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Thermal Stability Improvement of the Ni Germano-silicide formed by a novel structure Ni/Co/TiN using 2-step RTP for Nano-Scale CMOS Technology

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Abstract

In this paper, Ni Germano-silicide formed on undoped $Si_{0.8}Ge_{0.2}$ as well as source/drain dopants doped $Si_{0.8}Ge_{0.2}$ was characterized by the four-point probe for sheet resistance, x-ray diffraction (XRD), x-ray photoelectron spectroscopy (XPS) and field emission scanning electron microscope (FESEM). Low resistive NiSiGe is formed by one step RTP (Rapid thermal processing) with temperature range at 500 ~ 700℃. To enhance the thermal stability of Ni Germano-silicide, Ni/Co/TiN structure with different Co concentration were studied in this work. Low sheet resistance was obtained by Ni/Co/TiN structure with high Co concentration using 2-step RTP and it almost keeps the same low sheet resistance even after furnace annealing at 650℃ for 30 min.

1. Introduction

$Si_{1-x}Ge_x$ materials are receiving increased experimental attention because of their applicability in optoelectronic, high speed, and high power devices.[1-3] The use of these alloys allows the technique of band-gap engineering to be applied in silicon technology. Self-aligned silicides (salicide) are widely used in metal-oxide-semiconductor (MOS) manufacturing to reduce the sheet resistance and contact resistance of the gate polysilicon and diffusion areas. Although Co silicide ($CoSi_2$) has been widely used for VLSI process due to its good thermal stability, it is sensitivity to ambient contamination and has a high silicon consumption, which can result in drastic increase of junction leakage current in ultra shallow junction.[4-5] Ni is a good candidate for future salicide technology because of its low resistivity, low formation temperature, and little silicon consumption, but it has a poor thermal stability. Moreover, the thermal stability of Ni Geramno-silicide is much bad than that of Ni silicide.[6-8] To integrate SiGe into current ULSI process successfully, developing a high quality Germano-silicide technology is indispensable.

In this study, we used Ni/Co/TiN structure, and also a two-step RTP to realize highly thermal stable NiSi on the SiGe substrate. To characterize the thermal stability of Ni Germano-silicide, high temperature furnace annealing from 500℃ to 700℃ for 30 min at N_2 ambient is applied after silicidation. It is shown that the proposed method is effective in realizing low sheet resistances and improving thermal stability of Ni Germano-silicide.

2. Experiment

In this work, undoped as well as doped $Si_{0.8}Ge_{0.2}$ films epi-grown on Si wafers were used. After a surface cleaning of the $Si_{0.8}Ge_{0.2}$ films in dilute HF for 10s, Ni, Co and TiN were deposited sequentially by Ion Beam Sputter (IBS) with a base pressure of 7×10^{-7} Torr. The film structures used for experiment are (1) Ni (150Å), (2) Ni/Co/TiN (150Å/10Å/100Å) and (3) Ni/Co/TiN (112.5Å/37.5Å/200Å). Next, Ni Germano-silicide is formed using a rapid thermal processing (RTP) at 400~800℃ for 30s with a base pressure of 3×10^{-2} Torr. Then, 2nd RTP was carried out at 750℃ for 30s in the same ambient after selective removing the unreacted metal by wet etching (two-step RTP for short). Samples without 2nd RTP were also fabricated for comparison (one-step RTP for short). Finally, furnace annealing was carried out at a temperature of 450~600℃ for 30min. in N_2 ambient to check the thermal stability of the Ni Germano-silicide.

Phase identification was carried out using x-ray diffraction (XRD) and the sheet resistance was studied by four-point probe (FPP). The atomic redistribution and profile of Ni germano-silicide were characterized by x-ray photoelectron spectroscopy (XPS) depth analysis and Field Emission Scanning Electron Microscope (FESEM, Korea Basic Science Institute. Model: Hitachi, s-4700)

3. Results and discussion

A. Characteristics of the Ni Germano-silicide

For Ni only structure, well formation of Ni Germano-silicide phase using one step RTP is shown in Fig. 1. The XPS depth analysis in Fig.3 infers Ni:Si:Ge atomic ratio or intensity ratio of Ni Germano-silicide formation at 550℃ is close to 5:4:1. It shows the low resistive NiSiGe is formed after RTP at 550℃. Low resistive NiSiGe is formed by one step RTP with temperatures ranging from 500℃ up to 700℃ as shown in Fig. 2(a). The Ni Germano-silicide shows uniform profile with a thickness about 400Å as shown in Fig. 4(a). The phase transformation of low resistive NiSiGe to high resistive $Ni(SiGe)_2$ appears after post-silicidation annealing as shown in Fig.1. Ni Germano-silicide formed on undoped as well as on doped $Si_{0.8}Ge_{0.2}$ substrate showed little increase of sheet resistance up to 550℃, 30 min annealing as shown in Fig. 2(b). However, sheet resistance increased a lot above the annealing temperature of 550 ℃, which is mainly due to the agglomeration of Ni Germano-silicide as shown in Fig. 4(b).

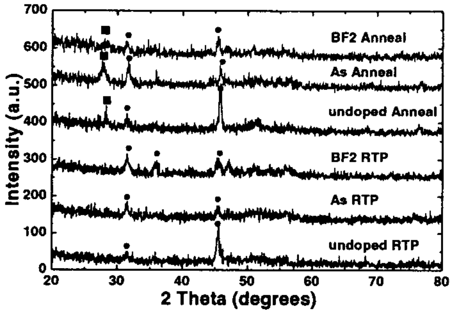
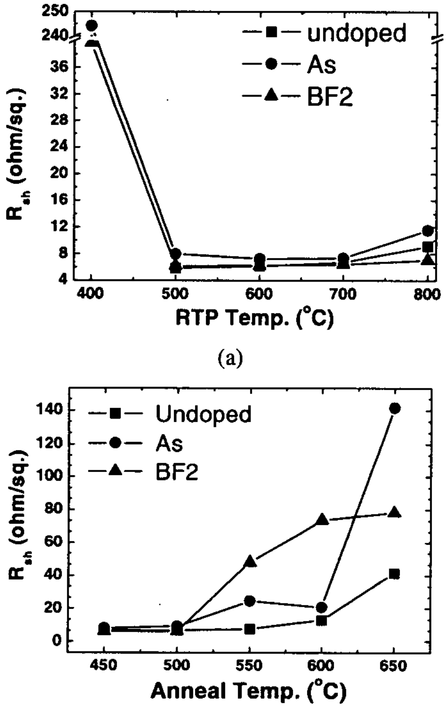


Fig. 1 XRD spectra of Ni Germano-silicide with and without post-silicidation annealing. ■ $Ni(SiGe)_2$ ● NiSiGe



(a)

(b)

Fig. 2 sheet resistance of SiGe (Ni150 Å) (a) after RTP and (b) after furnace annealing.

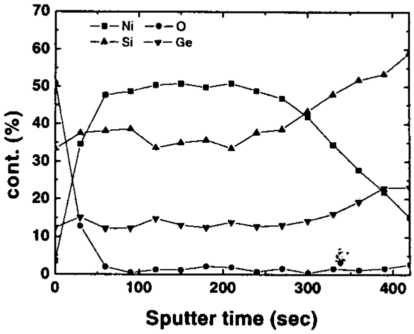
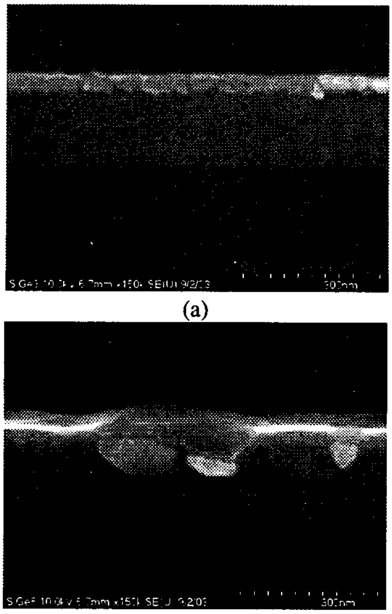


Fig. 3 XPS depth profiling of Ni Germano-silicide after RTP at 550℃



(a)

(b)

Fig. 4 FESEM images of Ni germano-silicide, (a) RTP in 500℃, 30s and (b) furnace annealing in 650℃, 30min.

B. A novel structure Ni/Co/TiN using 2-step RTP

The sheet resistances of Ni Germano-silicide formed by only one step RTP are shown in Fig. 5. Low resistive Ni germano-silicide was formed with temperatures ranges from 500℃ to 700℃ in case of Ni and Ni/Co/TiN (150Å/10Å/100Å- low Co concentration) structure. In case of Ni/Co/TiN (112.5Å/37.5Å/200Å- high Co concentration), however, low resistance can be obtained only at 800℃.

Fig. 6 shows the improvement of Ni germano-silicide using 2-step RTP for Ni/Co/TiN structure with high Co concentration. Low sheet resistance was obtained by 2-step RTP and it almost keep the same low sheet resistance after furnace annealing at 650℃ for 30 min. Fig. 7 shows the dependence of sheet resistance on the annealing temperature for all kinds of samples. The resistances of Ni germano-silicide formed using Ni and Ni/Co/TiN structure with low Co concentration show similar property, i.e., maintain low resistance for 500℃, 30 min furnace annealing and begin to increase from 550℃ annealing. Among the two structures, Ni/Co/TiN structure shows a better thermal stability even with low Co concentration. However, very stable sheet resistance of Ni germano-silicide, about 5Ω, was attained for the Ni/Co/TiN structure with high Co concentration using 2-step RTP. Also the thermal stability of the Ni germano-silicide is excellent, there is little difference of sheet resistance even with a 700℃ furnace annealing for 30 min. Ni/Co/TiN structure with high Co concentration using two step RTP is highly promising for nano-scale CMOS technology which needs high temperature process after silicidation.

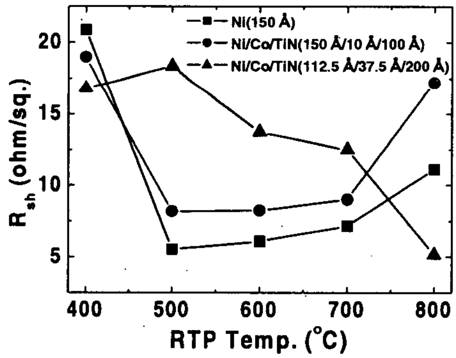


Fig. 5. Sheet resistance dependence of Ni germano-silicide on the 1st RTP temperature

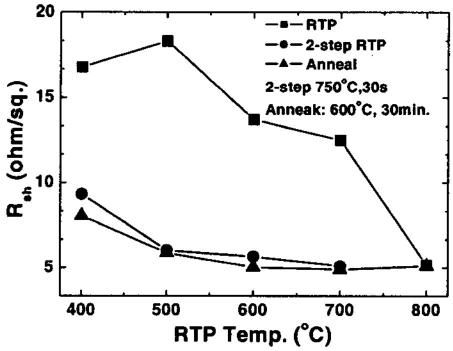


Fig. 6 Sheet resistance improvement using 2-step RTP of Ni germano-silicide with high Co concentration Ni/Co/TiN structure

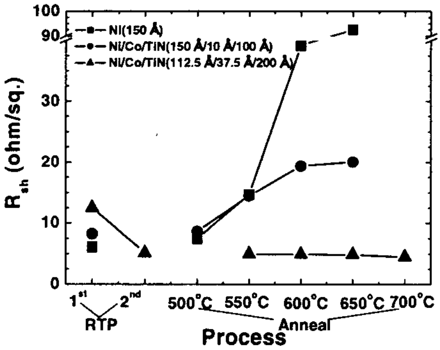
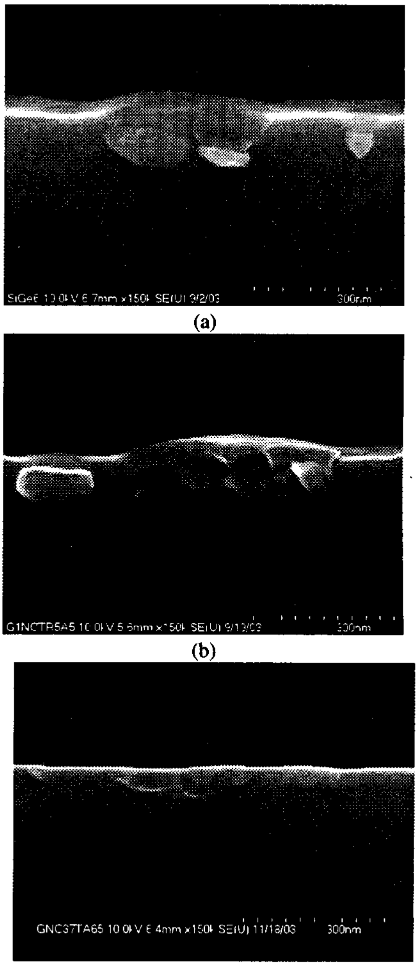


Fig.7 Dependence of Ni germano-silicide sheet resistances on the furnace annealing temperature after silicidation



(a)

(b)

(c)

Fig.8 FESEM images of Ni germano-silicide after a 550℃ furnace annealing for 30 min. (a) Ni, (b) Ni/Co/TiN (150Å/10Å/100Å) and (c) Ni/Co/TiN (112.5Å/37.5Å/200Å).

After a 550℃ furnace annealing for 30 min, a lot of agglomeration appears both Ni germano-silicide formed by Ni or Ni/Co/TiN structure with low Co concentration as shown in Fig.8 (a) and (b). And it is not easy to find the silicide layer. However, Ni/Co/TiN structure with high Co concentration shows quite uniform profile, while small agglomeration appears as shown in Fig.8 (c). Therefore, Ni/Co/TiN structure with high Co concentration is effective in improving the thermal stability of Ni germano-silicide by reducing agglomeration.

4. Conclusions

Ni germano-silicide with Ni/Co/TiN structure and two step silicidation is proposed for strained silicon CMOS technology. It is shown that Co concentration affects the Ni germano-silicide property, i.e, Ni germano-silicide formed by Ni/Co/TiN structure with high Co concentration using a 2-step RTP shows superior thermal stability to the Ni structure or Ni/Co/TiN structure with low Co concentration. It is also shown that 2-step RTP is better than 1-setp RTP in improving thermal stability of the Ni germano-silicide

Acknowledgments

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