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Implant Nitridation

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Ion implantation has been the dominant doping technique for Si integrated circuits for the past decades such as well doping, channel doping, source/drain doping and poly Si doping, etc. It is expected to retain this position of dominance for the foreseeable future. Ion implantation has been also used in applications other than Si-based integrated circuits and many of the species in the periodic table can be used for implantation in all kinds of applications and many of them are commercially available. In addition, recent efforts in the ultra-shallow junction (USJ) study explored the “co-implantation” scheme to reduce dopants (especially Boron) diffusion in the Si. It was reported that by co-implanting Boron and species like F, Ge, N, In, Ga, Al, or C, Boron diffusion can be reduced due to the electrical and strain effects [1, 2].

Some researchers reported the application of the ion implantation to the gate dielectrics to incorporate N into SiO_2 to form silicon oxynitride (SiON) [3]. However, due to the material characteristics of SiO_2, the R_p (projected range) and ΔR_p (straggle) were not small enough to form a good quality SiON film for advanced gate dielectrics application in 65 nm technology node and beyond where EOT less than 16 Å is required. Because in such advanced application, the starting SiO_2 thickness need to be less than 20 Å and the implant energy would need to be in the sub-hundred eV range to contain the majority of dose in the film. For such a low energy operation, it would be difficult for conventional implanters to maintain a reasonable amount of beam current and therefore, ion implantation is not commonly used in the SiON process for advanced gate oxide application. Currently, the plasma nitridation techniques are considered to be one of the solutions to form good quality SiON in the manufacturing and have been shown good results in SiON or HfSiON gate dielectrics.

Recent study showed that the projected range of the implanted species in HfO_2 is about half of that in the SiO_2 film suggesting that the stopping powers of HfO_2 is larger than in the SiO_2 [4]. In addition, since the dielectric constant is higher than SiO_2, high-k gate dielectrics would be normally grown thicker to gain the benefit of low leakage current especially for the low standby power applications. As a result, ion implantation of ultra-low energy could be a possible technique to incorporate N into the high-k gate dielectrics such as HfO_2 film with most of the dose residing in the film. To further reduce the effective N ion energy, molecular form of N can be used where the effective ion energy is divided by the number of atoms in the molecular. Additional advantage of using molecular form of N, for example N_2^+, is that presumably the molecular ion would be dissociated into its atomic form within a short period of the time after colliding with the target material due to that the incident energy is normally much higher than the binding energy of the molecular. When in its atomic form, N could be easier to react with the material and be incorporated into the material. In addition, the implant would damage the lattice such that during the subsequent thermal process, the lattice re-organization could further enhance the incorporation process. In this paper, a fabrication process for Hf-based high-k gate dielectrics using ion implantation of N_2^+ in ALD (Atomic Layer Deposition) films to form HfON was demonstrated. Results showed that a good quality HfON could be formed by N_2^+ implantation, which suggests nitrogen implantation can be an alternative high-k nitridation technique. This process was successfully integrated into a traditional CMOS flow and the electrical and reliability results of HfON, as compared to HfO_2, showed 10 times less Vt shift in the pulsed Id-Vg measurement and up to 70% gate leakage reduction. In addition, EOT, electron/hole mobility, TDDB and subthreshold slope of HfON also were performed better than those of HfO_2. Material analysis result and simulation result suggest that the defect states caused by oxygen vacancies might play a role in several electrical characteristics of HfO_2 and HfON devices. A model is proposed to explain the result by attributing the improvement to the reduction of defect states (oxygen vacancies) in the HfO_2 film by the presence of N in the HfON film. Selected electrical results are shown here and more detailed discussion will be reported in the extended paper.

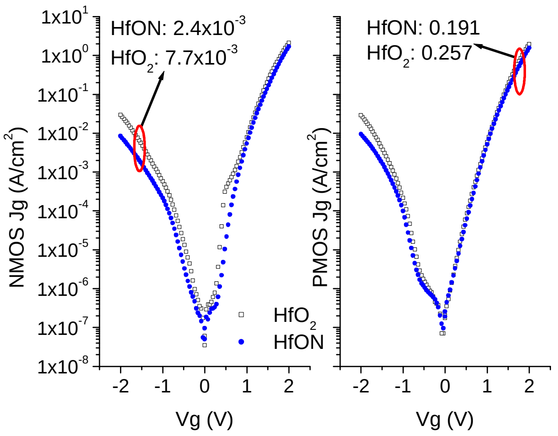

Fig. 1. Good quality HfON film was formed by implant with lower leakage compared to the control.

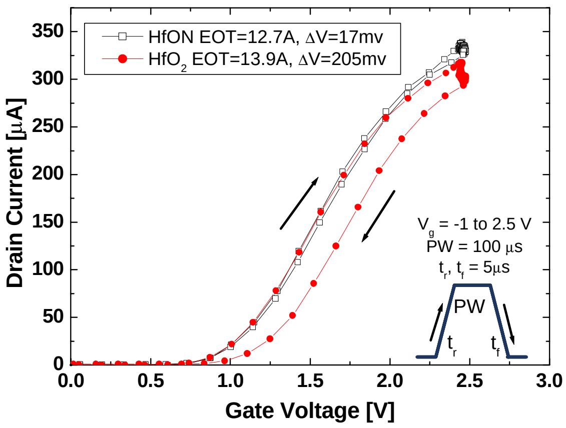

Fig. 2. Pulsed Id-Vg performance comparison.

[1] H.-J. Li, et. al *IEEE EDL*, vol. 23, pp. 646-648, 2002.
[2] H.-J. Li, et al. *APL*, vol. 77, pp. 2683, 2000.
[3] C. Krug and I. J. R. Baumvol, IIT 2004 p. 342, 2000.
[4] K. Suzuki and Y. Morisaki, *IEEE TED* vol. 49, pp. 1836-1838, 2002.