A REVIEW OF DEFECT GENERATION IN THE SiO_2 AND AT ITS INTERFACE WITH Si

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We have witnessed a steady increase of the market share of chips based on metal-oxide-semiconductor field-effect-transistors (MOSFETs) in the last four decades or so. The success of MOS devices heavily relies on the excellent insulating properties of gate silicon dioxides (SiO_2) and their near perfect interface with silicon. As the device size shrinks and doping density increases, the electrical field within the device increases. This high field accelerates charge carriers, which in turn causes damages to the oxide and its interface with silicon. Defect generation has become a major reliability concern for the complementary MOS (CMOS) technology and it has been suggested that it can be a showstopper for the downscaling of MOSFETs in the future (1,2).

In this invited article, a review will be given on the three most important defects in MOS devices: interface states, hole traps and electron traps. For each defect, the addressed issues include when it is important, its generation, its properties, and the recent improvement in our understanding.

For the creation of interface states, the review will start with the two well-known models: the hydrogen transportation (3) and the trapped hole conversion (4). Attention will be focused on the cases where these models are inapplicable. For example, it will be shown that both models cannot be used to explain the generation of interface states after terminating the hole injection (5). The hydrogen transportation across the oxide is too fast to be the rate limiting process here and it cannot explain the insensitivity of the generation kinetics to the oxide thickness. The trapped hole conversion model predicts that there is a correlation between the number of detrapped holes and the generated interface states, which was not observed (5). The majority of trapped holes are not converted into interface states following the detrapping.

To explain the creation of interface states following hole injection, new rate-limiting processes have been proposed. Under relatively high oxide field (≥6MV/cm) where Fowler-Nordheim injection occurs, the recombination between the injected electrons and the trapped holes is too rapid to be the rate-limiting process. In this case, the generation is controlled by the emission of the neutral hydrogenous species. For lower oxide fields, however, the tunnelling-induced detrapping of trapped holes slows down the creation.

During the substrate hole injection, the generation of interface states does not follow the two well-known models, either. It will be shown that the generation is dominated by the direct bombardment of hot holes. The generation does not require the supply of hydrogenous species. In this case, the interface states have a double peak distribution within the energy bandgap of silicon (6), similar to that induced by P_b centres. This is in contrast with the single peak distribution, typically reported when the stress released hydrogenous species (6).

Apart from the generation of interface states, it is shown that interface state precursors can also be created (7). The role played by the trapped holes and the hydrogen molecules will be clarified. The creation requires the simultaneous presence of trapped holes and the H_2. The essential reactive hydrogenous species is generated when the H_2 is cracked by the trapped holes. The conversion of the generated precursors into interface states is found to be much more efficient than that of the pre-existing precursors. This leads to the saturation for the former. In contrast, the saturation of the latter was not observed (7).

For the hole traps, both the as-grown and generated ones will be addressed. It is found that the as-grown traps can have two well separated capture cross sections, in the order of 10^{-13}~10^{-14}cm^2 and 10^{-15}cm^2, respectively (8). The former most likely originates from the oxygen vacancies, while the latter from some hydrogen-related defects (8). For a long time, it has been believed that the hole traps were fixed by the fabrication process and they will not be created during the device operation. In this article, clear evidences will be presented to show that new hole traps can be generated, when the hole injection level is well beyond 10^{14}cm^{-2}. The impact of the generation on trapping kinetics will be clarified. The generation of new traps is found to be responsible for the non-saturation behaviour of hole trapping at the high injection level.

For electron traps, the discussed generation models include the anode hole injection, the hydrogen release, and the electrical field energy. The generation was found to be insensitive to the oxide field, when plotted against the hole fluency (9). This makes it unlikely that the electron traps are created directly by the high field itself. It is shown that hole injection alone can create substantial amount of electron traps without the simultaneous electron injection. The recombination between the trapped holes and the injected electrons has little effects on the generation. However, the large number of injected electrons introduces additional generation process, which makes significant contribution to the generation (9).

On the properties of generated electron traps, unambiguous results will be given to show that two different types of electron traps, the high-field and the low-field traps, can be simultaneously created (10). The filling of the high-field traps is insensitive to either the oxide field or the filling current, while a decrease of oxide field or an increase of filling current will enhance the filling of low-field traps substantially. After the tunnelling-induced detrapping, the low-field trap is refillable, but the high-field trap is not. The generation of high-field trap is thermally activated, while the opposite is true for the lower-field traps.

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