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THE ELECTRO-IONIZATION CO LASER: A MULTIWAVELENGTH IR OSCILLATOR ($\lambda = 2.7$–$3.3\,\mu$m; 4.9–$6.0\,\mu$m)

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Abstract—The development of the electro-ionization method of pumping high gas density CO lasers is detailed. Energetic, spectral and temporal characteristics are described. Pulse outputs up to 800 J and efficiencies up to 30% have been achieved.

INTRODUCTION

Along with CO_2 lasers, high-pressure CO lasers are the highest energy IR lasers. The development of high-power CO lasers has become possible due to the discovery of the electro-ionization (EI) method of pumping high-density gases, and its application for CO excitation. The EI method gives the possibility of effectively exciting the vibrational–rotational levels of CO molecules. Application of the EI method for the excitation of CO molecules that represent an ensemble of anharmonic oscillators possessing unique characteristics (quantum efficiencies of about 90%) have allowed development of high-power pulsed and CW CO lasers characterized by outputs of 0.5–1.5 kJ, specific outputs up to 200 J/g, average powers of 10 kW and efficiencies of 30–40%.[1–4] High-pressure CO lasers are of great interest because they have several advantages over CO_2 lasers: (i) two or three times greater efficiency and specific output; (ii) an operational range of wavelengths of ~ 5 to $\sim 6\,\mu$m, and 2.7–3.3 μm; (iii) the existence of transparent atmospheric windows in the range around 5 μm; (iv) greater choice of optically-transparent materials and a higher damage threshold of these materials; (v) absence of laser radiation thermal "self-influence".

STRUCTURE OF THE LASER

The present paper reports on the EI pulsed CO laser investigations being carried out at the Lebedev Physical Institute of the Academy of Sciences of the USSR. We have developed a number of EI laser devices characterized by the active volume of 1–10 l. A typical laser is shown in Fig. 1. A general view of the 10 l. device is given in Fig. 2. Cryogenic EI CO-laser devices consist of the *e*(lectron)-gun chamber and the laser chamber. The latter is cooled by liquid N_2. At the same time the *e*-gun chamber

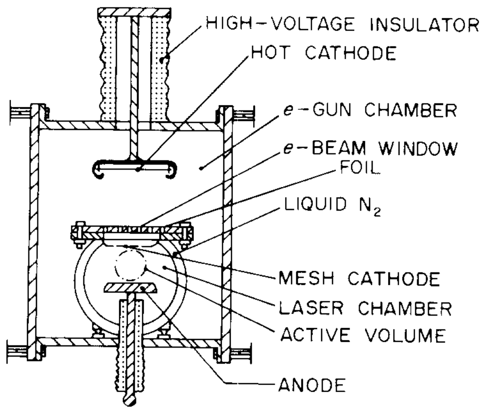
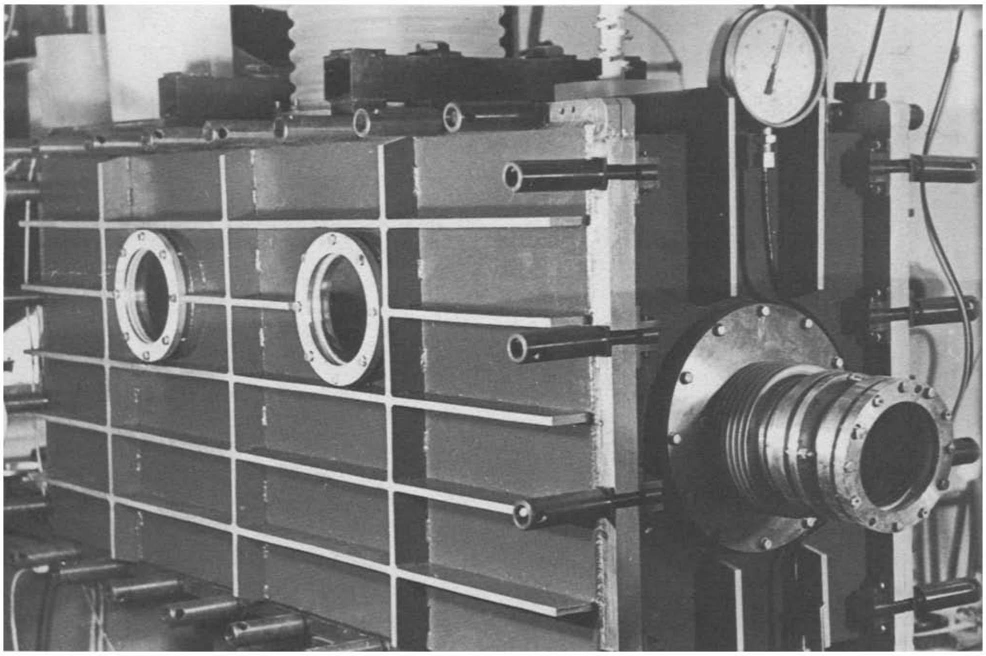


Fig. 1. Typical structure of a cryogenic EI CO laser.[2]



Figs. 2. General view of the laser device with an active volume of about 10 l.[2]

serves as a vacuum thermal isolator of the laser chamber. The e-gun, equipped with a hot or cold cathode, is the source of the electron beam that ionizes the active medium. The excitation pulse duration can vary within the following limits: 10^{-6}–10^{-3} s. The electron beam current density in the active medium is 10^{-4}–1 A/cm^2. To supply power to EI discharge we have used a capacity bank. The capacity of the bank can vary with respect to the experimental conditions ($C = 18\,\mu$F for the 10 l. device).

CHARACTERISTICS OF EI CO LASERS

We have studied the energy, spectral and time characteristics of the EI CO lasers. The free-running (FR) laser with 10 l. active volume generates multiwavelength pulses within the spectrum range 4.9–5.6 μm. The laser output energy is 800 J, and the efficiency is $\sim 30\%$. The specific output is 160 J/l. Amagat (Figs 3 and 4). Figures 3 and 4 also show the energy characteristics of the CO_2 laser, obtained with the same device. The output and the efficiency are much less than those of the CO laser. It should be noted that the possibility of obtaining effective generation at the same device with both the CO and CO_2 laser essentially widens its spectral range.

The CO-laser time characteristics depend on a great number of parameters, e.g. the active medium temperature and pressure, the pumping energy and the laser mixture. Depending on the conditions, the FR CO-laser pulse duration varies between 2×10^{-5}–2×10^{-3} s. Pulse halfwidth duration is about 150–200 μs under optimum excitation ($T \sim 100$ K, $CO:N_2 = 1:6$, $N = 0.5$ Amagat).

The radiation spectrum also depends on a number of parameters. For example, the greater the pumping energy, the wider the generation spectrum. Its short-wave boundary moves up to the short-wave range. More than 60% of the output can be concentrated within the range 5.0–5.2 μm ($CO:N_2:He$; $N = 0.5$ Amagat), this corresponds to minimum absorption of CO-laser radiation by water vapour. Introduction of air or water vapour cells into the laser cavity enables one to correlate the radiation spectrum and the optical transparency of the atmospheric window. By use of a grating one can easily carry out the frequency selection of laser radiation. The laser radiation spectrum and frequency–time distribution in the selection mode are shown in Fig. 5. The specific output at any CO-laser wavelength is several J/l. Amagat. By changing the laser mixture, gas temperature and pressure, the pumping energy and laser cavity spectral characteristics, one can provide the above specific output at 1% efficiency for any CO-laser wavelength.

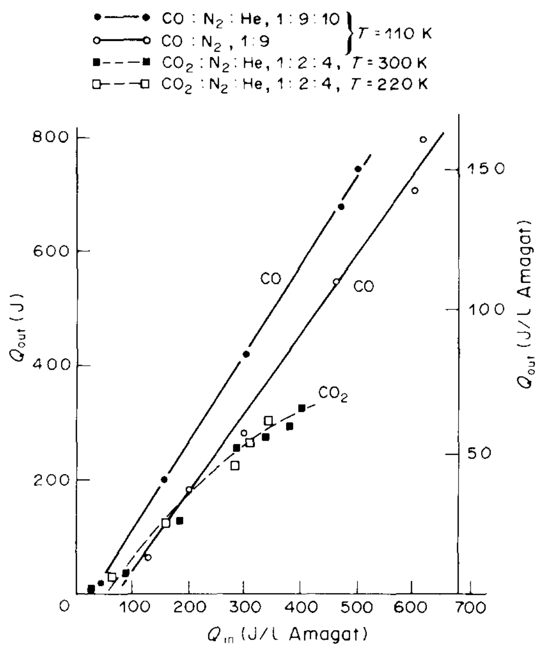


Fig. 3. Output energy of an EI CO laser and a CO_2 laser vs specific energy input. $N = 0.5$ Amagat, $V_{opt} = 10$ l., $\tau_{pump} = 25\,\mu s$.[2]

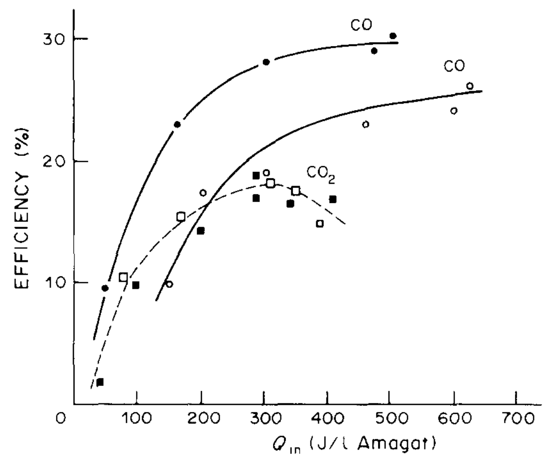


Fig. 4. Efficiency of an EI CO laser and a CO_2 laser vs specific energy input. $N = 0.5$ Amagat, $V_{opt} = 10$ l., $\tau_{pump} = 25\,\mu s$. Symbols as given in Fig. 3.[2]

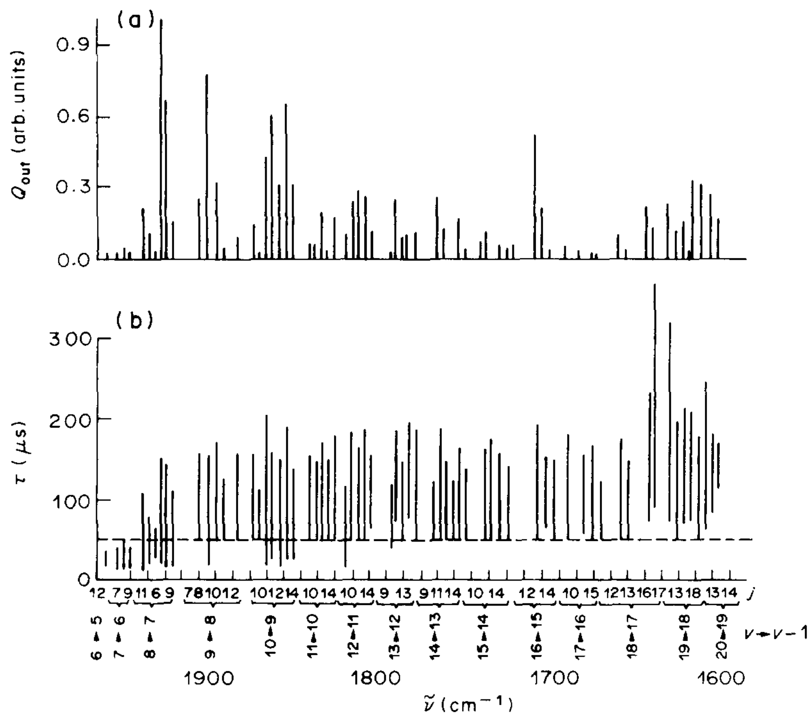


Fig. 5. The laser radiation spectrum (a) and frequency–time distribution (b) in the selection mode. CO:N_2:He, 1:9:10, $N = 0.5$ Amagat, $\tau_{pump} = 50\,\mu s$, $Q_{in} = 250$ J/l Amagat.[2]

HIGH PEAK POWER CO LASERS

It is of particular interest to develop a high peak power CO laser because the FR CO-laser peak power is relatively small due to the long pulse duration. In our experiments the CO laser with small active volume (about 0.6 l.) generates multiwavelength submicrosecond pulses under Q-switching (QS) with a rotating mirror. The pulse duration, form, energy and spectrum depend on the laser mixture, excitation level, QS speed and the time delay (Figs 6 and 7). The dependence of the energy on the QS delay time makes it possible to estimate the inversion population lifetime. The inversion lifetime for the laser mixture $CO:N_2$ (1:9) of 0.5 Amagat gas density is equal to $\sim 10^{-3}$ s. In our experiments the minimal pulse duration of the short-pulse laser is equal to $\sim 0.5\,\mu s$. The maximum peak power of our short-pulse CO laser is 5 MW under the efficiency of $\sim 5\%$ ($CO:N_2$, 1:9; $N = 0.5$ Amagat, $\tau_{pump} = 25\,\mu s$, rotating mirror speed = 1000 rev/s). In comparison to the FR laser the above laser has a relatively low efficiency and this is dependent on the low energy storage of the working CO molecules' levels. The energy storage amounts to about 10% of the total energy storage introduced at all vibrational levels of CO molecules. Repeated at certain time intervals, Q-switching (shown in Fig. 8) enables us to make the QS laser efficiency closer to the FR laser efficiency. The time intervals must be longer than the inversion recovery time value. A further possibility of increasing CO-laser peak power may come from amplifying short pulses with an amplifier of large volume.

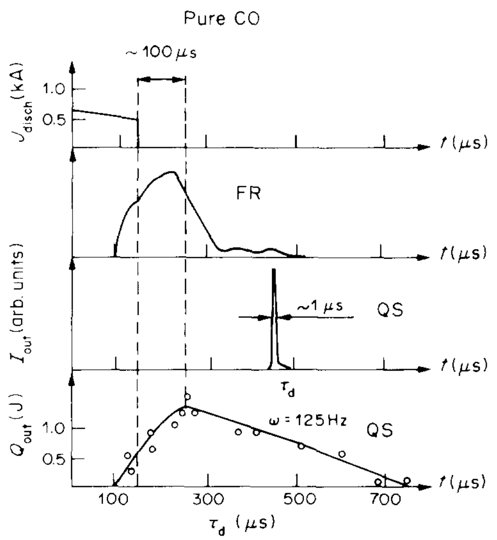


Fig. 6. Discharge current J_{dish} vs time. Oscillograms of laser pulses for the free-running (FR) and Q-switched (QS) lasers. Output energy Q_{out} vs QS time delay. Pure CO, $N = 0.5$ Amagat, $T \approx 80$ K, $Q_{in} = 300$ J/l. Amagat.[2]

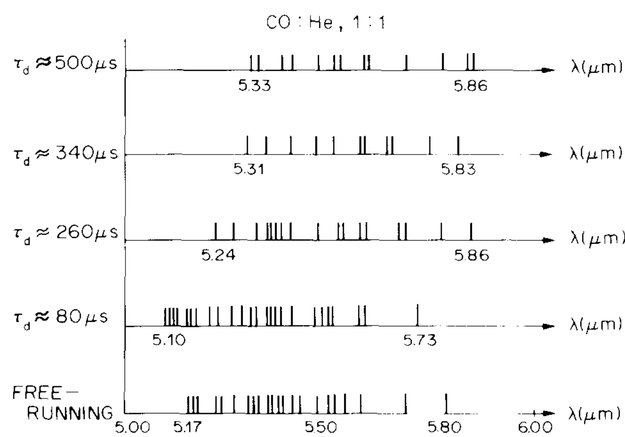


Fig. 7. The laser spectrum for a QS laser and an FR laser for different time delays. $N = 0.5$ Amagat, $T = 80$ K, $\tau_{pump} = 150\,\mu s$, $Q_{in} = 300$ J/l. Amagat.[2]

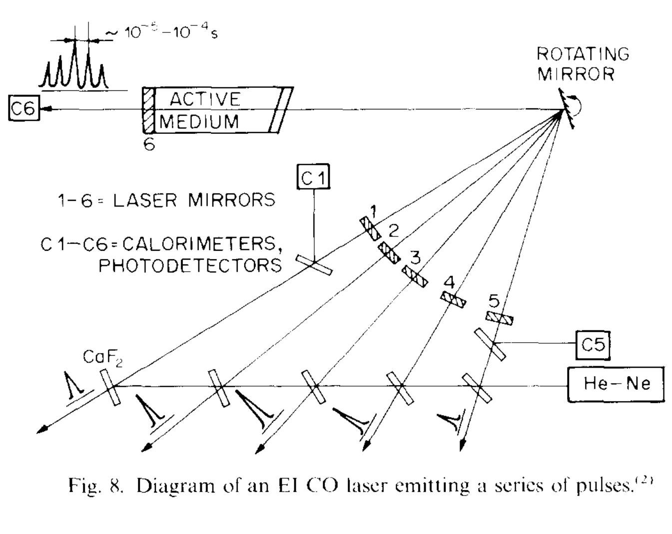


Fig. 8. Diagram of an EI CO laser emitting a series of pulses.[2]

OVERTONE CO-LASER

To make a wider CO laser, e.g. for laser chemistry, laser isotope separation etc., it is useful to widen its spectrum range. The CO-laser spectrum range can be widened by means of CO molecules' overtone transitions. At first overtones, the CO laser generates pulses within the 3 μm spectrum range. The possibility of operating a CO laser on first overtones is dependent on the anharmonic property of the two-atomic CO molecule. It turned out that at high vibrational levels, with the number $v \sim 20$, the Einstein coefficient and the laser gain are comparable to those obtained for the case of CO molecules vibrating at the main frequencies. So, the effective generation of the CO laser on the overtones can be obtained under the same excitation conditions realized in the CO laser on the main frequencies.[5] For the first time our experiments realized high-power generation of a CO laser on the first overtones. On the first overtones 10 l. laser we have: energy output = 50 J, specific energy output = 10 J/l. Amagat, laser efficiency = 4–5% (Fig. 9). A necessary condition to allow relatively high energy output is the suppression of the main frequencies' generation. To suppress it it is necessary to use a laser cavity equipped with dichroic mirrors. The mirror must have a low reflection coefficient at the wavelength of 5 μm and sufficient reflection in the 3 μm range. The output of the first overtones laser is decreased due to the generation on the main frequencies. Therefore, to improve the energy and efficiency of the first overtones laser it is necessary to use optical elements with antireflection coatings at $\lambda = 5\,\mu$m. The pumping of the laser by long and low-power pulses is optimal for reaching maximum laser specific energy and efficiency. The overtone laser operates in the "after-glow" regime. The delay time between the pumping and output pulse is longer than that for the laser on the main frequencies. The pulse duration of the first overtones laser is longer than that of the 5 μm laser, and reaches a few milliseconds. The greater is the specific output, the wider is the output spectrum. For the main frequencies the spectrum is shifted to the short-wave range, and for the first overtones it is shifted to the long-wave range (Fig. 10). Effective generation of the laser on second overtones ($\lambda \sim 1.7$–$2.3\,\mu$m) may be obtained by cooling the active medium to $T \sim 80$ K, and use of the corresponding selective laser cavity.

Thus, the EI CO laser is a highly effective source of IR coherent radiation in the 5 and 3 μm spectral range. The energy characteristics of the laser on the first overtones, i.e. the output and specific energy, and the efficiency, are relatively high. They are bettered only by those of an EI CO_2 laser and the CO laser on the main frequencies. The development of highly effective EI CO lasers, emitting both long (of the duration $\sim 10^{-4}$ s) and short pulses (of the duration $\lesssim 1\,\mu$s) within a wide spectral range in the vicinity of 5 and 3 μm, makes possible various applications of these lasers, e.g. in laser technology, chemistry, isotope separation and other areas.

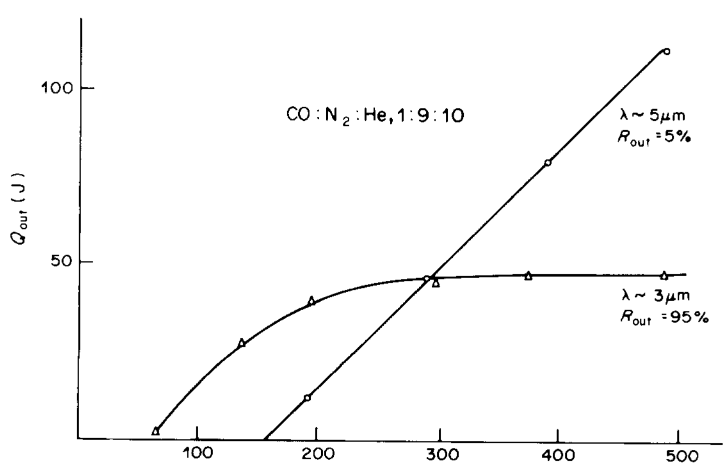


Fig. 9. Output energy of an EI CO laser operating on the main frequencies and first overtones vs specific energy input. $N = 0.5$ Amagat, $T = 100$ K, $\tau_{pump} = 50\,\mu$s.

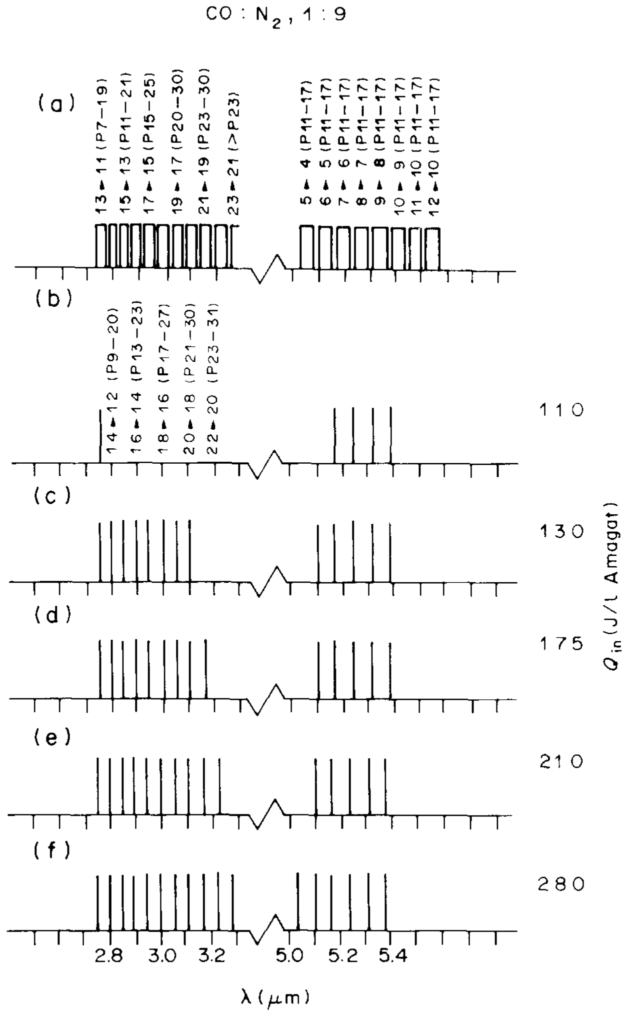


Fig. 10. Vibrational–rotational bands of the main and overtone frequencies (a), and the laser spectrum of the CO laser on the main and overtone frequencies (b–f). $N = 0.5$ Amagat.[2]

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