Stress Dependence of Thermal Stability of Nickel Silicide for Nano MOSFETs

Ying-Ying Zhang, Sung-Kyu Lim*, Won-Jae Lee, Zhun Zhong, Shi-Guang Li, Soon-Yen Jung, Ga-Won Lee, Jin-Suk Wang and Hi-Deok Lee
Chungnam National University, National Nanofab Center*

Abstract: The thermal stability of nickel silicide with compressively and tensilely stressed nitride capping layer has been investigated in this study. The Ni (10 nm) and Ni/Co/TiN (7/3/25 nm) structures were deposited on the p-type Si substrate. The stressed capping layer was deposited using plasma enhanced chemical vapor deposition (PECVD) after silicide formation by one-step rapid thermal process (RTP) at 500 °C for 30 sec. It was found that the thermal stability of nickel silicide depends on the stress induced by the nitride capping layer. In the case of Ni (10 nm) structure, the high compressive sample shows the best thermal stability, whereas in the case of Ni/Co/TiN (7/3/25 nm) structure, the high compressive sample shows the worst thermal stability.

Key words: nickel silicide, thermal stability, nitride, mechanical stress, nano MOSFETs

1. Introduction

Self-aligned-silicides (SALICIDEs) are often used in complementary metal oxide semiconductor field effect transistor (CMOSFET) manufacturing to reduce the sheet and contact resistance of gate, source and drain areas [1]. Recently, nickel mono-silicide (NiSi) has been considered as a viable candidate for contact material because of its low resistivity, relatively low formation temperature, no resistivity increase on narrow lines and low silicon consumption [2]. However, poor thermal stability of the nickel silicide is a weakness to be applied to nano-scale CMOSFET technology which needs high temperature processed after the silicide formation [3].

As the device dimensions scale down to sub-quarter micron regime, stress effects become more pronounced in semiconductor device fabrication [4]. Mechanical stress is researched to improve the performance of CMOSFETs [5]. In this paper, Nickel silicides by different metal structures are formed and the thermal stability of the nickel silicide with different stressed nitride capping layer is studied. It was found that the thermal stability of nickel silicide depends on the stress induced by the nitride capping layer.

2. Experimental details

A key process flow is shown in Fig. 1. In this study, the p-type Si (100) wafer was cleaned and dipped in an HF solution to remove the native oxide. The Ni (10 nm) and Ni/Co/TiN (7/3/25 nm) structures were deposited by RF magnetron sputtering system with a base pressure of 5 × 10^{-7} Torr and working pressure of 1 mTorr. The RTP was carried out to form Ni silicide at 500 °C for 30 sec. Un-reacted metals were removed by using a mixture of H_2SO_4 and H_2O_2 with the volume radio of 4:1. The 2000 Å thick stressed Si_3N_4 capping layer was deposited by PECVD using a standard recipe with SiH_4 and NH_3. To test the thermal stability of silicides, samples were furnace annealed in N_2 ambient at three different temperatures for 30 min. The wet etching of Si_3N_4 was carried out to measure the variation of sheet resistance of NiSi using H_3PO_4 at 150 °C.

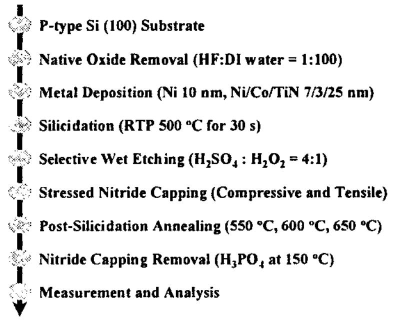

Fig. 1. Key process flow for the experiments

Sheet resistance was measured using conventional FPP. The interface uniformity of the silicide was observed by FESEM (Jeon-ju branch of Korea Basic Science Institute (KBSI), model: Hitach S-4700).

3. Results and discussion

The samples classifications of Ni (10 nm) and Ni/Co/TiN (7/3/25 nm) structures for experiments are shown in Table 1.

Table 1. the samples classification for experiments

Samples	Ni(10 nm)	Ni/Co/TiN(7/3/25 nm)
Ref.	Sample A	Sample A'
High Compressive: -600MPa	Sample B	Sample B'
Low Compressive: -110MPa	Sample C	Sample C'
High Tensile: +580MPa	Sample D	Sample D'
Low Tensile: +25MPa	Sample E	Sample E'

After post-silicidation annealing, the sheet resistance windows as a function of annealing temperature for samples A~E and samples A'~E' are shown in Fig. 2 (a) and (b), respectively. In the case of Ni (10 nm) structure, the difference between the stressed capping and uncapping samples cannot be observed after annealing below 600 °C. However, the sheet resistance of sample A annealed at 650 °C was too high to measure, while the sheet resistance of stressed capping samples was found to increase and decrease with the tensile and compressive stress level, respectively. In the case of Ni/Co/TiN (7/3/25 nm) structure, the sheet resistance of sample B' has a sharp increase from annealing 550 °C until to 650 °C. And the difference among the other stressed capping samples cannot be observed.

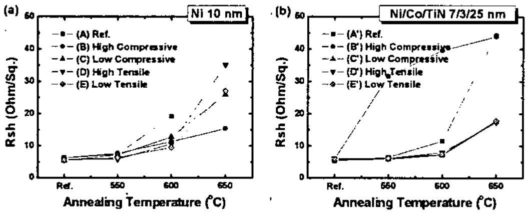

Fig. 2. the sheet resistance windows as a function of annealing temperature for (a) Ni 10 nm structure and (b) Ni/Co/TiN 7/3/25 nm structure

Fig. 3 shows the cross-sectional FESEM images of nickel silicide for samples after annealing at 650 °C. Here it is seen that, the remains of nitride capping layers can be seen in Fig. 3(b), (c), (e) and Fig. 3(b'), (c'), (d'). In case of Ni (10 nm) structure, the best interface property and more uniform silicide layer are found in sample B, as shown in Fig. 3 (b). And in case of Ni/Co/TiN (7/3/25 nm) structure, the worst interface property is found in sample B', as shown in Fig. 3(b'). The agglomerations can be observed in sample A, C, D, E and B', as shown in Fig. 3 (a), 3 (c), 3 (d), 3 (e) and Fig. 3(b'). It confirms that the lower sheet resistance can be attributable to less agglomeration formation. It was also observed that void formation was significant near the NiSi/Si interface in the stressed capping samples, which may be attributed to the influence of the stressed capping layer.

4. Conclusions

The nickel silicides were formed by Ni (10 nm) and Ni/Co/TiN (7/3/25 nm) structures. It was found that the thermal stability of nickel silicide depends on the stress induced by the nitride capping layer. In the case of nickel silicide formed by Ni (10 nm) structure, the high compressive sample shows the best thermal stability. Whereas in the case of nickel silicide formed by Ni/Co/TiN (7/3/25 nm) structure, the high compressive sample shows the worst thermal stability.

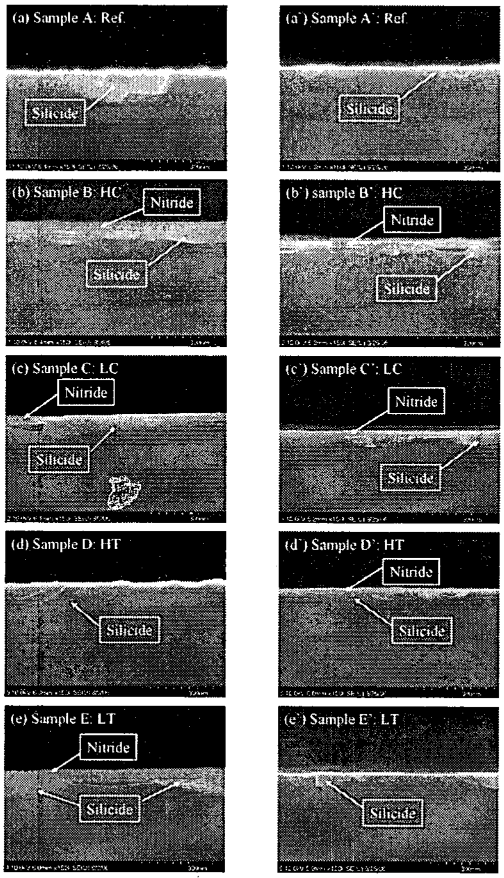

Fig. 3. FESEM images of nickel silicide for Ni (Fig.(a)~(e)) and Ni/Co/TiN (Fig.(a')~(e')) structures after annealing at 650 °C for 30 min in N_2 ambient

Acknowledgments

This work was supported by grant No. (R01-2003-000-11659-0) from the Basic Research Program of the Korea Science and Engineering Foundation (KOSEF), and Ying-Ying Zhang thanks Ilun Science and Technology Foundation for support of this work.

References

[1] S. P. Murarka, J. Vac. Sci. Technol. B Vol. 4, p. 1325, 1986.

[2] T. Morimoto, T. Ohguro, H. S. Momose, T. Iinuma, I. kunishima, K. Suguro, I. Katakabe, H. Nakajima, M. Tsuchiaki, M. Ono, Y. Katsumata and H. Iwai, IEEE Trans. Electron Dev. Vol. 42, No. 5, p. 915, 1995.

[3] F. Deng, R. A. Johnson, P. M. Asbeck, S. S. Lay, J. Appl. Phys. Vol. 81, No. 12, p. 8047, 1997.

[4] L. J. chen (Ed.), Institution of Electrical Engineers, London, UK, 2004.

[5] A. Steegen and K. Maex, Materials Science & Engineering R: Reports Vol. 38, p. 1, 2002