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High-temperature conductance quantization: the case of quasi-2D percolating structures

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Investigation of electron properties of disordered quasi-2D semiconductor objects is caused by fundamental interest to regularities of metal-to-insulator transition, which specifics is determined by both the system dimension and disorder parameters. Also known that up-to-date FETs (based on selectively doped semiconductor structures) are naturally disordered due to elevated impurity content. Effects of disorder are stronger when the gate voltage is lower, that is a case of weaken electron screening of the fluctuation potential (FP) induced by chaotic ensemble of built-in charges (ionized impurities).

The situation when conductance of disordered systems has the percolation character is of peculiar interest. In this case one should expect manifestation of both finite (macroscopic) spatial scales of self-averaging of the system resistance and local regions, where the regions determine a value of the resistance.

The report is devoted to consideration of electron transport properties of quasi-2D systems in dependence on disorder parameters controlled by built-in charges and (in gated structures) by electron screening of the FP [1]. Main experiments were performed on model objects. There are Si-MNOS structures with inversion n-channel, which allow variation of concentration of the FP sources ($10^{11}-10^{13}$ cm^{-2}) by controllable injection of electrons from Si onto traps at SiO_2-Si_3N_4 interface. At temperatures $T = 4.2-300$ K the conductance of inversion channel G vs. the gate voltage V_g was studied.

It was established that decreasing of the FET's gate length (from 100 to 5 μm) leads to strong changing of the $G(V_g)$ dependence: it manifests a region of quasi-plateau at $G \sim e2/h$. The peculiarity at G values being of an order of the conductance quant is a typical feature of FETs with relatively short (0.5–10 μm) but wide (50–1000 μm) gate and elevated concentration of built-in charges ($> 10^{12}$ cm^{-2}) [2]. It was observed in FETs with different material of semiconductor substrate and under-gate insulator, sign and effective mass of charged carriers, and nature of the FP sources, particularly in the GaAs-AlGaAs HEMTs, GaAs-MESFETs with bull or delta- doping, and even in Si-MOS FETs with inversion p-channel, regardless to the gate length-to-width relation.

We associate the peculiarity to be caused by transition from the 2D-regime of electron transport (high gate voltage, the FP is screened by 2D electrons) to the percolation-like quasi-1D regime at reduced V_g. Mechanism of this transition in percolating systems is discussed. Conducting paths are thought to be formed by wells of the chaotic potential relief connected by pass regions. We hope that the wells are responsible for macroscopic spatial scales of these paths, while the passes control a character of the system conductance.

Using computer simulation following analysis has been performed:
– spatial and energy scales of the FP;
– parameters and conductance of the passes;
– percolating characteristics of systems with fixed sizes (incoherent mesoscopics).

In frames of the percolation model under consideration we have determined conditions where
– electron transport is carried out along single paths and has reduced percolation level;
– the passes controlling the single path conductance are really manifest themselves as quantum-sized micro-constrictions even at elevated temperatures (up to room temperatures).

By this way we show that quasi-2D systems disordered by electrostatic FP could have quantum quasi-1D character of conductance regardless to their micrometer sizes.

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References

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[2] B. A. Aronzon, D. A. Bakaushin, A. S. Vedeneev, V. V. Ryl'kov and V. E. Sizov, *Semiconductors* **31**, 1261 (1997).