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Electrostatic Charges and Ion Implantation Impact on the MIS Transistors Parameters Degradation

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***Abstract* – Resistance to electrostatic charges is one of the most important problems limiting the very large scale integrated circuits reliability. Increased currents cause the degradation of the instruments characteristics, similar to the degradation that occurs when hot electrons stream passes through. In order to increase the very large scale integrated circuits reliability, under hot electrons occurrence, exposure to ionizing radiation, electrostatic charges, and ion treatment, it is necessary to study the MIS transistors parameters degradation mechanisms. The results of the study show that the maximum the threshold voltage shift occurs when aluminum is sprayed onto the structure with a floating gate. The reason for the MIS transistors characteristics degradation is the charges of the gate electrode and the current in the oxide arising from strong electric fields. The degree of characteristics degradation in the hot electrons injection case does not depend on the energy of the ions bombarding the substrate surface.**

Keywords – degradation; transistor; hot carriers; ion implantation; threshold voltage; electrostatic charge.

I. INTRODUCTION

To improve the reliability of very-large-scale integrated circuits (VLSI), when hot electrons occur, ionizing radiation, electrostatic charges, and ion treatment, degradation mechanisms should be studied, and when transitioning to creating ICs with ultra-submicron elements geometry and methods to reduce parameters degradation should be developed [1-3].

Resistance to electrostatic charges is one of the most important problems limiting the very large scale integrated circuits reliability [4, 5]. Protective circuits at the VLSI input, under electrostatic charges, triggers not always efficient, and the increased currents flow through the VLSI elements. Increased currents can cause instrument characteristics degradation, similar to the degradation that occurs when a hot electrons stream passes through. Typically, hot electrons and electrostatic charges impact are distinguished by the fact that hot electrons (a case of direct current) are a process associated with a small current and a long time, and an electrostatic charge with a process associated with a large current and a short time. Accordingly, there are various methods

When it comes to instability caused by the influence of a relatively small current left over from an electrostatic charge on the drain and the effect of hot electrons, the degradation of parameters can affect both output transistors and internal VLSI transistors [6, 7].

II. METHODS AND MATERIALS

The experiments were carried out on n-MIS transistors with a gate thickness of 22 nm with a silicon gate, a source and a drain built on a 500 nm under threshold current layer laid over the p +– substrate. N-MIS transistors with a channel width of 1 μm and various channel lengths were exposed to hot electrons at a maximum substrate current and gate voltage of 5 V, a drain voltage of 6.5 V, and grounded source and substrate.

Volt-ampere characteristics were measured as a function of the duration of stay in this mode. After staying in this mode for 48 hours, the linear drain current degradation measured at a drain voltage of 0.1 V and a gate voltage of 5 V was 20%, and the threshold voltage offset was 60 mV. The number of intermediate states was measured using the charge pumping method. The gate was energized by a rectangular alternating voltage with a frequency of 1 MHz with amplitudes of -4 and + 4 V. The measured charging current I_{av} was 300 pA.

Then, transistors with a 0.5 μm channel length were subjected to direct current pulses with amplitude of 15 mA and a duration of 250 ns applied to the drain. The amplitude of the pulse was sufficient for the transistor breakdown. Most transistors broke through to the source and a small amount broke through to the substrate under pulse exposed.

After electrostatic discharge exposure, the transistor characteristics, as well as the interface state Nit magnitude, had no noticeable changes. Even if the electrostatic charge caused the transition to degrade, the substrate current peak remained unchanged. Then the same transistors were exposed to hot electrons. The current-voltage characteristics and current during charge pumping were recorded. It was found that the current linear degradation, measured at a drain voltage of 0.1 V and a gate voltage of 5 V, after exposure to hot electrons was greater for transistors that were previously subjected to electrostatic charges.

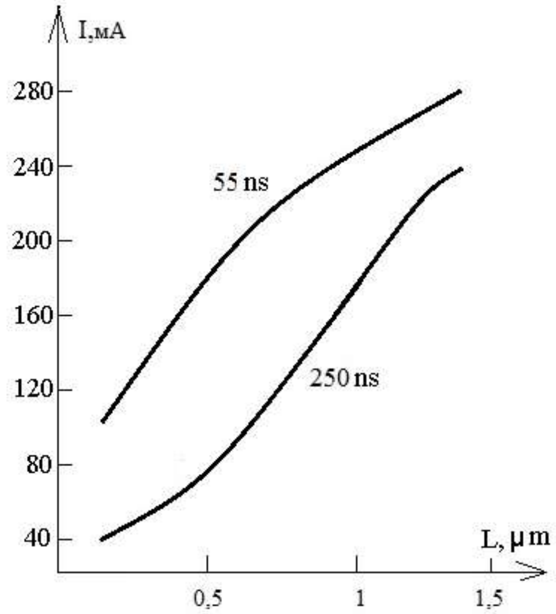

Fig. 1. The current dependence on the channel length of transistors exposed to hot electrons at different pulse durations.

Fig. 2 shows the current degradation dependence on the time of exposure to hot electrons, after 5 pulses simulating a “residue” on electrostatic charges (15 mA, pulse length 250 ns).

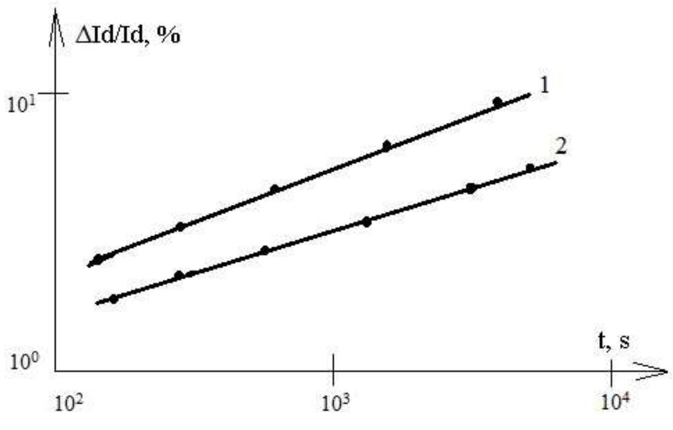

Fig. 2. The current degradation dependence on the time of exposure to hot electrons: pre-subjected to electrostatic charges 1 and without prior exposure to electrostatic charges 2

Charge pump current measurement identified that this current for two transistors groups remains almost unchanged. This reflects that the effect of relatively weak stationary electric charge residues on the drain affects both the transition, and the dielectric. With weak electrostatic charges on the drain, the gate oxide deteriorates. The gate dielectric fatigue was confirmed by subsequent experiments.

Transistors were subjected to electrostatic charges, then their service life was measured in comparison with transistors not exposed to discharges. All transistors subjected to electrostatic charges had 4–5 times less service life than transistors that were not subjected to electrostatic charges.

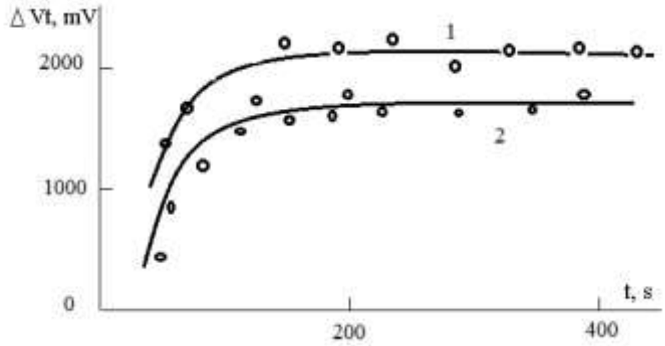

Fig. 3. The threshold voltage dependence on the time of exposure to hot electrons.

A similar effect was observed under direct current injection between the gate and drain with a “floating” source and the substrate. The gate current is 500 nA, the current-voltage characteristics were taken at regular intervals. The results are shown in Fig. 3.

It can be seen that the threshold voltages of transistors subjected to electrostatic effects (curve 1) are shifted in time noticeably stronger than those of transistors that are not subjected to electrostatic effects (curve 2). This proves that transistors previously subjected to electrostatic effects before the study have a larger trapped charge at the same injected current. Since the electrostatic effects did not initially change the current-voltage characteristics, it can be concluded that the gate oxide fatigues from electrostatic charges. The reexamination with direct current injection between the gate and the substrate with a gate current of 5 nA showed the same shift of the threshold voltage for instruments subjected to and not exposed to electrostatic charges. Obviously, the gate oxide near the drain under the action of electrostatic charges is deteriorating and thus the results obtained when the transistors are loaded with hot electrons are repeated.

Further studies have shown that when transistors are impacted by pulses that copy the electrostatic charges effects, there is a current amplitude limit below which the impulse has flimsy affected the instruments characteristics. With a pulse length of 250 ns and a ratio of channel width to its length of 5/1, the critical amplitude of the pulse current is 40-50 mA, and at a ratio of 25/1, the critical level reaches 140-150 mA.

The intermediate states growth degree was estimated by changing the current I_{av} when the number of pulses applied to the transistor with a width-to-length ratio of 25/1 changes, for cases when pulses of the same length are fed to the transistor, but with different current amplitudes.

When exposed to electrostatic pulses, there is a high change degree in intermediate states compared to hot electrons. This indicates differences in the physics of the degradation of transistors when exposed to hot electrons and when exposed to an electrostatic pulse [8].

The conducted studies show that the hot electrons effect causes the transistors characteristics degradation, but at the same time does not impair the transistors resistance to the electrostatic charges effects. The electrostatic charges effect causes the transistors characteristics degradation, including reduces the resistance to the hot electrons effects.

The effect of defects formed in ion implantation processes on the threshold voltage of MIS transistors is investigated. MIS transistors with n-channel were used as a test instrument. The gate length and the channel width were 0.5 µm and 2.5 µm, respectively, and the gate oxide thickness was 50 nm. The structure of the test device is shown in Fig.4.

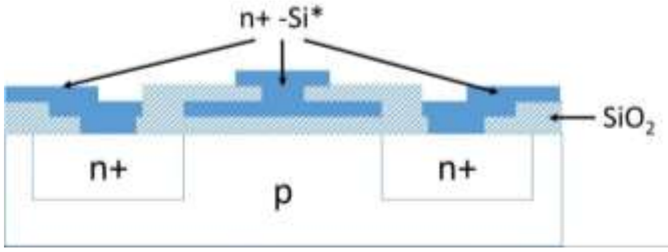

Fig. 4. The structure of the test device MIS transistor

Instrument characteristics were measured before and after ion bombardment processes, as well as after high-temperature annealing. As ions with a dose of 5 · 1015 cm-2 were implanted at an energy of 25 eV. In the process of Al sputtering, the ion energy did not exceed 100 eV. Before and after each process, the threshold voltage shift was determined, conded by both the process direct influence and the subsequent injection of hot electrons. Hot electrons were measured at a field strength in the gate oxide layer of 1.17 MV/ cm, a current density in the oxide of 5 µA / cm2 and a total number of injected electrons of 3.1 · 1016 cm $_{-2.}$

Fig. 5 demonstrates the changes in the threshold voltage due to the processes of ion implantation and annealing after implantation

After ion implantation there was a large negative shift in the threshold voltage. Even annealing for 9 h at 450 ° C did not ensure the initial threshold voltage value restoration. Hot electrons injection was accompanied by a positive shift of the threshold voltage. Before implantation, this shift was 0.07 V, and after implantation its value reached 2.7V. The strong hot electrons influence on the test MIS transistors threshold voltage was also observed after annealing at 450 ° C. The negative shift of the threshold voltage after implantation is explained by the positive charge that appears in the gate oxide. During the implantation process, neutral traps are also formed in the oxide. These traps are capable of capturing the injected hot electrons, after which a negative charge is formed in the oxide, leading to a MIS transistors threshold voltage positive shift. Ion implantation was also accompanied by the formation of such states at the interface between a semiconductor and a dielectric, which led to a change in the magnitude of the instruments subthreshold characteristics steepness. The injection of hot electrons did not affect the density of boundary states.

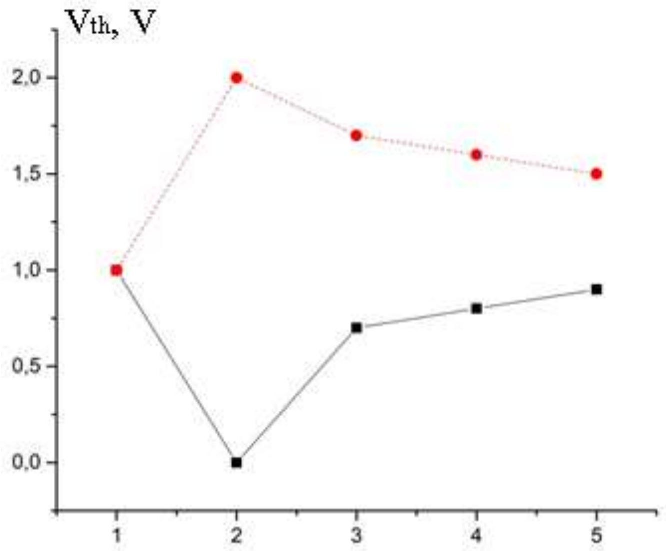

Fig. 5. Changes in the threshold voltage due to ion implantation processes (•, after injection and after implantation annealing) (•, before injection): 1 is the initial value along the abscissa axis; 2 - implantation of As; 3–3 h in N2; 4-30 min in H2 / N2; 5-6h in N2

Fig. 6 demonstrates that annealing at 450 ° C does not allow to completely eliminating either positively charged or neutral traps arising in the process of ion implantation. Such defects can be eliminated using annealing at a temperature of 900 ° C for one hour. Annealing at 900 ° C is associated with serious difficulties, since low-temperature processes are widely used in VLSI technology. The area of the gates during the ion bombardment process was protected by a 0.45 µm thick oxide layer. However, charge accumulation takes place in the polysilicon gate contact pads. Therefore, defects in MIS transistors arising during ion implantation may be due to the influence of a charged gate electrode, which is under a floating potential. These defects can occur under the action of X-rays generated by high-energy ions.

In samples with the gate in the ion implantation process grounded, the hot electrons effect on the change in threshold voltage magnitude conded by the hot electrons injection was relatively weak. In the case when the implantation was carried out at a floating potential at the gate, the hot electrons injection was accompanied by a significant change in the threshold voltage. Consequently, the cause of the degradation of the characteristics of MIS transistors was the appearance of a charge on the gate electrode, and not the effects associated with ion bombardment.

To study this effect, the hot electrons injection impact on the threshold voltage of MIS transistors at an external bias at the gate was determined. Hot electrons were injected at an electric field strength of 1.17 MV / cm. The results are shown in Fig. 6

The negative shift of the threshold voltage at strong electric fields in the gate oxide, caused by the gate electrode charge in the ion implantation process, is associated with the capture of holes released by lattice atoms ionization by a strong electric field [9, 10]. Subsequent partial compensation of this shift is due to the electrons capture. The large positive shift of the threshold voltage in weak fields in the gate oxide can be explained by the neutral electron traps presence, which was formed during the experiments. The instruments degradation caused by the very low-energy ions bombardment was also investigated. Substrate surface bombardment with Ar ions with energies of not more than 100 eV took place during the A1 films deposition by sputtering. The threshold voltage shift after such a bombardment was absent, however, some degradation was observed due to the hot electrons injection.

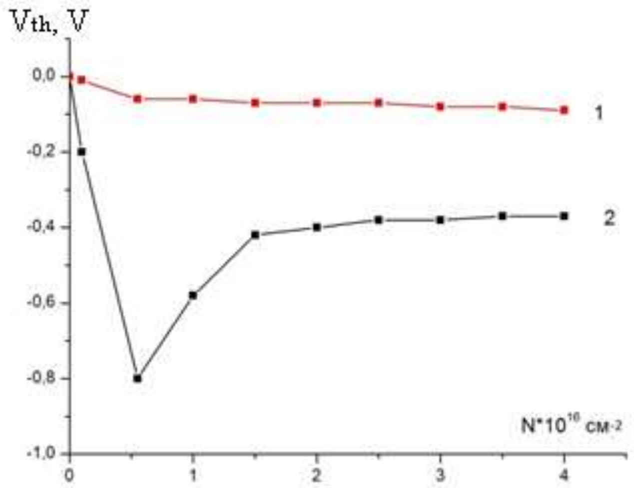

Fig. 6. Changes in the threshold voltage due to the hot electrons injection, injection at high field strength, 1 - at an electric field strength of 5.7 MV / cm; 2 - at an electric field strength of 7 MV / cm

III. Conclusion

The results obtained indicate that the maximum threshold voltage shift occurred when A1 was sprayed onto the structure with a floating gate. The cause of the degradation of the MIS transistors characteristics was the charge of the gate electrode and the current flowing in the oxide under strong electric fields, and not the effects associated with the ions introduction. It should be noted that the characteristics degradation degree in the hot electrons injection case does not depend on the energy of ions bombarding the surface of the substrate, since the described degradation is due to the gate electrode charge; it can be eliminated by grounding the gate in the ion bombardment process.

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