The Investigation of Ni Thin Film by Atomic Layer Deposition

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Low resistance Ni thin films for using NiSi formation and metallization by atomic layer deposition (ALD) method have been studied. ALD temperature window is formed between 200℃ and 250℃ with deposition rate of 1.25Å/cycle. The minimum resistance of deposited Ni films shows 4.333 Ω/□ on the SiO_2/Si substrate by H_2 direct purging process. The reason of showing the low resistance is believed to be due to formation of the Ni_3C phase by residual carbon in Bis-Ni. The deposited film exhibits excellent step coverage in the trench having 1(100 nm): 16 (1.6 um) aspect ratio.

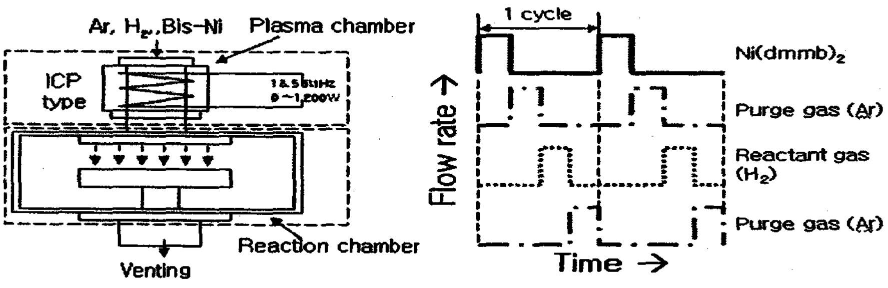
1. Introduction

The NiSi have been widely investigated as a promising source/drain contact and FUSI gate for sub-65nm CMOS device, due to its non-size dependence on the gate length and low resistance [1-3]. Prior to forming the NiSi the deposition of Ni thin film with low resistance Ni thin film using chemical vapor deposition (CVD) has been found to be difficult because of carbon and oxygen incorporation into the film during vapor phase deposition process[4]. We deposited a high purity Ni thin film on SiO2/Si and Si substrates by using atomic layer deposition (ALD) method, which has many advantages over a conventional CVD method, such as lower deposition temperature, almost perfect step coverage, accurate thickness control and etc. Its structural and material properties were characterized by 4-point probe, XRD and TEM.

2. Experiment

All samples were deposited by utilizing the ALD equipment shown in Fig. 1(a), designed for the 8-inch process. Bis-Ni (Ⅱ)($Ni(dmamb)_2$) and H_2 were used as metal-organic precursor and reactant gas, respectively. Ar, as purge gas, was used to remove the non-reacted molecules on the substrate. Basic injection sequence was as follows; Bis-Ni(Ⅱ) →

purging(Ar) → H_2 → purging(Ar) per 1cycle as shown in Fig. 1(b). Sometimes, Ar purge steps were omitted to find the difference between ALD and cyclic CVD processes. ALD window was obtained by varying the deposition temperature from 175℃ to 300℃ with increasing temperature by 25℃ per step., also changing the flow rates of Ar and H_2. The thickness and sheet resistance of the film was measured with X-ray reflectormetry, along with ellipsometer, and 4-point probe, respectively. Atomic force microscope measurement (AFM) and transmission electron microscopy (TEM) measurement was applied to check the surface morphology according to variation of process temperature and the step coverage of the film after depositing the Ni film and forming the NiSi in the contact hole trench patterned with 1:16 aspect ratio, respectively.



(a) Chamber schematic (b) Process cycle

Fig. 1 Schematic of chamber and cycle pulse diagram

3. Results and Discussion

Fig. 2 (a) and (b) show the thickness and deposition rate of the Ni film deposited on SiO_2/Si substrate at temperatures from 175℃ to 300℃, indicating that temperature window for ALD is between 200℃ and 250℃ and the deposition rate was estimated as approximately about 1.25Å per cycle.

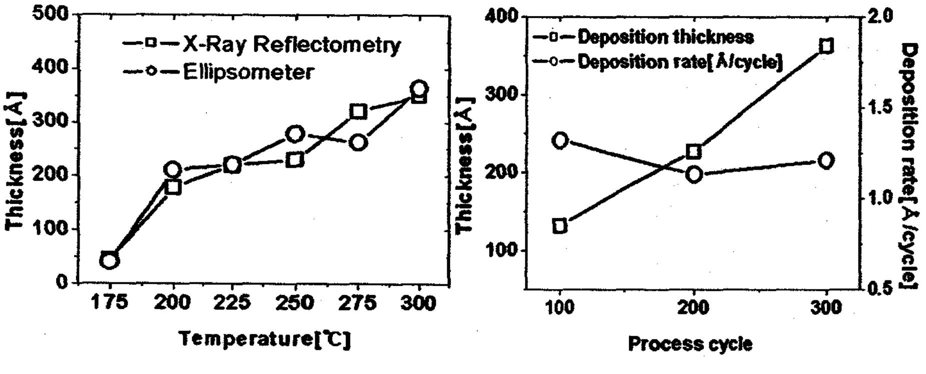


Fig. 2 ALD temperature window and deposition rate by X-ray reflectometry and ellipsometer

The measured sheet resistances for Ni film deposited at temperatures from 200℃ to 300℃ on SiO_2/Si and Si substrates were shown in Fig. 3. In case of SiO_2/Si substrate, the values of sheet resistance of the film deposited by the cyclic CVD process were smaller than those deposited by the ALD process, as can be seen in Fig. 3(a). The lowest values of 18.56 and 4.3 Ω /□ were obtained for the samples deposited at 220 ℃ for the ALD and the cyclic CVD process, respectively. These values are comparable to or even lower than those obtained from the PVD methods. It seems that an adequate amount of H_2 during the cyclic CVD, which has no Ar purge cycle, gives positive influence to the SiO_2/Si substrate forming a lower-resistive Ni film.

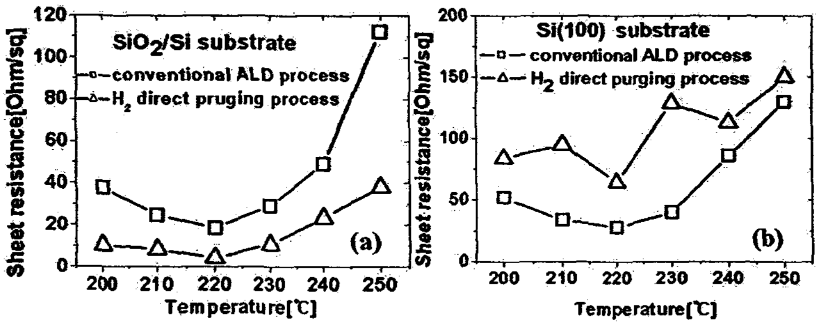


Fig. 3 Sheet resistance of depositied Ni thin film on SiO2/Si and Si bulk substrate by conventional ALD process and H_2 direct purging process

When the film was deposited at 220 ℃ directly on the Si surface, however, the sheet resistances were increased to 27.60 and 67.26 Ω /□ respectively for the cyclic ALD and cycle CVD processes, as shown in Fig. 3(b). This might be because the deposited Ni partially reacts with Si even at such a low temperature and hence forms Ni_2Si phase at the interface between Ni and Si. This tendency was observed at all deposition temperatures tested in this work. An interesting point is the fact that the Ni film deposited on Si surface shows opposite tendency to that on SiO_2/Si substrate. The Ni film by the ALD process, which includes Ar purge cycle, gives lower sheet resistance. This might be concluded that a properly-controlled amount of H_2 impedes the Ni-Si reaction to form Ni_2Si at the interface so that the bulk characteristics of Ni film remains superior. However, too much amount of H_2 would result in bulk defects in the deposited Ni layer.

Fig. 4 shows the diffraction pattern of sample deposited with varying the deposition temperature from 200℃ to 300℃, exhibiting several peaks related to Ni_3C and Ni phases. The Ni_3C is formed by the residual carbon in the Bis-Ni due to incomplete dissociation at such a low temperature. As the deposition temperature increased, the Ni_3C phase decreases. This is because the dissociation becomes easy and the possibility of the residual carbon incorporation into the film becomes low as the deposition temperature increases. Considering Fig. 3 and Fig. 4, the Ni_3C phase in the deposited Ni thin film plays an important role in decreasing the sheet resistance of the film. The decrease of sheet resistance is believed due to carbon incorporation effect.

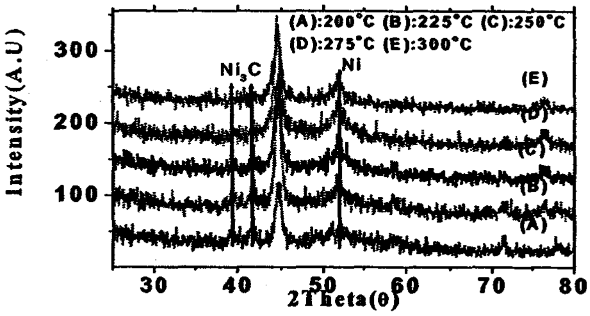


Fig. 4 Composition measurement of XRD deposited Ni thin film

Fig. 5 AFM images of deposited Ni film surface.

Fig. 5 shows the surface image of deposited films by AFM measurement. The Surface morphology is degraded with increasing deposition temperature due to decreasing carbon incorporation.

In order to observe step coverage of the ALD Ni film, the film has been deposited on the 8 inch SiO_2/Si substrate with deep contact hole trenchs having 1(100nm):16(1.6um) aspect ratio. Cross-sectional HR-TEM picture (shown in Fig. 6) exhibits good step coverage of the film over the patterned structure.

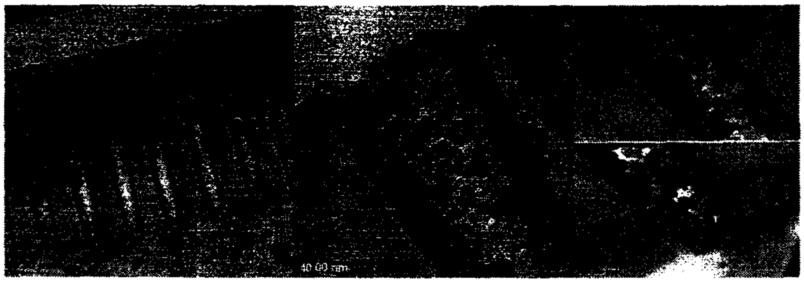


Fig. 6 Cross sectional TEM and SEM images of the deposited Ni film in the trench with aspect ratio of 1:16.

4. 결론

A high-quality Ni thin film at low temperature has been deposited by conventional ALD and cyclic CVD process. The composition measurement of the deposited Ni film by XRD revealed that Ni_3C phase plays a key role in decreasing the sheet resistance.

Acknowledgements

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참고문헌

[1] J. Liu et al., IEEE Electron Device Lett, Vol. 26, No. 4 (2005)
[2] Qi Xiang et al, Symp. On VLSI Tech., 3A-4 (2001)
[3] Y.-L. Jing *et al.*, Electronics letters, Vol. 41, No.2 (2005)
[4] Mikko Utriainen et al., Appl Surf, p.151-158(2000)