Chapter 6

Conclusions

6.1 Summary of Contributions

A computer-automated transient measurement system with a switching time down to microseconds is developed in this work. With the use of the system, a novel single charge emission technique involving direct measurement of single charge emission for characterization of microscopic trap properties is demonstrated. The activation energy for charge emission is extracted from experiments, and is found to be dependent on the gate dielectric material (high-k or SiO_2), not on the de-trapped charges (electrons or holes). Trap density can also be evaluated simply by measuring the ratio of the first two charge emission times in small-area devices or by extracting the slope of recovery drain transient in large-are devices.

Furthermore, interesting bias and temperature instabilities in high-k nMOSFETs (PBTI) and in high-k pMOSFETs (NBTI) easily ignored in conventional characterization methods are observed. On the one hand, PBTI induced drain current degradation in nMOSFETs is found to have a two-stage feature. The first stage is dominated by initial trap filling featuring a logarithmic time evolution and negative temperature dependence, while the second stage is dictated by additional trap creation exhibiting a power law time relation and positive temperature dependence. On the other hand, an anomalous turn-around drain current instability is measured in high-k pMOSFETs. The initial increase in drain current stems from valence band electron trapping from the poly-gate into the high-k traps. At prolonged stressing, hole charging and interfacial layer degradation take over and the polarity of drain current change becomes opposite.

6.2 Suggestions for Future Works

By taking the advantages of transient measurement, one retrieves valuable information, like those disclosed in this dissertation, that has been long masked. However, there are some suggestions for future works. First, lifetime projection strategies based on the distinct characteristics identified in Chapter 4 and Chapter 5 need to be developed. Second, the single charge measurement provides two useful quantities: the charge emission times which are fully utilized in this work, and the amplitude of each current jump (ΔI_d). ΔI_d is affected by a combinational effect of mobility and number fluctuation in conduction carriers [6.1]. As transistors scales down to the nanometer regime, the impact of a single trapped charge may expectedly enhance and imposes a severe reliability concern. Once charges are trapped into the pre-existing traps, transistors may suffer from huge drain current fluctuation even before they are really stressed. Therefore, single charge induced ΔI_d deserves extensive investigation to comprehend its correlations with dielectric materials, device structures, substrate engineering, and so forth.