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Low Resistance Ni Thin Film Deposition for Nickel Silicide by Atomic Layer Deposition

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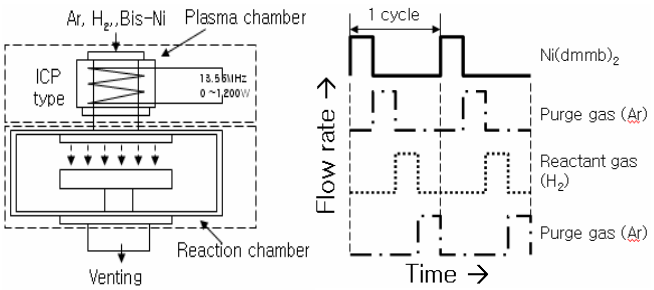
1. Introduction

The NiSi have been widely investigated as a promising source/drain contact and FUSI gate for sub-65nm CMOS device [1]~[3], due to its non-size dependence on the gate length and low resistance. Prior to forming the NiSi, the deposition of Ni thin film with low resistance is most important. Differently from the PVD method, however, deposition of high purity and 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 deposition process[4].

We deposited a high purity Ni thin film on SiO_2/Si and Si substrates by using atomic layer deposition (ALD) method, which has many advantages compared to a conventional CVD method such as lower deposition temperature, almost perfect step coverage, accurate thickness control and etc. Formation of NiSi was performed by rapid thermal process (RTP) and its structural and material properties were characterized by 4-point probe, XRD, and TEM .

2. Experimental



(a) Chamber schematics (b) Process cycle

Fig. 1 Schematics of chamber and cycle pulse diagram.

All samples were deposited by utilizing the ALD equipment shown in Fig. 1 (a), designed for the 8-inch process. Bis-Ni(II) ($Ni(dmmb)_2$) 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; Bi-Ni(II) -> purging(Ar) -> H_2 -> purging(Ar) per 1 cycle as shown in Fig. 1 (b). To obtain the ALD window, the deposition temperature was varied from 175 ^{o}C to 300 ^{o}C with increasing temperature by 25 ^{o}C per step. The thickness and sheet resistance of the film was measured with X-ray reflectometry (XRR), along with ellipsometer, and 4-point probe, respectively. High resolution TEM(HR-TEM) measurement revealed that all deposited samples were partially crystallized. A possible pre-NiSi formation during the deposition on Si substrate at temperatures ranged from 200 to 300 ^{o}C was checked by HR-TEM and 4-point probe by measuring the sheet resistance. Finally, NiSi was formed by the rapid thermal process at higher temperatures varied from 400 to 900^{o}C. The step coverage of the film was checked after depositing the Ni film and forming the NiSi in the contact hole trench patterned with 1:16 aspect ratio.

3. Results and Discussion

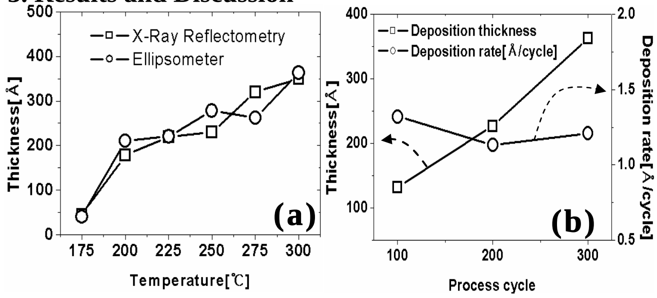


Fig. 2 ALD temperature window and deposition rate by X-ray reflectometry and ellipsometer.

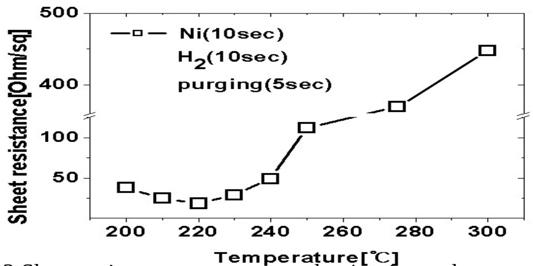


Fig. 3 Sheet resistance measurement by 4-point probe.

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^{o}C to 300^{o}C, indicating that temperature window for ALD is between 200^{o}C and 250^{o}C and the deposition rate was estimated as approximately about 1.25A per cycle. The measured sheet resistances for Ni films deposited at temperatures from 200^{o}C to 300^{o}C were shown in Fig. 3. The lowest value of 18.56 ohm/sq was obtained for the sample deposited at 220^{o}C. This value is comparable to or even lower than those obtained from the PVD methods. When the film was deposited directly on the Si surface at same temperature, however, the sheet resistance was increased to 27.60 ohm/sq. This is 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 surface. This tendency was observed at all deposition temperatures tested in this work.

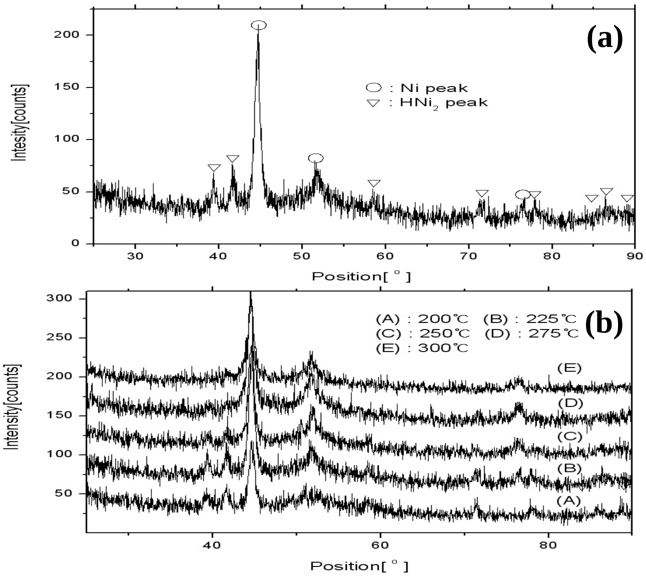


Fig. 4 Composition measurement of XRD deposited Ni thin film.

Fig. 4(a) is the diffraction pattern of sample deposited at 220^{o}C, showing several peaks related to HNi_2 and Ni phases. The HNi_2 is formed by the residual hydrogen ligands in the Bis-Ni due to incomplete dissociation at such a low temperature. As shown in Fig 4(b), the HNi_2 phase decreases with increasing deposition temperature. This is because the dissociation becomes easy and the possibility of the residual hydrogen incorporation into the film becomes low as the deposition temperature increases. Considering Fig. 4(b) and Fig. 3, the HNi_2 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 hydrogen incorporation effect; hydrogen in the deposited Ni film passivates the defects in the film by forming HNi_2 phase. It is, therefore, to keep the deposition temperature relatively low (below 250^{o}C) to take advantage of the hydrogen passivation.

In order to observe step coverage of the ALD Ni film, we deposited Ni film on the 8 inch SiO_2/Si substrate with deep contact hole trench having 1(100nm):16(1.6um) aspect ratio. Cross-sectional HR-TEM picture (Fig.5) exhibits good step coverage of the film over the patterned structure. A conformal deposition on the patterned substrates with high- aspect ratio or 3-D device structures like Fin-FET is very important in keeping good device and circuit performance, which can be easily achieved by ALD, but not by the PVD or conventional CVD techniques.

The variation of sheet resistances of the film (deposited at 200^{o}C on the Si-substrate) after formation of silicide with RTP at temperatures from 400 ^{o}C to 900 ^{o}C is shown in Fig. 6 and compared to that of the film deposited by PVD technique. The PVD sample maintained low values of sheet resistance of about 4~9ohm/sq with annealing temperature

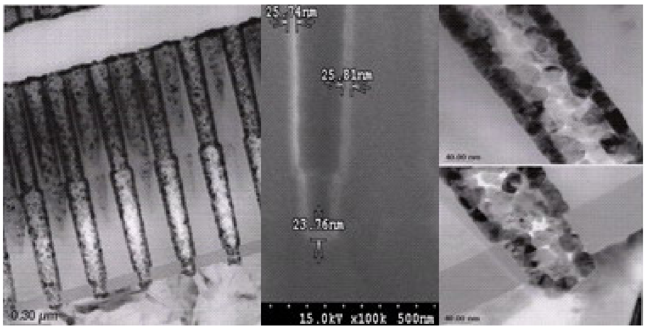


Fig. 5 Cross sectional TEM and SEM images of the deposited Ni film in the trench with aspect ratio of 1:16.

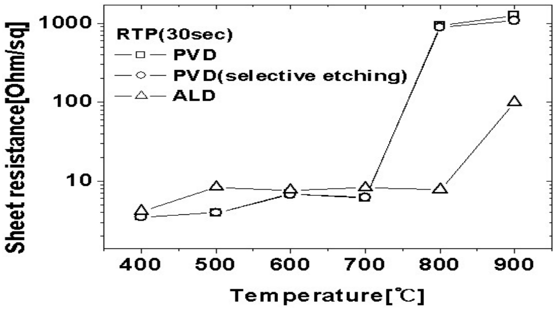


Fig. 6 Sheet resistance Ni-silicide after RTP process at temperatures from 400 ^{o}C to 900 ^{o}C.

below transition temperature of about 700^{o}C, but rapid increase in sheet resistance was observed above transition temperature, indicating that the formation of NiSi is dominant below transition temperature, which exhibits a lower sheet resistance than that of $NiSi_2$ undesirably formed above transition temperature. On the other hand, the ALD sample exhibited similar values of sheet resistance below transition temperature, but the temperature is increased to 800^{o}C and in addition the increase in sheet resistance above transition temperature was slow. This is believed that hydrogen incorporated into the film during the ALD process may prevent the formation of $NiSi_2$ which is very good point when considering this offer a better process margin for the ULSI fabrication technology.

3. Conclusions

We deposited high quality Ni thin film at low temperature by using ALD for the formation of low resistive NiSi. Hydrogen incorporation into the film during the deposition is responsible for the obtaining low sheet resistance and also may prevent the formation of $NiSi_2$.

Acknowledgements

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