Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 311-314

C-6-6

Hot-Carrier-Immunity Degradation in MOSFETs Caused by Ion-Bombardment Processes

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The degradation in MOS device characteristics as well as in their hot-electron injection immunity caused by ion-bombardment processes have been investigated. It has been found that neutral electron-traps were generated due to the charging-up of the gate electrode during ion implantation. These neutral traps contribute to positive threshold shifts by hot-electron injection. It has been demonstrated that such problems are able to be removed by grounding the gate electrode during ion implantation. Similar effects were also observed for a low-energy bias sputtering deposition process.

1. Introduction

Hot-electron induced device degradation is one of the most important reliability issues for scaled-down ULSI devices. A number of studies have been conducted to understand the hot-electron injection phenomena and resultant device characteristics changes under a variety of biasing conditions[1][2]. Several hot-electron immune device structures have been proposed to circumvent the difficulties[3][4]. The hot-carrier immunity of a certain device structure, however, is greatly influenced by device fabrication processes, especially by processes utilizing energetic ion bombardment. MOSFETs subjected to bias-sputtering planalization of interlevel insulators, for instance, have been reported to show degraded hot-carrier immunity, i.e., such devices have shown greater threshold shifts as compared to the one without the process[5]. However, such process-induced degradation in hot-carrier immunity has not been clearly understood so far. Then, the purpose of this paper is to investigate the degradation in hot-carrier immunity caused by ion-bombardment processes.

2. Experimental

Ion-bombardment-induced damages were studied in both high-energy and low-energy regimes by subjecting test devices to ion implantation and low energy bias sputtering processes, respectively. Test devices were n-channel MOSFETs having 20μm-gate length, 100μm-channel width, and 50nm-thick gate oxide. Substrate hot-electron injection techniques[6] were utilized to investigate hot-electron trapping phenomena in gate oxide as a function of gate electric field and current. Test devices utilized in this experiment had a special structure, i.e., polysilicon pad patterns are connected to source, drain and gate electrodes as shown in Fig.1. As a result, device characteristics were able to be measured at various process steps, for instance, before and after the ion-bombardment processes and

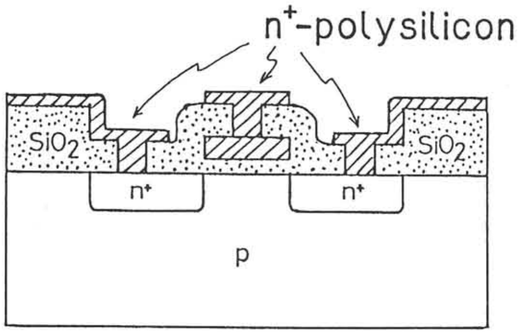

Fig.1 Cross section of test device utilized in this study.

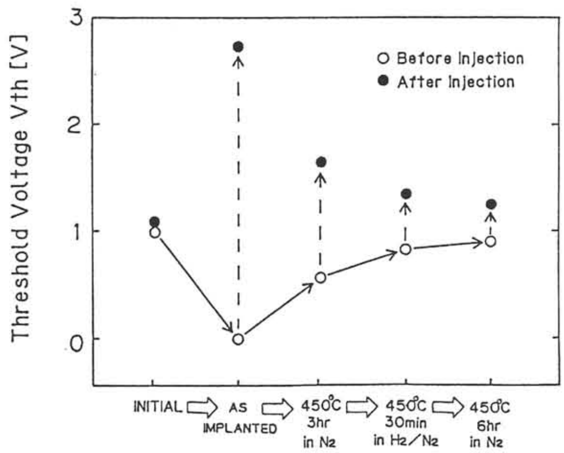

Fig.2 Threshold voltage variation caused by ion-implantation and post-implantation anneal(shown by ○ ——> ○) and threshold shift due to hot-electron injection experiment performed on each samples(shown by ○ ----> ●).

also after high temperature annealing processes without any additional device fabrication processes. Therefore the direct measurement of ion process effects on device characteristics has become possible. Arsenic ions were implanted at 25KeV with a dose of $5\times10^{15}cm^{-2}$. Low-energy bias-sputtering Al deposition was carried out using Low Kinetic Energy Particle Process[7], where the ion bombardment energy for the substrate was varied from 10eV to 110eV. Both before and after the process, threshold voltage shifts caused by the process as well as that caused by the subsequent hot-electron injection were measured. Hot-electron injection measurement was carried out under gate oxide field of 1.17MV/cm, and gate oxide current of $5\mu A/cm^2$ with the total number of injected electrons of $3.1\times10^{16}cm^{-2}$.

3. Results and discussion

In Fig.2, threshold voltage variation due to ion implantation and post-implantation anneal processes is shown by open circles. A large negative threshold shift is seen after ion implantation, which is not recovered even after a total annealing period of 9.5 hours at 450°C. The threshold voltages after hot-electron injection are also shown in Fig.2 by solid circles. The implanted samples showed much larger positive threshold shift after hot-electron injection as compared to the non-implanted one. Such large positive shifts are also seen for all samples subjected to post-implantation anneal at 450°C. Thus it is known that ion implantation induces positive-oxide-charge build up in the gate oxide as well as neutral electron trap generation. And they are not eliminated by low temperature annealing at 450°C. However, it was found that such damages disappear after 900°C annealing for 1 hour. This will present a serious problem since low temperature processing is one of the most essential requirements for advanced ULSI device fabrication.

The gate area in the test device was protected by a thick oxide (0.5μm) from direct ion bombardment. However, the polysilicon pad contacting the gate electrode serves as a charge collection antenna during ion implantation. Therefore, such phenomena can be understood as due to the charging-up of the floating gate electrode. Or they can be alternatively interpreted as due to the x-ray irradiation caused by high energy ion-bombardment.

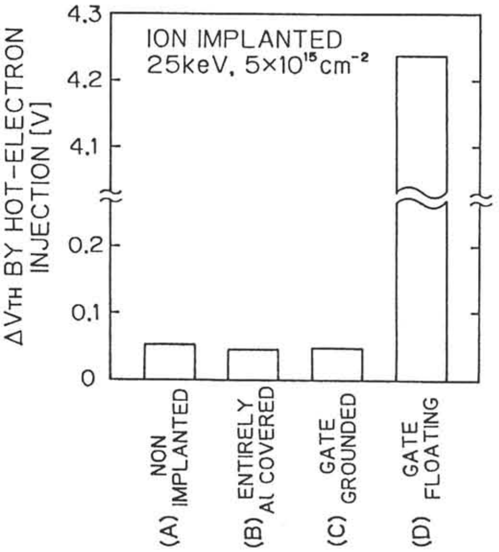

Fig.3 Threshold voltage shifts due to hot-electron injection after ion-implantation. In (B) and (C), the gate electrode is electrically grounded during implantation. The entire surface was covered by an Al film for (B), while gate areas were exposed to ion beam in (C).

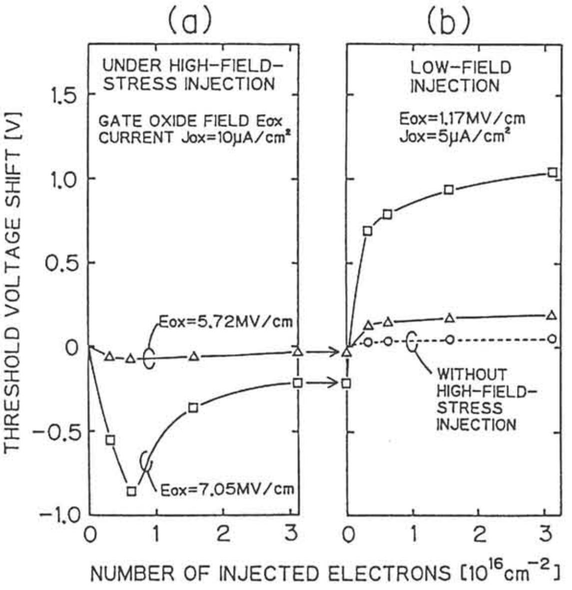

Fig.4 Threshold voltage shifts due to the current conduction in gate oxide under high-field stress (a) and those observed after subsequent hot-electron injection (b). These measurements were carried out using substrate hot-electron injection method.

Figure 3 shows the threshold voltage shifts due to hot-electron injection after ion implantation. In this experiment, the charging-up of gate electrodes was prevented by electrically connecting gate electrodes to the substrate. In the case of (B) and (C), where gate electrodes were grounded, no degradation in hot-electron immunity is observed. Although the gate area was exposed to ion beam in sample (C) as in the case of (D), degradation is not observed. However, serious degradation occurred in (D), where the gate electrode was not grounded. From these observations, we conclude that the degradation in device characteristics as well as in hot-electron immunity is caused by the charging-up of gate electrode.

In order to simulate the charge-up phenomena during ion implantation, current stress was applied to gate oxide of test devices under varying gate oxide field stresses. Then the samples were subjected to hot-electron injection under low field condition of 1.17MV/cm to see the degradation in hot-electron immunity. Examples of such experimental results are shown in Fig.4. Figure 4(a) shows the threshold voltage shift as a function of the number of injected electrons under high gate-oxide field stress condition, that simulates the gate charging-up during ion implantation. Negative shifts followed by partial recovery are observed. The negative shift observed at the initial stage is caused by trapping of holes which were created by impact ionization under high field. The following recovery would be due to electron trapping. Figure 4(b) demonstrates the results of hot-electron injection to the samples subjected to current stress under high field shown in Fig.4(a). Large positive shifts with saturation characteristics indicate a number of neutral electron traps were generated during current stress experiment of Fig.4(a).

Since the degradation is not due to the ion impact effect but to the charging-up of a floating MOS gate, similar problem occurs in plasma processes with very small ion bombardment energies (~40eV) as shown in Fig.5. Increase in threshold shift due to hot-electron injection is only observed for floating gate samples. When gate electrodes were grounded, no degradation in hot-electron injection immunity was observed for ion bombardment energies up to 110eV. Therefore it is concluded that hot-electron immunity degradation is also able to be eliminated by grounding the gate electrode during the process.

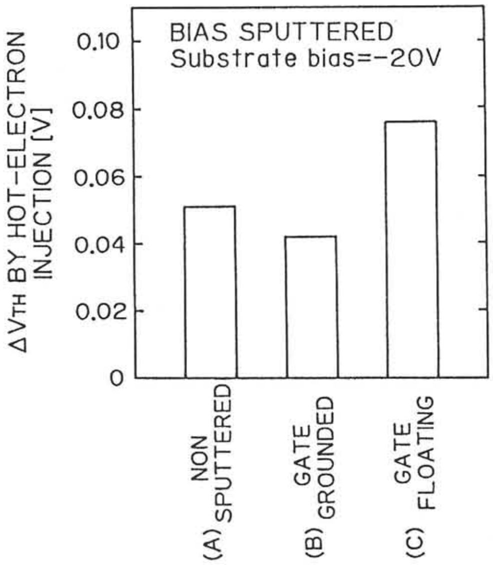

Fig.5 Threshold voltage shifts due to hot-electron injection. Test devices were deposited with Al films by low-energy bias sputtering process. Ion bombardment energy was approximately 40eV. In sample (B), the gate electrode was electrically grounded during deposition.

4. Conclusions

The degradation in MOS device characteristics as well as in their hot-electron injection immunity caused by ion-bombardment processes have been investigated. It has been found that neutral electron-traps were generated due to the charging-up of the gate electrode during ion implantation. These neutral traps contribute to positive threshold shifts by hot-electron injection. It has been demonstrated that such problems are able to be removed by grounding the gate electrode during ion implantation processes. Similar effects were also observed for a low-energy bias sputtering deposition of aluminum films.

Acknowledgment

The majority of this work was carried out in the Superclean Room of Laboratory for Microelectronics, Research Institute of Electrical Communication, Tohoku University.

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