Stratification of electron-hole plasma and blue electroluminescence near a static domain of GaAs

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Experiments have been carried out on *n*-GaAs films in which a static domain forms near the anode, while at the same time a Gunn domain forms and travels away from the cathode. The electron-hole plasma which is produced homogeneously by a traveling domain becomes striated near the static domain, where a highly inhomogeneous short-wave emission is observed. Included in this emission are bright blue points ~ 1–2 μm in size, spaced ~ 4 μm apart.

1. As electrons are heated in GaAs in an electric field, a traveling Gunn domain forms. The field in this domain increases with increasing concentration of equilibrium electrons,[1] n_0. At high values of n_0, an intense interband impact ionization occurs in the domain, with the result that the sample becomes filled essentially homogeneously with an electron-hole plasma.[1] In this letter we report a study of high-quality GaAs films of various thicknesses w with $n_0 \simeq 2\times10^{17}$ cm^{-3}, grown on a semi-insulating GaAs substrate (Fig. 1). The experiments are carried out at a crystal temperature $T_0 \approx 300$ K. In "thick" films, with $w > 0.5$ μm, and at voltages $U > 11$ V, a traveling Gunn domain arises at a frequency $f \approx 3\times10^9$ Hz, which gives rise to an essentially homogeneously distributed electron-hole plasma. The presence of this plasma and its distribution along the sample are determined through a study of the luminescence with a spatial resolution of 1 μm with a cooled FÉU-79 photomultiplier. We observe an edge emission with a broad spectrum, whose intensity is distributed essentially uniformly along the sample. More precisely, the emission is homogeneous along the y axis (Fig. 1) and increases slightly (by a factor no greater than two) from the cathode toward the anode as a result of an increase in the amplitude of the Gunn domain which is nucleated near the cathode. In a thin film, with $w < 0.3$ μm, it is a static domain, rather than a traveling domain, which forms, as expected.[2] No radiative recombination is observed in these films at voltages up to that ($U \simeq 25$ V) at which avalanche breakdown occurs near the anode.

2. In films of intermediate thickness (0.3 μm $< w <$ 0.5 μm), a static domain forms near the anode, and a traveling domain is generated periodically, at a frequency $f \simeq 3\times10^9$ Hz, from the cathode side.[3] The formation at $U > 11$ V of a traveling domain causes the abrupt appearance in the static domain of local regions of a hot electroluminescence, with a size $l \approx 1$ μm, separated from each other by a distance $L \approx 4$ μm. These regions are observed under a ordinary microscope as brightly glowing bright-blue points. A study of this luminescence shows that the emission is distributed uniformly along the y axis, perpendicular to the

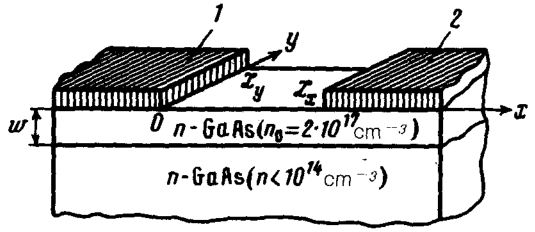

FIG. 1. Structure of the samples. 1—anode; 2—cathode ($\mathscr{L}_x = 25$ μm; $\mathscr{L}_y = 15$ μm).

current lines, outside the static domain, while in the domain there are sharply defined peaks (Fig. 2). The distribution of the integrated intensity of the emission is qualitatively the same as the distribution of the short-wave (blue) light which is observed through a bandpass filter with a transparency band of 0.46–0.48 μm.

These experimental results show that the electron-hole plasma which is produced by the traveling domain becomes stratified into hot blobs as it is heated in the vicinity of the static domain. The short-wave emission in the blobs corresponds to a recombination of holes with hot electrons from the upper valley of the GaAs. To confirm these conclusions, we studied films in which an additional narrow electrode (2 μm wide) in the form of a Schottky barrier was fabricated in addition to the anode and cathode antiblocking contacts. This narrow electrode was placed 3 μm from the cathode. The picture of a stratifying electron-hole plasma observed earlier does not change when a negative bias voltage up to $U_3 = U_{\rm cr} \approx 4$ V is applied to this electrode. At $U_3 > U_{\rm cr}$ we observe a threshold effect: The Gunn generation vanishes; i.e., the traveling domain disappears. At the same time, there is an abrupt disappearance of the luminescence, including that in the form of blue points in the vicinity of the static domain near the anode. This result proves unambiguously that at $U < 25$ V there is no impact ionization in the static domain, and the source of the electron-hole plasma is the impact ionization of carriers in the traveling domain. At $U_3 > U_{\rm cr}$, brightly glowing blobs appear in the static domain only when the voltage across the structure is $U > U_s \simeq 25$ V, as a result of the impact ionization of carriers near the anode. The picture of the

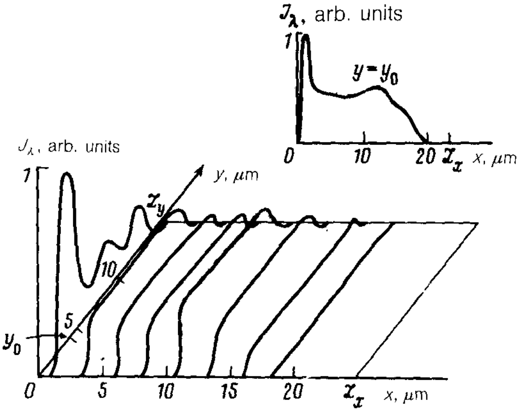

FIG. 2. Distribution of the emission of the electron-hole plasma, $J_\lambda(x,y)$, along the area of the film for $U = 11.5$ V, $\mathscr{L}_x = 25$ μm, $\mathscr{L}_y = 15$ μm, and $w = 0.35$ μm. The coordinate axes correlate with those shown in Fig. 1. The inset at the top shows the emission distribution $J_\lambda(x)$ in the cross section $y_0 = 4$ μm.

stratification of the electron-hole plasma here is similar to that which has been observed previously[4] in thin GaAs films, with a thickness $w = 0.25\ \mu m$.

3. It follows from an analysis of the current-voltage characteristic and the emission intensity that the average density of the electron-hole plasma is $n \gtrsim 10^{18}$ cm^{-3}; according to estimates, the carrier mobility is determined by electron-hole scattering. The picture of the stratification of the electron-hole plasma which is observed in the luminescence (Fig. 2) can be explained by the theory of Ref. 5, where it was shown that a dense electron-hole plasma stratifies in the direction perpendicular to the current lines under the condition $L \gg l$,

$$3/2 + s > 0, \tag{1}$$

and that its effective temperature is $T > T_0(5+2s)(3+2s)^{-1}$. Here $s = \partial \ln \tau_\epsilon / \partial \ln T$; and τ_ϵ, l, and L are the energy relaxation time, and cooling length, and the diffusion length of the hot carriers.

Outside the static domain, the electrons are in the lower Γ valley of GaAs, and as the electric field is increased, they undergo transitions to higher-lying X and L valleys. Consequently, the value of τ_e of these electrons is a sharply decreasing function of the energy, and for them condition (1) does not hold. The situation is different when the electrons are heated in the static domain. In it the electric field is $E > 10$ kV/cm, and most of the electrons are in the highest valley. Their kinetic energy is dissipated in an interaction with optical phonons and in transitions between equivalent valleys. For these energy-dissipation mechanisms, if there is a decrease at all in τ_e with increasing T, the decrease is apparently not faster than $T^{-1/2}$; i.e., for the hot electrons in the upper valley, condition (1) does hold. For this reason, the essentially uniform distribution of the electron-hole plasma outside the domain is stable, and in the region of the static domain the electron-hole plasma stratifies in the direction perpendicular to the current lines. According to the theory of Ref. 5, the distance between the maxima in the $T(y)$ distribution in the electron-hole plasma (Fig. 2) is on the order of L, which in GaAs with $n \simeq 10^{18}$ cm^{-3} is a few microns. At $T_0 \simeq 300$ K, we have $L \gg l$. The numerical studies of the problem considered in Ref. 5 show that the maximum carrier temperatures $T_{\max}$ in the stratification of an electron-hole plasma may be bounded by an intervalley impact ionization. Despite the fact that $T_{\max}$ in the layer is above 10^3 K, the carrier density falls off by only 20–30% from the average density of the electrons in the upper valley of the GaAs. These results explain the appearance of local regions of a bright-blue emission in the region of the static domain of n-GaAs. In the films studied in Section 2, the traveling domain appeared at $U \simeq 11$ V, when the width of the static domain was ~ 3–$4\ \mu m$. The distance between the peaks formed upon this stratification was also $\sim 4\ \mu m$. Consequently, upon the stratification of the electron-hole plasma, one can observe under an ordinary microscope bright-blue regions in the form of points near the anode, where the static domain is located.

4. A traveling domain of a strong electric field plays the role of only a source of an electron-hole plasma along the entire length of the n-GaAs film in these experiments (Section 2), and this comment applies to the region of the static domain also. The results here suggest that during the photoproduction or injection (from an auxiliary contact) of holes in films with a thickness $w < 0.3\ \mu\text{m}$, in which only a static domain forms, one can also observe a stratification of the electron-hole plasma and the appearance of local regions of a blue electroluminescence.

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