Improved NiSi Salicide Process Using Presilicide N_2^+ Implant for MOSFETs

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***Abstract*—An improved Ni salicide process has been developed by incorporating nitrogen (N_2^+) implant prior to Ni deposition to widen the salicide processing temperature window. Salicided poly-Si gate and active regions of different linewidths show improved thermal stability with low sheet resistance up to a salicidation temperature of 700 and 750 °C, respectively. Nitrogen was found to be confined within the NiSi layer and reduced agglomeration of the silicide. Phase transformation to the undesirable high resistivity $NiSi_2$ phase was delayed, likely due to a change in the interfacial energy. The electrical results of N_2^+ implanted Ni-salicided PMOSFETs show higher drive current and lower junction leakage as compared to devices with no N_2^+ implant.**

***Index Terms*—Ni salicidation, nitrogen implant.**

I. Introduction

NiSi has become one of the promising candidates for silicide applications in submicron CMOS technology due to its one step low temperature formation and low sheet resistance with no linewidth dependence. Compared to Ti and Co silicides, NiSi has the lowest Si consumption during silicidation, which is an attractive feature for future CMOS devices. However, potential problems with NiSi are agglomeration even at temperature as low as 600 °C [1] and transformation to the high resistivity $NiSi_2$ phase at 750 °C.

Ni sputtering in nitrogen containing ambient has been shown to result in improved silicide film properties like the interface roughness of NiSi [2]. Incorporation of N_2^+ implant into poly-Si has been proposed as a mean of reducing agglomeration of $CoSi_2$ on the gate region [3]. Recently, there has been study on the effects of nitrogen implantation on the shallow junction formation with Ni silicide [4]. However, the implantation of nitrogen, which was done before junction formation, can cause poor electrical activation of dopants. In the present study, the incorporation of nitrogen implant was done on the gate and active regions prior to Ni deposition. The incorporation of the presilicide N_2^+ implant was able to reduce agglomeration of the silicides and delay the nucleation of $NiSi_2$. The improved electrical performance of this new Ni–salicide scheme is reported for PMOSFETs.

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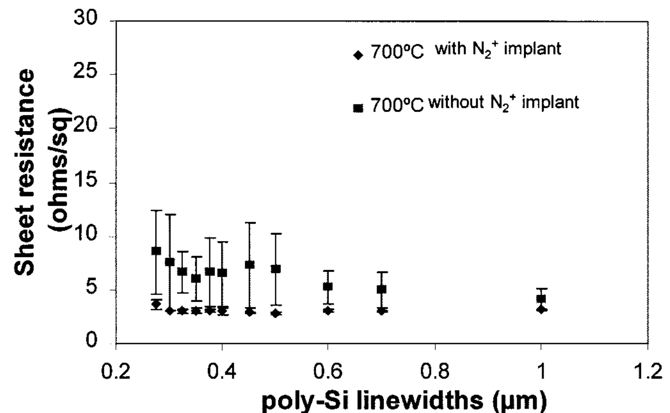


Fig. 1. Sheet resistance of poly-Si with and without N_2^+ implant after Ni–salicidation at 700 °C as a function of poly-Si linewidths.

II. Experiment

After the growth of a 6.5 nm gate oxide on (100)-p-type Si substrate, 2550 Å poly-Si was deposited using LPVD. n^+ and p^+ dopings were carried out by As implant of 2×10^{15} cm^{-2}, 50 keV, and BF_2 implant of 2×10^{15} cm^{-2}, 40 keV, respectively. After thermal activation of the dopants, a N_2^+ implantation of 6×10^{14} cm^{-2} at 15 keV was blanket implanted onto both gate and active regions. This was followed by an annealing step at 950 °C for 60 s. Ni films of about 25 nm was sputter deposited after a dilute HF dip. Ni salicidation was carried out at 600 °C to 900 °C by rapid thermal annealing in N_2 ambient for pattern and blanket wafers with and without N_2^+ implant. Unreacted Ni was removed using H_2SO_4: H_2O_2 etchants. Sheet resistance of poly-Si and diffusion regions was measured as a function of linewidths using Kelvin structures. Electrical characterization was done on PMOSFETs after Ni salicidation using the presilicide nitrogen implantation scheme.

III. Results and Discussion

Fig. 1 shows the sheet resistance of Ni-salicided n^+ poly-Si of different linewidths after rapid thermal annealing at 700 °C. For samples without N_2^+ implant the sheet resistance of the poly-Si lines deteriorates once the annealing temperature reaches 700 °C due to agglomeration. This could also be attributed to the formation of $NiSi_2$ but $NiSi_2$ usually forms at higher temperatures ($\geq$750 °C). In contrast, no degradation

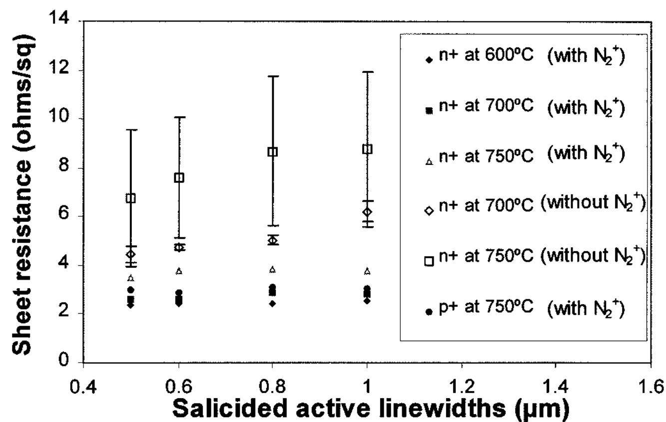


Fig. 2. Sheet resistance of Ni-salicided n^+ and p^+ narrow active lines of various linewidths with and without N_2^+ implant.

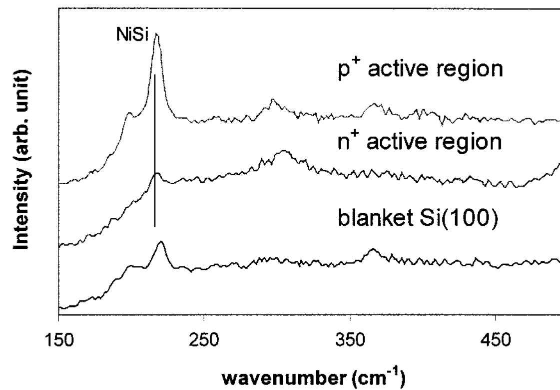
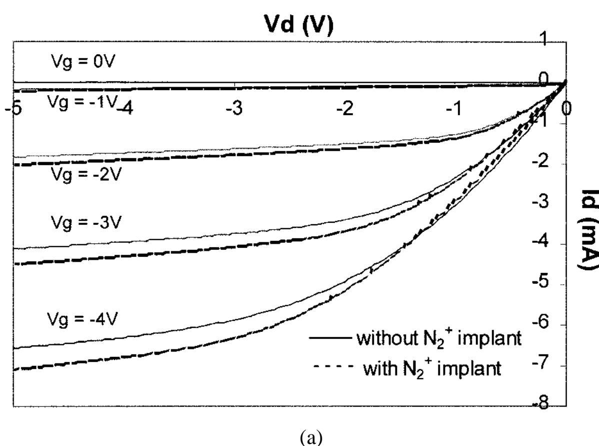


Fig. 3. Raman spectra of Ni–silicide formed at 750 °C on N_2^+ implanted blanket Si and narrow active regions.

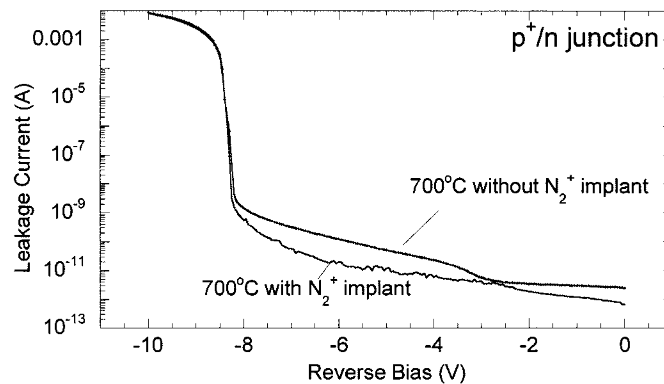
in sheet resistance was observed for N_2^+ implanted poly-Si lines due to the absence of agglomeration or alleviation of poly-inversion [5]. Fig. 2 shows the sheet resistance of the Ni-salicided active lines of various linewidths with and without N_2^+ implant. For Ni-salicided active lines without N_2^+ implant, high values of n^+ sheet resistance were obtained consistent with the results of Ohguro *et al.* [2]. Improvements using N_2^+ implant were observed particularly on the salicided n^+ active lines, which exhibit uniform low sheet resistance as compared to those without N_2^+ implant. Both n^+ and p^+ salicided lines can achieve low sheet resistance up to 750 °C. However a slight increase in sheet resistance of n^+ lines after annealing at 750°C was observed and will be discussed later.

Nitrogen seems to be effective in retarding agglomeration for Co [3] and Ti [6] silicides as well as Ni silicides as indicated by our results. Agglomeration results from the solid-state diffusion to minimize the surface/interface energy in the system and depends on the film thickness, grain size, interfacial and surface energies as well as the surface and interface diffusion [5]. However, the exact influence of these parameters is still not fully understood [5]. SIMS results (not shown) indicates that the implanted nitrogen is confined within the silicide layer after annealing at 600 °C. This may be due to segregation of nitrogen at the grain boundaries which can change the grain boundary energies. Nitrogen can also react with Si or Ni to form nitrides and improve the agglomeration resistance by changing the interfacial energies or/and surface diffusion.

From micro-Raman analysis as shown in Fig. 3, NiSi was found to be present after annealing at 750 °C for blanket Si wafers and narrow p^+ and n^+ active regions that were implanted with N_2^+ whereas $NiSi_2$ was formed on wafers without N_2^+ implant. This was shown by the presence of a peak at around 217 cm^{-1} [7]. For n^+ active lines annealed at 750 °C, the decrease of the NiSi peak intensity at 217 cm^{-1} together with the presence of the Si Raman peak at 521 cm^{-1} indicates a partial agglomeration and can explain the slight increase in the sheet resistance (Fig. 2). Since the formation of $NiSi_2$ is known to be nucleation controlled, the change in $NiSi_2$ formation temperature may be related to a change in the interfacial energies induced by nitrogen. Thus, N_2^+ implant has an effect on both the Ni silicide agglomeration resistance and phase transformation temperature.



(a)



(b)

Fig. 4. (a) I_d–V_d characteristics of a 0.35 μm PMOS transistors with Ni–salicidation at 700 °C with and without N_2^+ implant. (b) Junction leakage current for Ni-salicided on N_2^+ implanted p^+/n junctions. Area of the junction is 9936 μm^2.

Incorporation of the Ni–salicide process with N_2^+ implantation was done on PMOSFETs. Fig. 4(a) shows the I_d–V_d characteristic of a 0.35 μm gate length and 25 μm width PMOSFET after Ni-salicided at 700 °C with and without the N_2^+ implant. The drain current of the device with N_2^+ implant increased by about 8% compared to that without N_2^+ implant, due to the reduced sheet resistance of the source and drain region. Fig. 4(b) shows the improvement in the junction leakage for the N_2^+ implanted p^+/n

junction with Ni-salicided at 750 °C (diode size $= 9936\ \mu m^2$). It was reported that nitrogen doped Ni-salicided junctions have improved junction leakage due to the reduced interface roughness [2]. Moreover, nitrogen implant into Si forms a secondary surface defect region, which acts as a proximity gettering site and eliminate the end of range defects of implantation [8].

IV. Conclusion

The incorporation of nitrogen implant prior to Ni deposition has allowed a wider processing temperature window for Ni–salicide process by improving the silicide thermal stability. N_2^+ implantation can retard NiSi agglomeration and the change in interfacial energy has resulted in delayed nucleation of the high resistivity $NiSi_2$ formation. Low sheet resistance was achieved on poly-Si and active lines at temperatures of 700 °C and 750 °C, respectively. These optimized properties of NiSi at high temperatures were integrated into PMOSFETs, which show increased drive current and improvements in junction leakage current.

Acknowledgment

The authors thank R. Lee and W. D. Wang for technical assistance, and A. See and C. S. Ho for valuable discussions.

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