Formation Temperature Dependence of Thermal Stability of Nickel Silicide with Ni-V Alloy for Nano-scale MOSFETs

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Abstract − In this paper, investigated is the relationship between the formation temperature and the thermal stability of Ni silicide formed with Ni-V (Nickel Vanadium) alloy target. The sheet resistance after the formation of Ni silicide with the Ni-V showed stable characteristic up to RTP temperature of 700 ℃ while degradation of sheet resistance started at that temperature in case of pure-Ni. Moreover, the Ni silicide with Ni-V indicated more thermally stable characteristic after the post-silicidation annealing. It is further found that the thermal robustness of Ni silicide with Ni-V was highly dependent on the formation temperature. With the increased silicidation temperature (around 700 ℃), the more thermally stable Ni silicide was formed than that of low temperature case using the Ni-V.

Index terms − Ni silicide, formation temperature, thermal stability, Ni-V alloy target, nano-scale MOSFETs.

I. INTRODUCTION

SALICIDE (Self-Aligned Silicide) is one of the indispensable techniques for high-performance CMOS technology. $TiSi_2$ has been eventually replaced by $CoSi_2$ generally from 0.25 μm CMOS technology because $CoSi_2$ has relatively stable nature of line width effect. In spite of this, for sub-100-nm technology nodes, even $CoSi_2$ will not be a satisfactory material, considering the ultra-shallow junction depth and low resistance requirement, and NiSi is now drawing attention as one of the most suitable salicide material candidate for next technology nodes. NiSi has several advantages over $TiSi_2$ and $CoSi_2$ for the ULSI (Ultra-Large Scale Integration) technology: low temperature silicidation process, low silicon consumption, no bridging failure property, smaller mechanical stress, little narrow line width effect on sheet resistance, smaller contact resistance for both n- and p-Si [1], and higher activation rate of B for SiGe poly gate electrode [2]. However, NiSi has poor thermal stability which turns out to be its barrier to be applicable for nano-scale MOSFETs. Many attempts have been made to improve the thermal robustness of Ni silicide such as ion implantation, application of alloying target materials and deposition of inter- and/or capping-layers [3-9].

In this paper, formation temperature dependence of thermal stability of Ni silicide with Ni-V alloy was investigated for the nanoscale CMOS technology. Ni silicide with Ni-V indicated more thermally stable characteristic in comparison to pure-Ni silicide. The thermal robustness of Ni silicide with Ni-V was highly dependent on the formation temperature.

II. EXPERIMENTAL

For experiments, Ni/TiN (100/250 Å) and Ni-V/TiN (100/250 Å, V atomic % ~ 5 %) layers were deposited on the p-type Si wafer using RF magnetron sputtering system with Ar ambient. During the deposition, the sample holder was rotated to deposit the metals uniformly. TiN capping is applied to prevent the abnormal oxidation of NiSi [4]. Nickel silicide formation was achieved by rapid thermal process (RTP) at five different temperatures (400, 500, 600, 700 and 800 ℃) for 30s to investigate the thermal stability dependence on the formation temperature.

To test the thermal stability of silicides, samples were furnace annealed in three different temperatures (600, 650 and 700 ℃) for 30 min. Sheet resistance was measured using conventional four point probe (FPP). AFM (Atomic Force Microscope) and XRD (X-ray Diffraction) analysis were performed to investigate surface roughness and silicide phase of the silicides formed with pure-Ni and Ni-V, respectively.

III. RESULTS AND DISCUSSION

Nickel silicides were formed using two different target materials of pure-Ni and Ni-V with thickness of 10 nm on p-type silicon wafer. Fig. 1 shows the sheet resistance of nickel silicide as a function of the formation temperature. It can be seen that low sheet resistance is already achieved at 400 ℃, which is the lowest temperature considered in this study. It is found that the nickel silicide with pure-Ni has a relatively narrow RTP temperature window than that with Ni-V and resistance of pure-Ni showed drastic increase from 700 ℃. Based on the results from previous studies on thermal stability, the observed increase of sheet resistance is suggestive of nickel film agglomeration and phase transition from low resistive nickel mono-silicide (NiSi) to high resistive nickel di-silicide ($NiSi_2$) at high temperatures [10].

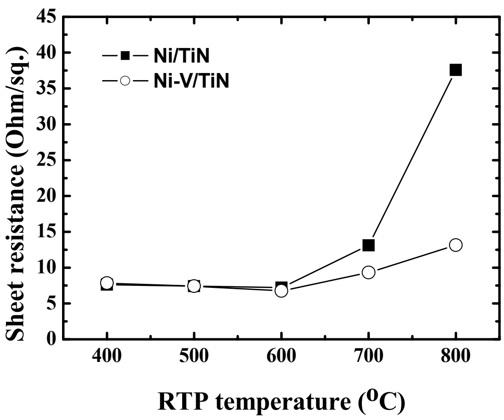


Fig. 1 Nickel silicide sheet resistance as a function of the formation temperature for both silicides with pure-Ni and Ni-V alloy.

Fig. 2 shows the thermal stability characteristic with different annealing temperatures for 30 min. In spite of the high temperature furnace annealing, nickel silicides with Ni-V showed quite strong thermal robustness while pure-Ni samples almost all failed beyond reasonable sheet resistance. Moreover, it was shown that thermal stability of nickel silicides strongly dependent on the formation temperature of Ni-silicide.

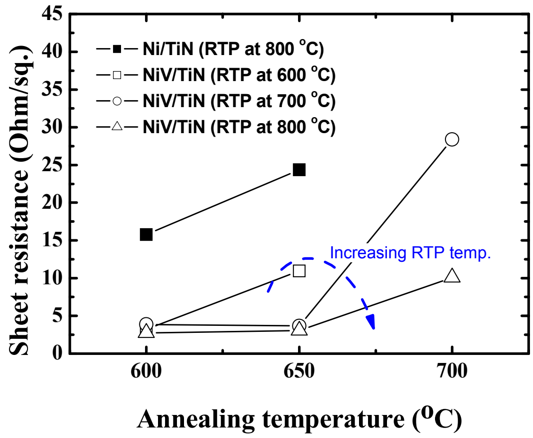


Fig. 2 Nickel silicide sheet resistance after the post-silicidation annealing with different temperatures for 30 min.

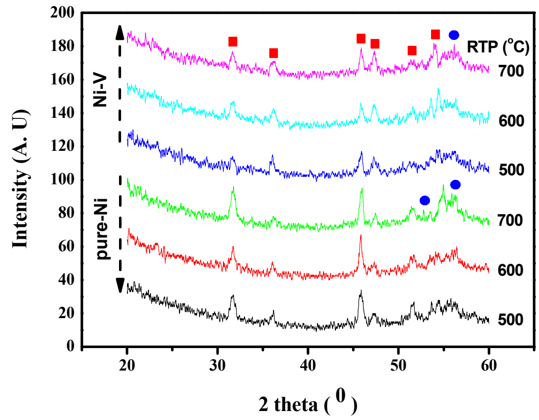
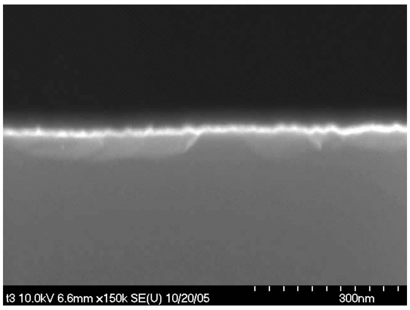


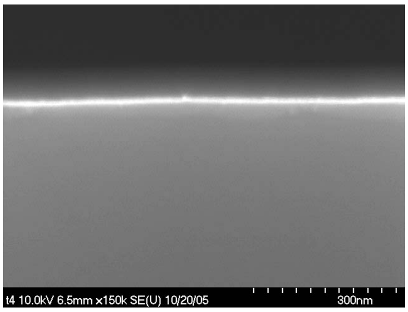
Fig. 3 XRD scans for pure-Ni and Ni-V silicide for both RTP temperatures of 500-700 ℃. (■ for NiSi and ● for $NiSi_2$)

XRD was used to identify the silicide phases as presented in Fig. 3. Almost same profiles were obtained between pure-Ni and Ni-V cases. However, in case of Ni-V, less $NiSi_2$ peaks were observed reflecting that better thermal stability than pure-Ni case. At RTP temperature of 700 ℃, there were observed high resistive of $NiSi_2$.

FESEM (Field Emission Secondary Electron Microscopy, S-4700, Jeonju branch of KBSI) images for pure-Ni and Ni-V alloy after RTP at 700 ℃ are shown in Fig. 4(a) and Fig. 4(b), respectively. Pure-Ni silicide shows agglomeration which can explain the drastic increase of sheet resistance in Fig. 1. Contrary to the pure-Ni case, Ni-V silicide which is formed at the same temperature showed better silicide/silicon interface profile.



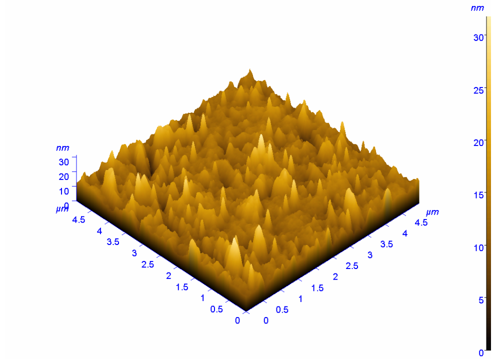
(a)



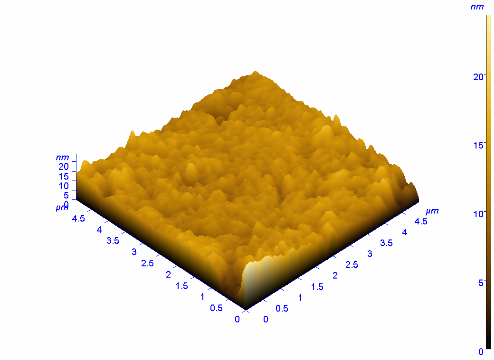
(b)

Fig. 4 Cross sectional FESEM images of nickel silicides formed with (a) Ni and (b) Ni-V after RTP at 700 ℃.

Fig. 5 shows AFM surface roughness for both silicides formed with pure-Ni and Ni-V alloy, respectively. Silicide formed with Ni-V (RMS = 1.2 nm) shows better surface roughness than that formed with pure-Ni (RMS = 2.1 nm) after post-silicidation annealing at 650 ℃ for 30 min.



(a)



(b)

Fig. 5 AFM surface roughness for (a) Ni and (b) Ni-V silicides after post-silicidation annealing at 650 ℃ for 30 min (RTP at 700 ℃)

V. CONCLUSION

At low formation temperatures (≤ 600 ℃), both nickel silicides with pure-Ni and Ni-V show almost same thermal stability. However, characteristics of silicides formed with pure-Ni and Ni-V alloy changed dramatically before and after the post-silicidation annealing. Better thermal stability was achieved using vanadium-added Ni and thermal robustness of both silicides strongly depends on the formation temperature. Therefore, nickel silicide with Ni-V alloy could be promising material for next generation CMOS technology.

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