and 2) and the laser pulse (curve 3) vs. time. The reflected power shows exactly the features described in [11]. The filling of the cavity starts as soon as the microwave pulse has reached its maximum. The microwave power is totally reflected during the rise time. The storage of the electromagnetic energy in the resonant cavity under study required approximately 200 ns indicated by the exponential drop of the reflected power.

The extraction of the stored energy, represented by the fast rising step in the reflected power curve, is accomplished by the build-up of a plasma of high electron density in the quartz tube. The realized surprisingly high pulse energy was only achieved in the RES mode of operation. Increasing the height of the double ridges in the coupling structure caused a higher electrical field strength

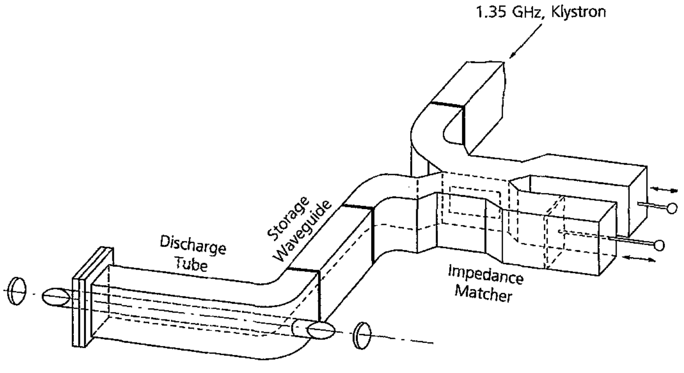

Fig. 1. Investigated microwave cavity consisting of the impedance matcher and the coupling geometry

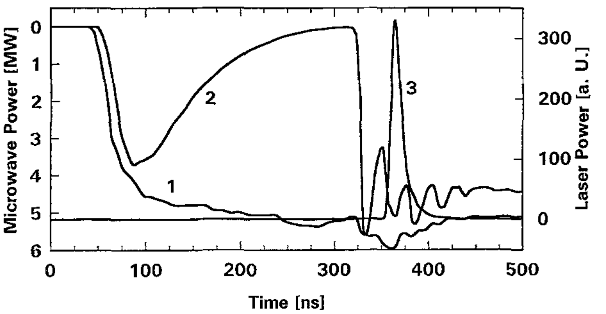

Fig. 2. Resonant energy storage (RES) mode of operation. Incoming (curve *1*), reflected (curve *2*) microwave power in MW, and XeCl laser pulse (curve *3*) vs. time

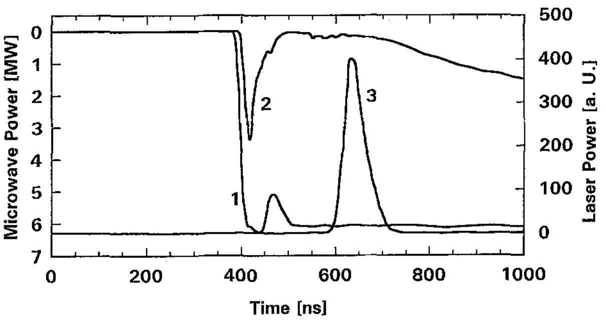

Fig. 3. Matched coupling structure (MCS) mode of operation. Same axis description as in Fig. 2

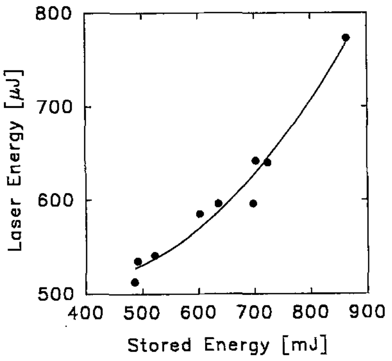

Fig. 4. Resonant energy storage (RES) mode of operation. XeCl laser energy against stored energy in the resonant microwave cavity

in the discharge tube. This improved the performance of the system featuring a 2.7 mJ pulse energy in a 16 ns long pulse.

With the klystron transmitter the previously reported data [9] obtained with a magnetron generator could also demonstrate another mode of operation: the "matched coupling structure" MCS mode. In this mode of operation the discharge was matched during the XeCl lasing time. Figure 3 depicts the time dependence of the incoming and reflected microwave power (curves 1 and 2), and the XeCl laser pulse (curve 3). In the MCS mode of operation XeCl pulse energies of approximately 20 μJ and pulse duration of 65 ns were measured.

The coupling of the microwave power into the discharge tube depicted in Fig. 3, curve 2, indicates a later occurrence of the UV laser pulse of approximately 150 ns as would be expected from the shown coupling [12]. This delay could be assigned to the limited electron density rise time of the discharge. The threshold for the UV laser was measured to 700 kW/cm^3.

Further investigations of the more favourable RES mode of operation are shown in Fig. 4. Here, the amount of stored energy in the resonant microwave cavity is plotted dependent on the performance of the XeCl laser.

In summary, we have investigated a XeCl excimer laser gas mixture under the influence of a fast rising high power microwave pulse. Together with an improved coupling geometry this facilitated a "resonant energy storage" (RES) mode of operation yielding a XeCl laser peak pulse energy of 2.7 mJ in a 16 ns long pulse. The actively pumped volume was 12 cm^3. The corresponding energy deposition was 0.2 J/l. No preionization has been used.

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References

1. P.J.K. Wisoff, A.J. Mendelssohn, S.E. Harris, J.F. Young: IEEE J. QE-**18**, 1839 (1982)
2. C.P. Christensen, R.W. Waynant, B.J. Feldmann: Appl. Phys. Lett. **46**, 321 (1985)
3. V.N. Slinko, A.S. Sulakshin, S.S. Sulakshin: Sov. J. Quant. Electron. **18**, 186 (1988)
4. A.N. Didenko, A.M. Prokhorov, V.N. Slinko, A.S. Sulakshin, S.S. Sulakshin: Sov. Phys. Dokl. **33**, 448 (1988)
5. H.H. Klingenberg, F. Gekat: Appl. Phys. Lett. **58**, 1707 (1981)
6. H.H. Klingenberg, F. Gekat: Proc. European Quantum Electronics Conference, Edinburgh (1991) p. 15
7. L. Hünermann, R. Meyer, F. Richter, A. Schnase: Topical Meeting: Excimer Lasers and Applications III, The Hague (1991)
8. T. Weiland: Part. Acc. **15**, 245 (1984)
9. H.H. Klingenberg, F. Gekat, G. Spindler: Appl. Optics **29**, 1246 (1990)
10. F. Gekat, H.H. Klingenberg: Proc. SPIE (Society of Photo-Optical Instrumentation Engineers) **1411**, 47 (1991)
11. R.A. Alvarez, D.P. Byrne: Rev. Sci. Instrum. **57**, 2475 (1986)
12. H.H. Klingenberg, F. Gekat: Proc. SPIE **1412**, Gas and Metal Vapor Lasers and Applications, 103 (1991)