High-frequency instability of recombination radiation in strong electric fields

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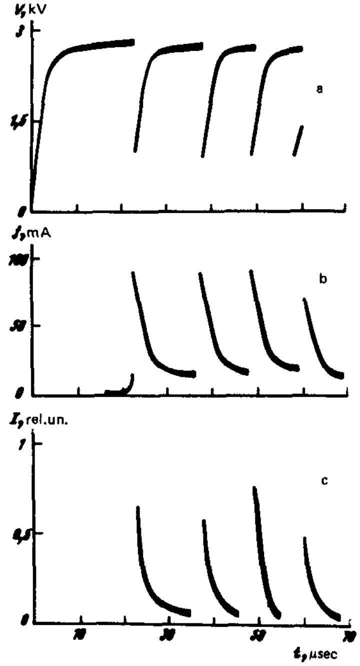
We describe a new effect of high-frequency instability of the intensity of recombination radiation, observed in strong electric fields under conditions of current instability. The effect was registered in symmetrical In-GaAs(Cr)-In structures with S-shaped current-voltage characteristics (CVC) at 77 °K.

We have recently reported an effect of high-voltage switching in such structures, accompanied by a short-duration ($\sim 10^{-7}$ sec) pulse of intrinsic recombination radiation at the instant of switching.[1] A stable state of the system, with S-shaped CVC was obtained by formation of a thermal current pinch. In structures in which no pinching takes place, oscillations of the current and of the voltage across the section occur, in the region of negative resistance (NR). An instability of the recombination-radiation intensity is observed at the same time.

We investigated diode structure of semi-insulating GaAs compensated with chromium, having a resistivity $\sim 10^8$ Ω-cm at 300 °K, with indium contacts fused-in at 350 °C in vacuum. The length of the high-resistance base was ~ 100 μ, and the contact area was $\sim 10^{-2}$ cm^2. The investigations were carried out by applying on the diode a voltage pulse of 100—3000 V with duration 100—120 μsec.

With a voltage on the order of 3000 V across the structure, corresponding to an average field $\sim 3\times 10^5$ V/cm, nearly-periodic oscillations of the current and of the recombination radiation set in, with a frequency on the order of 10^5 Hz. The figure shows oscillograms of the voltage across the structure (a), of the current (b), and of the radiation intensity (c) under instability conditions. The depth of the voltage modulation is ~50% and the modulation amplitude is 1500 V. The amplitude of the current oscillation reaches 100 mA. The frequency of the observed oscillations does not depend on the resistance of the external circuit. As seen from the figure, the current and voltage pulses are in counterphase; the maximum current is observed at the instant when the structure voltage is minimal. The radiation pulses are in phase with the current pulses. The leading and trailing edges of all the indicated pulses differ strongly: the rise time of the current and of the radiation intensity coincides with the fall-off time of the voltage and turns out to be less than 10^{-7} sec. The current fall-off curve is described by two exponentials with time constants $\tau_1 = 2.7\times 10^{-6}$ sec and $\tau_2 = 2.3\times 10^{-5}$ sec. The growth kinetics of the voltage across the structure is characterized by the same two times. The radiation-intensity attenuation curve is close to a hyperbola. The maximum of the radiation spectrum is observed at energies $h\nu = 1.5$ eV, corresponding to interband carrier recombination in the GaAs.

The independence of the oscillation frequency and of the current-pulse fall-off time of the resistance of the external circuit indicates that the observed oscillations are connected with physical processes that occur in the



a) Oscillogram of oscillations of voltage on the structure, b) oscillograms of current oscillations, c) oscillograms of recombination-radiation oscillations.

crystal. The following instability mechanism can be proposed:

The high-voltage switching in symmetrical In—GaAs(Cr)—In structures is connected with the breakdown of the high-voltage base in the region of the strengthened field and with the modulation of the base resistance by the field-generated carriers.[1] The resistance modulation may be due either to the τ_p mechanism[2-6] or to the "captured plasma" mechanism.[7] In the switched state, the base of the structure is filled with free carriers, and this leads to a drop in the voltage across it and to a vanishing of the region of cascade multiplication. The existence of an electron-hole plasma in switching is evidenced by the recombination radition observed in this state. The recombination of the nonequilibrium carriers leads to a vanishing of the plasma. The system relaxes to an equilibrium state and the base resistance increases. The conditions necessary for the realization of the local breakdown are then again produced. A region of cascade multiplication is thus produced periodically in the crystal, and the base resistance is periodically modulated. Instability of the current and of the radiation is observed. With such a mechanism, the oscillation frequency is determined by the time of restoration of the high-resistance state, i.e., by the lifetime of the nonequilibrium electrons.

The asymmetry of the observed current pulses is connected with the fact that the growth time of the current pulse is determined by the rate of modulation of the base resistance, and the fall-off time is determined by the rate of recombination of the nonequilibrium carriers. The relaxation curves of the photoconductivity under intrinsic excitation were compared with the current-pulse fall-off curves for one and the same crystal. Both curves are described by two exponentials with identical time constants ($\tau_1 = 2.7 \times 10^{-6}$ sec and $\tau_2 = 2.3 \times 10^{-5}$ sec), thus offering evidence in favor of the discussed mechanism. The new type of the radiation instability differs in principle from the previously observed low-frequency photoluminescence instability[8] that takes place upon carrier photogeneration, from the slow motion of glowing regions in crystals in strong electric fields, as observed in[9], and also from radiation instability, connected with emergence of an electroacoustic domain.[10]

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