Session 9: Modeling and Simulation - Modeling and Simulation of Negative Capacitance Transistors
Monday, December 3, 1:30 PM
Plaza A
Co- Chairs: L. Smith, Synopsys
N. Xu, Samsung

1:35 PM - 2:00 PM
9.1 Multi-Domain Dynamics of Ferroelectric Polarization and its Coherency-Breaking in Negative Capacitance Field-Effect Transistors, *H. Ota, T. Ikegami, K. Fukuda, J. Hattori, H. Asai, K. Endo, S. Migita and A. Toriumi*, National Institute of Advanced Industrial Sceince and Technology (AIST) *The University of Tokyo*

In this paper, we, for the first time, clarified the multidomain dynamics of ferroelectric polarization in the Negative Capacitance Field-Effect Transistors (NCFETs) by an in-house Technology Computer-Aided Design (TCAD) module. It enables self-consistent simulations among the time-dependent Landau-Khalatnikov equation and the other equations that govern operation of FETs. Our simulation reveals that domain-wall thickness Tdw, which reflects a correlation strength between domains predominates coherency of the NC polarization. In a strong correlation (large Tdw) case, a coherent NC polarization is realized at least to a degree of Tdw. On the other hand, in a weak correlation (small Tdw) case, perturbation from peripherals easily leads to incoherence of polarization, where a uniform polarization is split into multiple spontaneous polarization domains. This coherency breaking found to give rise to deteriorated voltage amplification of NC. Design methodology to maintain the NC coherency is also proposed.

2:00 PM - 2:25 PM
9.2 Modeling of Multi-domain Switching in Ferroelectric Materials: Application to Negative Capacitance FETs, *A. Dasgupta, P. Rastogi*, D. Saha*, A. Gaidhane*, A. Agarwal* and Y. S. Chauhan*, Univ. of California, Berkeley, *IIT Kanpur*

We present a new multi-domain model for polarization switching in ferroelectric materials. The computationally efficient model captures the time evolution of multi-domain ferroelectrics with good accuracy along with the frequency dependent switching behavior. We have fabricated (PVDF) and measured P-E characteristics of PZT and PVDF capacitors and have validated the model with measurements. The model allows the visualization of time dependent domain switching allowing further physical insights. We have also proposed a method to extract the distribution of domain orientations experimentally.

2:25 PM - 2:50 PM
9.3 On the Microscopic Origin of Negative Capacitance in Ferroelectric Materials: A Toy Model (Invited), *A. Khan, Georgia Institute of Technology*

We present a simple, physical explanation of underlying microscopic mechanisms that lead to the emergence of the negative phenomena in ferroelectric materials. The material presented herein is inspired by the pedagogical treatment of ferroelectricity by Feynman and Kittel. In a toy model consisting of a linear one dimensional chain of polarizable units (i.e., atoms or unit cells of a crystal structure), we show how simple electrostatic interactions can create a microscopic, positive feedback action that leads to negative capacitance phenomena. We point out that the unstable negative capacitance effect has its origin in the so called "polarization catastrophe" phenomenon which is essential to explain displacement type ferroelectrics. Furthermore, the fact that even in the negative capacitance state, the individual dipole always align along the direction of the local electrical field not opposite is made clear through the toy model. Finally, how the "S"-shaped polarization vs. applied electric field curve emerges out of the electrostatic interactions in an ordered set of polarizable units is shown.

2:50 PM Coffee Break

3:15 PM - 3:40 PM

9.4 Effect of Polycrystallinity and Presence of Dielectric Phases on NC-FinFET Variability, *Y.-K. Lin, M.-Y. Kao, H. Agarwal, Y-H Liao, P. Kushwaha, K. Chatterjee, J. Pablo Duarte, H-L Chang, S. Salahuddin, and C. Hu University of California, Berkeley*

A Monte Carlo TCAD simulation study of the impact of polycrystallinity and dielectric phases of the ferroelectric film on an 8/7 nm node NC-FinFET is presented. The study considers the random variation of ferroelectric remnant polarization (Pr) and the presence of dielectric phases. In order to keep the ferroelectric-film induced device variability less than those induced by other sources (RDF, GER, FER, and MGG), we found that the DE content must be less than 20%, which is theoretically possible, and the grain to grain Pr variations less than 27%. While uniform single-crystalline ferroelectric film would provide the least device variation, we found 4 nm grains to produce less device variability than 5.3 nm grains due to the larger number of grains in the channel area.

3:40 PM - 4:05 PM

9.5 A simulation based study of NC-FETs design: off-state versus on-state perspective, *T. Rollo, H. Wang, G. Han*, D. Esseni, Università degli Studi di Udine, *Xidian University*

Analytical and numerical models are presented for a better insight of physics and design of Ferroelectric-NCFETs. A steep-slope hysteresis-free design is difficult to obtain, while on-state enhancement is more feasible and improves both SS and on-current. NC-FETs reduce temperature sensitivity compared to baseline FETs, but magnify the sensitivity to thicknesses.