The Reverse Anneal of Junction Characteristics in Forming Shallow p^+-n Junction by BF_2^+ Implantation into Thin Co Films on Si Substrate

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Abstract—**Silicided shallow p^+-n junctions, formed by BF_2^+ implantation into thin Co films on Si substrates and subsequently annealed, show a reverse anneal of junction characteristics in the temperature range between 550 and 600°C. The reverse anneal means a behavior showing the degradation of considered parameters with increasing anneal temperature. A higher implant dosage causes a more distinct reverse anneal. The reverse anneal of electrical characteristics was associated with the reverse anneal of substitutional boron. A shallow p^+-n junction with a leakage current density lower than 3 nA/cm^2, a forward ideality factor better than 1.01, and a junction depth of about 0.1 μm was therefore achieved by just a 550°C anneal.**

I. INTRODUCTION

THE self-aligned metal silicide technology has proven to be a highly desirable technique for fabricating submicrometer MOS integrated circuits [1]–[4]. As the device dimensions shrink, a concomitant reduction in source/drain junction depth is required to minimize short-channel effects. Anomalous boron diffusion will considerably deepen the junctions during high-temperature processing, especially if the implant dosage is high. Hence, shallow p^+-n junctions with good characteristics are difficult to implement by traditional techniques. An alternate method to make silicided shallow junctions is to deposit a thin metal layer and then implant dopant through the metal layer (ITM scheme). This technique is promising because most of the implant-induced damage affects the metal layer rather than the Si substrate, thus lowering the required thermal budgets. In addition, the implantation also serves to ion-mix the metal/Si interface and thus promotes the silicide formation [5]–[7].

In this paper, silicided shallow p^+-n junctions were formed by BF_2^+ implantation into thin Co films on Si substrate and subsequent drive-in/silicidation. Different implant conditions were used to determine their effects on the resultant junctions.

II. EXPERIMENTAL PROCEDURE

(100) oriented, 0.55–1.1 Ω · cm, phosphorus-doped Si wafers were used. A 4500-Å-thick thermal oxide layer was grown for patterning the active region of the diodes as well as for the utilization of selective etching. After the patterning, a thin Co film of 300 Å thickness was deposited onto the wafers in an electron-gun evaporation system. An amorphous-Si (a-Si) capping layer of 50 Å thickness was then evaporated to prevent Co from being oxidized during annealing. The as-deposited samples were then BF_2^+-implanted at 70 keV to doses of 1×10^{14}, 5×10^{14}, and 1×10^{16}-cm^{-2}. A two-step annealing process was undertaken to form self-aligned silicided junction regions [8]. The second-step annealing was processed at temperatures ranging from 500 to 800°C for 30 min in an N_2 ambient.

III. RESULTS AND DISCUSSION

The J_r value is defined to be the leakage current density at −5 V at room temperature. At least ten diodes for each sample were taken to evaluate the average value. Fig. 1 shows the dependence of J_r on annealing temperature for the samples implanted to a dose of 1×10^{14} cm^{-2}. The J_r values monotonically decreased with increasing anneal temperature, for better damage annihilation and dopant activation at higher temperatures.

However, as the implant dosage was raised to 5×10^{14} cm^{-2} (medium dose) or even to 1×10^{16} cm^{-2} (high dose), significant phenomena occurred in the temperature region between 550 and 600°C. Fig. 2 shows the dependencies of J_r on annealing temperature for the specimens implanted to doses of 5×10^{14} and 1×10^{16} cm^{-2}. Fig. 3 shows the forward ideality factor corresponding to Fig. 2. The medium- and high-dose implants led to better junctions than the low-dose one, since the dopant activation was enhanced with increasing implant dose. More defects were induced by higher implant doses. In this ITM scheme, however, a low-dose implant is unfavorable to junction formation. Thereby, a proper implant dose should be used to optimize the resultant junctions.

From Figs. 2 and 3, the J_r and n values considerably decreased with increased anneal temperature from 500 to 550°C. This decrease is due primarily to the enhanced annihilation of point-defect disorders and increased dopant activation. Also, higher temperature annealing provides higher drive-in efficiency. Thereby, although a reverse anneal of substitutional boron, forming junctions by direct B^+ implantation into Si [9], [10], was shown to occur at 500 ~

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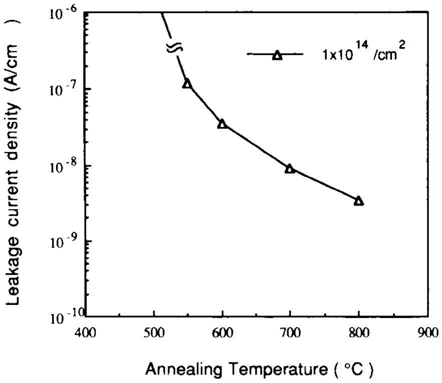

Fig. 1. Dependence of leakage current density on annealing temperature for the samples implanted at 70 keV to a dose of 1×10^{14} cm^{-2}.

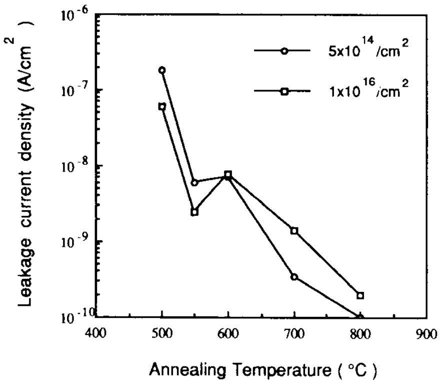

Fig. 2. Dependencies of leakage current density on annealing temperature for the samples implanted at 70 keV to doses of 5×10^{14} and 1×10^{16} cm^{-2}.

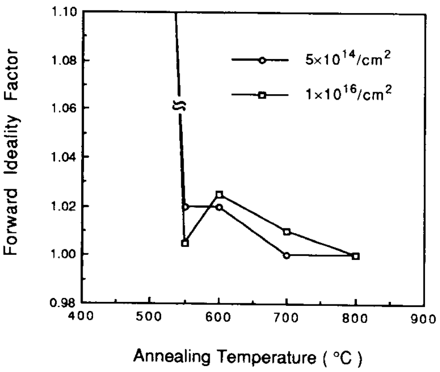

Fig. 3. Forward ideality factors corresponding to Fig. 2.

550°C, no reverse anneal of junction characteristics was observed in junctions formed by the present ITM scheme. This also reflects that boron precipitation is less significant relative to other factors impacting the junction characteristics at 500 ~ 550°C. The reverse anneal means a behavior showing the degradation of considered parameters (electrically activated dopants and junction characteristics here) with increasing anneal temperature. The high-dose implant led to better junctions than the medium-dose implant at annealing temperatures lower than 600°C due to larger dopant concentration. At annealing temperatures higher than 600°C, however, the high-dose implant resulted in worse junctions than the medium-dose one. Lower implant doses induced less damage. Hence, as the annealing temperature was high enough to activate sufficient dopant to form good junctions, the samples with less damage inherently developed better junctions. High-temperature annealing did not deteriorate the junctions, implying the absence of Co penetration in this scheme.

However, it is found from Fig. 2 that as the annealing temperature increased from 550 to 600°C, the junction formation was slightly degraded. The medium- and high-dose implants resulted in reverse annealing of junction characteristics at 550 ~ 600°C, in contrast to the low-dose implant. In addition, the high-dose implant manifested more distinct reverse annealing than the medium-dose one. The leakage of both samples displayed deviations within 10% of the mean value J_r, indicating a good reliability.

Being accompanied with a small increase of sheet resistance in junction regions, the occurrence of reverse anneal of junction characteristics was suggested to be associated with the reverse anneal of activated dopants in the temperature region. Transmission electron microscopy examination of the junctions showed extended defects (dislocations). And the junctions formed at 700°C exhibited fewer defects than at lower temperatures. The formation of the dislocation structure in the temperature range was coincident with the removal of substitutional boron [9], [10]. The boron may be precipitated on or near dislocations. As a result, the junctions for the samples annealed at 600°C were worse than at 550°C due to the decrease of activated dopants. The medium-dose implant generated much less damage than the high-dose one, thus inducing less extended defect and boron precipitation after annealing. Dislocations were suggested to be absent for the low-dose implant, thus showing no reverse anneal. Annealing at temperatures higher than 600°C, vacancies were generated and then moved to the nonsubstitutional boron (precipitated), allowing the boron to dissociate from the nonsubstitutional precipitated site. Therefore the junctions were improved significantly.

Shallow p^+-n junctions, formed by the high-dose implant and subsequently annealed at 550°C, showed a leakage current density lower than 3 nA/cm^2, a forward ideality factor better than 1.01, a junction depth of about 0.1 μm below the silicides, and a hard-breakdown behavior with a breakdown voltage above 25 V. The junction depth was achieved using a spreading resistance probe apparatus and also a SIMS analysis. Previously, shallow p^+-n junctions were difficult to realize at low temperatures, resulting from the severely damaged junctions, though higher activation efficiency can be obtained at lower temperatures because of the reverse anneal. Thereby, annealing temperatures higher than 800°C were needed to form good junctions. The present ITM scheme with Co as the implantation barrier, on the other hand, can provide sufficient dopant activation at low annealing temperatures and cause scarce defects in junction regions. The silicidation of Co into $CoSi_2$ would greatly annihilate the damage. And the crystallinity of $CoSi_2$ formed at low temperatures is good enough to drive the implanted dopant into junctions, reflecting the lessened dopant confinement caused by silicide grains. This process makes it possible to use the characteristics of boron activation to form good junctions, indicating a good activation efficiency even at low temperatures. Hence, the present modified reverse anneal greatly facilitates fabricating CMOS devices in VLSI circuits at very low thermal budgets.

IV. CONCLUSIONS

Silicided shallow p^+-n junctions formed by the present ITM scheme showed a reverse anneal of junction characteristics at 550 ~ 600°C. It is associated with the reverse anneal of substitutional boron. Higher implant doses formed more extended defects coincident with the boron precipitation, after annealing, thus causing more distinct reverse annealing. This scheme provides sufficient dopant drive-in and good damage annihilation, which makes it possible to use the good activation efficiency at low temperatures to form good junctions even for just a 550°C anneal.

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