

PACS numbers: 42.55.Lt; 84.40.-x
DOI: 10.1070/QE2002v032n05ABEH002219

Features of emission from a submillimeter laser under intense optical pumping

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***Abstract*. The emission of a submillimeter laser pumped by a high-power (up to $\sim$ 1 kW) CO_2 laser is studied. It is found that lasing of CH_2F_2 molecules saturates at the pump power $\sim$ 350 W. A delay of submillimeter lasing depending on the gas pressure in the active medium and the pump intensity is observed. The possibility of a rapid tuning (in about 1 ms) of the submillimeter laser emission by scanning the emission from the CO_2 laser is demonstrated experimentally.**

Keywords: *submillimeter laser, optical pumping, saturation effect, delay effect, CO_2 laser.*

The search for new lines at which comparatively high-intensity lasing can be achieved is one of the most important problems in the mastering of the submillimeter spectral range [1]. This problem is closely related to another problem concerning the development of methods of increasing the submillimeter lasing power, the most obvious way to accomplish this being an increase in the optical pump power.

Note that submillimeter lasing power was not saturated in experiments at pump powers up to 30 W [2]. Hence, the maximum submillimeter lasing power attainable by increasing the pump power has not been established. The submillimeter frequency tuning by varying the frequency and amplitude of the pump field is important for the development of submillimeter spectrometers.

In this paper, we present the results of the experimental study of CH_2F_2 and CH_3OH molecular submillimeter lasers pumped by a CO_2 laser operating in different regimes.

The submillimeter laser was pumped by a rapidly tunable 2.5-kW CO_2 laser [3, 4] whose cavity ensured a high quality of the beam ($M^2 = 1.7$). The CO_2 laser could operate in the following regimes:

(i) a cw or quasi-cw single-frequency lasing with a maximum power of 2.5 kW and a rapid tuning within the lasing spectrum (a total of 70 lines in the 9.4- and 10.4-μm bands);

(ii) repetitively pulsed Q-switch lasing at any spectral line with pulse repetition rates up to 20 kHz, pulse duration varied from 5 μs, and power varied up to 100 kW;

(iii) simultaneous cw or repetitively pulsed two-wave lasing on nonadjacent spectral lines (including about 1000 combinations of lines from different branches and spectral bands) with a nearly total overlapping of radiation beams in near- and far-field zones.

However, because of the peculiarities of the optical scheme and a high gain, the laser had a low self-excitation threshold caused by back reflection from the elements of the external optical systems. This circumstance forced us to use only a part ($\sim$ 5 %) of the radiation power for pumping. It was also necessary to take into account the fact that the threshold cw power at which the output mirror of the submillimeter laser is damaged [5] did not exceed 150 W, which corresponds to less than 6 % of the CO_2 laser power in the cw mode.

To increase the pump power range, we used the repetitively pulsed Q-switching, which made it possible to work with pulsed powers up to 1000 W at low average pump powers. In particular, short pump pulses (shorter than 5 μs) were used in experiments on a rapid tuning of the submillimeter laser, while the saturation and delay effects were studied by using 140-μs pump pulses and an off – duty ratio 100. This made it possible to study quasi-stationary submillimeter lasing, and to maintain the temperature of the active medium (before the pump pulse) at $\sim$ 300 K.

Fig. 1 shows the block diagram of the experimental setup. Radiation from a CO_2 laser passes through two optical wedges (*12*) and (*13*) and is incident on the power meter (*1*). A small fraction (4 %) of the beam power reflected from the wedge is directed to a concave spherical mirror (*9*) with a radius of curvature 9.8 m and, after passing through two adjusting diaphragms (*15*) and (*16*), enters the optical system for measuring the spectral – time characteristics of radiation. This measuring system consists of an echelette (*6*), a concave mirror (*11*) (of radius 1 m), and a plane mirror (*5*). The echelette – concave mirror system forms an array of waists of CO_2 laser radiation spectral lines on the plane mirror and ensures a linear dispersion that is sufficient for their resolution and identification.

The radiation reflected by the plane mirror (*5*) at a small angle relative to the incident beam is directed by a beamsplitter to the IR photodetector (*3*). The second wedge (*13*) reflects 6 % of the beam power to the spherical concave mirror (*10*), which focuses the pump radiation at the hole of the input mirror of the submillimeter laser (*8*). The submillimeter radiation is directed on a fast Shottky diode

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Received 20 February 2001; revision received 28 February 2002
Kvantovaya Elektronika **32** (5) 460 – 462 (2002)
Translated by Ram Wadhwa

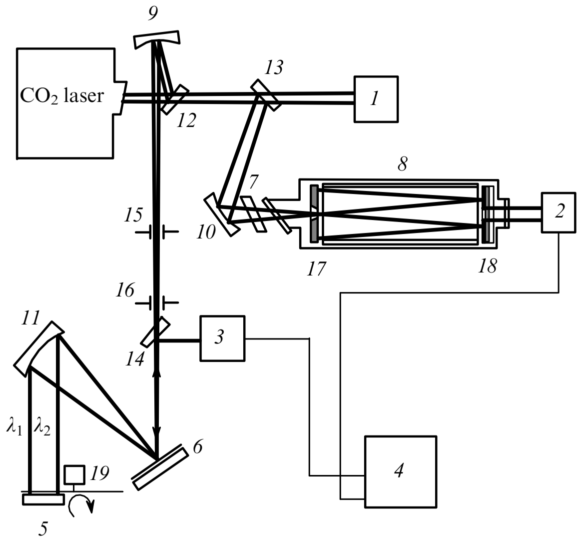

Figure 1. Schematic of the experimental setup: (*1*) power meter; (*2*) Schottky diode; (*3*) IR detector; (*4*) oscilloscope; (*6*) echelette; (*7*) attenuator; (*8*) submillimeter laser; (*5*, *9*, *11*) mirrors; (*12*–*14*) wedge beamsplitters; (*15*, *16*) adjusting diaphragms; (*17*, *18*) submillimeter cavity mirrors; (*19*) chopper.

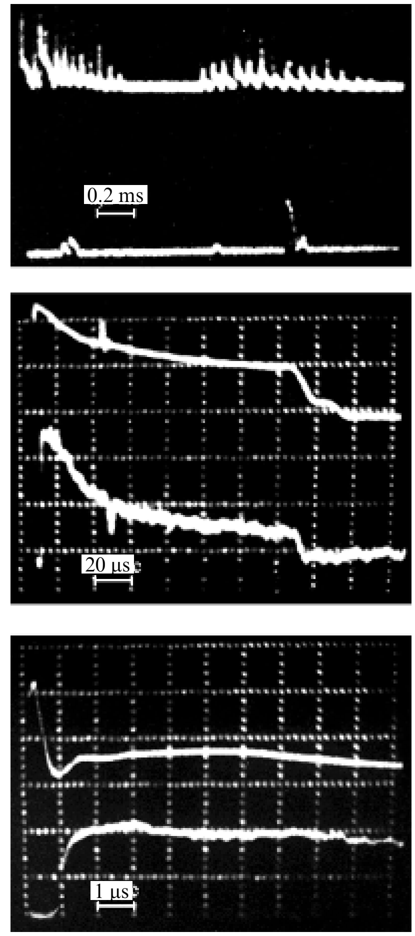

Figure 2. Oscillograms of the pump pulse (upper trace) and the corresponding submillimeter radiation signal during the operation of a CO_2 laser (lower trace) in the 9*R* and 9*P*-line spectral scanning mode (a) and in the 9*P*(16)-line repetitively pulsed mode (b, c).

(*2*) with the time constant 10^{-12} s. Output signals from the IR photodetector and Shottky diode are fed to the double-beam oscilloscope (*4*). The signal from the IR photodetector makes it possible to control and set the operational modes of the CO_2 laser, while the output signal from the Shottky diode allows the observation of rapid processes manifested in the submillimeter radiation during optical pumping.

The submillimeter laser cavity consists of two plane mirrors (*17*), (*18*) mounted at the ends of a 1-m long quartz waveguide with an inner diameter of 24 mm. Mirror (*17*) is made of copper with a gold coating and has a hole of diameter 4 mm serving as the inlet for the pump radiation. A gold-plated dielectric mirror (*18*) has a hole of diameter 6 mm at the centre for outcoupling submillimeter radiation. The pump beam was focused by concave mirror (*10*) (with a radius of curvature 6 m) in such a way that the beam diameter at mirror (*18*) was about 12 mm. In other words, the pump radiation passed through the laser resonator almost without any loss.

Consider now the experimental results. The oscillograms in Fig. 2a show the lasing lines of the CO_2 laser (upper oscillogram) and the corresponding lasing lines in the submillimeter region (for the CH_2F_2 laser). Similar oscillograms were also obtained for the CH_3OH laser.

The excitation and relaxation processes occurred faster than for 10^{-6} s. We studied the transient processes in the regime of repetitively pulsed lasing with a pulse duration longer than 10^{-5} s. The 105.5-μm line was used, which was observed upon pumping by the 9*P*(16) line of a CO_2 laser. According to Ref. [1], upon such pumping, a comparatively high-power submillimeter lasing occurs only at 105.5 μm, so that undesirable effects caused by a competition between different simultaneous lasing transitions were absent.

Fig. 2b (top) shows the trace of a pump pulse with a steep leading edge of duration ~ 0.5 μs. The radiation power near the pulse edge could attain a significant value within ~ 15 μs, which made it possible to observe the related effects. The lower trace in Fig. 2b shows the submillimeter radiation pulse.

A simultaneous analysis of oscillograms of the pump and submillimeter pulses shows that the beginning of the submillimeter pulse is delayed relative to the beginning of the pump pulse (in most cases, the delay was 1 μs). We studied the delay as a function of the pressure of the active medium of the submillimeter laser and of the pump power (field effect). The results of the processing of the experimental data are presented in Figs 3a, b. One can see that these dependences are nonlinear, and that $\Delta\tau$ is independent of p in a certain pressure range (Fig. 3a). For low pump powers, $\Delta\tau$ decreases rapidly and then falls insignificantly with increasing P.

The delay of the leading edge of the submillimeter pulse indicates that the energy of the initial part (of duration ~ 1 μs) of the pump pulse is spent for creating population inversion in the active medium. In the subsequent time interval (~ 15 μs) during which a correspondence of profiles of the submillimeter lasing and pump pulses was observed (for all investigated values of the active medium pressure and the pump power), lasing can be treated as quasi-stationary. For the sake of convenience, we shall call this part of the pulse the 'peak'. Fig. 4 shows the dependences of the submillimeter radiation power at the pulse peak on the peak pump power for two pressures of CH_2F_2 (the results were obtained from an analysis of the oscillograms). For the active medium pressure of 375 mTorr, we observed satu-

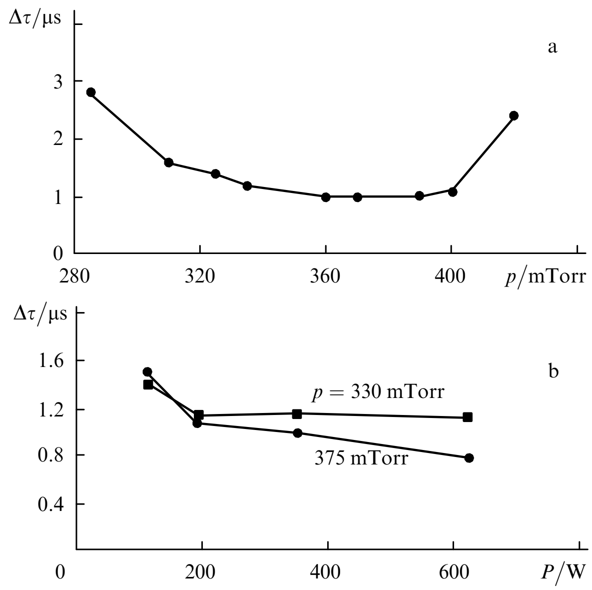

Figure 3. Dependences of the delay time for the leading edge of the submillimeter laser radiation pulse relative to the pump pulse [9P(16) line] (a) on the CH_2F_2 pressure for a constant pump power and (b) on the peak pump power for different values of the CH_2F_2 pressure.

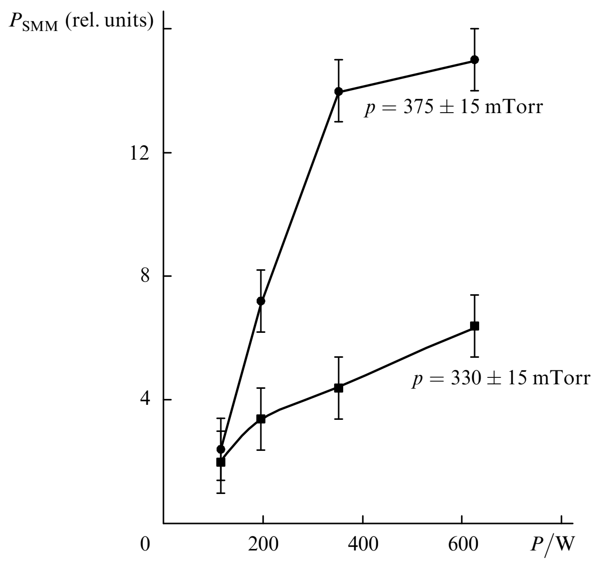

Figure 4. Dependence of the submillimeter signal amplitude on the ‘peak’ power of the pump radiation [9P(16) line] for different values of the CH_2F_2 pressure.

ration with increasing pump power, beginning from ~ 350 W. The energy of the leading edge of the pump pulse corresponding to this power was ~ 4.7 mJ.

Note that because the cross section of the pump beam inside the submillimeter cavity has a complex configuration, it is difficult to make any judgement about the specific values of power density and saturation energy.

Thus, we have shown by the example of CH_2F_2 and CH_3OH submillimeter lasers that the fabricated multifunctional CO_2 laser system makes it possible to carry out versatile studies of optically pumped submillimeter lasers.

Acknowledgements. This work was supported by the Russian Foundation for Basic Research (Grant No. 98-02-17799).

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