CONDUCTANCE FLUCTUATIONS IN ULTRA-SHORT-CHANNEL Si MOSFETs

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Conductance fluctuations with gate voltage near threshold are observed at temperatures up to 10 K in metal-oxide-semiconductor field-effect transistors (MOSFETs) with wide (44 μm) but short (≤0.15 μm) channels. The reproducible variations are consistent with the universal conductance fluctuations predicted by Lee and Stone.

LEE AND STONE [1] have predicted that all disordered conductors will display universal fluctuations in their conductance from one sample to another, one value of the Fermi energy to another or one value of magnetic field to another. At zero temperature, the fluctuations are predicted to be of order e²/h, independent of the size, shape or composition of the conductor.

The universal fluctuations have been observed in metal wires and rings [2] and in GaAs quantum-wells [3] and Si MOSFETs [4] that are long and narrow. The full e²/h magnitude of the fluctuations is only seen if the length L and the width W of a two-dimensional sample are short compared to the inelastic diffusion length L_in, that is, when the conductance experiment is equivalent to a measurement of the transmission of electrons through the disordered sample. For samples with L and W larger than L_in the fluctuations are predicted to be the incoherent superposition of the fluctuations from the sub-channels with dimensions L_in. Of course, these blocks add differently in series and parallel. The resulting prediction for the fluctuations is

\[ \Delta G = \frac{e^2}{h} \left( \frac{W}{L_{in}} \right)^{1/2} \left( \frac{L}{L_{in}} \right)^{1/2} \] (1)

This prediction was tested in elegant experiments by Skocpol et al. [5] using multiprobe Si MOSFETs fabricated using electron-beam lithography. Relying on the empirical relation

\[ L_{in} = 15G \frac{h}{e} T^{-1/2} \] (2)

where G is the conductance per square and with T in K and L_in in nm, they found that equation (1) predicts the magnitude of the fluctuations for devices with widths in the range 40 nm ≤ W ≤ 200 nm and lengths in the range 150 nm ≤ L ≤ 705 nm.

In an effort to study short-channel devices, we have fabricated MOSFETs that are short and wide. However, these devices also show fluctuations of the conductance consistent with the predictions of Lee and Stone [1].

N-channel MOSFETs with channel lengths ranging from 60 nm to 5 μm and widths of 44 μm were fabricated on a single (100) Si substrate. The fabrication technique, described previously, involves a combination of X-ray and optical lithographies [6, 7]. The channel length was determined by comparing the electrical properties of devices with various lengths [7, 8].

A rough estimate of the length was also obtained from Shubnikov–de Haas oscillations [9]. The MOSFETs have a 10 nm thick gate oxide and a channel doping of B at 5 × 10^{17} cm^{-3}. The electron mobility in the channel is 330 cm²/V·s at 300 K and 2200 cm²/V·s at 4.2 K, as determined from drain current (I_D) vs gate-to-source voltage (V_GS) curves at low drain-source (V_DS) bias.

Figure 1 displays I_D as a function of V_GS at various temperatures between 4.2 and 15 K for a 110 nm-channel MOSFET. For a given device, the fluctuations, which are clearly seen below ~10 K, are completely reproducible. However, the specific pattern of the fluctuations is peculiar to a given device. All devices with lengths in the range 90–150 nm display the fluctuations at 4.2 K, but long-channel devices (5 μm) do not. Figure 2 shows that the fluctuations become smaller with increasing V_GS. This may be simply a result of electron heating.

At 4.2 K the magnitude of the fluctuations is ~5 × 10^{-4} S, about ten times larger than e²/h. This is in good agreement with the prediction of equation (1)

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with $T$ because of the term $(W/L_{in})^{1/2}$. Figure 1 shows that the fluctuations do not change in size from 4 to 6 K indicating that $L_{in}$ may approach $L$ in this temperature range.

The interpretation of the data as evidence for the universal fluctuations is, by no means, unambiguous, however. For example, the empirical relation, equation (2), predicts an inelastic length much shorter than $L$ for the low conductance region near threshold in which the fluctuations are most easily seen. Furthermore, there are peculiar non-linearities in the dependence of $I_{DS}$ on $V_{DS}$ which have not yet been thoroughly explored.

It is clear that magnetoresistance and lower temperature measurements are necessary before we can be sure that the fluctuations seen in Figs. 1 and 2 are fully consistent with the theoretical predictions. If they prove to be so this will be the first observation of the universal conductance fluctuations in devices which are short and wide.

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REFERENCES