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STIMULATED EMISSION FROM ZINC TELLURIDE SINGLE CRYSTALS EXCITED BY FAST ELECTRONS

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Stimulated radiation at λ = 5330 Å was emitted by ZnTe single crystals excited with fast electrons of 60 and 80 keV energies. The threshold current density was 4 A/cm^2 and the sample temperature 110°K.

THE method of excitation of stimulated recombination radiation by electrons of energies between tens of keV and 1 MeV is nowadays frequently used to investigate various semiconducting compounds. Several investigators [1-4] studied single crystals of the $A^{III}B^{V}$ and $A^{II}B^{VI}$ groups and found that stimulated radiation was emitted by some of these crystals (for example, CdS) only if they were excited by electron bombardment. One such material is zinc telluride, which was investigated by us. Attempts to generate stimulated radiation in ZnTe using other excitation methods[5] have not been successful.

We observed stimulated radiation in an undoped ZnTe single crystal when it was bombarded with fast electrons. We used an electron-beam gun producing a beam of 60 or 80 keV energy. A current density in the beam of 25 A/cm^2 can be attained, and the pulse duration was 0.15 μsec. The investigated single crystals had the following properties (determined by measuring the Hall effect at T = 300°K): electrical resistivity $\rho = 1.8$ Ω-cm; mobility $\mu = 65$ cm^2 V^{-1} sec^{-1}; hole density $p = 5.5 \times 10^{16}$ cm^{-3}. Polished and cleaved resonators of 0.3—0.6 mm dimensions were employed. The investigations were carried out at a temperature of 110°K. The stimulated radiation was observed along a direction perpendicular to one of the faces of the optical resonator. Spectroscopic investigations were carried out using an ISP-51 spectrograph.

The generation was observed to be in the green part of the spectrum at current densities of 3.5—4 A/cm^2. The features of the generation were strong directivity of the radiation, narrowing of the emission spectrum, and appearance of a mode structure in the spectrum. The generation threshold was determined from the dependence of the radiation intensity on the density of the exciting beam (Fig. 1).

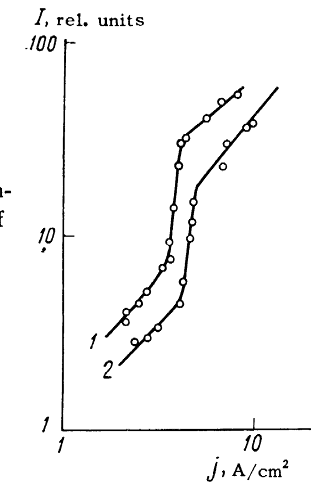

FIG. 1. Dependence of the intensity of radiation I on the density of the excitation current for two samples of ZnTe.

For currents above the threshold value the recombination radiation spectrum narrowed from ≈ 80 Å to ≈ 20 Å, the maximum shifted markedly toward short wavelengths, and the intensity increased. It can be seen from Fig. 2 that a current slightly above the threshold value for a given sample caused the characteristic appearance of a mode on the long-wavelength side, which indicated that the generation conditions were easier at longer wavelengths. When the current was increased, the generation maximum first shifted rapidly toward short wavelengths and then slowly toward long wavelengths, because of heating of the crystal. In some cases, an increase of the current produced an additional generation maximum, which was shifted by about 60 Å toward long wavelengths. The absence of a mode structure in this case was obviously due to a large number of nonaxial oscillation modes, so that the modes almost completely filled the whole generated line profile and are not resolved by the instrument used. Moreover, instability of the mode pattern smeared out the mode structure during exposure. A bright narrow horizontal band was observed in the far field and this

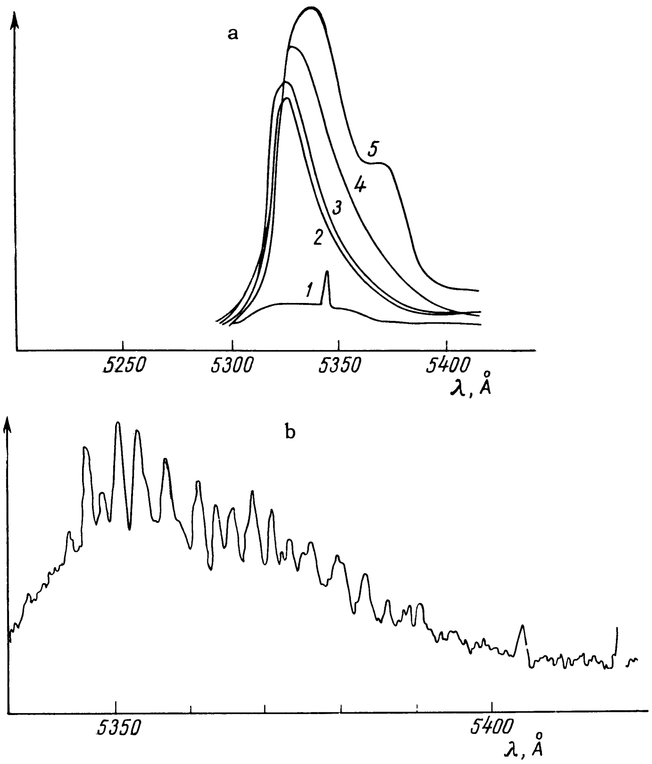

FIG. 2. Stimulated radiation spectrum of ZnTe single crystals. a) Dependence on the excitation current density (sample 1): 1) J = 6 A/cm²; 2) j = 10 A/cm²; 3) j = A/cm²; 4) j = 14 A/cm²; 5) j = 16 A/cm². b) Mode structure of the radiation of ZnTe at a current density of 25 A/cm² (sample 2).

band corresponded to emission angles of ≈ 8° in the vertical plane (the electron beam plane) and ≈ 30° in the horizontal plane.

In some resonators the far-field radiation exhibited an interference pattern of axial modes in the form of a regular system of vertical and horizontal bands indicating spatial coherence of the radiation. In this case the spectrograph recorded a clear mode pattern, consisting of a series of equidistant lines (Fig. 2b). The mode separation was 2.4 Å on the short-wavelength side and 2.8 Å on the long-wavelength side of the band, which was in agreement with the values calculated on the assumption that the dispersion term was positive and equal to, respectively, 3.6×10^{-4} $(\text{Å})^{-1}$ and 4×10^{-4} $(\text{Å})^{-1}$. Thus the generation was observed in the anomalous dispersion region, i.e., in the region of an absorption band. The spontaneous recombination radiation of ZnTe was not polarized, while the stimulated radiation was completely polarized in the horizontal plane. The wavelengths of the stimulated and spontaneous radiations varied from sample to sample in the range 5325–5360 Å, which was probably due to different stresses and orientations of the crystals.

When the pulse repetition frequency was increased from 10 cps to 3 kc, the wavelength and intensity of the radiation were not affected greatly, which indicated that the crystal did not become hot. The shape of the spontaneous radiation pulse was the same as that of the current pulse, but in the case of stimulated radiation the emitted pulse became much shorter, which has been observed before [3] and ascribed to heating of the crystal.

To determine the mechanism of recombination radiation of ZnTe, we recorded the luminescence and absorption spectra. We attempted to determine approximately the forbidden band width from the absorption edge of the investigated samples. The value of ΔE_g, determined in this way at 77°K, was approximately 2.33 eV, which was in good agreement with the published values.[6] Changes in the spontaneous radiation spectra of ZnTe with increase of the exciting current density are shown in Fig. 3 (the radiation was observed on the bombarded side). The short-wavelength maximum (which disappeared when the current was increased further) was at 5280 Å, which was close to the exciton energy [6,7] at T = 110°K (assuming that the temperature shift of the forbidden band width was linear and equal to 4.5×10^{-4} eV/deg). The stimulated radiation maximum coincided with the second maximum of the spontaneous luminescence. The separation between the two luminescence peaks (0.027 eV) was close to the energy of longitudinal optical phonons in ZnTe.[6,7] The second stimulated radiation peak, which appeared at higher current densities, was separated (as already mentioned) from the first peak also by about 0.027 eV. Thus, by analogy with CdS, we may

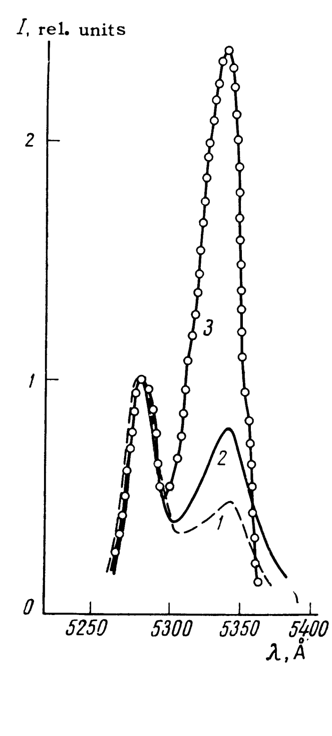

FIG. 3. Spontaneous luminescence spectrum of ZnTe at low current densities $J_1 < j_2 < j_3$ = 0.5 A/cm².

assume that the stimulated recombination radiation mechanism in ZnTe is the annihilation of an exciton accompanied by the generation of one or more phonons.

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55