TEMPERATURE REGIME OF METAL VAPOR LASER OPERATION

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The temperature distribution along the active zone of self-heating metal-vapor laser is studied. Significant contribution of the near-electrode region into the temperature field formation is shown. It is demonstrated for Cu- *and* Pb-*vapor lasers as an example that the proper choice of the discharge tube construction and the experimental conditions may favor creation of the "temperature locks" which hinder the metal vapor removal from the laser active zone.*

When investigating operation of metal-vapor lasers their temperature regime is of great importance. In our earlier work (see Ref. 1) we have considered a self-heating discharge tube. Temperature field in this tube is formed due to the discharge energy dissipation. The gas discharge is characterized by the near-electrode voltage drop, positive column, i.e., the temperature field is already non-uniform at the stage of its formation. Besides, maintenance of the working temperature is achieved by the use of heat insulator whose inherent property is thermal gradients determined by both boundary effects and the insulator design. When considering thermal regime of a metal-vapor laser operation it is important to find the system parameters which are responsible for the temperature distribution over the active zone, their scales and action conditions in order to control the temperature field formation. Such a work appears to be important not only for achieving better laser efficiency but also from the standpoint of increasing the lifetime of an active element and the device as a whole.

EXPERIMENTAL SETUP

For the temperature field along the discharge channel to be measured an experimental discharge tube with thermocouples (*1*) positioned along its working channel was made (see Fig. 1*a*). To maintain the lifetime of the tube and to reduce the discharge action on the thermocouples we use the tube design with the working substance (*2*) placed in the insert (*3*). The insert was positioned inside the carrying tube (*4*) surrounded by the heat insulator (*5*). In this device the temperature measured with the thermocouples is much lower than that in the active volume and it is smoothed to a high degree. However, this qualitative pattern of the temperature distribution along the discharge channel is acquired correctly. Besides, some local nonuniformity of the heat insulator at the thermocouple sites affects the measurements, but its action is insignificant. The insert was 30 mm in the inner diameter and 500 mm in length. The thermocouples were spaced by 110 mm distance and 30 mm from the insert ends. Platinum – platinum-rhodium thermocouples provide temperature measurements over the whole working range. ZrO_2 powder was used as the heat insulator. Vacuum jacket (*6*) was made from fused silica. Niobium electrodes (*7*) were mounted at the tube ends. Copper pieces of the total weight of 2 g were distributed along the discharge channel. Entrance windows (*8*) were made from ordinary glass.

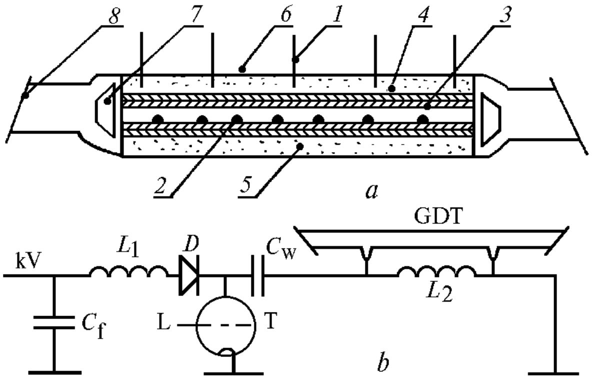

FIG. 1. Design of discharge tube (a): thermocouples (1), working substance (2), insert (3), carrying tube (4), heat insulator (5), vacuum jacket (6), electrodes (7), and windows (8). Electric circuitry (b): gas discharge tube (GDT), *thyratron TGI 1-1000/25* (T), *charging inductor (L_1), capacitive filter (C_f), working capacitor* (680 pF) *(C_w), shunting inductor (L_2), and diodes (D).*

The electric circuitry used (see Fig. 1*b*) is typical for the self-heating metal-vapor lasers (see Ref. 1). The power supply operates in the following regime: $U = 3$ kV, $I = 200$ mA, $f = 10$ kHz. The laser power was measured with a calorimetric power meter IMO–2. Optical cavity consists of a plane total reflection mirror with the dielectric coating and plane-parallel glass plate with the reflectance of 15%. The thermocouple readings were recorded with a PP–63 device providing measurement accuracy of 10%. For a comparison a Pb-vapor laser tube was also investigated.

EXPERIMENTAL RESULTS AND DISCUSSION

Temperature profiles inside the tube were measured at different buffer gas (neon) pressure (3, 7, 10, 20, 50, 100 and 150 Torr). First of all, we were interested in the difference between the readings from thermocouples and actual temperature inside the discharge channel. As was mentioned above, use of the insert significantly increases the difference between the readings. Our previous experiments showed that occasionally ceramic experiences local destruction under the action of high temperature while in our case the thermocouples and the tube were damaged as a whole. Simultaneous measurements of the temperature inside the channel with a pyrometer “Promin” and the thermocouples showed the difference to be 600°C as high. The pyrometer was tuned to ceramics. The difference was found to be significant, but we were only interested in a qualitative pattern of the temperature field along the channel.

The temperature distribution along the channel is shown in Fig. 2*a*. It is not only non-uniform along the length but also essentially depends on the buffer gas pressure. One can isolate three regions where the temperature behavior has peculiarities. There are near-cathode, central and near-anode zones. In the central zone the temperature increases with pressure when the latter is low. At the pressure above 20 Torr no temperature variations occurred. Near-cathode and near-anode zones are to be characterized by a significant temperature fall due to the boundary losses. Nevertheless, it is seen that the near-cathode zone exhibits relatively high temperature which in all cases exceeds that in the near-anode one. This allows one to assume that a significant portion of energy releases in the near cathode zone due to the cathode drop. Moreover, the conditions at low gas pressure the temperature in the near-cathode zone is higher than that in the tube center. The construction of the gas discharge tube was symmetric with respect to the tube center. Therefore the cathode-anode substitution should not affect the near-cathode zone property revealed. The effect of changing the places of the electrodes is shown in Fig. 2*b*. It is seen from this picture that the near-cathode zone temperature is higher than that in the central and near-anode zones. Hence, the near-electrode zones are of significant importance in the temperature field formation. Figure 2*c* depicts the temperature field distribution along the channel in 10 min intervals with increasing temperature. Attention is drawn to the fact that during several starting minutes of the tube operation the heating of the near-cathode zone occurs at an enhanced rate. Gradients are small, the related losses are in a certain degree over the length. Therefore on this background the temperature distribution reflects relative difference in the energy dissipated within the above zones. Measurements of the temperature field in Pb-vapor laser performed at low buffer gas pressure show that in this case the regime with higher temperature in both cathode and anode zones is realized (see Fig. 3).

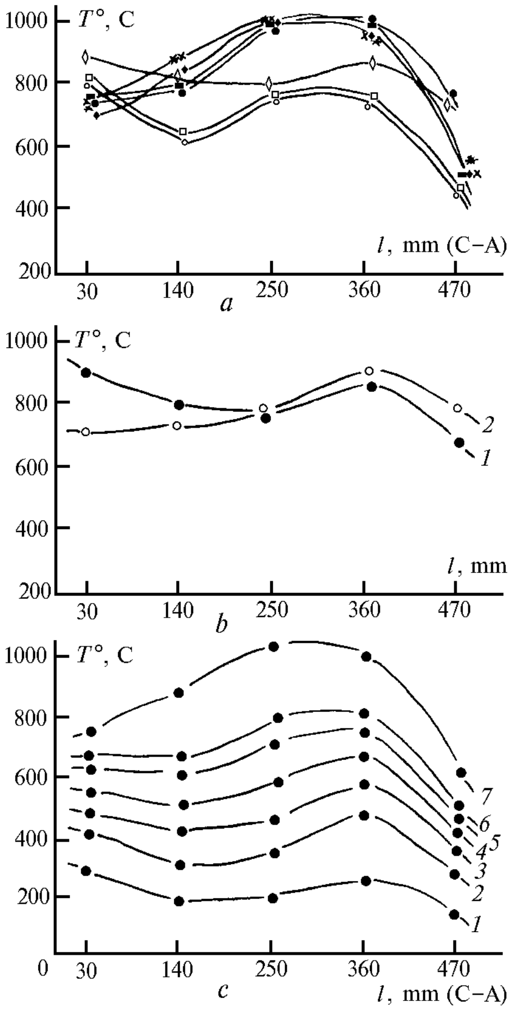

FIG. 2. Temperature distribution along the discharge channel. Buffer gas is neon. $p = 3$ (o), 7 (□), 10 (◊), 20 (•), 50 (◆), 100 (×), *and* 150 (∗) Torr *(a). Variation of the temperature field when interchanging the cathode* (C) *and anode* (A), *1* – C–A; *2* – A–C *(b). The temperature field development as the temperature increases. The measurements were made in* 10 min *intervals (1, 2, 3, 4, 5, 6), after* 40 min *(7). Gas pressure is* 50 Torr *(c).*

Such a boundary temperature rise can be used for creation of the so-called ”temperature” locks which hinder removal of the active substance from the working volume and improve lifetime of a sealed-off discharge tube. As for Cu-vapor laser, both the design solution enhancing that effect and electrical circuitry interchanging the cathode and anode thus creating identical “temperature” locks can be realized. Higher temperatures in the near-cathode zone can be used when laser operates on different active media in the same volume. An example of this application is the laser on gold and copper vapor. Gold-laser efficiency is improved when gold is placed on the cathode side. Therewith, the increased voltage near cathode improving the laser action is also to be considered. In any case, one should take account of this effect when designing gas discharge tubes. The temperature in the near-cathode zone falls as the pressure increases. This phenomenon is due to a decrease in the cathode drop length and enhancement of the gas heat conductivity. The results obtained in this work are in a good agreement with those presented in Ref. 2.

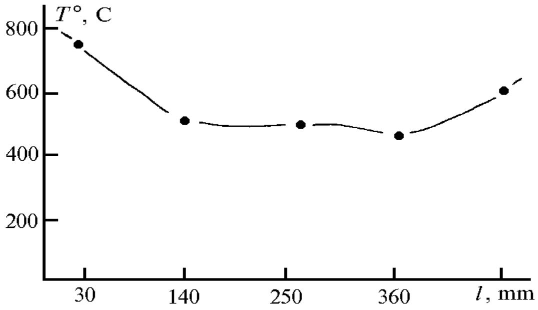

FIG. 3. Temperature field in the Pb-*vapor laser at helium pressure* $p = 4$ Torr.

The data obtained testifies that the fraction of the energy dissipated within the central zone increases with buffer gas pressure increase. This causes the temperature in the near-cathode zone to decrease and that in the central one to increase. Under the conditions of our experiments the factor controlling the temperature field formation varies when the pressure varies in the range from 10 to 50 Torr. Therewith important role of the gas heat conductivity and, correspondingly, increased integral heat conductivity of the gas and heat insulator should be pointed out. This is reflected in smoothening of the temperature distribution. The heat conductivity increase retards, to a certain degree, the temperature rise in the central zone and extends the length of high-temperature zone forming the region with a constant temperature.

The output laser emission power versus buffer gas pressure is shown in Fig. 4. Pumping power was fixed. At a low pressure rapid rise in the output power is evident. Then it comes to some value and begins to fall. From the temperature distribution plots presented it follows that at low pressure a major part of the energy is dissipated within the near-electrode zones with high losses. The average, over the discharge channel, temperature is correspondingly lower and the laser operation occurs just at the threshold. Under these conditions small increase in the temperature and the energy dissipated in the central zone gives rise to a significant rise of the output power. As the pressure reaches optimal value, the extension of the high temperature zone becomes insufficient. Therewith the growth of temperature in the central zone terminates. In otherwords, certain stable regime is formed. Besides, one should take into account other factors influencing the output laser power that are superimposed on the pattern described. Thus, as the pressure increases the power dissipated in the system switch-discharge tube is redistributed and the rise-time of pumping pulse varies. As a result, slow fall off of the output power is observed at a further pressure increase.

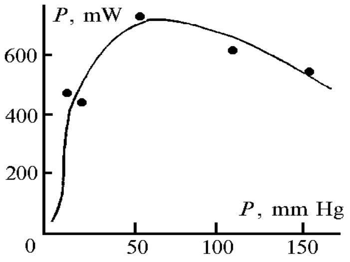

FIG. 4. Laser power versus neon pressure obtained at constant input power (600 W).

Local overheating zones affect the lifetime of the discharge tube. In our experiments high temperature differences are formed within the near-cathode zone when the laser is forced into the operation regime. If the laser is switched on in two steps (preliminary discharge tube heating during 10 min at a halved power, and then operates at a full power) the gradients were reduced by a factor of two. Therewith the time it takes the laser to reach the operation regime increases by no more than 5 min.

In summary, we should like to emphasize that temperature regime of a self-heating laser is non-uniform both when forcing into operation regime and in that regime as well. Considering the peculiarities revealed in our experiments one can design lasers with an improved efficiency and reliability.

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