COHERENT MICROWAVE RADIATION OF n-InSb

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In numerous investigations of the microwave radiation of indium antimonide (see, e.g., [1, 2], the observed radiation had a continuous spectrum of the noise type. In electric fields E > 50 V/cm, radiation close to coherent was obtained to date only by Robinson and Swartz, who used special p-InSb crystals on the side faces of which were cut transverse grooves 10 - 25 μ wide and 10 - 15 μ deep [3, 4]. The authors of [3, 4] relate the mechanism of this radiation to the instability of thin layer of a two-component collision plasma in crossed electric and magnetic fields.

We report here observation of coherent microwave emission of n-InSb crystals, on the free side surface of which there were no noticeable inhomogeneities. The investigation was carried out in the temperature interval 77 - 100°K.

The microwave radiation was induced in the frequency band 1.5 - 5 GHz with the aid of a broadband direct-amplification receiver using traveling wave tubes. The radiation spectrum was analyzed with a tunable resonant filter having a bandwidth 10 - 15 MHz and a type P5-7 superheterodyne receiver with an IF band of 5 MHz.

The sample was placed in a break of the internal conductor of a coaxial cable with a wave resistance 50 ohm, placed between the poles of an electromagnet in such a way that the current through the sample was always perpendicular to the magnetic field.

Pulses of the voltage U (or current I) of duration 0.2 - 10 μsec were fed to the crystal from a source having an internal resistance 2.2 kilohm. The current through the crystal with resistance 0.8 - 4 kilohm was determined from the voltage drop across a series-connected 100-ohm resistor.

The coherent microwave radiation was observed from compensated InSb crystals with relatively low concentration ($n = 0.8 \times 10^{13}$ cm^{-3}) and mobility ($\mu = 1.17 \times 10^{5}$ cm^{2}/V-sec at T = 77°K) of the electrons. The crystal length L was about 4 mm, and the cross section varied from 0.69 x 1.08 to 0.85 x 0.34 mm. All crystal faces were polished. The absence of surface roughness and of scratches deeper than 0.5 μ was specially checked. The contacts on the end faces were produced with indium and a neutral flux.

A characteristic feature of the described samples are the relatively high values of the contact resistances for one or both contacts, exceeding by 1.5 - 3 times the volume resistance of the crystal. With increasing amplitude of the supply pulse, the impedance of the sammple decreases more or less sharply (depending on the state of the contacts and on the polarity of the pulse); the sharper this decrease, the earlier does the coherent radiation arise. The process of establishment of the new value of the resistance lasts $\tau \approx 0.3 - 1.5$ μsec, and accelerates with increasing applied voltage. Corresponding to this are characteristic forms of the current and voltage pulses, and also superlinear current-voltage characteristics of the samples (Figs. 1a and 1b).

The radiation occurs at one or several frequencies in the indicated band, starting with

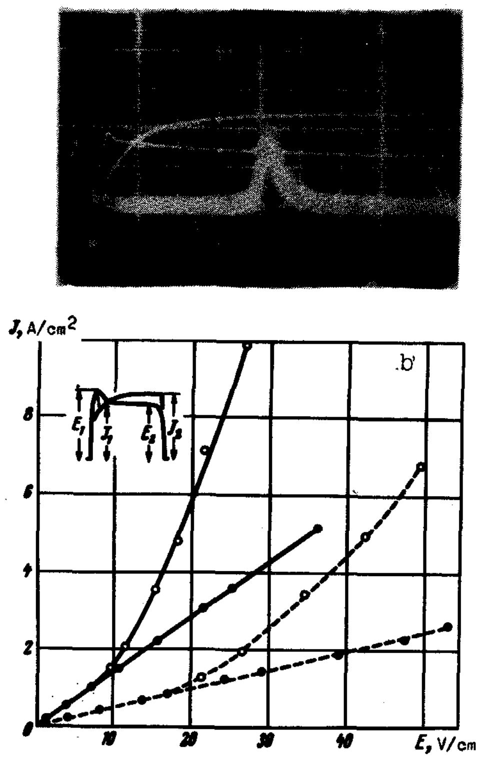

Fig. 1. a) Oscillograms of voltage (1), current (2) and envelope of microwave pulse (3). b) Current-voltage characteristics of sample No. 8. Solid lines - H = 0, dashed - H = 2.3 kOe; ● - $J_1(E_1)$, o - $J_2(E_2)$.

certain (threshold) values of the magnetic field intensity $H = H_{thr}$ and current density $J = J_{thr}(H)$ or average electric field intensity $E = U/L$, the ranges of which for the investigated samples are $H_{thr} \approx 1100 - 5000$ Oe, $J_{thr} \approx 3 - 10$ A/cm^2, and $E_{thr} \approx 50 - 150$ V/cm. With increasing current, the radiation spectrum gradually broadens and assumes the usual noise-like character.

A study of the spectrum of the coherent radiation along the pulse as a function of the amplitude of the latter has shown that the value of the radiation frequency $f(\Delta t)$ at an instant Δt after the start of the pulse is determined mainly by the values of H, J, and Δt and is not connected directly with the mean value of the electric field in the sample $E = U/L$.

Figure 1a shows an oscillogram of the current and voltage pulses, and also of the envelope of the microwave radiation passing through a narrow-band filter. An increase of the current at a fixed setting of the filter (i.e., at a fixed radiation frequency) is accompanied by a shift of the

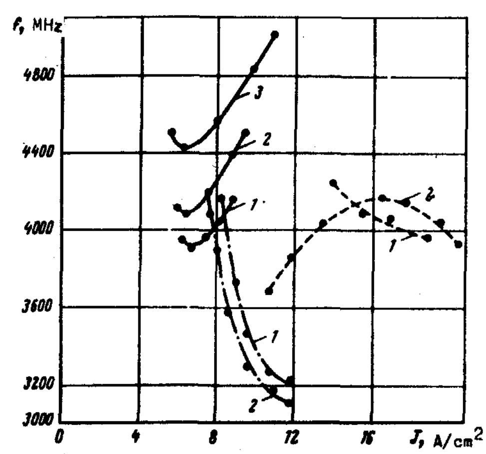

Fig. 2. Radiation frequency f vs. current density J. Dashed lines - sample No. 6 (4.0 x 0.65 x 0.46 mm), H = 4200 Oe (1) and 4900 Oe (2). Dash-dot lines - sample No. 8 (4.2 x 0.75 x 0.43 mm), Δt = 1 μsec (1) and 2 μsec (2). Solid lines - sample No. 5 (4.2 x 1.02 x 0.69 mm), H = 1525 Oe (1), 1925 Oe (2), and 2100 Oe (3).

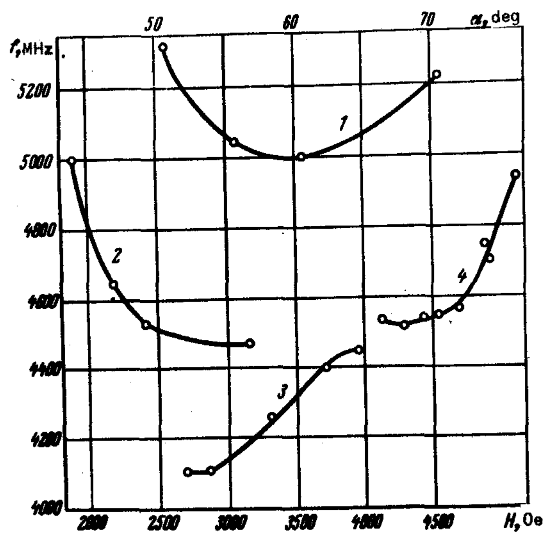

Fig. 3. Radiation frequency f vs. azimuthal angle α for sample No. 8 (1) and vs. the transverse magnetic field H for samples 8 (2), 5 (3), and 6 (4).

"spike" of microwave radiation along the pulse, so that the value of the current J at the instant of appearance of the "spike" remains practically constant, while the field changes noticeably.

The dependences of the radiation frequency f on the indicated parameters are fully regular and are well reproducible. The frequency of the coherent oscillations decreases in most cases with increasing interval Δt, and can either increase or decrease with increasing current. The slope of the f(J) curve can vary with H, changing from negative to positive with increasing H (Fig. 2).

The f(H) dependence can also be either increasing or decreasing (Fig. 3). The rate at which the frequency changes can vary over a wide range, reaching 700 MHz/mA and 1 MHz/Oe. The coherent radiation is critical to the orientation of the sample in the transverse magnetic field, and is observed as a rule in narrow angle intervals ($\Delta\alpha \approx 10 - 15^\circ$) near the largest values of the magnetoresistance. The $f(\alpha)$ dependence for H = const (Fig. 3) is determined by the variation of the H component normal to the broad face of the sample with changing α.

The mechanism of the described phenomena is not yet clear. It can be supposed that it is connected with the instability of the magnetoactive electron-hole plasma produced near one of the contacts as a result of hole injection or impact ionization. The time of establishment of the stationary crystal resistance is 0.3 - 1.5 μsec (see Fig. 1a) and is apparently determined by the rate of filling of the near-contact section, which has an increased resistance, with plasma. The plasma concentration in this section may greatly exceed the electron concentration ($n_0 = 10^{13}$ cm^{-3}) in the volume of the crystal, and can reach values $p \approx n \geq 3 \times 10^{15}$ cm^{-3}, which are sufficient to produce two-stream instability in InSb [4]. The theory developed for this case in [4], however, does not explain the experimental dependences even qualitatively. The question of the nature of coherent radiation from InSb calls therefore for further study.

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FINE STRUCTURE OF RAYLEIGH LINE IN SAPPHIRE CRYSTAL

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We present here results of an investigation of the fine structure of the Rayleigh scattering line in a synthetic sapphire crystal.

The scattering excitation source was the 4880 Å line of the Ar^+ laser whose construction was described in [1]. The investigated sample of sapphire crystal of high optical quality[1)] was cut, as shown in Fig. 1, in the form of a hexagonal prism. The optical axis of the crystal

1) The crystal was grown at the Crystallography Institute and kindly placed by Kh. S. Bagdasarov at I. L. Fabelinskii's disposal. The authors are grateful to Kh. S. Bagdasarov for the opportunity of working with a first-class crystal.