Compact capacitively coupled N_2 laser with a new electrode design

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Lasing in N_2 at 337 nm was achieved in a capacitively coupled discharge device having a cylindrical discharge volume with a length of 50 mm and a diameter of 3 mm. The cylindrical dielectric electrodes provide a nearly constant initial electric field throughout the discharge volume. Laser pulses with a width of 2.5 nsec (FWHM) and an energy of 8 μJ were obtained.

Recently capacitively coupled discharges CCD's with dielectric electrodes have stimulated some interest, as they offer a promising pumping scheme for miniature gas lasers that can be used in such applications as spectroscopy, metrology, and communications. As every surface element of a dielectric electrode is capacitively ballasted, gas discharges between such electrodes are free of arcing over a wide pressure range without the need for preionization.

A XeF and a KrF excimer laser excited by a coaxial CCD in a Pyrex tube have been reported.[1] Replacing the metal electrodes of a transverse discharge laser by similarly shaped or flat slabs of barium titanate yielded lasing in CO_2,[2] N_2,[3] HF,[4] and Ne.[5] As, however, the initial electric field produced in these devices is inhomogeneous because of the edge effects of the electrodes, the discharge may fail to be homogeneous, especially at a high specific power deposition and high gas-fill pressures.[2,6]

In this Letter we describe an extremely simple and compact CCD device with a new electrode design that produces a nearly constant electric field throughout the discharge volume. Lasing in N_2 yielding pulse energies up to 8 μJ is demonstrated.

The laser device, together with the equivalent electrical circuit, is shown in Fig. 1. The lasing gas is contained in a 3-mm cylindrical channel that has been bored through the diameter of a commercial $BaTiO_3$ doorknob capacitor with a nominal capacity of 3.6 nF. The length of the discharge volume is 50 mm, and the distance between its axis and each of the capacitor electrodes is 10 mm. Brewster windows incorporating a gas inlet are glued to both ends of the 3-mm bore. To achieve lasing in N_2, a resonator 100 mm long that consisted of an Al total reflector and a quartz flat is used.

The charge of a second capacitor of 3.6 nF loaded to 30 kV of electricity is transferred to the laser capacitor by means of a triggered spark gap. The resonance frequency of this L-C circuit was measured to be 12.7 MHz. The rise time of the voltage across the laser thus has a duration of 40 nsec.

The temporal behavior of the spontaneous emission from excited N_2 and He and of the laser pulse was monitored with either vacuum photodiodes (PD's) or a photomultiplier (PM) directly or in combination with a 0.3-m grating monochromator. The rise times of the PD's (ITT F4115, ITL TF 1850) and the PM (Philips 56 AVP) were 0.5, 0.2, and 2.3 nsec, respectively.

The device described here produces in essence a transverse discharge with the circular segments of the bore surface opposite the outer electrodes forming the discharge electrodes. The start of a homogeneous discharge in our system is favored by the presence of an electric field, which, before the discharge, is uniform throughout the discharge volume, except for small distortions at the ends of the bore. The near uniformity of the field can be inferred from the law that the electric field inside a dielectric body of an ellipsoidal shape is constant when it is brought into an originally constant

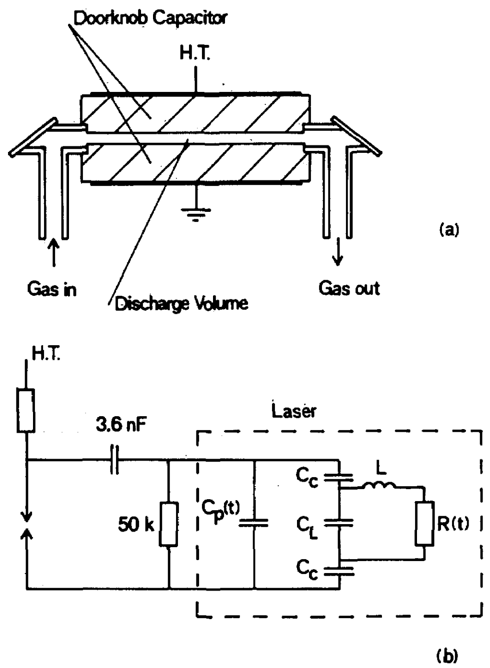

Fig. 1. (a) Cross-sectional illustration of the laser device. (b) Equivalent circuit of the capacitively coupled laser and the external circuit.

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external field. The same law is approximately valid for a long, thin cylinder.[7]

In spite of the rather slow excitation pulse of our device (which has a rise time of 40 nsec) compared with those reported elsewhere,[3,5] our device produces homogeneous discharges in He up to a fill pressure of 150 kPa. At higher pressures, streamers are visible. No inhomogeneities were observed in N_2 up to a pressure of 30 kPa. Above this value no discharge could be generated, even at the maximum voltage of 30 kV, because of the high dielectric strength of N_2.

The temporal behavior of the spontaneous emission arising from N_2 and of the laser pulse at a wavelength of 337 nm are shown in Fig. 2. The trigger points for the spontaneous emission and for the laser pulse as well as the relative pulse height are arbitrary. The spontaneous emission corresponds to all radiation emitted within the wavelength region (250–850 nm) for which the PD (ITL TF 1850) is sensitive. For N_2 the pulse of the spontaneous emission has a rise time of 3.5 nsec (10–90%), independently of fill pressure. Measurements of the radiation arising from He at 587 nm with the PM–monochromator combination produce the same rise time. Thus the fast rise of the emission from N_2 cannot be attributed to stimulated radiation of N_2 lines exhibiting high gain. From the N_2 spontaneous-emission pulse, which, for fill pressures above 10 kPa, has a length of 6 nsec (FWHM), we conclude that in our device the discharge phase exhibiting a high specific field strength has at most the same duration.

The laser pulse has a width of 2.5 nsec, independently of pressure. As the N_2 laser transition is self-terminating, this short pulse indicates that a rather high power deposition[8] can be achieved in the system described.

The peak power of the laser pulse as a function of fill pressure was measured with a PD (ITT F4115) and is shown in Fig. 3 for pure N_2 and N_2–He mixtures. The maximum power of 3.3 kW occurs in N_2 at a pressure of 18 kPa. The reproducibility of the laser was only 30%, and the output decreased rapidly with the number of shots in a static fill. This degradation may be due to degassing of the $BaTiO_3$ ceramic that contaminates the laser medium. The highest laser energy obtained, as derived from the measured power and pulse length, is approximately 8 μJ.

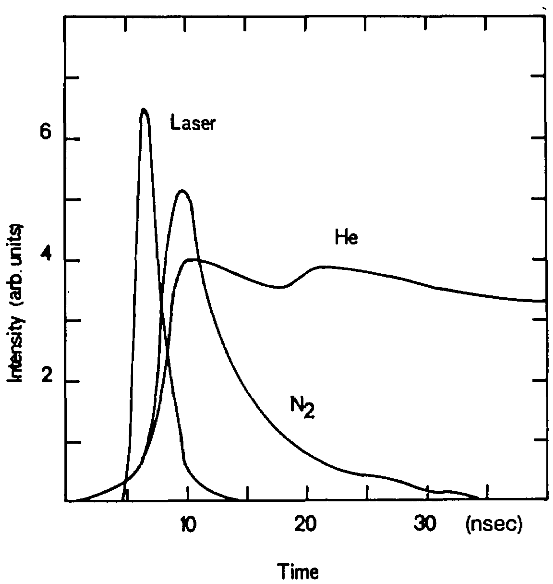

Fig. 2. Temporal behavior of the spontaneous emission from N_2 (180 mbar) and He (1 bar) and of the laser pulse.

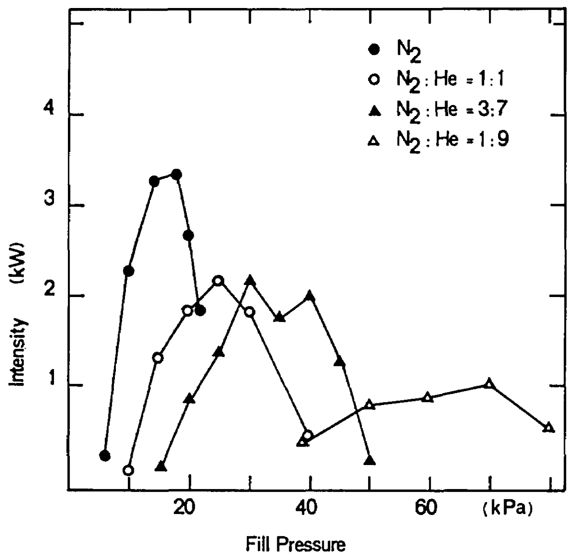

Fig. 3. Peak power of the laser pulse achieved in N_2 and N_2–He mixtures with He as a function of fill pressure.

The energy deposition into the laser gas cannot be easily calculated, as the initial values and the time dependence of $R(t)$ and $C_P(t)$ are not known (see Fig. 1). As a rough estimate, however, the following may be stated: Before the discharge takes place [i.e., when $R(0) = \infty$], the total capacitance of the laser is given essentially by $C_P(0)$, as the capacitors C_C do not contribute much because of the small value of C_L (which in presence of a uniform field is calculated to be 0.9 pF). $C_P(0)$ has about the same value as an original doorknob capacitor and was measured to be 3.47 nF. When the laser gas is in a conducting state [i.e., when $R(t) \sim 0$], the capacitance of the laser is given by $C_P(t) + C_C/2$. By inserting a conductor into the discharge volume in order to simulate the plasma, we determined that this sum was 3.6 nF. As the discharge phase relevant for the excitation of N_2 is short compared with the charging time, the charge on the laser can be assumed to be constant over this period. With the further assumption that $R(t)$ is infinite and zero before and after the discharge, respectively, the energy dissipated into the laser gas is given by

$$E = Q^2/2\,\{[C_P(0)]^{-1} - [C_P(t) + C_C/2]^{-1}\},$$

where Q denotes the charge on the laser. With this formula E is calculated to be 56 mJ, which corresponds to a specific energy of 160 mJ/cm^3. The intrinsic efficiency of the N_2 laser is thus of the order of 1.4×10^{-4}.

As no optimization with respect to the external circuit or to the coupling capacities C_C has been performed, we conclude that the laser output energy can be considerably increased with a carefully designed device of this type.

In conclusion, we have shown that lasing in N_2 can be achieved in a compact capacitively coupled discharge device in which the dielectric electrodes are formed by just a simple bore in a doorknob capacitor. Homogeneous discharges in N_2 and He can be produced up to fill pressures of 30 and 150 kPa, respectively. The energy of the laser output obtained with our unoptimized system is 8 μJ in a 2.5-nsec-wide (FWHM) pulse at 337 nm.

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