LASER RADIATION EMISSION IN Ti^{3+}: Al_2O_3 CRYSTALS PUMPED BY ELECTRON BEAMS

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Lasing of a Ti^{3+}: Al_2O_3 crystal excited by an electron beam with a current density at the crystal surface of from 10 to 500 A/cm^2 and an electron energy of from 200 to 600 keV has been realized. Lasing has been achieved in the range from 0.76 to 0.86 μm, controlled by the dielectric mirrors of the laser cavity. Intense crystal super luminescence is observed in the visible and near-IR spectral regions mainly between 0.6 and 1.02 μm. On the basis of an analysis of the results obtained we foresee the construction of efficient and reliable lasers operating over a wide spectral range, based on Ti^{3+}: Al_2O_3 crystals excited with high-energy electrons. Such lasers can be used to solve a number of atmospheric optics problems.

A promising type of laser for application to problems of atmospheric optics is the laser based on an activated crystal of Ti^{3+}: Al_2O_3, which can be tuned over a wide spectral range.[1] So far, the generating characteristics of this laser have been investigated only for optical excitation.[2–4] The use of other lasers or fast flash-lamps to pump the Ti^{3+}: Al_2O_3 crystal does not provide high total efficiency and makes the construction of the transmitter very complicated, thus decreasing its reliability.

The present article describes the results of an investigation into the possibility of creating a tunable laser based on a Ti^{3+}: Al_2O_3 crystal pumped by a beam of fast electrons. The motivation for such an investigation is the high radiative strength of the Al_2O_3 matrix (Ref. 5), which even increases with its activation by Ti^{3+} ions, and the high energy yield of the cathode luminescence of Ti^{3+}: Al_2O_3.

The investigation was carried out using two experimental devices. The first device involved an electron gun delivering a pulsed (50-ns duration) electron beam of 190-keV energy, providing a current density of about 10 A/cm^2 on the sample, at a pulse repetition rate of up to 5 Hz. A 25-mm long active element made of a Ti^{3+}: Al_2O_3 crystal with an activator concentration of 0.03% by weight was grown by a modified Kiropulos method (the author of this method was V.N. Matrosov). The laser cavity is formed by mirror coatings of the end faces of the active element. The reflectivity of these mirrors reached 0.98% in the spectral range 700 to 900 nm.

A block diagram of the experimental device is presented in Fig. la. The active element is located so that its flat lateral surface is up against the output window of the electron gun made of beryllium foil. The current characteristics of the beam were measured with the Faraday cylinder taking the place of the active element. The spectral characteristics of the crystal emission were recorded with the STE-1 spectroscope on the photographic film or by a photomultiplier and an osci1loscope.

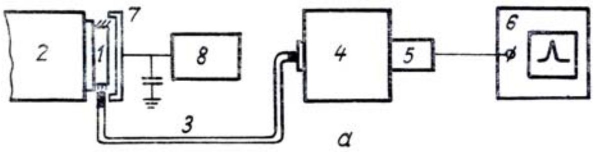

FIG. 1a. Block diagram of the experimental setup: 1) active element; 2) electron beam; 3) optical waveguide; 4) spectral device; 5) PMT; 6) oscilloscope: 7) Faraday cylinder; 8) voltmeter.

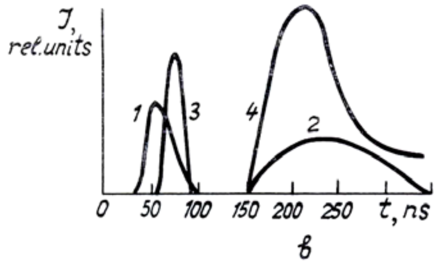

FIG. 1b. Oscillograms of current pulses produced by electron beams with energy 190 (1) and 600 keV (3), and of the corresponding laser radiation pulses (curves 2 and 4).

Upon excitation of the Ti^{3+}: Al_2O_3 crystal by the electron beam, a wide band luminescence in the visible and near infrared ranges was observed. The luminescence spectrum is a superposition of several broad bands. The most intense of them (with maximum at λ_m = 800 nm) has a decay time of about 3.5 μs, and is definitely associated with the Ti^{3+} ions. For an exciting beam current density of about 10 A/cm^2 lasing was observed with the dynamics shown in Fig. 1b (curve 2).

Lasing occurs within 100 to 150 ns after the pumping pulse. Duration of the laser pulse is about 80 ns. The laser pulses are reliably reproduced at a repetition frequency of up to 15 Hz.

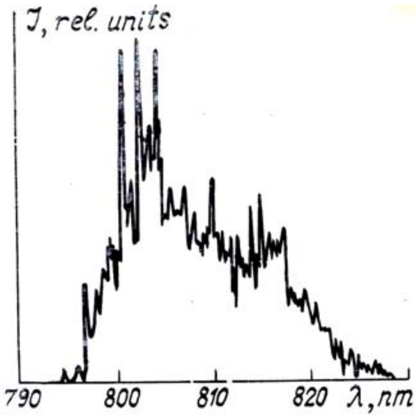

FIG. 2. Spectrum of the Ti^{3+}: Al_2O_3 laser emission at an energy of the pumping electron beam of 190 keV.

A typical spectrum of the laser emission is shown in Fig. 2. The structure of the spectrum can be explained by the interference effects at the mirrors and spatial resonance structures[6] observed in the implemented crystal. The laser beam cross-section had the form of a band with a divergence angle of about 3 mrad along the direction of the pumping electron beam and up to 5° in the perpendicular direction. The angular characteristics of the beam are well explained by the experimental geometry. The temporal, spectral, and spatial characteristics of the radiation confirm the presence of lasing in the Ti^{3+}: Al_2O_3 crystal upon excitation by an electron beam.

A second device was used to investigate the possibility of obtaining laser generation in the external cavity. In this case the electron gun delivered a current pulse of 25-ns duration between half maxima with a density of 150 to 500 A/cm^2 and an electron energy of up to 600 keV (Fig. 1b, curve 3). The experimental arrangement was similar to that described above. The cavity was formed by two mirrors with radii of curvature 300 and 500 mm, with the reflectivity of 0.96 and 0.97% in the spectral range of the expected emission. The mirrors were spaced 330 mm apart. The active element with dimensions 6×6×10 mm consisted of a Ti^{3+}: Al_2O_3 crystal with activator concentration 0.09% by weight. The end surfaces of the crystal were polished to laser accuracy. The emission spectrum was observed using an MDR-12 monochromator.

In the absence of the mirrors or in a detuned cavity the characteristic superluminescence was observed in the spectral range 0.6 to 1.02 μm. The luminescence pulse shape was similar to curve 4 in Fig. 1b. The pulse amplitude increased considerably and the duration of the leading edge reduced by a factor of two, which clearly demonstrated the influence of the cavity. In our experiments on electron beam excitation neither the optical quality of the active elements nor the lasing properties of the Ti^{3+}: Al_2O_3 crystals deteriorated up to a fluence of 10^{17}.

Thus, this study has demonstrated the possibility of obtaining stimulated emission of radiation in the red and near-IR ranges of the spectrum in Ti^{3+}: Al_2O_3 crystals upon excitation by electron beams.

Our estimate of the energetic efficiency of Ti^{3+}: Al_2O_3 lasers with electron beam excitation indicates the possibility of building lasers with efficiencies of 4–8% with respect to the energy stored in the electron beam. Such laser heads can be very useful in lidar sensing of aerosol and gaseous components of the atmosphere.

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