Quantum Electronics **32** (5) 447 – 448 (2002)

CONTROL OF LASER RADIATION PARAMETERS

PACS numbers: 42.55.Lt; 42.60.Lh
DOI: 10.1070/QE2002v032n05ABEH002216

Effect of pulsed nanosecond ionisation on the characteristics of an electric-discharge CO_2 laser

L.M. Vasilyak, S.P. Vetchinin, P.G. Kadieva, D.N. Polyakov, V.E. Fortov, A.V. Khotina

***Abstract*. The possibility of improving the electric discharge stability, increasing the efficiency, and expanding the dynamic operating range of an industrial self-sustained discharge CO_2 laser using additional ionisation by high-voltage nanosecond pulses is studied.**

Keywords: *CO_2 laser, pulsed ionisation, electric discharge.*

Pulsed preionisation by a fast-electron beam or high-voltage electric pulses allows an efficient use of a nonself-sustained discharge for pumping high-power fast-flow CO_2 lasers [1 – 3]. In this case, it is possible to substantially increase the limiting energy input into the discharge and extend the range of volume discharge in current and voltage. It is also of interest to investigate how the characteristics of high-power self-sustained electric-discharge CO_2 lasers are affected by additional ionisation produced upon a low energy consumption.

In this paper, we studied the effect of additional ionisation produced by high-voltage nanosecond pulses (an amplitude up to 30 kV, half-width duration of 50 – 150 ns, and a repetition rate of 1 kHz) on the operation of a closed-loop gas-flow industrial CO_2 laser, which is similar to the laser described in Ref. [4], with an output power up to 1.5 kW and a self-sustained transverse electric discharge. The pulses were applied to the working electrodes of the laser via stopping capacitors. An 80-cm long copper rod 1.4 cm in diameter served as the cathode, the anode was made in the form of an 80-cm long plate 15 cm in width, and the cathode – anode separation was 6 cm. We measured the electric characteristics of both the combined and self-sustained discharges, the output power, and the uniformity of laser radiation depending on the mixture composition for a gas flow rate of 60 m s^{-1}.

Irradiation by the nanosecond pulses improves the uniformity of emission of the entire discharge gap, which improves the uniformity of laser radiation in the configuration with an unstable cavity. The additional ionisation results in the expansion of the glow discharge range and provides a stable operation at weak and strong currents. It also eliminates the discharge contraction at strong currents in a circuit without ballast resistors. Because the amplitude of high-voltage pulses is much higher than the breakdown voltage, the pulse energy is spent mainly for ionising the medium without heating it. The nanosecond discharge takes place in the discharge gap wherein the preionisation is produced by a stationary discharge and manifests itself as a high-velocity ionisation wave [5].

One can see from Fig. 1 that the addition of a pulsed discharge results in an increase in the electron concentration and the conductivity in the discharge gap. As shown in Ref. [6] in the numerical investigation of transient processes in a glow discharge, this is related to the change in ion concentration in the positive column and to a reduction of the electron attachment rate after removal of the pulsed electric field. The deficiency of low-mobility negative ions caused by a sharp decrease in the attachment rate leads to their replacement by electrons moving from the cathode. The pulsed ionisation causes the shift of the reduced field strength to lower values than those realised in a self-sustained discharge (Fig. 1) and is more favourable for pumping vibrational laser levels. All this results in an increase in the laser efficiency (Fig. 2). In the combined discharge, most of the energy that goes to pump the laser levels is deposited in the recombining plasma produced by the dc power source. In this case, a higher output power is realised for a lower energy deposition, resulting in an increase in the laser efficiency. Note that a dc source without ballast resistors was employed to power the dc discharge in our experiments, and therefore the energy losses

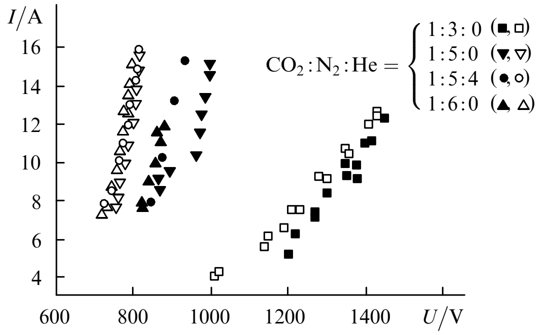

Figure 1. Current – voltage discharge characteristics for $CO_2 - N_2 - He$ laser mixtures of different composition and a molecular mixture pressure of 8 Torr; empty symbols correspond to the combined discharge and the full symbols to the self-sustained discharge.

L.M. Vasilyak, S.P. Vetchinin, P.G. Kadieva, D.N. Polyakov, V.E. Fortov, A.V. Khotina Institute for High Energy Densities, Joint Institute for High Temperatures, Russian Academy of Sciences, ul. Izhorskaya 13/19, 127412 Moscow, Russia; e-mail: lab58@ihed.ras.ru

Received 13 August 2001; revision received 25 March 2002
Kvantovaya Elektronika **32** (5) 447 – 448 (2002)
Translated by E.N. Ragozin

in the power supply circuit were minimised. The power deposited in the discharge gap by the pulsed power supply was calculated from the charging voltage and the capacitance of the storage capacitor. It was equal to 1 % – 2.5 % of the power of the self-sustained discharge, if it is assumed that all the energy stored in the capacitor was deposited in the discharge.

The experimental points in Fig. 2 correspond to the highest efficiency values depending on the nitrogen content in the molecular mixture. The largest efficiency increment was obtained for an output laser power of 0.3 – 0.8 kW. In this case, the efficiency increases with increasing ratio between the energy deposited in the discharge from the pulsed source and the energy deposited from the stationary discharge, and the relative efficiency increment amounts to 55 % (Fig. 3). One can see from Figs 2 and 3 that the mixtures with a higher nitrogen content are more advantageous to use in the case of pulsed ionisation. In a self-sustained discharge, ionisation between pulses also occurs, which does not take place in a nonself-sustained discharge. If the pulse repetition rate is low in the combined nonself-sustained discharge, there exist time intervals between the pulses when the electron concentration decays to the extent that there occurs no inversion in the medium [2, 3]. In our case, the interpulse vibrational excitation is more efficiently maintained by the self-sustained discharge.

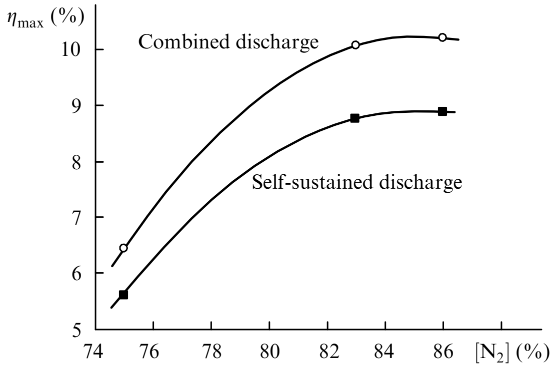

Figure 2. Maximum laser efficiency as a function of the nitrogen content in the helium-free molecular mixture at a pressure of 8 Torr.

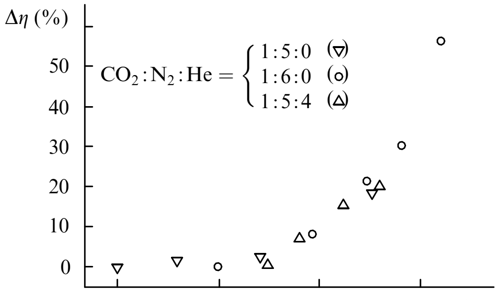

Figure 3. Dependence of the relative efficiency increment on the ratio between the nanosecond source power W_{ns} and the self-sustained discharge power W for $CO_2 - N_2 - He$ mixtures of different composition pumped by a combined discharge.

Therefore, the application of short nanosecond pulses to a self-sustained discharge is a promising technique for improving the pumping efficiency of a self-sustained transverse-discharge CO_2 laser without the laser reconstruction. This allows an increase in the laser efficiency and the operation without discharge contraction with simple (non-sectioned) electrodes and helium-free mixtures with a high nitrogen content. In this case, the operating laser characteristics are improved: the control range in current is broadened, the discharge initiation becomes simpler, and the discharge stability and homogeneity at strong currents are improved.

References

1. Velikhov E.P., Golubev V.S., Pashkin S.V. *Usp. Fiz. Nauk*, **137**, 117 (1982).
2. Generalov N.A., Zimakov V.P., Kosynkin V.D., Raizer Yu.P., Solov'ev N.G. *Kvantovaya Elektron.*, **9**, 1549 (1982) [*Sov. J. Quantum Electron.*, **12**, 993 (1982)].
3. Naumov V.G., Shashkov V.I. *Kvantovaya Elektron.*, **4**, 2427 (1977) [*Sov. J. Quantum Electron.*, **7**, 1386 (1977)].
4. Ivanchenko A.I., Krasheninnikov V.V., Ponomarev A.G. *Elektrotekhnika* (11), 37 (1987).
5. Vasilyak L.M., Kostyuchenko S.V., Kudryavtsev N.N., Filyugin I.V. *Usp. Fiz. Nauk*, **164**, 263 (1994) [*Fiz.-Usp.*, **37**, 247 (1994)].
6. Breev V.V., Dvurechenskii S.V., Pashkin S.V. *Teplofiz. Vys. Temp.*, **17**, 250 (1979).