Oscillations of the electron mobility in the channel of a GaAs field-effect transistor

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Oscillations have been found in plots of the conductivity of the channel in a field-effect transistor versus the voltage on the Schottky gate and versus the substrate voltage at $T < 15$ K. The gate-channel capacitance does not oscillate as the gate voltage is varied. The oscillations are attributed to fluctuations of the hopping conductivity of a sample of small dimensions.

In this letter we report a study of the conductivity of the electron channel formed in an epitaxial GaAs layer ($N_d \sim 10^{17}$ cm^{-3}) by potential walls: a Schottky barrier and a $\mathrm{Ga_{0.8}Al_{0.2}As}$ insulating layer. The GaAlAs-GaAs structure (Fig. 1) is grown on a conducting substrate by a method of epitaxy from metal-organic compounds.[1] The dimensions of the aluminum gate (2 μm long and 200 μm wide) determine the dimensions of the channel. For the particular structure which we studied, with a thin ($\sim$0.3-μm) GaAsAs insulating layer, it is possible to adjust the position of the channel in the GaAs layer and to adjust the number of electrons in the channel by varying the gate and substrate potentials. In the case of a thin conducting channel ($t \lesssim 400$ Å), at temperatures in the interval 1.5–15 K, we find oscillations on the plots of $G(V_g)$ and $dG/dV_g(V_g)$ (G is the conductivity of the channel, and V_g is the voltage on the

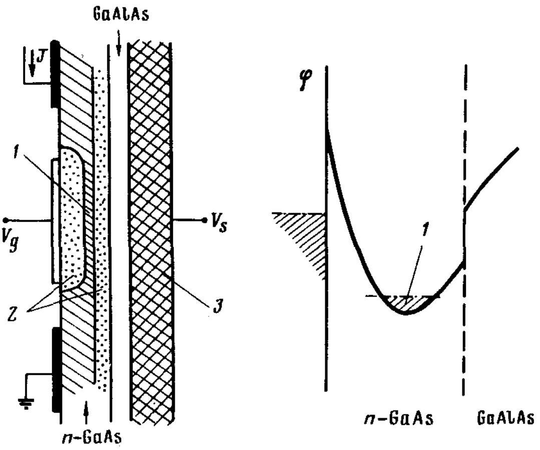

FIG. 1. The device and its energy diagram. 1—Channel; 2—space-charge region; 3—substrate. The thickness of the *n*-GaAs layer is ~3000 Å.

gate with respect to the channel). These oscillations die out as the temperature is raised or as the external field is raised ($E \gtrsim 5$ V/cm; Fig. 2).

Oscillations of the conductivity of GaAs field-effect transistor as the voltage on the Schottky gate was varied were first observed by Pepper *et al.*,[2] who suggested that the oscillations were a consequence of the formation of a 2*D* Wigner crystal in an impurity band of the semiconductor. Chenskiĭ and Tkach[3] showed that Wigner crystallization could not lead to multiple oscillations of the conductivity, and in an effort to explain the effect they offered a model of a nonequilibrium Wigner lattice which undergoes changes through the formation of superlattices as the number of electrons changes. It has been pointed out that during crystallization a structural feature in the conductivity should be accompanied by a structural feature in the gate-channel capacitance.[4]

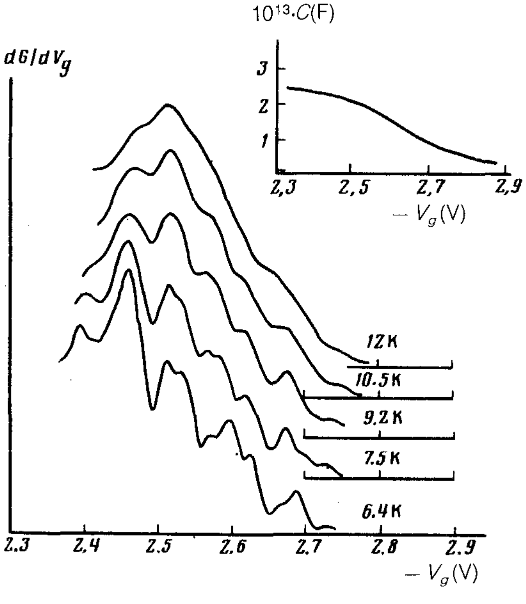

FIG. 2. The dependence $dG/dV_g(V_g)$ for the channel at various temperatures (the curves have been displaced along the Y axis). The inset shows the capacitance of the Schottky layer versus the gate voltage.

In the present letter we report a study which shows that conductivity oscillations in the structure studied are of an equilibrium nature (variation of the rate at which V_g is swept over the range 3×10^{-2}–10^2 mV/s and a reversal of the sweep direction have no effect on the oscillations). In addition to measuring the conductivity of the channel at frequencies from $f=10$ Hz to 100 kHz, we measured the differential capacitance of the Schottky layer, $C(V_g)$ ($f=10$–100 kHz); we found no deviation from a monotonic behavior. The results therefore do not agree with the correlation model.[3]

Since the conductivity is $G=eN\mu/L^2$ (L is the length of the channel, N is the total number of electrons in the channel, and μ is the electron mobility) and the measured capacitance is $C=edN/dV_g$, when there are oscillations in the number of particles, the structural features in $dG/dV_g(V_g)$ and $C(V_g)$ would be comparable in relative amplitude, in contradiction of experiment. It can therefore be concluded that the conductivity oscillations stem from oscillations of the electron mobility. Measurements of the functional dependence $C(V_g)$ make it possible to directly determine the number of electrons in the channel at various gate voltages

$$N(V_g) = -\frac{1}{e}\int_{V_T}^{V_g} C(V_g)\,dV_g$$

(V_T is the threshold voltage), and also the effective mobility. In the sample studied, the mobility μ was ~500 cm^2/(V·s) for $V_g=0$ to $T=4.2$ K; it decreased two or three orders of magnitude as the thickness of the channel was reduced.

We observed oscillations of the conductivity not only upon a change in the voltage on the Schottky gate, V_g, but also upon a change in the voltage on the substrate, V_s, at a fixed V_g. The typical oscillation period ΔV_s is several times the typical period ΔV_g, in accordance with the lower substrate-channel capacitance. The implication is that the conductivity oscillations are related to a change in the number of electrons in the channel. Further evidence that the number of particles plays a governing role comes from the fact that as the substrate temperature is raised the position of the oscillations in V_g remains essentially the same (corresponding to a constant number of particles in the channel), although the conductivity of the channel increases by an order of magnitude here.

In the structure studied, we were able to displace the channel a distance ~1000 Å along the thickness of the GaAs layer by varying the voltage on the substrate. In this manner we were able to change the realization of the random potential and the positions of the impurities in the channel. For the displaced channels we did not observe a substantial difference in the typical amplitude and typical period of the oscillations in $dG/dV_g(V_g)$ (Fig. 3). If we focus on an individual structural feature, however, we find that its shape and amplitude change radically as the channel is displaced $\Delta t\sim100$ Å.

The temperature dependence of the channel conductivity at values of T and N at which the oscillations typically are present reveals that an activation energy $\epsilon\simeq2$ meV is involved. As the thickness of the channel is reduced (as the number of electrons, N, is reduced), a metal-insulator transition thus occurs in the system, and the conductivity is of a hopping nature. It may thus be possible to explain the oscillations with the help of a model which deals with fluctuations of the conductivity upon a change in the

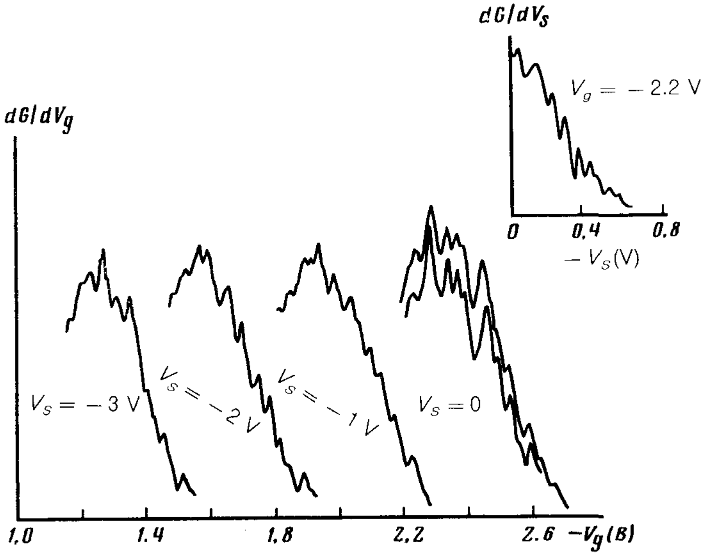

FIG. 3. Oscillations in $dG/dV_g(V_g)$ for various channels displaced along the depth in the GaAs layer (the curve for $V_s = 0$, shifted along the Y axis, was obtained at the end of the cycle of measurements). The inset shows the oscillations in dG/dV_s versus the substrate voltage V_s.

number of particles in a sample of small dimensions with a hopping conductivity. Lee[5] has demonstrated that fluctuations of this sort are possible for a $1D$ structure with a hopping conductivity and a variable hopping length.

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