The Influence of Ge-Implantation on the Electrical Characteristics of the Ultra-Shallow Junction Formed by Using Silicide as a Diffusion Source

C. T. Huang, T. F. Lei, C. H. Chu, and S. H. Shvu

Abstract—**The electrical characteristics of ultra-shallow p^+/n junctions formed by implanting a 60 keV Ge^+ into a $TiSi_2$ layer have been studied. A very low reverse leakage current density (≅0.4 nA/cm^2 at −5 V) and a very good forward ideality factor n (≅1.001) were achieved in these ultra-shallow p^+/n junctions. From the secondary ion mass spectrometry (SIMS) analysis, the junction depth was measured to be 600 Å and the surface concentration was about 3 times higher than that of the conventional samples.**

I. Introduction

DUE to the continuing scaling-down of the silicon integrated circuit, shallow junctions are needed to minimize device punchthrough and short-channel effects. $TiSi_2$ has been found widespread applications in VLSI as gate electrodes, interconnections, and contacts for its low resistivity, good thermal stability, and ability to be used in a self-aligned (salicide) process. In the conventional implant through silicide (ITS) process, the higher chemical affinity of As and B to the Ti-silicide results in dopant trapping during silicidation [1], [2] and only a small percentage of the implanted dopant is diffused into the silicon substrate.

Recently, germanium has been the prime candidate for preamorphizing the crystal substrate in order to eliminate channeling effects and reduce junction depths. However, in the preamorphized B-implanted junctions, the point defects created by the implantation can have a strong influence on the junction leakage [3], [4]. One approach uses implantation of Ge^+ ions through the silicide to suppress boron channeling by preamorphization of silicon and obtains higher dopant activation during a RTA cycle [5]. However, dislocation loops below the original amorphous/crystalline (a/c) interface and the existence of deep level defects due to knock-on Ti atoms induce an unacceptable leakage. Another approach using ion beam mixing to form p^+/n shallow junctions was proposed using germanium-implantation through the Ti metal films [6]. Similarly, knock-on Ti gives leaky junctions. In this study, implanted Ge atoms were completely located inside the $TiSi_2$ layer instead of amorphizing the silicon substrate. The I–V characteristics of the shallow p^+/n junctions with Ge-implant are greatly improved as compared with junctions without Ge-implant. Electrical effects of the Ge-implant and the dopant redistribution are discussed.

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II. Experiments

P-type (100)Si wafers with resistivity of $1 \sim 5\ \Omega \cdot$cm were used in this work. Oxide with thickness of about 5500 ~ 6000 Å was thermally grown by pyrogenic oxidation at 1050°C for 60 min. After defining the active regions by BOE solution, thin bilayer films of Ti (500 Å) and amorphous Si (50 Å) were deposited and annealed at 625°C for 20 min in a conventional furnace. The unreacted Ti and TiN were chemically removed and the thickness of $TiSi_2$ was about 650 Å. Following the implantation of Ge^+ at an energy of 60 keV to a dose of 5×10^{14} cm^{-2}, boron was implanted at 10 keV to a dose of 5×10^{15} cm^{-2}. Using TRIM Code [7] simulations of 60 keV germanium and 10 keV boron implant shows that the implanted atoms were all located inside the 650 Å $TiSi_2$ layer. Finally, the "Drive-in" process was carried out at 800~950°C for 15 min in an N_2 ambient to form C54-$TiSi_2$ and p^+/n junctions. In this experiment, the control samples were fabricated by the conventional implant through silicide (ITS) scheme. The Ti-silicided p^+/n junctions were characterized by I–V and secondary ion mass spectrometry (SIMS) measurements.

III. Results and Discussion

The average leakage current of the samples with and without Ge-implantation are shown in Fig. 1. The reverse current densities (Jr) at −5 V reverse bias were plotted as a function of the second silicidation temperatures. In this experiment, at least ten diodes (with $500 \times 500\ \mu$m^2) were measured to obtain the average value of Jr. As shown, the reverse leakage of the Ti-silicided p^+/n junction is improved by the Ge-implant. At a reduced thermal budget, such as 800°C for 15 min, Jr values were measured to be 0.5 nA/cm^2 for the diodes with the Ge-implant. While, at the same thermal budget, poor Jr values (5 nA/cm^2) were obtained from the control samples. The leakage currents of the conventional $TiSi_2$ contacted p^+/n junctions were in a larger range between 2 nA/cm^2 ~ 10 nA/cm^2 at −5 V reverse bias. Diodes with the Ge implant showed uniform leakage (0.5 nA/cm^2). From atomic force

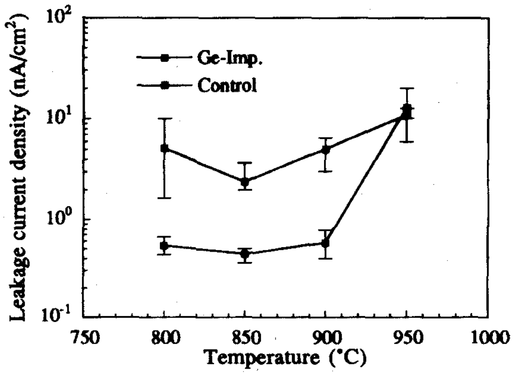

Fig. 1. Reverse leakage current density after annealing for 15 min at various temperatures in an N_2 ambient.

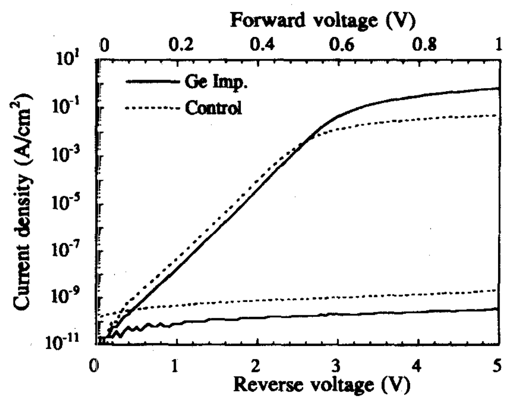

Fig. 3. Log I–V plots of p^+/n junctions with and without Ge implantation.

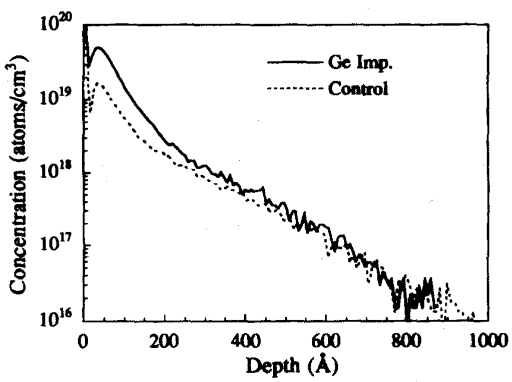

Fig. 2. SIMS boron profiles of both conventional and Ge-implanted $TiSi_2$ p^+/n junctions annealed at 850°C for 15 min.

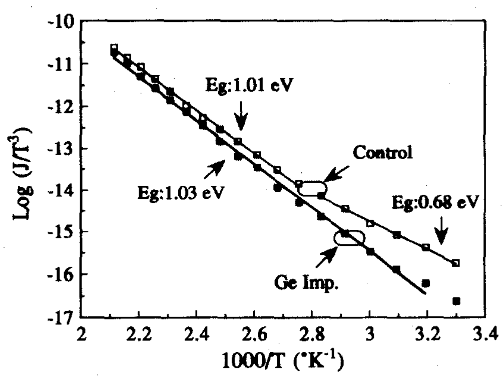

Fig. 4. An Arrhenius plot for p^+/n junctions, with the same condition of Fig. 3 at −5 V reverse bias.

microscopy (AFM) and scanning electron microscopy (SEM) investigations, surface roughness of both samples are the same. The larger leakage current observed in the control samples is expected to be induced by the lateral injection of vacancies across the junction edges [8]. In the silicided junctions with Ge-preimplant, the edge defects induced leakage current is suppressed. As the annealing temperature increases up to 950°C, the leakage current for both samples drastically increases due to the agglomeration of the Ti-silicide.

The dopant redistributions measured after removing the silicide layer are shown in Fig. 2. The junction depths in both samples were measured to be about 600 Å, at a concentration level of 10^{17} cm^{-3}. The well-known immobility of B in $TiSi_2$ is due to the precipitation of TiB_2. The formation of metal-dopant compound reduces the dopant concentration beneath the $TiSi_2$/Si interface. The diffusivity of Ge in the $TiSi_2$ film is faster as compared with other dopants, such as P, As, B, and Sb atoms and the solubility is very high [9]. It is suggested that the probability of TiB_2 formation is suppressed due to the addition of the mobile Ge atoms which attract boron to diffuse together [10]. The surface concentration of B in a Ge-implanted sample is about 3 times higher than that in the control sample as shown in Fig. 2.

Fig. 3 shows the typical forward and reverse I–V characteristics of both samples appealed at 850°C for 15 min. The diodes fabricated with Ge-implantation achieve nearly ideal forward-bias behavior with an ideality factor $n \leq 1.001$ over 7 decades on a log scale and the reverse current density of 0.4 nA/cm^2 at -5 V reverse bias.

According to the theory for the temperature dependence of junction current, the reverse leakage is composed of diffusion current and generation current. Fig. 4 shows an Arrhenius plots of $\log(J_S/T^3)$ versus $1/T$ for the samples shown in Fig. 3. For conventional ITS diodes, there is a distinct change of slope at 90°C, which indicates the change of dominate component of leakage current, while in Ge-implanted diodes a constant activation energy of 1.03 eV, which are fairly close to the silicon bandgap of 1.12 eV was obtained. It clearly indicates that in a silicided junction with a Ge-implant, diffusion current is the dominate component of reverse leakage current.

IV. Conclusions

In this study, we have demonstrated that the Ge atoms implanted into the $TiSi_2$ layer can effectively improve the I–V characteristics of the conventional ITS junctions. From SIMS data analysis, it was found that a higher surface concentration is obtained in the samples with Ge-implantation. The leakage current in the p^+/n diode with Ge-implantation is much lower than that of the conventional one. The higher B concentration in the $TiSi_2$/Si interface with Ge-implantation will effectively lower the contact resistance.

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