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Performance Improvement of Nickel Salicided n-Type Metal Oxide Semiconductor Field Effect Transistors by Nitrogen Implantation

Tien-Sheng CHAO[1,2] and Liang Yao LEE[2]
[1]*Department of Electrophysics, National Chiao Tung University, Hsinchu, Taiwan 30050, R.O.C.*
[2]*National Nano Device Laboratory, Hsinchu, Taiwan 300, R.O.C.*

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Nitrogen implantation was used to improve the performance of Ni-salicide process for n-type metal oxide semiconductor field effect transistors (MOSFETs). It is found that the driving current and transconductance of nMOSFETs increase with the nitrogen implantation. The hot carrier degradation of the nMOSFETs is significantly reduced as the nitrogen dosage increases.
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KEYWORDS: nickel, salicide, nitrogen implant

The silicide-related technology has been used in submicron devices to reduce the parasitic resistance in order to improve the devices and circuit performance. Before 0.25 μm nodes, $TiSi_2$ has been widely used in industry. However, the sheet resistance of the $TiSi_2$ lines increases as line width decreases that limits the application of $TiSi_2$ salicide in 0.1 μm complementary metal oxide semiconductor (CMOS) applications and beyond.[1,2] The NiSi salicide technique has been developed as an alternative to $TiSi_2$ due to without such narrow line effect.[3] However, the problems encountered in the NiSi silicidation process are anomalously large junction leakage current and sheet resistance degradation. Recently, using TiN cap,[4] nitrogen-doped,[5] and Ti-cap[6] techniques have been reported to reduce junction leakage current. The improvement was found due to the formation of nitride layer, which prevents oxidation of silicide/silicon interface and suppresses interface roughness to a certain degree. In this paper, nitrogen implantation was used in the Ni-salicide processes to improve the n-type metal oxide semiconductor field effect transistors (MOSFETs') performance. We found that devices with this nitrogen implantation technique show an improved performance, and a significant reduction of hot carrier degradation.

Devices were fabricated on p-type (100) oriented Si wafers with resistivity of 15–25 $\Omega\cdot$cm. Processes were followed the standard nMOSFETs' processes. After well formation, local oxidation of silicon (LOCOS), was used to form isolation of devices. Thickness of gate oxide and poly-Si gate was 4-nm and 200-nm, respectively. The n^+/p junction was formed by As^+ implantation with energy of 40 keV, to a dosage of 5×10^{15} ions/cm^2. Then, nitrogen ion implantation was conducted with energy of 15 keV, to dosage of 1×10^{13}, 1×10^{14}, 5×10^{14}, and 1×10^{15} ions/cm^2. Thermal annealing was carried out in a rapid thermal process (RTP), at 1050°C for 20 s in nitrogen. After cleaning, Ni-salicide processes were conducted. Nickel (25 nm) and titanium (5 nm) films were deposited using sputtering method. All the samples were then annealed to form the salicide process in the N_2 ambient for 30 s at 600°C in a RTP system. Unreacted metal was removed by wet etching.

Figure 1 shows the I_d–V_d curves for 1 μm nMOSFETs with the Ni-salicide processes. The threshold voltages were almost the same for these devices. It is noted that devices with nitrogen implantation exhibit an increase in drain-current, or I_d, than that of device without nitrogen implantation (control). As the nitrogen dosage increases to 5×10^{14} and 1×10^{15} ions/cm^2, the I_d slightly decreases. But, it is still higher than control. The stability of the NiSi is improved by the nitrogen implantation and has reported in elsewhere.[7] Figure 2 shows the resultant transconductance at maximum in linear region, gm_{max}, for these five samples. It exhibits the same trend that nitrogen implantation increases the gm, but reduces slightly when dosage is larger than 5×10^{14} ions/cm^2. Figure 3 shows the resultant sheet resistivity, or R_s, with different nitrogen dosages for the NiSi n^+/p junctions. This was done using the Kevin structure with line width of 4 μm. It can be seen that R_s increases slightly with nitrogen implantation. However, as the dosage is larger than 5×10^{14} ions/cm^2, the R_s increases significantly. This can explain the reduction of I_d as the nitrogen dosage is larger than 5×10^{14} ions/cm^2, as shown in Fig. 1. The slight increase on R_s could be explained by the nitrogen diffusion upward into the NiSi grain boundaries.[8] The too much stuffing nitrogen at grain boundaries will increase the barrier-height; this results in an increase of R_s of NiSi n^+/p junctions. It has been reported that the nitrogen implantation on narrow active lines (0.5 μm to 1 μm) results in a decrease on sheet resistance. This reduction of the resistivity exhibits an increase (8%) of I_d for pMOSFETs.[9] Since we did not find the reduction of R_s for the n^+/p NiSi

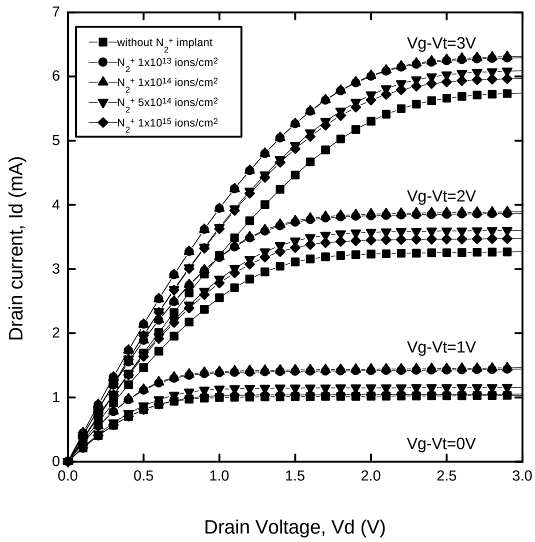

Fig. 1. The I_d–V_d curves for 1 μm nMOSFETs with and without nitrogen implantation in Ni-salicide processes.

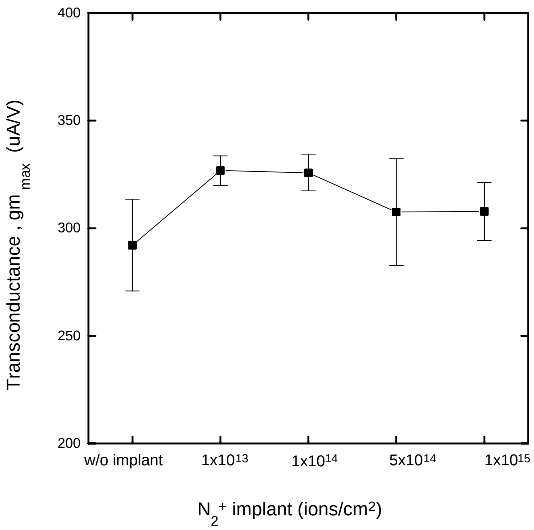

Fig. 2. The maximum transconductance for $1\,\mu$m nMOSFETs with and without nitrogen implantation in Ni-salicide processes.

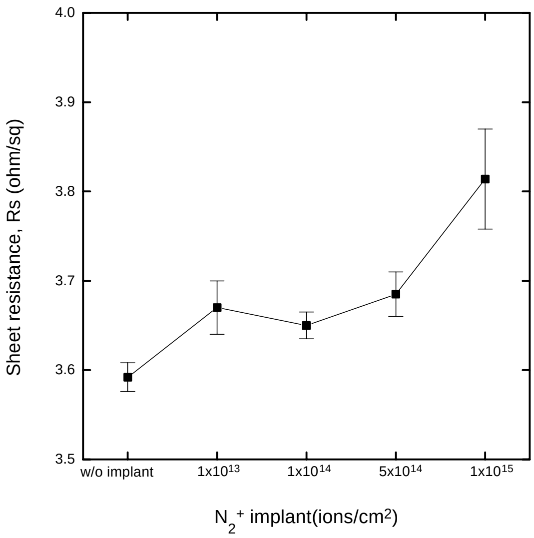

Fig. 3. The sheet resistance for $1\,\mu$m nMOSFETs with and without nitrogen implantation in Ni-salicide processes.

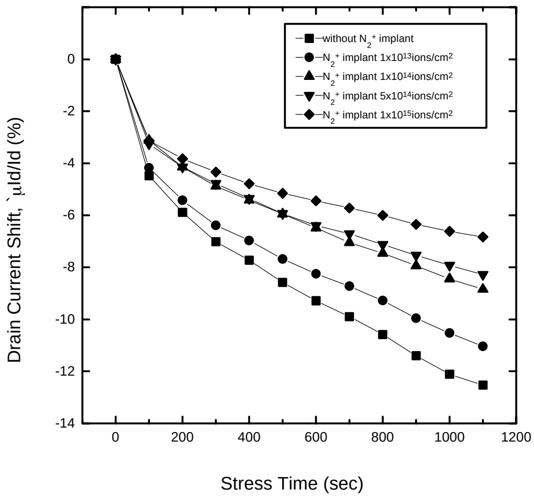

Fig. 4. The shift of drain current (%) for $1\,\mu$m nMOSFETs with and without nitrogen implantation in Ni-salicide processes under stressing at $V_g = 2$ V and $V_g = 5$ V.

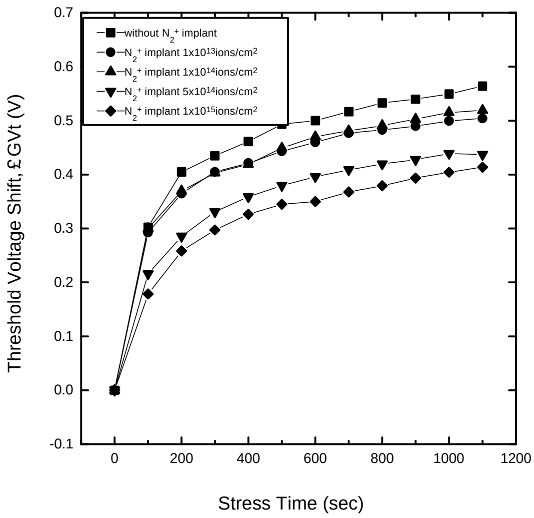

Fig. 5. The shift of threshold voltage for $1\,\mu$m nMOSFETs with and without nitrogen implantation in Ni-salicide processes under stressing at $V_g = 2$ V and $V_g = 5$ V.

junctions, it needs further investigation for this increase of I_d. The subthreshold swing, or S. S. and interface defect density, or D_{it}, were measured. We found that the S. S. decreases monotonically from 90 to 88 mV/dec as the nitrogen dosage increases to 5×10^{14} ions/cm^2. The D_{it} shows the same trend from 3×10^{12} (without nitrogen) to 2×10^{12} cm$^{-2}\cdot$eV^{-1} (with 5×10^{14} nitrogen ions/cm^2). This implies the interface property of the SiO_2/Si is improved by this nitrogen implantation, resulting in the increase of the I_d and *gm*. This is reasonable since nitrogen atoms stuffed in poly-Si grain boundaries will retard the diffusion of Ni atoms during the salicide process. Besides, the diffused nitrogen at the interface of SiO_2/Si will improve the interfacial property, and also the reliability under stressing, as we will show in followings.

Figure 4 shows the shift of drain current (percent, %) under the hot carrier stressing at Isub.max. (at $V_g = 2$ V and $V_d = 5$ V). It is noted that the shift of drain current reduces significantly as the nitrogen dosage increases. The device with higher nitrogen implantation shows the smallest shift of I_d. Figure 5 shows the shift of threshold voltage. The control device without nitrogen implantation shows the largest shift on threshold voltage, and the shift decreases as the nitrogen dosage increases. This implies that the nitrogen implantation can improve the resistance to hot carrier stressing. Since nitrogen were implanted in the salicide processes, that means poly-Si and the S/D regions were all implanted with the nitrogen. Theses nitrogen atoms will diffuse and pile up at the oxide/silicon interface. The nitrogen bonds reduce the stress at the interface,[10] which enhances the resistivity to hot carrier stressing in return.

In summary, we have developed a nitrogen implantation technique on the Ni-salicide for nMOSFETs. From this scheme, we found that the nMOSFETs' performance was improved, including drain current, transconductance, especially the resisting capability in hot carrier degradation.

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