Reliability and Characterization Challenges for Nano-Scale Electronic Devices

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Scaling electronic devices to nano-scale dimensions may introduce unforeseen physical mechanisms that may seriously compromise device reliability. It has been discussed that as individual atoms comprise a larger fraction of the actual device area, defects associated with atomic-level changes may dominate failure and drift mechanisms [1]. Also, it is expected that failure distributions will become more dispersed as the activation energy for defect generation is not expressed as a single value but as a distribution of values [2].

As device area shrinks single electron trapping kinetics can produce a significant noise and random telegraph signal (RTS) fluctuations in FET channel current [3]. It has been reported that Si FinFETs with an area of .02 μm^2 showed drain current fluctuations up to 25% [4]. Recently, single-wall carbon nanotube FETs exhibited RTS fluctuations up to 60% of the total current [5]. We have observed significant noise and RTS in ZnO nanowire field effect transistors [6]. The device had a diameter of 140 nm and a channel length of 4μm. Fig.1 shows a typical low frequency noise spectrum when the device is biased in strong inversion at 4.2 k. The noise is observed to show a Lorentzian spectrum indicating trapping and detrapping of a single defect in the gate dielectric. The RTS signature of this single trap state is shown in the inset of the figure where the current switches between two discrete channel current values.

The reliability and stability of nano-scale devices will also be dominated by mechanisms occurring at interfaces. It will become important to characterize and model the chemistry of these interfaces to determine its influence on device parameters. Figure 2 shows typical device $I_d - V_g$ characteristics before and after the introduction of dry O_2 when characterizing a typical ZnO nanowire FET. The threshold voltage is observed to shift from 0.05 V to 0.87 V under the oxygen environment. This observation agrees with previously published reports that showed ZnO NW FETs' oxygen sensing properties [7]. O_2 molecules can be chemisorbed at surface vacancy sites of the metal-oxide nanowire and produce a significant threshold voltage shift. For extremely scaled devices only a few molecules need to be chemisorbed to produce a large affect in device performance.

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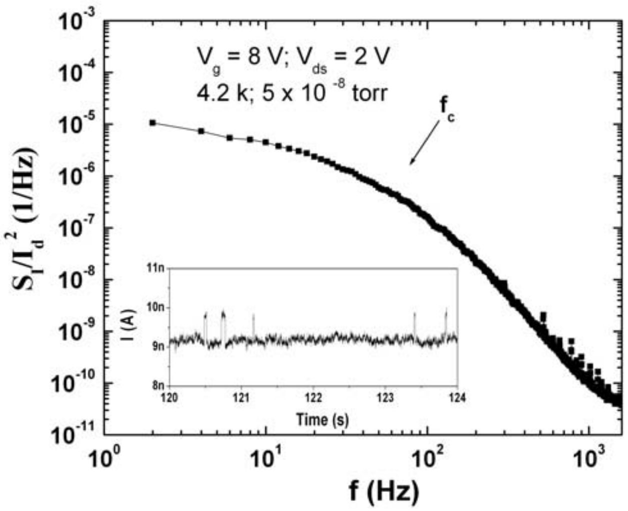

Fig 1. Typical noise spectrum obtained form a ZnO nano wrire FET biased in inversion. The inset shows RTS drain current fluctuations associated with single trap states.

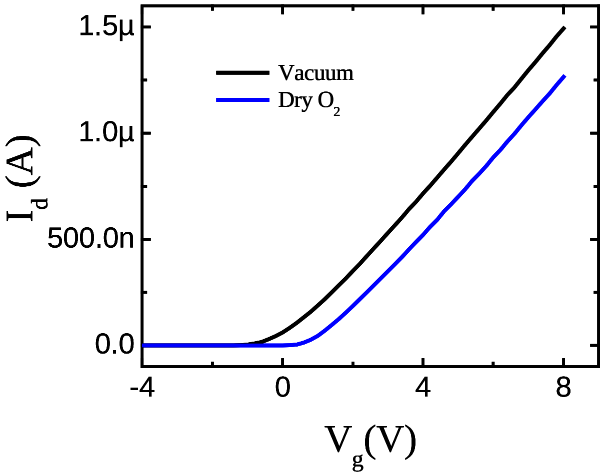

Fig 2. I_d–V_g characteristics of the ZnO NW FET device in vacuum and dry oxygen environments. V_d = 1 V.