of a magnetic field is $\Delta i/i \approx -0.06$. With increasing magnetic field intensity, $|\Delta i/i|$ decreases and vanishes in fields $H \geq 8$ kOe. The bias voltage U_d corresponding to the dip Δi is practically independent of the magnetic field. The obtained data can be explained by assuming that the tunneling electrons are inelastically scattered by quasiparticles with energy $\epsilon_q = eU_d = 1.3$ meV, reckoned from the Fermi level. We have not established the nature of these quasiparticles. At helium temperature we observed on the $d^2i/dU^2(U)$ curves distinct maxima due to the interaction of the tunneling electrons with the phonons. The energies of the phonons in the condensed aluminum film, obtained from tunnel measurements, are $h\omega = 8.0$, 13.3, 19.6, and 30.8 meV. These results are in satisfactory agreement with the data given in [6].

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TWO-LEVEL GAS LASER WITH COHERENT OPTICAL PUMPING

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1. In [1] we proposed a method of coherent optical pumping, making it possible to obtain exceedingly narrow amplification lines (up to 10^4 - 10^5 Hz) within the Doppler line of a beam of atoms or molecules. This is of interest for the development of a quantum frequency standard in the optical band (see the review [2]). In the present paper we propose to obtain narrow amplification lines by coherent optical pumping using a two-level scheme in a low-pressure gas, and a two-level gas laser based on coherenet pumping by its own radiation.

2. Coherent optical pumping of low-pressure gas in accordance with a two-level scheme consists of combining pulsed inversion of molecules as they pass through a coherent light field ("π-pulse") and "tubular" geometery of the pumping light beam, thus ensuring spatial isolation of the inverted molecules without using a directional flux (beam) of molecules. Let the field of the pump beam have the form $E = \mathcal{E}_0(r_\perp)\cos(\omega t - \vec{k}\cdot\vec{r})$, where $\mathcal{E}_0(r_\perp)$ describes an annular distribution of the amplitude in the transverse directions. If the molecule mean free path greatly exceeds the beam diameter, then the molecules whose velocity $\vec{v}$ satisfies the resonance condition

$$|\omega_{12} - \nu + kv| < \frac{\pi}{\tau} \qquad (1)$$

interact effectively with the field (ω_{12} is the frequency of the center of the Doppler line and τ is the time of flight of the molecule through the field). At a certain field intensity, determined by the condition $(p\mathcal{E}_0/\hbar)\tau = \pi$ (p is the diple moment of the transition), the molecules that are in exact resonance with the field go over into the excited state.

An exact 180° transition is impossible immediately for all the molecules entering the pump field, owing to the frequency detuning, the thermal distribution of the molecule velocities, and the dependence of the time of stay in the field on the impact distance ρ. The inverted population is produced in a narrow frequency band $\Delta\nu = 0.65/\tau_0$ (Hz) with a center at the field frequency ν ($\tau_0 = a/v_0$ is the average time of flight of the molecules through the field, a is the thickness of the beam "wall," and v_0 is the average velocity of the molecules.

We consider here a case when the amplifying molecules enter the beam practically perpendicularly to the axis, i.e, when ω_1 ν. As will be shown subsequently, a laser with coherent pumping can be excited only in this case.

The maximum inversion is attained on the beam axis and equals

$$\rho_{22} - \rho_{11} = 0{,}53(\rho^\circ_{11} - \rho^\circ_{22}), \qquad (2)$$

where ρ^0_{ii} and ρ_{ii} are the probabilities of populating the i-th level prior to entering the beam and inside the beam, respectively. The inversion decreases somewhat in the radial direction as a result of the increase in the fraction of molecules entering the beam with a larger impact distance ρ. The radial distribution of the inversion inside the beam cavity is shown in Fig. 1. For three values of the ratio of the inside radius of the beam R to the "wall" thickness this calculation was made for the case $p\mathcal{E}_0 a/\hbar v_0 = \pi$.

3. A narrow amplifying peak can be used to generate radiation. Owing to the narrowness of the amplification line, the generation frequency is very close to the pump radiation frequency. This makes it possible to use for the coherent pumping the amplified radiation of the laser itself. A diagram of such a two-level gas laser is shown in Fig. 2. The "tubular" beam is formed from the generated beam with the aid of an optical amplifier, a telescope, and a diaphragm. The gas pressure in the cell is chosen to satisfy the condition that the molecule mean free path be several times larger than the diameter of the pump beam. If the distance between the cell walls is of the order of the mean free path, then complete relaxation of the molecule excitation at the instant when the molecule returns to the beam can apparently be attained by selecting the wall material. The generation

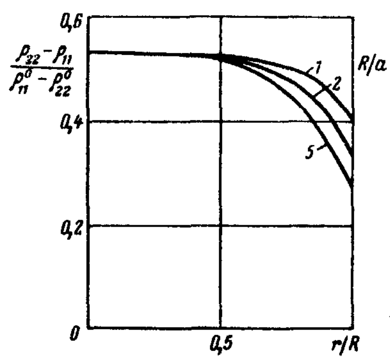
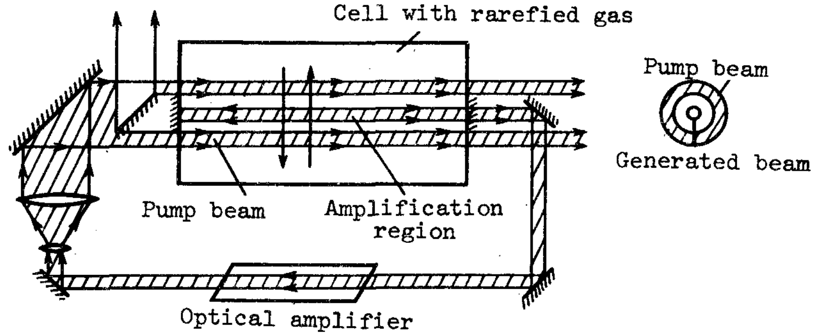


Fig. 1. Distribution of inverted population inside the beam in coherent optical pumping by a "tubular" beam.

Fig. 2. Diagram of two-level laser with coherent pumping by its own radiation



frequency of such a laser is automatically maintained in the vicinity of the center of the gas absorption line. The center is unique for this laser, for whenever the generation (pump) frequency coincides with the center of the absorption line with accuracy π/τ_0, the amplifying peak is capable of amplifying both traveling waves in the resonator [3].

The properties of such a laser (excitation regime, dynamics, frequency stability, etc.) coincide in many respects with the properties of the beam laser with coherent pumping considered in [3]. The proposed laser, however, is free of many effects that limit the frequency stability of the beam laser (the traveling-wave effect, the instability of the beam direction). At an amplifying peak width $\Delta\nu \simeq 10^5$ Hz and a resonator bandwidth $\Delta\nu_r \simeq 10^7$ Hz, the resonator frequency must be maintained stable with accuracy 10^{-10} in order to obtain a frequency stability 10^{-12}. This is apparently perfectly attainable if, for example, generation is produced with the same resonator at another frequency with the aid of an additional amplifying cell, and if this generation is stabilized by one of the known atomatic resonator frequency control methods [2].

4. The atoms and molecules suitable for pumping in accordance with a two-level scheme are those having an absorption line at the generation frequency of a laser with a sufficiently high gain. An example is the P(7) absorption line of methane, which coincides with the 3.39 μ emission line of the He-Ne laser [4]. The absorption coefficient of CH_4 in this transition is $\kappa_0 = 0.18$ cm^{-1}Torr^{-1}, and the constant of the intrinsic line broadening is $\delta\nu \simeq 7$ MHz-Torr^{-1} [5]. At a methane pressure 3×10^{-3} Torr, the mean free path of the molecules relative to collisions is $\ell = 4$ cm, and the absorption coefficient is $\eta \simeq 6\%$ per meter. Consequently, at this pressure it is possible to obtain in a methane cell an amplification peak with width $\Delta\nu = 10^5$ Hz and a gain $\alpha_0 \simeq 3\%$ per meter. With such a gain, generation can be obtained even in a low-Q resonator, by placing inside the resonator an He-Ne amplfiying cell to compensate for most of the losses, with the exception of a small fraction compensated for by the gain in the narrow frequency band of the methane cell.

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