Introduction to the Special Issue on Negative Bias Temperature Instability

I. Introduction

NEGATIVE bias temperature instability (NBTI) is a significant reliability concern for submicrometer CMOS technologies. NBTI in pMOSFET devices is not a recently discovered wearout mechanism. It was originally observed in the early phases of CMOS development almost 40 years ago, but it was not considered of great importance because of the low electric fields in operation. However, technology scaling has resulted in the convergence of several factors, which have together made NBTI the most critical reliability concern for deep submicrometer transistors. These trends include the introduction of nitrided oxides (required to reduce boron penetration in p^+ poly-pMOSFETs), as well as the increase in gate oxide fields and operating temperature with technology scaling.

Tremendous amount of research has been carried out by both the industry and academia over the last few years, resulting in significant advances in our understanding of NBTI. However, some key aspects of the physics of NBTI remain controversial. In particular, questions related to gate oxide nitritation and its relation to hole trapping and interface state generation, and the appropriate choice of stress/test methodologies to characterize NBTI remain unresolved. Additionally, the impact of NBTI in new materials such as HfO_2 gate stacks is beginning to attract attention given the possible use of these high-k films in 45-nm technologies and beyond.

II. Editorial Preview

This Special Issue on NBTI of the IEEE Transactions of Device and Materials Reliability (TDMR) focuses on recent progress in the aforementioned areas. The nine invited papers in this second Special Issue are intended to reflect the current thinking among different researchers on the controversial aspects of the NBTI mechanism.

The first paper addresses one of the primary reasons for the rising importance of NBTI, namely the role of nitrogen in exacerbating NBTI. Mitani *et al.* find hydrogen to be a significant player in NBTI degradation in nitrided oxide as well. Additionally, they report that while plasma nitridation does result in lower degradation than thermal nitridation, the poststress recovery is also suppressed for plasma nitridation. This finding may have implications for setting ac NBTI specifications and deriving benefits from it.

Wang *et al.* identify three distinct causal agents for NBTI: 1) trapped holes, which populate preexisting defects; 2) generated positive charge, which is created during stress; and 3) interface states, which follow the reaction–diffusion model. They also find that the dominant component is dependent on the measurement scheme. Ang *et al.* demonstrate the generation of a broad distribution of positive charges and conclude that the relative differences in energy levels could be a reason for the traps to behave as interface states or as an oxide-trapped charge.

Mahapatra *et al.* conduct a survey of the experimental data published in the literature (including their own). They conclude that for ultrathin dielectrics (< 2 nm), interface trap creation is the dominant mechanism, and nondispersive molecular hydrogen transport modeled within the reaction–diffusion framework provides an adequate model of observed trends.

Neugroschel *et al.* report that NBTI in high-k gate stacks is still dominated by the degradation of the interfacial SiO_2 layer. They propose a new methodology to separate out the fast component from the slow one to make an accurate lifetime projection.

Li *et al.* tackle the challenges of measuring NBTI. They compare various measurement schemes and highlight the issues involved in interpretation of data from the different schemes. They also conclude that the dominant component that impacts lifetimes is the creation of interface traps during stress.

Nigam *et al.* focus on a different manifestation of recovery, namely the reduction in degradation under ac conditions. They report a four-decade enhancement in lifetime for continuously switching circuits, which would make NBTI degradation an insignificant issue for continuously switching circuits.

The last two papers of this Special Issue deal with modeling NBTI and the use of models to design robust circuits. Grasser *et al.* derive a generalized reaction–diffusion model incorporating dispersive transport and show that the different dispersive transport models reported in the literature can all be obtained from the generalized model by adding specific constraints. The final paper in this invited section by Li *et al.* focuses on the incorporation of different device wearout mechanisms in a SPICE simulator. It introduces new accelerated

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lifetime and SPICE compact models for different reliability mechanisms, including NBTI.

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