Frequency beats between orthogonal polarizations in a water-vapor laser

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Generation of two orthogonal linear polarizations belonging to the same resonator mode and differing in frequency by several dozen kHz was observed in a water-vapor laser whose beam was extracted through a thin grid. It is shown that the difference between the frequencies is due to anisotropy of the grid.

An appreciable beam divergence is inevitable in the widely used method of extracting radiation from infrared and far-infrared lasers, namely through a small opening in the mirror. To decrease the divergence of a far-infrared water-vapor laser, we used as the output mirror a nickel grid with a square mesh of 30 μ, thickness 20 μ, and working-part diameter 4.5 cm. This grid and a spherically concave aluminum-coated glass mirror of curvature radius 7 m formed a laser resonator 340 cm long. A dc discharge (up to 1 A) was produced in the laser in a gas mixture $H_2O + H_2$ (0.1–0.5 Torr) or $D_2O + D_2$ (0.1–0.5 Torr), with a voltage drop across the discharge column not larger than 2000 V. The radiation was detected with Ge : B and InSb photoreceivers cooled to low temperatures. The laser generated at the wavelengths 118.6 and 220 μ (H_2O) or 107.1 and 171.7 μ (D_2O).

The radiation polarization was investigated with a rotating wire polarizer of 60 μ pitch, placed in front of the detector. It turned out in the measurements that the laser emission registered with the detector, at all the wavelengths indicated above, is amplitude-modulated almost sinusoidally with a frequency Ω on the order of several dozen kHz (see the table). The measured dependence of the detector signal P on the polarizer rotation angle θ is given by

$$P = P_0\,(1 - \cos\Omega t\,\cos 2\theta).$$

The detector signal contained also harmonics with frequencies 2Ω, 3Ω, etc., of much smaller amplitude, with the amplitudes of the even harmonics weakly dependent on the angle θ. The even harmonics were distinctly observed at $\cos\theta = 0$, and also without the polarizer.

It was concluded from these experiments that the laser radiation consists of two mutually-perpendicular linearly-polarized waves with frequencies that differ somewhat from each other. Being orthogonally polarized, these waves practically do not interfere at the

Beat frequencies Ω at different wavelengths λ of the laser, us using one and the same grid. The laser resonator was tuned to the center of the generation band.

λ, μ	220.2	171.7	118.6	107.7
Ω, kHz	15	25.2	38	50.6

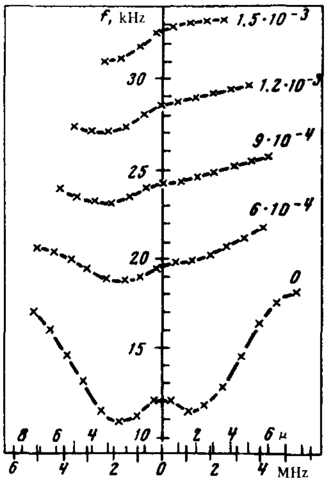

FIG. 1. Dependence of the beat frequency at λ = 118.6 μ on the detuning of the resonator length (in μ and MHz) for a grid stretched in one direction (the relative magnitudes of the deformations of the gird mesh are indicated). The initial undeformed grid was already anisotropic.

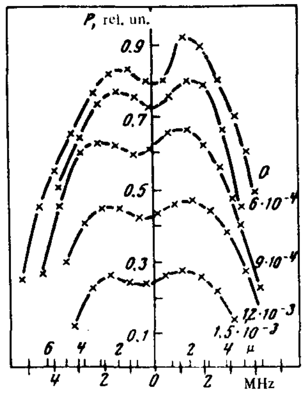

FIG. 2. Dependence of the beat amplitude at λ = 118.6 μ on the detuning of the resonator length (see caption of Fig. 1). The polarizer is mounted in front of the detector in such a way that a maximum fully-modulated signal is obtained.

detector, and beats at the difference frequency are separated at the detector in the presence of a polarizer.

We note that a frequency shift of the different polarizations, amounting to several dozen kHz, was also observed in previously described experiments[1] with an He-Ne laser, but this phenomenon was not studied in detail.

We have assumed that in our case the frequency shift is due to a small geometric anisotropy of the grid relative to the waves with different polarizations. Indeed, if the grid meshes are not strictly square, then waves of different polarizations are reflected from the grid with somewhat different phases, and this can lead to a relative shift of their resonant frequencies.

To verify this assumption, we used as the output mirror a grid with an adjustable degree of anisotropy. The grid was stretched and glued to a thick square steel frame, the corners of which were cut such that it could be easily deformed by a micrometer screw and assume a diamond shape, thereby stretching the grid in the direction parallel to the side of the square mesh. To keep the grid plane during the stretching, a flat spring-mounted ring was clamped to it.

Preliminary results of these experiments are shown in Figs. 1 and 2. For a resonator tuned exactly to the center of the generation band the beat frequency turned out to be proportional to the change in the period of the grid, with a proportionality coefficient 0.1 MHz/μ. At large deformation of the grid, the beat signal is practically sinusoidal, and the beat frequency depends both on the tilt of the mirrors and on the change in the wavelength of the resonator. At small deformations, the dependence of the beat frequency on the resonator detuning increases strongly and when the beat frequency reaches about 5 kHz the beat amplitude drops abruptly to zero. When this vanishing point is approached, the beat ceases to be sinusoidal and the detector signal consists immediately before the vanishing of a sequence of pulses. At any grid deformation, the amplitude of the fundamental harmonic of the beat depends on the angle of rotation of the polarizer, in accordance with relation (1), and is maximal when the analyzer wires are parallel to the diagonals of the grid meshes.

It should be noted that the observed phenomenon is of interest for the understanding of processes that occur in a laser, inasmuch as the waveforms of the beats and their frequencies can yield information on the properties of the resonator and of the active medium. On the other hand, when a laser is used as a source for active far-infrared spectroscopy, the presence of amplitude modulation makes it possible to increase significantly the sensitivity and accuracy of the measurements, all the more since the development of a high-speed modulator in the far infrared region is a rather complicated problem. The laser described in this article was successfully used in experiments on the diagnostics of a dense pinch-discharge plasma.[2]

In conclusion, the authors are deeply grateful to P. L. Kapitza for constant interest and for support of the work.

[1]A. Javan, E.A. Balik, and W. Bond, JOSA 52, No. 1, 96 (1962).
[2]V.G. Zatsepin, Candidate's dissertation, Institute of Physics Problems, USSR Academy of Sciences, Moscow, 1974.