MOSFET Tunneling Spectroscopy at Low Temperature

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Tunneling spectroscopy was introduced in 1960 by R.N. Hall [1] in studying current-voltage characteristics of Esaki tunnel diodes at low temperature. It revealed that the tunneling process was assisted by phonons. Because tunneling spectroscopy has high sensitivity and resolution, it was soon spread to the study of the density of states and bandgap of superconductors, molecular vibration and its band structure, organic structure, and defects [2-4]. More recently, there has been a great deal of interests in applying this method to study traps and molecular band vibration in ultrathin oxides [5] and high-k gate dielectrics [6]. All above works were focused on studying the tunneling process through metal-insulator-metal (MIM) tunneling structure. In this abstract, we will present the use of tunneling spectroscopy to study MOSFETs, in the subthreshold region and the linear region.

Unlike a MIM tunneling structure, when an MOSFET is biased under the subthreshold region and the linear region, nearly all drain current is conducted by the gate inversion charges, which is not the tunneling current. Therefore, the tunneling current through traps constitutes only a very small portion. Even though the tunneling current is very small, it is still detectable by tunneling spectroscopy because the double differentiation (or 2nd derivative) of a current-voltage curve (d^2I/dV^2) can reduce the background and is a very sensitive means of detecting small nonlinear changes.

Fig.1 shows the current-voltage characteristics of an n-channel MOSFET with gate length 340nm and width 360nm at liquid helium temperature (4.2K). The corresponding 2nd derivative measured with a standard lock-in method is shown in Fig. 2. The peak positions in the d^2I_{ds}/dV_{ds}^2 vary with V_{ds} for the different V_g bias. It also could be found that the new peak would appear and disappear at certain gate voltages, and Fig. 3 shows the details of a new peak appearing. In addition, our further experiment shows that at higher temperatures, the peak height of the 2nd derivative is lower, and the half-width of the peak becomes wider. At temperatures higher than 63K, all peaks disappear and $d^2I/dV^2 \approx 0$. One of the possible explanations of the experimental results is that the peak is related to one of three types of traps, as the result of electron motion: 1. Trap being activated by obtaining the energy from the electrons passed by; 2. The trap, which assists electron resonant tunneling; 3. Multiple traps, which are lined up and assist electron tunneling.

References:

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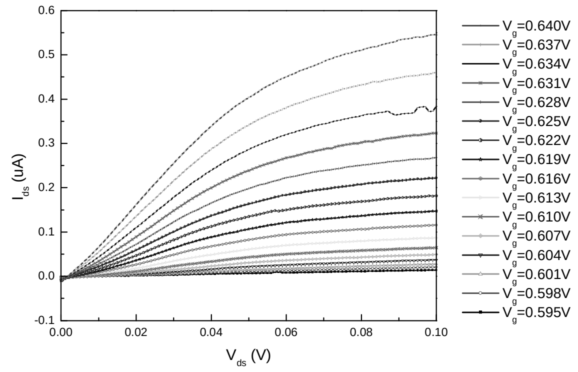

FIG. 1. The typical I-V characteristics under different gate voltages of the n-channel MOSFET with the gate length of 320nm and gate width of 360nm.

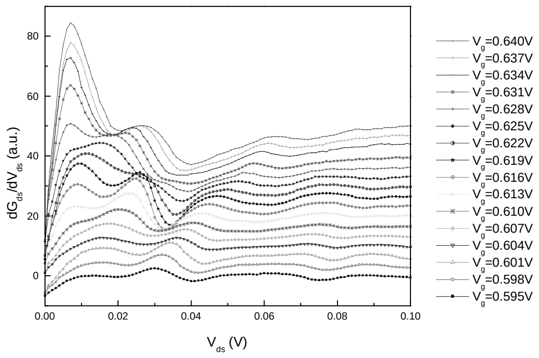

FIG. 2. 2nd derivative spectroscopy of I-V characteristics at different DC biases. The amplitude of ac signal is 2.5mV and frequency is 1kHz.

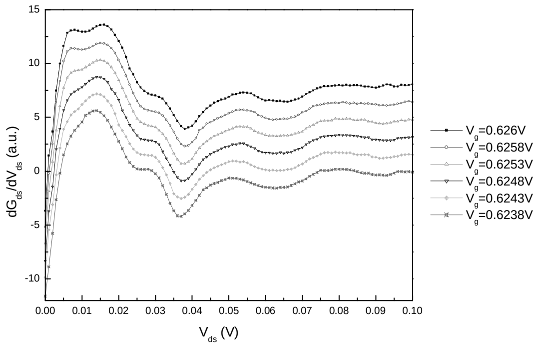

FIG. 3. A new peak is appearing with a smaller gate bias step.