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Reduction of Nickel-Silicided Junction Leakage by Nitrogen Ion Implantation

Tien-Sheng CHAO[1,2] and Liang-Yao LEE[2]

[1]*Department of Electrophysics, National Chiao Tung University, Hsinchu, Taiwan, R.O.C.*
[2]*National Nano Device Laboratories, 1001-1 Ta Hsueh Road, Hsinchu, Taiwan, R.O.C.*

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Nickel-silicided junctions with low leakage by using a nitrogen implantation process are demonstrated in this paper. This technique can significantly improve the leakage problem of Ni-silicided junction. Junctions formed by this method exhibit a very low leakage current density of about 1×10^{-9} A/cm^2, which represents 2–4 times reduction compared to conventional counterparts. [DOI: 10.1143/JJAP.41.L124]

KEYWORDS: nickel, silicide, junction, leakage, nitrogen

The silicide-related technology has become an integral part of submicron devices for reducing the parasitic resistance in order to improve device and circuit performance. In the past two decades, TiSi$_2$ has been widely used in industry. However, the sheet resistance of TiSi$_2$ lines increases with decreasing line width and limits the use of TiSi$_2$ salicide in 0.1 μm complementary metal oxide semiconductor (CMOS) applications.[1,2] NiSi salicide technique, which is free from the above-mentioned narrow line effect, has been proposed as an alternative to TiSi$_2$.[3] However, NiSi silicidation process suffers from an anomalous high junction leakage current and sheet resistance degradation. Recently, techniques such as TiN cap,[4] nitrogen-doped,[5] and Ti-cap[6] have been reported to reduce junction leakage current. The improvement is believed to be due to the formation of nitride layer, which prevents oxidation of silicide/silicon interface therefore suppresses interface roughness to a certain degree. In this paper, nitrogen ion implantation in the source/drain junctions was demonstrated to reduce junction leakage of both n$^+$/p and p$^+$/n junctions. Very low junction leakage of about 1 nA/cm^2 can be achieved.

Devices were fabricated on p-type (100)-oriented Si wafers with resistivity of 15–25 Ω·cm. A standard CMOS process was adopted for both n$^+$/p and p$^+$/n junctions. After well formation, local oxidation of silicon, or LOCOS, was used to form isolation of devices. The n$^+$/p junction was formed by As$^+$ implantation with energy of 40 keV, to a dosage of 5×10^{15} ions/cm^2. While p$^+$/n junction was formed by B$^+$ implantation with energy of 30 keV, to a dosage of 6×10^{15} ions/cm^2. Then, wafers were split to receive nitrogen ion implantation of various dosages, i.e., 1×10^{13}, 1×10^{14}, 5×10^{14}, 1×10^{15}, and 5×10^{15} ions/cm^2, all with energy of 15 keV. Thermal annealing was carried out in a rapid thermal process (RTP) at 1050°C for 20 seconds in nitrogen. Nickel (25 nm) and titanium (5 nm) films were deposited using sputtering method. All samples were then annealed to form the salicide process in N$_2$ ambient for 30-s at different annealing temperatures (i.e., 600, 700, 750, 800, and 850°C) in a RTP system. Unreacted metal was removed by wet etching. Current–voltage (I–V) characteristics of the junctions were measured by Hp-4156. Areas of both junctions were $100 \times 900\,\mu$m^2, $300 \times 300\,\mu$m^2, and $1000 \times 1000\,\mu$m^2. The voltage biases were 3 V for n$^+$/p and -3 V for p$^+$/n, respectively.

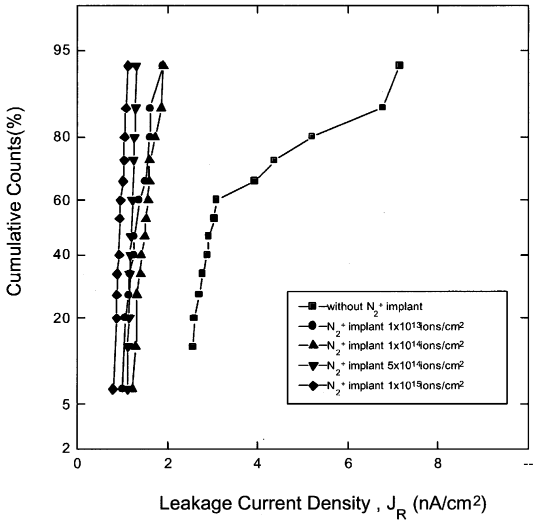

Fig. 1. Distribution of junction leakage of p$^+$/n at -3 V.

Figure 1 shows distribution of leakage of p$^+$/n Ni-silicided junctions. The area is $1000 \times 1000\,\mu$m^2. It is found that junctions without nitrogen implantation (i.e., control) show a wider and larger distribution of leakage than samples with nitrogen implantation. Nitrogen implanted samples exhibit tight distributions, which implies that more uniform electrical properties can be obtained by nitrogen implantation scheme. Leakage lower than 1 nA/cm^2 can be achieved with an implant dosage of 1×10^{15} ion/cm^2. However, when the dosage increases to 5×10^{15} ion/cm^2, the leakage increases and becomes comparable to that of the control. This is due to large defects generated by high-dose nitrogen implantation. These defects cannot be annealed out in the short thermal cycle by RTP. There are two possible reasons for the observed improvement by nitrogen implantation. The first is that nitrogen diffuses out at the interface of NiSi–Si junction and forms a barrier layer to retard the oxygen diffusion into junctions. This is possible since the solid solubility of nitrogen in silicon is low.[7] The second reason is due to the stuffing of nitrogen into NiSi grain boundaries. In NiSi formation processes, the diffusion specie is Ni, stuffing the grain boundary by nitrogen can limit the diffusion, which reduces the roughness of the junction and therefore the leakage. In general, the direction of leakage was analyzed and could be separated into two components, J_a and J_p, by using the equation $J_r = J_a + (P/A) \times J_p$, where P is the perimeter and A is the area of the junction. J_p, perimeter junction leakage, can be deduced from the slope of the curves of J_r vs P/A, while J_a can be deduced from inter-

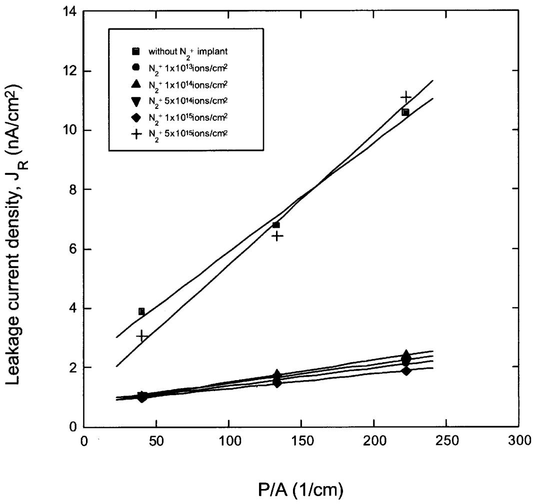

Fig. 2. Leakage current density (J_r) of NiSi silicided p$^+$/n junction at -3 V vs different P/A ratios.

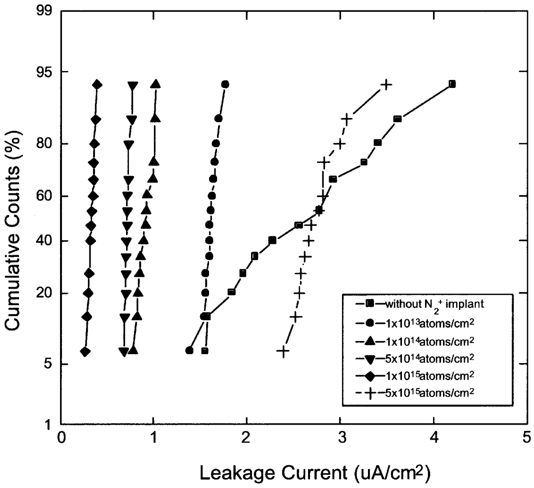

Fig. 3. Distribution of junction leakage of n$^+$/p at $+3$ V.

sect. In Fig. 2, it is clear that both J_a and J_p are reduced significantly by the nitrogen implantation. When nitrogen dosage increases to 5×10^{15} ions/cm^2, the leakage increases to a level comparable to that of the control.

The impact on n$^+$/p junction leakage distribution is shown in Fig. 3. Since we did not include the channel stop implantation before the formation of n$^+$/p junction, the leakage level is higher than that of the p$^+$/n junction. Nonetheless, significant leakage reduction can be found in Ni-silicided n$^+$/p junction. Similar trend is found in that the distribution of the p$^+$/n junction leakage is wider and larger for the control, and tighter and smaller for the nitrogen-implanted counterpart. A higher dosage results in a lower leakage. However, when the dosage increases to 5×10^{15} ion/cm^2, the leakage increases due to the large defects generated by the high dose ion implantation. Figure 4 shows the J_r vs P/A curves. It is clear that the J_a and J_p are all reduced by the nitrogen implantation.

As mentioned above, the most serious problem of NiSi is the thermal stability. When the annealing temperature increases to 750°C, NiSi will either change its phase to NiSi$_2$ or agglomerate. Both result in undesirably high resistivity. Figure 5 shows the leakage of n$^+$/p Ni-silicided junction with nitrogen implantation at different annealing temperatures. The dosage used is 1×10^{15} ion/cm^2. The area of the junction is $500 \times 500\,\mu$m^2. No increase in leakage is found for temperature up to 800°C. This indicates that the nitrogen implantation can gain some processing margin, i.e., increasing the thermal stability from 750°C to 800°C.

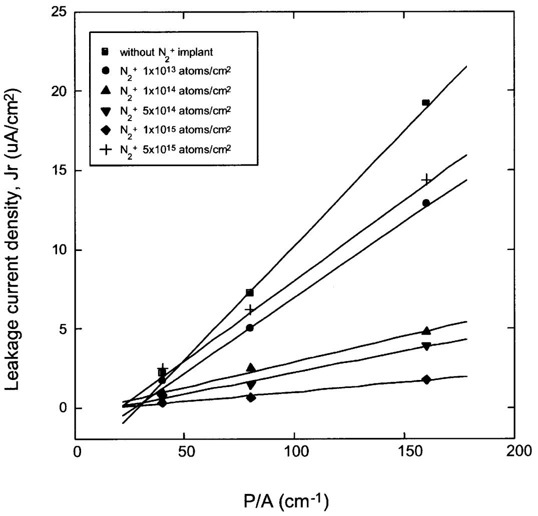

Fig. 4. Leakage current density (J_r) of NiSi silicided n$^+$/p junction at $+3$ V vs different P/A ratios.

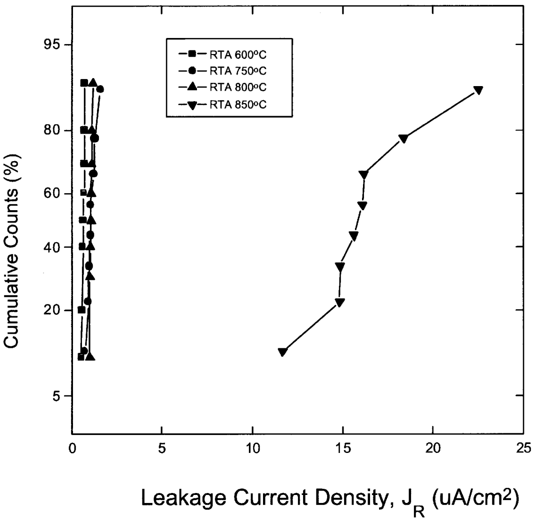

Fig. 5. Leakage current distribution of n$^+$/p junction under different annealing temperatures.

In summary, we have developed a NiSi process with nitrogen implantation process. Our results show that this technique can significantly reduce junction leakage currents for both n$^+$/p and p$^+$/n. The process temperature can also be extended to as high as 800°C.

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