Nature of High-Temperature Charge Instability in Fully Depleted SOI MOSFETs

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This paper investigates a high-temperature charge instability (HTCI) phenomenon found in the buried oxide (BOX) of SOI fully depleted (FD) MOSFETs fabricated on SIMOX and UNIBOND SOI materials.

Dynamic current-voltage (DIV_{BG}) characteristics of BOX SOI capacitors have been studied in combination with drain current vs. back-gate voltage ($I_D V_{BG}$) characteristics of FD inversion mode (IM) n-channel SOI MOSFETs, located in the same chip, in the temperature range between 20 and 320^{o}C. The devices were fabricated in high-dose single-implantation SIMOX and thin UNIBOND SOI materials with similar CMOS process fabrication sequence. The thickness of the BOX, the silicon film and the gate oxide were 400, 80 and 40 nm, respectively.

It has been shown that a negative bias applied to the Si substrate at a temperature above then 200^{o}C leads to drain current “jump” in the back-gate ($I_D V_{BG}$) characteristics both in SIMOX and UNIBOND SOI FD IM n-MOSFETs. Observed phenomena resuling in the creation of drain current fluctuations observed in the $I_D V_G$ characteristics of the FD IM n-MOSFETs have previously been related to front-gate HTCI [1]. The important point reported here is that the occurrence of a current “jump” in the $I_D V_{BG}$ characteristic correlated with the creation of a current peak in the DIV_{BG} characteristic of the BOX, which is usually associated with high-temperature ion movement [2]. Furthermore, the observed hysteresis of the subthreshold region of the $I_D V_{BG}$ characteristics corresponds to positively charged ion movement through the BOX.

The increase of the hold time of the negative bias initially applied to the substrate at high temperature, V_{BG}, before ramping V_{BG} results in an increase of both the drain current “jump” in the $I_D V_{BG}$ characteristic and the ion current peak amplitude in the DIV_{BG} characteristics (Fig.1). The charge calculated from the current “jump” of the $I_D V_{BG}$ characteristic (as this was proposed in [3]) and the ion moving charge calculated from the dynamic current peak square show good correlation. Thus, we can conclude that fast moving positively charge ions generated in the BOX at temperature above 200^{o}C are responsible for the current “jump” in the $I_D V_{BG}$ characteristics. The negative bias applied to the substrate during the generation of the moving positive charge shows that this generation occurs in the BOX/substrate interface, which is the most imperfect interface in both SIMOX and UNIBOND materials. The activation energy of the positive charge generated in SIMOX material has been calculated in [3] to be equal to 1.2 eV. Employing the same method of the calculation for UNIBOND structures we have obtained the positive charge generation activation energy to be distributed in the range between 0.9 and 1.5 eV.

After being generated at high temperature the positively charged ions can remain in charged state in the BOX at low temperature up to 50^{o}C for quite long time. From the measurements of the current peak shift in DIV_{BG} characteristic as a function of temperature and sweep rate, the mobility of the positively charged ions, μ, the diffusion coefficient, D, and the activation energy of the diffusion process can be calculated using following expressions [4]

$$\mu = 2d^2\alpha/(V_M^2) \text{ and } D = (kT/q)\mu ,$$

where d is the BOX thickness, α is the back-gate voltage sweep rate, V_M is the maximal voltage of the current peak, and other quantities have common meaning. Thus, ion mobility and diffusion coefficient can be expressed as follow:

$\mu = 1.3\text{x}10^{-2}\exp(-0.55/kT)$ and $D = 4\text{x}10^{-4}\exp(-0.55/kT)$.

Calculated diffusion coefficient for observed ions is in a good accordance with those obtained for protons in SIMOX BOX [5].

In conclusion, our results demonstrate that temperature above 200^{o}C and for negative voltage applied to substrate, positively charged ions are generated in the BOX/substrate interface of SIMOX and UNIBOND SOI materials. These ions reduce the SOI FD MOSFETs stability at high temperature. Protons are suggested to be these generated ions.

References

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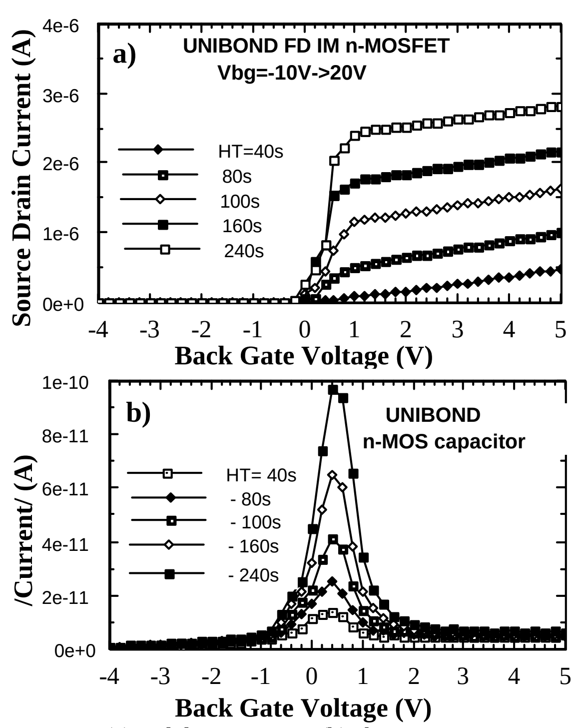

Fig.1. $I_D V_{BG}$ (a) and dynamic IV_{BG} (b) characteristics, measured at 280^{o}C for different hold time at the initial negative voltage applied at back gate (here –10V).