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EFFECTIVE PULSED COPPER-VAPOR LASER WITH HIGH AVERAGE GENERATION POWER

A.A. Isaev, M.A. Kazaryan, and G.G. Petrash
P.N. Lebedev Physics Institute, USSR Academy of Sciences
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At the present time there are no visible-band lasers with high efficiency and appreciable average generation power. The most widely used lasers for this region of the spectrum (helium-neon and neon) have efficiencies of about 0.1% or worse, and their applications are thus sharply limited. The problem of developing an effective laser for the visible band is therefore very acute.

We present here the results of investigations of a pulsed copper-vapor laser, which have made possible, for the first time, generation in the green and yellow regions of the spectrum with a high average power (15 W) and with a practical efficiency of 1%. Heretofore, copper-vapor lasers delivered an average power of 0.5 W [1, 2]. The efficiency in terms of the discharge was about 1%, but the practical efficiency was apparently much lower, since additional energy was needed to heat the working tube in the oven.

We used in our experiments alundum discharge tubes of volume 35 cm^3 (8 mm diameter and 70 cm length) and 125 cm^3 (15 mm diameter and 70 cm length). The copper was placed in pieces along the entire tube. The pulsed discharge was excited in the tube by discharging a capacitor through a thyratron. Inert buffer gases were used at a pressure of several dozen Torr. The tubes were heated to the working temperature (about 1500°C) without an oven, by the heat released in the discharge. The resonator consisted of a spherical mirror with a multilayer dielectric coating and a flat glass plate. The generation pulses were registered with an FEK-16 coaxial photocell and an I2-7 oscilloscope with a time resolution 0.5 nsec. The average power was measured with a KIM-1 meter.

Under the indicated experimental conditions, generation was observed in both tubes without a noticeable decrease of the peak power, both on the green (5105 Å) and on the yellow line (5782 Å) up to a pulse repetition frequency 20 kHz. Further increase of the frequency was limited by the available power supply. The largest average generation power on both lines in the 35 cm^3 tube was obtained at 18 kHz and amounted to 6 W at an efficiency 0.35%. An increase of the tube volume led to an increase of the power and of the efficiency. The maximum average power in the 125-cm^3 tube reached 15 W and was obtained under two conditions: 1) At a pulse repetition frequency 15 kHz and a capacitor voltage 21 kV. In this case the generation pulse duration was 5 nsec, and the peak power (on both lines, with the green line much stronger) reached its maximum value 200 kW at an efficiency of 0.8%. The specific peak power was 1.6 kW/cm^3. 2) At a pulse repetition frequency 18 kHz and 18 kV on the capacitor. In this case the peak power was 170 kW and the efficiency 1.0%. These efficiency values were calculated in both cases from the ratio of the generation energy to the energy stored in the working capacitor.

The values given here for the average power, the peak power, the specific peak power, and the pulse repetition frequency are at present unprecedented for all pulsed gas lasers operating in the visible region of the spectrum. It should be noted that the specific values given here were calculated by dividing by the full volume of the tube. Owing to the large temperature gradient and the copper vapor density gradient along the tube, the real active volume was smaller, and the local values of the per-unit power and the efficiency, taking everything into consideration, are noticeably higher. We note also that not all the parameters were optimized. This raises hopes of a further considerable improvement of all the characteristics of this layer.

It is therefore of interest to estimate the maximum capabilities of lasers operating on transitions from a resonant to a metastable level in atoms. An increase of the average generation power (or of the cw generation power) is limited in most cases by the heating of the working medium. Raising the temperature is particularly important for high-efficiency lasers whose working levels lie close to the ground levels, so that the equilibrium population increases rapidly with increasing temperature. From this point of view, lasers operating in the visible or ultraviolet region of the spectrum have an advantage, in principle, over lasers operating in the middle infrared region, since their lower level can have an energy higher by about one order of magnitude at the same efficiency. They can therefore operate at much higher temperatures, and therefore can take a much higher pump power. We note also that the rate of heat dissipation increases with temperature.

We have made a comparative estimate of the permissible power input to the active medium without overheating the working gas, for copper- and lead-vapor and for CO_2 lasers. It was assumed that the population of the lower level should on the average be not larger than 1% of the population of the ground level, that the thermal conductivity of the gas is determined by the helium buffer gas and is constant, and that the heat sources are uniformly distributed through the volume of the gas. It was also assumed that the active medium is produced in a cylindrical tube whose wall temperature corresponds to the required pressure of the working gas, and is equal to room temperature in the case of the CO_2 laser. In this approximation, it turns out that the permissible discharge power per unit tube length is independent of the tube diameter, but is determined by the energy of the lower level and by the thermal conductivity of the gas. The results of the estimate are listed in a table containing the wavelength of the working line, the energy E_L of the lower level, the wall temperature T_W, and the limiting discharge power P_{lim} per unit tube length. The last column of the table gives the output generation power from a unit active length, estimated under the assumption that the generation efficiency reaches the value indicated in the parentheses. We see that such an estimate yields for the CO_2 laser an output power of $\sim$100 W/m, which is close to that observed in experiment. The estimated value of the average generation power for lead- and copper-vapor lasers is much higher. This increase is determined by the possibility of operating at a high gas temperature.

The experimental results and the estimates indicate thus that rather large average generation powers at high efficiencies can be obtained with lasers of

Atom	λ, Å	E_L, cm^{-1}	T_w, °K	P_{lim}, W/cm	P_{out}, W/cm (effic.)
Cu	5105	11203	1850	250	25 (10%)
Pb	7229	21458	1300	600	12 (2%)
CO_2	10.6 μ	1390	300	10	1 (10%)

relatively modest dimensions, operating on transitions from a resonant to a metastable level. They are therefore expected to find many scientific and practical applications.

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MOTT TRANSITION IN QUASI-ONE-DIMENSIONAL DISORDERED SYSTEMS

L.N. Bulaevskii, R.B. Lyubovskii, and I.F. Shchegolev
Institute of Chemical Physics, USSR Academy of Sciences; P.N. Lebedev Physics Institute, USSR Academy of Sciences
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The initial conduction band in high-conductivity complexes of tetracyanoquinodimethane (TCNQ) is partly filled, but the temperature dependence of their conductivity has a nonmetallic character (a review of their properties is given in [1]). It was shown in [2] that below ~15°K the electrons in these complexes are in a state of a one-dimensional disordered Mott dielectric (DMD). Owing to the presence of the Mott gap in the spectrum of the electronic excitations, the low-lying states of the system in this temperature region are well described by a Heisenberg Hamiltonian, and the disorder of the lattice leads to random variations of the exchange parameter and to a fractional-power dependence of the susceptibility χ on the temperature T and of the magnetic moment on the field H at $kT \ll g\mu_B H$. The disorder of the lattice is apparently a property inherent in all high-conductivity TCNQ complexes and is connected with the random character of the packing of the asymmetrical cations [3, 4], which leads to the occurrence of a random potential along the conducting chains of the TCNQ molecules. This leads to a random distribution of the electron density on the TCNQ molecules and causes by the same token random variations of the exchange integral.

The DMD state can apparently not exist at temperatures much higher than the Mott gap [5]. The latter can be estimated from data [1, 6] on the temperature dependence of the conductivity σ. At 10 - 15°K the slope of the plots of $\ln \sigma$ against 1/T does not exceed 80°K in high-conductivity TCNQ complexes, so that it can be assumed that these complexes should be, at any rate above this temperature, in a state that can be called the state of a one-dimensional disordered metal (ODM). The nonmetallic character of the $\sigma(T)$ dependence may be connected in this case with the spatial electron localization caused by the disorder of the lattice [1, 6, 7].

A general property of the energy spectrum of the one-dimensional disordered systems is apparently the existence of a singularity in the density of states at the center of the energy band. Such a singularity arises for example in a number of exactly calculated models [8, 9]. For narrow impurity bands, a proof of its existence was given in [10]. It was noted in [2] that in the "metallic" state n the behavior of a complex with a half-filled band, in the presence of such a singularity, should differ qualitatively from the behavior of a complex with a quarter-filled band, for in the former case the Fermi level lies exactly in the center of the band. Strictly speaking, the absence of such a difference at low temperatures was one of the arguments in favor of the DMD state of high-conductivity TCNQ complexes.