1D electron transport in InAs nanowires

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I. INTRODUCTION

InAs nanowires (NW) are very promising materials for nanoscaled electronic transistors due to high-mobility channel transport, one dimensional conductivity and low power consumption[1,2]. The low effective mass of electrons in these materials may allow utilization of novel quantum effects and single-electron phenomena[3-5]. In this respect fluctuation phenomena in such unique nanowire structures have to be studied to understand working principles of nanowire structures at nanoscale.

Here we report on the results of transport and noise properties investigation of InAs nanowires with 30nm diameter and different lengths. We registered that the quantization effect determines noise properties in nanostructures. The effect is more pronounced with decreasing temperature and nanowire length.

II. EXPERIMENTAL DETAILS

InAs nanowire samples with diameter of 30nm and different lengths were studied. The optical image of InAs nanowire chip under study is shown in Fig. (1). The InAs NW is contacted with electrodes for studies according to the transmission line model[6]. The chip was encapsulated and investigated at different temperatures. The noise spectra of the samples were measured in the frequency range 1 Hz - 3 kHz at different temperatures and substrate voltages in the linear mode: source-drain voltage V_{DS} = 20 mV.

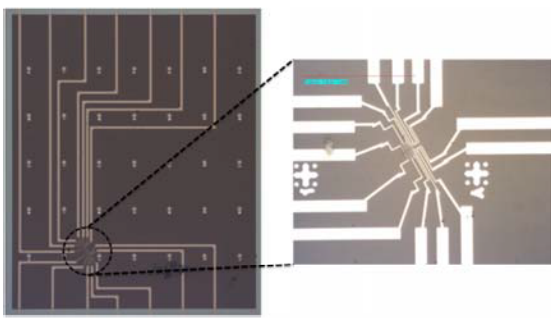

FIG. 1. The optical image of InAs NW chips under study.

We have studied several NW segments with lengths of 600 nm, 900 nm, 1200 nm and 3000 nm. The Si substrate was used as a gate electrode for the current flow control.

III. RESULTS AND DISCUSSION

In general, InAs nanowires demonstrated n-type FET behavior. Fig.(2) shows a typical dependence of drain current on back gate voltage applied to the InAs nanowire biased at V_{DS} = 10 mV. The characteristic was measured at room temperature. It should be noted, that the leakage current was negligibly small for all cases.

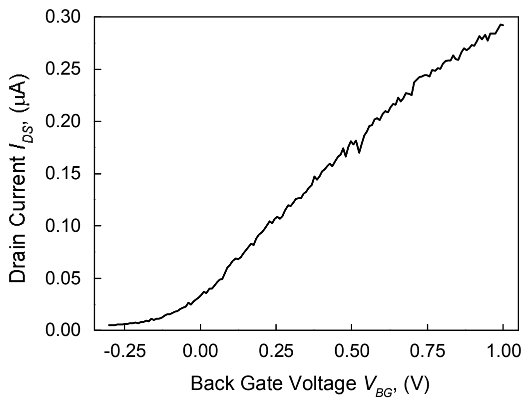

FIG. 2. Typical transfer characteristic of InAs NW segment with length of 600 nm measured at room temperature. V_{DS} = 10 mV.

The noise measurement results are shown in the Fig.(3). Measured noise spectra of InAs nanowires demonstrated mainly $1/f^{\gamma}$ (flicker) noise behavior with exponent depending on back gate voltage. Value γ changes from 1.5 to 1 with decreasing of temperature from T=300K to 100K. Several Lorentzian components related to random telegraph signal (RTS) noise can be resolved on the noise spectra of InAs NW at relatively high temperatures. Such noise components are associated with slow generation-recombination (GR) fluctuations that results in deviation from $1/f$ behavior at low frequencies. With temperature decrease, the contribution of these components decreased and completely disappeared at temperatures lower than T=175K. The value of normalized flicker noise S_I/I_{DS}^2 was weakly temperature dependent at temperatures below 175K.

The Lorentzian component of noise reflects generation-recombination processes, S_I^{GR}, and can be described using following relation:

$$S_I^{GR} = I^2 \frac{\overline{\Delta N^2}}{N} \frac{1}{N} \frac{\tau}{1 + (2\pi f \tau)^2} \quad (1)$$

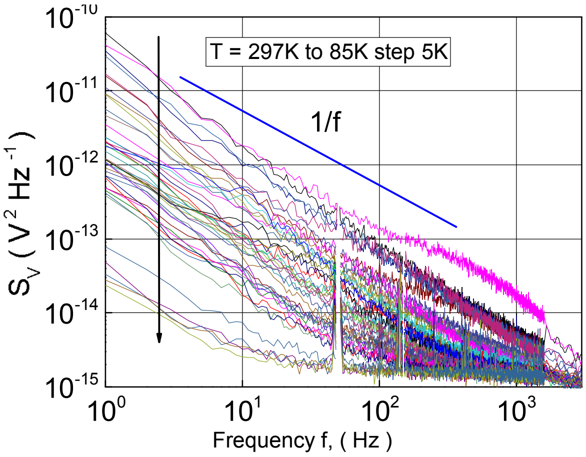

FIG. 3. Noise spectra measured for sample with L= 3000nm at V_{BG} =0 and V_{DS}=20mV at different temperatures from T=300K down to T= 85K with a step equal to 5K.

As it can be derived from equation (1), S_I^{GR} changes are related to the changes of τ. This reflects that the amplitude of the relative dispersion $\frac{\overline{\Delta N^2}}{N}$ for each Lorentzian component in the noise spectrum decreases with increasing of charge carriers number N. In addition, extracted characteristic times as a function of gate voltage $\tau(V_{BG})$ are reflecting capture and emission processes related to several active centers (1 to 5 centers) which are present in InAs nanowire structure. At low gate voltages $\tau(V_{BG})$ can be linear fitted in semi-logarithmic scale followed by saturation region at voltages greater than V_{BG} = 0.3V. The value of low frequency Lorentzian-shape noise plateau, $S_I(0)$, extracted from measured noise spectra, demonstrate similar behavior as a function of back-gate voltage. The results reflect excellent controllability of trapped centers using back gate voltage and, in turn, communication with 1D channel transport, as it will be shown below.

Amplitude of flicker noise, obtained at certain frequency in subthreshold regime, strongly decreases with voltage decrease. Surprisingly, the value of dimensionless Hooge parameter, α_H, decreases considerably in about two orders of magnitude. The fact reflects that interaction of electrons with traps of dielectric layer became negligibly small. This can be explained by decreasing of free carrier concentration near the interface between InAs and dielectric layer caused by increasing of conductive channel confinement α_H (V_{BG}-V_{th}) dependence considerably differs for samples with different lengths at large voltages. It should be noted that α_H decreases with (V_{BG}-V_{th},) decrease as well as α_H decreases with temperature decrease. The results cannot be explained by the increased contribution of contact resistance, since in the latter case the dependence has to be opposite. In addition, threshold voltage dependencies on temperature, obtained for samples with different lengths, reflect non trivial behavior as a function of sample length. The shorter length the stronger correlation effect is registered resulting in single electron phenomena and dynamic barrier processes. This is in good agreement with reported in literature formation of 1D conductivity at temperatures below 295K. Noise spectra allow us detailed study of dynamic barrier processes which are observed with temperature decrease. Moreover noise spectroscopy allows us to identify the stronger 1D conductivity and formation of ballistic transport in the channel. This is confirmed by the linear dependence of the $1/f$ noise component on the current in power equal unity obtained in the experiment. Such noise behavior in structures with 1D conductivity can be described by similar model[7] as in the case of carbon nanotube sample in frame of Hooge-Kleinpenning phenomenological model.

IV. CONCLUSIONS

Transport and noise properties of InAs NW samples with different lengths are studied in a wide temperature range down to 85K. We registered space quantization of electron gas and formation of 1D conductivity with stronger quantization effect in low temperature range. Transport and noise characteristic behavior as a function of length support the reliability of this explanation and strong influence of dynamic barrier effect on transport and current fluctuations.

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