Characterization of Single Defects: from Si to MoS_2 FETs

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The performance and reliability of modern FETs is limited due to trapping of charge carriers by various defects. In particular, this problem prevents commercialization of 2D FETs, which typically have large defect densities (10^{12} cm^{-2}). This makes reliability studies of 2D FETs extremely important.

Following Moore's law, Si MOSFETs have already achieved ultra-scaled dimensions with less than 10 defects per channel area. Nevertheless, charge trapping by these discrete defects has been found to severely affect the channel electrostatics, thus causing fluctuations of the drain current known as random telegraph noise (RTN) [1]. Statistical analysis of RTN measured in ultra-scaled Si MOSFETs is a very powerful method for the characterization of microscopic defect properties [2]. However, our previous experiments on the reliability of 2D FETs have been performed for large-area devices [3-4]. As such, only the issues appearing as a superposition of simultaneous charge trapping by multiple defects, such as a hysteresis and long-term drifts of the I_D-V_G characteristics, have been analyzed. These averaged data do not provide detailed insight into the properties of each particular defect.

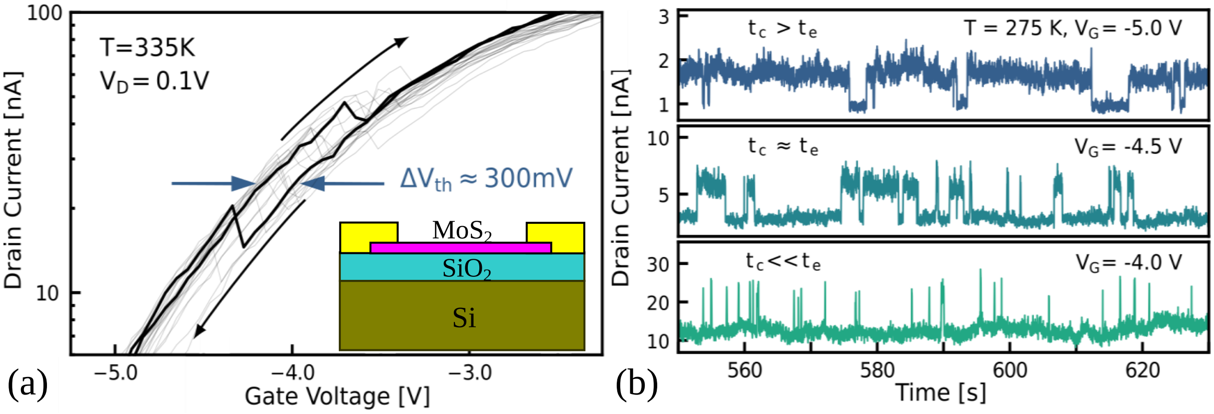

Fig.1. (a) A single trap changes its charge state during an I_D-V_G sweep, leading to a discrete V_{th} shift. (b) Typical RTN signal measured at different V_G. The time constants t_c and t_e are strongly bias-dependent.

In order to obtain more information about the nature and origin of the defects in 2D FETs and understand the scaling potential of these devices, we have recently performed a first detailed reliability study on scaled (65×50 nm^2) MoS_2 FETs. First, we observed that charge trapping by a single defect during an I_D-V_G sweep may lead to a discrete shift of V_{th} (Fig.1a). The counterpart of this issue in large-area devices is the hysteresis [4] which originates from simultaneous charge trapping events by multiple defects. Then we have measured a number of RTN traces at different gate voltages and temperatures and analyzed the results using our four-state non-radiative multiphonon (NMP) model [2]. In addition to capture (t_c) and emission (t_e) times, this allowed us to extract the energy levels and vertical positions of several defects. In particular, we found that for some defects t_c and t_e are strongly bias-dependent (e.g. Fig.1b), while for others they remain constant within a wide V_G range. The former defects were identified as oxide traps in SiO_2, and the latter as adsorbates on top of the MoS_2 channel. Furthermore, some adsorbate-type defects were found to switch from periods of high activity to inactivity. This issue, known as anomalous RTN, has been analyzed using hidden Markov models.

In this presentation an overview of previous single-defect studies of Si MOSFETs [2] and GaN/AlGaN devices [5] will be followed by our most recent results for ultra-scaled MoS_2 FETs.

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