APPENDIX

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DESIGN NOTE

A compact low-voltage TEA-N_2 laser

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Abstract. A compact TEA-N_2 laser has been designed using a double-fold, two-stage Blumlein circuit which enabled operation at low voltage (4.5–7.5 kV) and a laser channel gap of 1 mm. An output energy of 150–370 μJ per pulse was obtained and its average electrical-to-optical conversion efficiency of about 0.06% was comparable to the values reported for most compact TEA-N_2 lasers operated at 15–40 kV.

Keywords: TEA-N_2 laser, double-fold, two-stage Blumlein, low-voltage laser

1. Introduction

A compact, transversely excited atmospheric-pressure nitrogen (TEA-N_2) laser with a few hundred microjoules of output energy provides a convenient ultraviolet (UV) light source for dye-laser pumping, fluorescence lifetime studies, and optical diagnostics of transient plasmas. Although several compact designs of parallel-plate, Blumlein-driven TEA-N_2 laser have been reported [1–5], their operating voltages are usually in the range of 15–40 kV. It is always desirable to lower the operating voltage so as to reduce the generation of electromagnetic interference and to minimize the dielectric breakdown of the insulator layer in parallel-plate capacitors. A TEA-N_2 laser was reported [5] to operate at 5–10 kV, but its output energy of 40–150 μJ was barely sufficient for most of the above applications. A miniature TEA-N_2 laser employing 3 cm silicon electrodes was recently reported [6] to operate at 5 kV, but its laser output energy was merely 3 μJ per pulse.

In previous articles [7, 8], we reported on the improved performance of a TEA-N_2 laser using a two-stage Blumlein circuit. Although the input power is significantly improved in a two-stage Blumlein circuit owing to an increase of the breakdown voltage for laser discharge initiation by about 25%, the total size of the parallel-plate capacitors is increased several times [1–5]. We thus attempted to reduce the total capacitor size by using both double-fold and overlay techniques for packaging the TEA-N_2 laser system. To enable low-voltage operation, the UV preionizers were geometrically optimized to prevent arc formation in the laser discharge and a swinging cascade spark gap of lower inductance was used. As a result, a compact TEA-N_2 laser, of dimensions 25×17 cm^2, was operated at 4.5–7.5 kV and delivered an output energy of 150–370 μJ per pulse.

2. Experimental set-up

A laser channel of length 25 cm and gap 1 mm was forn between two laser electrodes, each of which had a cr section of 4×4 mm^2. These electrodes, as shown figure 1(*a*), were shaped out of the edge of two brass pla 25 cm long, 6 cm wide and 1.2 cm thick. A gas fl tunnel, with a cross section of 3×3 mm^2, was mil at the edge of the two brass plates. N_2 gas was flush into the laser channel via equally spaced 1 mm^2 transve grooves along the two flow tunnels. The laser channel v sealed by an aluminium-coated back mirror at one end an microscope slide at the output end. The back mirror, howev could only increase the laser output by about 20% owi to the narrow laser channel and lack of a mirror alignme mechanism. Two UV preionizers were introduced abo and below the laser channel; UV radiation was provided corona discharges between the two opposite aluminium stri protruding beneath the laser electrodes. In our earlier wo [7], the position of these aluminium strips was not critic to the laser output consistency since the operating volta was $\geqslant$10 kV. In this work, where the operating voltage w between 4.5–7.5 kV, arc discharges occurred readily in t laser channel at the initial development stage. These we strongly suppressed by aligning the edges of two aluminiu foils with the laser channel, one of which was directly abo and the other one directly below (see figure 1(a)). A optimization study of the position of these aluminium foi could not be carried out since these foils were totally obscur by the various layers of Mylar, aluminium foil and foam.

A double-fold, two-stage Blumlein circuit (figure 1(*c* was used, which consisted of parallel-plate capacitors on bo sides of the brass plates. Thus, the two capacitors responsib for the laser discharge, C_1 and C_2, were formed betwe the inner aluminium foil, Al-1, and the brass plates, L and RP respectively. The dielectric insulator used for C

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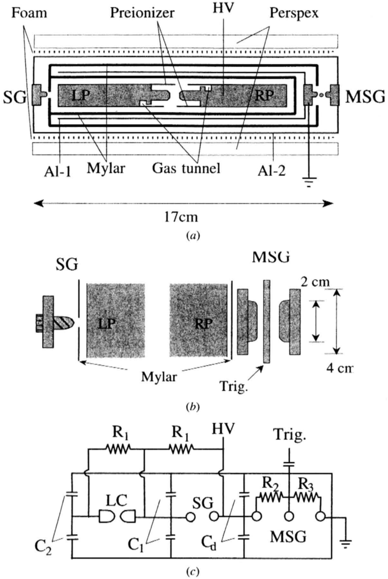

Figure 1. (*a*) End-on view of the double-fold, two-stage Blumlein-driven TEA-N_2 laser: MSG, main spark gap; SG, second spark gap. (*b*) Top view of the MSG and the SG. (*c*) Equivalent circuit of the TEA-N_2 laser. R_1, R_2, R_3 are 100 MΩ, 40 MΩ and 60 MΩ respectively; $C_1 = C_2 = 3.2$ nF and $C_d = 6.4$ nF; LC is the laser channel with gap varying between 1–1.5 mm.

and C_2 was formed from two layers of 50 μm Mylar. By overlaying Al-1 with two layers of 50 μm Mylar followed by another aluminium foil, Al-2, the dummy capacitor, C_d, was formed. The laser assembly was packaged by pressing the multilayer structures between two thin layers of foam and two 1.2 cm thick Perspex plates. These capacitances were estimated, using $C = \varepsilon A/d$, to be $C_1 = C_2 = 3 \times 2$ nF and $C_d = 6 \times 2$ nF.

The main spark gap (MSG), shown in figure 1(*b*), consisted of three electrodes arranged in parallel. The centre electrode is a 1 mm rod used as a trigger pin, and the other two breakdown electrodes are semi-cylindrical rods. The MSG was tightened by two screws to the top and bottom Perspex plates. The charging voltage across the MSG was resistively divided in a ratio of R_2:R_3 = 1:2 between the two breakdown gaps: the first between the high-voltage anode and the centre electrode (1 mm pin) and the second between the centre and ground electrodes. Upon triggering at the centre electrode, the first gap would break down first which then triggered a breakdown across the second gap to the ground electrode. The main reason for using this flat-type of swinging cascade spark gap instead of a normal trigatron was due to the difficulty in introducing a triggering pin to the ground electrode which was situated further inside the laser system. In this design, the centre electrode was exposed to the side of MSG chamber which provided easy access for the trigger pulse. The trigger pulse was obtained from a SCR circuit the output pulse of which was 300 V and was stepped up to more than 12 kV by a car ignition coil.

3. Results and discussion

The laser output energy as a function of both the charging voltage, V_o, and the breakdown gap in the second spark gap (SG) is presented in figure 2. A minimum breakdown gap in the SG of about 0.3–0.5 mm was necessary to achieve a high laser output at any operating voltage from 4.5–7.5 kV. For a SG breakdown gap smaller than 0.3 mm

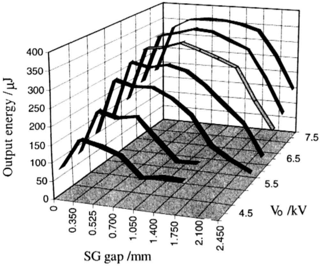

Figure 2. Laser output energy as a function of charging voltage (V_o) for different SG breakdown gaps.

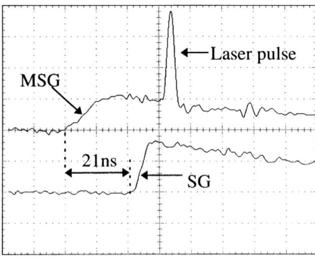

Figure 3. Temporal characteristics and time delays between light emissions from the MSG and the SG and the laser pulse.

the laser output energy not only decreased sharply, it was also irreproducible. This was caused mainly by arc formation in the laser discharge. As the SG gap was increased to more than 0.5 mm, the laser output energy began to decrease gradually and its shot-to-shot variation increased. These were caused mainly by the presence of streamers in the laser discharge which gave rise to a spatially nonuniform input power loading and optical inhomogeneity. The effects of the SG gap on the laser output curve were investigated previously [7].

The temporal sequences of spark gap breakdown in the MSG and the SG with respect to laser discharge are shown in figure 3, represented by their respective photodiode (FND 100, EG&G) signals of light emissions from the MSG and SG and the laser emission. These signals, which were measured with a SG gap of 0.5 mm and a charging voltage V_o of 6 kV, were recorded using a 200 MHz digital oscilloscope (Teknotrix TDS 320). The time delay between MSG and SG firings was between 28–18 ns, which decreased linearly as V_o was increased from 4.5–7.5 kV. The change in the time delay between the laser pulse and SG firing could not be measured accurately, although it is expected to decrease accordingly. It should be noted that the laser pulse was about 3 ns at its FWHM—this may not be the true laser pulse width but the risetime of the 200 MHz oscilloscope.

The risetime of the photodiode signal for the SG was about 5 ns, as compared with about 15 ns for the MSG. The difference is mainly due to a C_d capacitance in the first discharge loop, C_d–L_1–ground, as shown in figure 1(*c*). On the other hand, when the SG was fired the second discharge loop was much faster because C_1 and C_d formed a reduced capacitance, $C_s = C_1C_d/(C_1 + C_d) = 4$ nF. The inductance, L_1, of the MSG may be estimated by assuming that the timing of the laser pulse, as previously observed to correspond to the maximum voltage inversion in the first discharge loop [7], was at 3/4 of the period, T, of the first discharge loop. Thus, $T = 2\pi(L_1C_d) \approx 47$ ns and $L_1 \approx 4.7$ nH. The inductance, L_2, of the SG may also be estimated as the laser pulse emerged around the maximum voltage inversion of the second discharge loop [7], thus $T = 2\pi(L_2C_s) \approx 12 \times 2$ ns. Since $C_s = 4$ nF, $L_2 \approx 3.6$ nH.

The electrical-to-optical conversion efficiency, calculated by dividing the laser output energy by the total energy stored in the three capacitors ($1/2(C_1 + C_2 + C_d)V_o^2$), was on average close to 0.06%. Although this value is comparable to the reported values of around 0.05% of other compact systems operating at 15–40 kV [1, 4–6], it is lower than 0.18% reported in [3]. The high efficiency in [3] was mainly attributed to the back mirror which increased the laser output 2.5 times, as compared to an increase of only 20% in this work. If we neglect the feedback effect by the back mirror the single-pass conversion efficiency of 0.05% obtained in this work is more comparable to the 0.072% reported in [3].

4. Conclusion

A compact TEA-N_2 laser has been designed and operated at voltages from 4.5–7.5 kV to deliver an output energy of 150–370 μJ. Despite a large dummy capacitance, C_d = 12 nF, the electrical-to-optical conversion efficiency of about 0.06% is comparable to most of the reported values obtained at 15–40 kV. The laser was also tested at 4 kV, but its output energy in this case was less than 70 μJ and its shot-to-shot output variation was more than 25%.

One of the prerequisites of the present system is a narrow laser channel gap in order to enable low-voltage operation: this was reduced from the normal value of 3 mm to 1 mm. Another is alignment of the edges of two aluminium foils with the laser channel, one directly above and the other directly below the laser channel. This has hardly ever been reported to be important since the operating voltage of TEA-N_2 laser is seldom below 10 kV. However, in the recently reported miniature TEA-N_2 laser, it was noted that streamers or plasma filaments occurred readily at a 5 kV operating voltage [5]. Thus, our results may suggest that sufficient UV radiation at several kilovolts can still be harnessed from corona discharges along the edges of the aluminium foils.

References

[1] von Bergmann H M, Hasson V and Preussler D 1975 Pulse corona excitation of high-power uv nitrogen lasers at pressures of 0–3 bar *Appl. Phys. Lett.* **27** 553

[2] Herden W 1975 Compact high power subnanosecond nitrogen and 'open air' laser at 760 torr *Phys. Lett.* A **54** 96

[3] Iwasaki C and Jitsuno T 1982 An investigation of the effects of the discharge parameters on the performance of a TEA N_2 laser *IEEE J. Quant. Electron.* **18** 423

[4] Santa I, Kozma L, Nemet B, Hebling J and Gorbal M R 1986 Experimental and theoretical investigation of a traveling wave excited TEA N_2 laser *IEEE J. Quant. Electron.* **22** 2174

[5] Bergmann E E 1977 Compact TEA N_2 laser *Rev. Sci. Instru* **48** 545

[6] Meisel M-G and Langhoff H 1997 Homogeneous high-pressure gas discharge using semiconductor electrodes *Appl. Phys.* B **64** 41

[7] Tou T Y, Kwek K H and Ong D S 1996 Operation and performance of a two-stage Blumlein TEA N_2 laser *Japa J. Appl. Phys.* **35** 5338

[8] Tou T Y, Tham K K, Siew W O and Yee Y C 1998 Circuit modelling of a two-stage Blumlein-driven TEA-N_2 laser *Meas. Sci. Technol.* **9** 1247