TEMPERATURE EFFECTS IN A HELIUM–NEON LASER


It is well known [1, 2] that the gas temperature has a considerable influence on the amplification factor and generating intensity of a helium–neon laser. Raising the gas temperature in the laser tube improves the generation conditions for the $2s_2-2p_4(\lambda = 1.15 \mu)$ and $3s_2-2p_4(\lambda = 0.63 \mu)$ transitions of neon in the He–Ne mixture. In order to optimize the thermal conditions it was proposed in [2] to make use of the self-heating of the gas laser under conditions of impeded heat transfer.

The temperature of the discharge tube and the gas filling it may in fact be varied both by changing the discharge current and by changing the conditions of cooling. The wall temperature of the discharge tube (or the gas temperature itself, on allowing for the temperature gradient inside the tube) may be found by considering the equation governing the balance between the heat evolved in the gas discharge and the cooling thermal fluxes; for a thin-walled tube of length $l$ and radius $r$, this equation takes the following form under steady-state conditions [3]:

$$\frac{aP}{2\pi rl} = \varepsilon_k \sigma_0 (T^4 - T_0^4) + A (T^4 - T_0^4)^{1/4} (2r)^{-1/4}. \quad (1)$$

On the left-hand side of this equation is that part of the electrical discharge power $P$ used in heating unit surface area of the laser tube. The first term on the right-hand side describes the specific power losses suffered by the heated tube through radiation (here $\sigma_0$ is the Stefan–Boltzmann constant, $\varepsilon_k$ is the integrated emissivity of the tube at the temperature of its outer surface $T_2$, $T_0$ is the temperature of the coolant). Under normal conditions, in taking heat away from the laser tube surface the main part is played by convective heat transfer, as described by the second term in (1), where $A$ is the dimensional convection coefficient:

$$A = 0.18 \left( \frac{\beta g}{\nu \alpha} \right)^{1/4} \rho^{1/2}. \quad (2)$$

g is the gravitational acceleration, $\beta$, $\nu$, $\alpha$ are the coefficient of volume expansion, the kinematic viscosity, and the thermal diffusivity respectively. It is not difficult to show that the values of $A$, and hence the amount of heat released from the tube surface, diminish considerably on reducing the pressure $p$ of the air surrounding the tube. In addition to this, the coefficient $A$ depends on the nature of the surrounding gas and the gas temperature.

The pressure dependence of the temperature of the laser tube walls was calculated graphically. Figure 1 shows this relationship for several values of the excitation power fed into the discharge in the case of a tube 250 mm long with an outer diameter of 6 mm. It is easy to see that, as a result of the self-heating of the discharge tube, a reduction in the pressure of the surrounding air leads to a considerable temperature rise.

Analysis of the mechanism underlying the generation of a helium–neon laser [3] shows that, at first, a rise in gas temperature causes an increase in the amplification factor; this results from the increase in...
the probability of the diffusion-induced disruption of the metastable Ne levels, and also from the very strong temperature dependence of the specific probability of energy transfer in the collisions of metastable helium atoms with neon atoms. On further raising the temperature, there is a broadening of the generating transition, an increase in the captivation of the emission, and an increase in the rate of disruption of the metastable helium levels, which all lead to a fall in the amplification factor.

We carried out our experimental work on a small single-mode He–Ne laser of the LG-58 type with a generation wavelength of 0.63 μm. The resonator was formed by a plane mirror and a spherical mirror with a radius of curvature of 30 cm. The mirrors and the gas-discharge tube between them (with quartz exit windows) were placed in an optical holder of three-rod construction with a uniform disposition of Invar rods around the circumference. The laser emission intensity was monitored with an FD-7K photodiode and an automatic recorder. The active element and the resonator, together with the radiation receiver, were placed in a hermetically sealed space, the air pressure in which was reduced by means of a vacuum pump.

Experimental curves relating the generation power (in relative units, normalized to the initial values of the power under normal conditions) to the air pressure in the vacuum space are shown in Fig. 2a. It is easy to see that, on reducing the pressure, the average level of the power generated increases. The modulation of the emission power seen in Fig. 2a is due [4, 5] to a displacement of the generation frequencies on the amplification curve and to the periodic competition which arises between generation at 0.63 and 3.39 μm when the optical length of the resonator is varied. In this case the change in the optical length is determined not so much by the thermal expansion of the resonator and its optical elements as by the change in the refractive index n of the air:

$$(n - 1) = (n_0 - 1) \frac{p}{760}$$

where $n_0$ is the refractive index of the air under normal conditions and p is the air pressure (in mm Hg).