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Similarities between Ionizing Radiation Effects and Negative-Bias Temperature Instability (NBTI) in MOSFET Devices

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Advanced, radiation-hard silicon-based MOSFETs are needed for space-based applications. The quality of the dielectric-Si interface plays an extremely important role in the development process [1], and much of the success of MOS devices has followed from improvements in this interface. As part of the continued development of these devices, work continues on primary degradation processes, such as negative-bias temperature instability (NBTI) [2] and radiation effects [1]. In this presentation, we focus on the common features of these phenomena and show that they have many similarities. As will be discussed in this presentation, these similarities allow us to use NBTI data to develop models that apply to both NBTI and radiation effects. For both cases discussed here, we focus on the creation of interface traps. As will be shown, injected holes start the processes that create the interface traps for both the radiation and NBTI mechanisms. In the case of NBTI, an electric field leads to injection of the holes into the oxide. This mechanism involves tunneling of holes from the Si substrate to traps in the oxide located near the interface. In the case of radiation effects, the holes are released by ionizing radiation throughout the dielectric.

For both radiation effects and NBTI, the holes cause the release of atomic hydrogen in the form of protons which react with the hydrogen-passivated interface traps to create depassivated interface traps. Thus, for both mechanisms, the end result is the creation of interface traps. The understanding and control of these phenomena has received much attention. In the presentation, calculations focused on these phenomena will be compared with experiments.

The phenomena involve release of protons following capture of holes at oxygen vacancy sites. Some of these protons are released by the cracking of molecular hydrogen at charged oxygen vacancy sites. The released protons undergo further reactions to be discussed. A fraction of them reach the interface where they create interface traps by a depassivation reaction. In the case of NBTI, the cyclical process of using a gate bias causes a flow of holes into and out of the oxide. However, the creation of interface traps is an irreversible process at the temperatures used in the experiments.

The threshold voltages were measured as a function of time in response to cyclical biases [3]. These measurements were performed on 130 nm channel length p-channel MOSFETs manufactured using a proprietary technology, the gate dielectric being SiON with [N] ~ 0.5 atomic percent. In order to enhance the degradation effect, devices were stressed at 120 C with the gate biased at -3.25 V with respect to the source, drain and body contacts; relaxation at 0 V was also carried out at 120 C. Details of the stress/relaxation and measurement methodology and the conversion of measured source-drain current variations into threshold voltage shifts can be found elsewhere [3].

In the data to be presented, three threshold voltage shift contributions will be discussed: recoverable charge, field recoverable charge and non-recoverable charge [3]. The recoverable charge will be linked to oxygen vacancies near the interface. The permanent, non-recoverable charge will be linked to interface states. As discussed, their presence is linked to hydrogen reactions at the oxygen vacancies.

In summary, our data and analysis indicate that the NBTI data can be interpreted in terms of the same defects identified in radiation studies. Thus the physics of radiation effects and NBTI will be shown to have similarities that arise from the common role of the hydrogen cracking reaction that releases protons as a consequence of trapped charge. The end result is the creation of permanent interface traps in both phenomena.

References

1. J. R. Schwank, M. R. Shaneyfelt, D. M. Fleetwood, J. A. Felix, P. E. Dodd, P. Paillet and V. Ferlet-Cavrois, IEEE Trans. Nucl. Sci. vol. 55, no. 4, pp. 1833-1853, 2008.
2. J. Franco, B. Kaczer, G. Eneman, Ph. J. Roussel, M. Cho, J. Mitard, L. Witters, T. Y. Hoffmann, G. Groeseneken, F. Krupi and T. Grasser, IEEE Proc. IRPS11, pp. 624-629, 2011.
3. D. D. Nguyen, C. Kouhestani, K. E. Kambour, H. P. Hjalmarson, and R. A. B. Devine, Phys. Stat. Sol. (c), accepted, (2013).

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