Two-step Ni silicide process and influence of protective N_2 gas

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Abstract: A two-step process of Ni silicide formed on bulk silicon, and the effects of different process conditions, including two-step RTA temperature and time, selective etching, and process protective nitrogen gas on the properties of the Ni silicide film have been studied. In particular, the experiments show that the quality of NiSi film is very sensitive to the process conditions of the first RTA. The experiments also show that the quality of the film is very sensitive to the flow of protective nitrogen gas. The corresponding mechanisms are discussed.

Key words: NiSi; silicide; Ni-silicide
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1. Introduction

The silicide process not only decreases sheet-resistance of S/D, gate electrodes and contact resistance but also shortens the RC delay. So the silicide process makes a strong contribution to the scaling of MOS devices. NiSi has become one of the most promising candidates for silicide applications in nano-micron CMOS technology due to its low temperature formation and low sheet resistance with no line width dependence for the two-step RTA process[1−3]. Compared to Ti and Co silicides, NiSi has the lowest Si consumption during silicidation, which is an attractive feature for future advanced CMOS devices[4].

Nickel mono-silicide (NiSi) is the most suitable among the various nickel silicides[5]. However, the one-step Ni silicide process shows that various phases of nickel silicide can coexist, which makes single-phase NiSi formation problematic[3, 6−8]. Furthermore, the one-step salicide process contains problems of excess silicidation which usually causes off state current of MOSFET abnormity[4, 9]. In order to overcome these problems, we develop a two-step silicide process which results in a single-phase NiSi film, and the film thickness can be controlled exactly[2, 4, 10].

The oxygen in Ni films results in high resistivity of the Ni-silicide film, poor thermal stability, and poor electrical interface which usually results in leakage current increase[11]. The protecting N_2 gas can scavenge oxygen onto the silicide surface and result in comparable low resistivity during the RTA process. So we want to evaluate the influence of the annealing ambient on the Ni-silicide process in order to improve its stability[12].

In this paper, we investigate the two-step Ni silicide process and the effects of different process conditions, including two-step RTA temperature and time, selective etching, and process protective nitrogen gas on the properties of the Ni silicide film.

2. Experimental details

Blanket p-type (15–25 Ω·cm) Si (100) substrates were used in this work. After $H_2SO_4 + H_2O_2$ and $NH_4OH + H_2O_2 + H_2O$ cleaning and IPA dip, those wafers were immediately loaded into the MLH-2306 RDE sputtering system. Ni film was deposited by physical vapor deposition (PVD) in high purity Ar ambient. Then TiN film was deposited on the Ni film using reactive sputtering of Ti in N_2/Ar ambient. Two types of structures were prepared: one was Ni/Si and the other was TiN/Ni/Si. The Ni-silicidation process was carried out *ex situ* by two-step RTP in high pure nitrogen ambient using AG610 equipment. The sequence of two-step annealing is low temperature RTA1, selecting etch and higher temperature RTA2. A four-point probe (FPP) was used to measure the sheet resistance of the formed Ni-silicide films. X-ray diffraction (XRD) with Cu Kα radiation was employed for Ni-silicide phase analysis, and high resolution transmission electron microscopy (HRTEM) was used to analyze the character of the Ni-silicide/Si interface and to measure the thickness of the Ni-silicide films. The experimental conditions are listed in Table 1.

3. Results and analysis

Figure 1 shows the sheet resistance of Ni(150 Å)/Si samples after each step process at different RTA1 temperatures. A gradual decrease in the sheet resistance was found for the Ni(150 Å)/Si samples from 250 to 290 °C as shown in Fig. 1. This is caused by more NiSi formation following increase of RTA1 anneal temperature. No variation in the sheet resistance was observed after selecting etch. This is due to the complete transformation of Ni (150 Å) to Ni-silicide phase at temperatures $\geqslant$ 250 °C after 40 s anneal.

The XRD spectra for TiN/Ni/Si samples annealed after RTA1 of 260 °C and RTA2 of 515 °C are shown in Fig. 2. Analysis of the diffraction peak location after RTA1 shows that both NiSi and $Ni_{31}Si_{12}$ phases exist after an RTA1 of 260 °C, but the $Ni_{31}Si_{12}$ phase is main one. However, from the analysis after RTA2, the XRD spectra exhibit only NiSi diffraction peaks. This indicates that the $Ni_{31}Si_{12}$ to NiSi transformation was almost complete after the 515 °C / 30 s anneal.

Figure 3 shows the cross-sectional HRTEM images of the

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Table 1. Conditions of the two-step Ni-silicide process.

	Flow of N_2 gase（slm）	RTA1 temperature（°C）	RTA1 time（s）	RTA2 temperature（°C）	RTA2 time（s）
	2	260–480	40	515	25
Ni(150 Å)/Si	4–6	260	40	515	25
TiN(120 Å)/Ni(220 Å)/Si	4	260	50	515	30

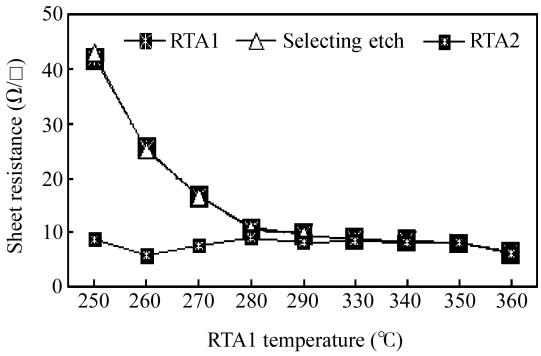

Fig. 1. Sheet resistance of Ni(150 Å)/Si samples as function of the silicidation temperatures.

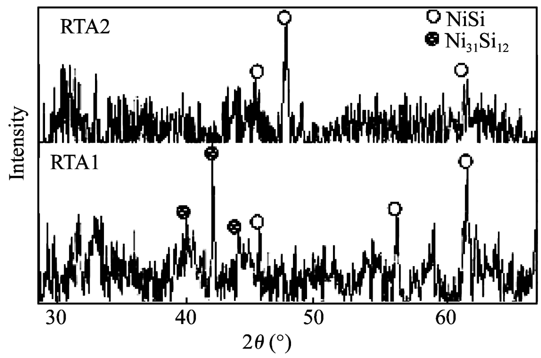

Fig. 2. XRD spectra for TiN/Ni/Si samples annealed after RTA1 and RTA2.

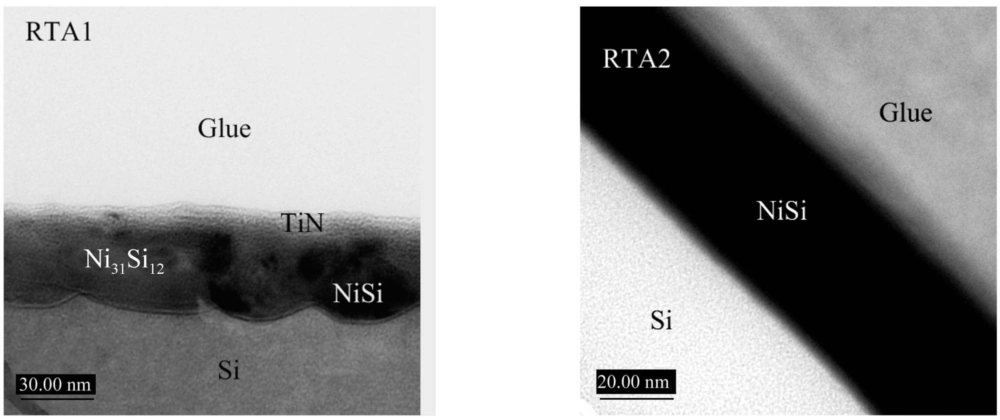

Fig. 3. Cross-sectional HRTEM images of TiN/Ni/Si samples after RTA1 and RTA2.

TiN/Ni/Si samples after RTA1 at 260 °C for 50 s and RTA2 at 515 °C for 30 s. In case of RTA1, the Ni film has reacted completely and more kinds of Ni-silicide phases are formed, while the interface of Ni-silicide/Si is very rough. However, in the case of RTA2, only one Ni-silicide phase exists and a smooth Ni-silicide/Si interface is obtained. Previous study shows that smooth silicide/Si interface is helpful to decrease leakage current[13, 14]. Measuring from the HRTEM images of RTA2, the thickness of Ni-silicide was 48 nm; combining with the XRD result, we are convinced that the 22 nm Ni had transformed into NiSi completely. This ratio of Ni to NiSi transformation is consistent with the results in Ref. [4].

Figure 4 shows the dependence of sheet resistance on flow rate of the protecting N_2 gas. A gradual decrease in the sheet resistance after RTA1 and a gradual increase in the sheet resistance after RTA2 was found for Ni (150 Å)/Si samples in the N_2 flow range of 2 to 6 slm. Furthermore, the difference of the sheet resistance between RTA1 and selecting etch was noteworthy.

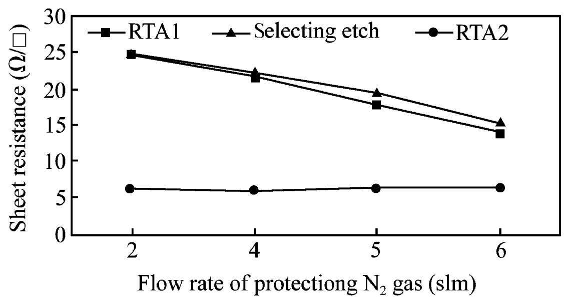

Fig. 4. Dependence of sheet resistance on flow rate of the protecting N_2 gas.

The protecting N_2 gas has two functions; one is to maintain an inert anneal environment and the other is to cool the process wafer. So under the halogen light anneal system, the surface temperature of the process wafer is lower than its inner temperature. With the increase of flow rate, the difference between surface temperature and inner temperature increases. The process temperature measurement system is performed by a K-type thermocouple (TC) and monitors the back temperature of the process wafer. When the measurement temperature

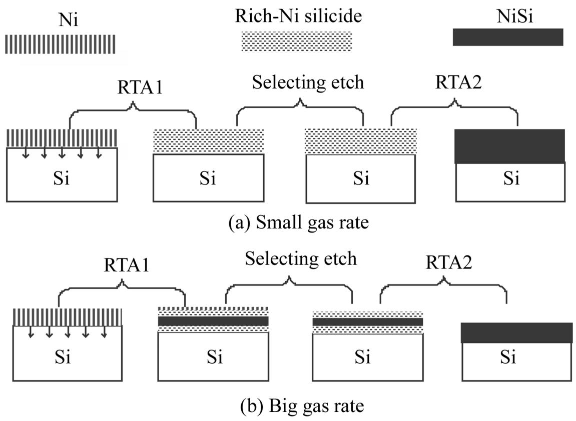

Fig. 5. Schematic diagram for a Ni-silicide process sequence: (a) Small N_2 flow rate; (b) Large N_2 flow rate.

is 260 °C, the inner temperature of the process wafer is higher than this, resulting in more NiSi being formed at high flow rate and so the sheet resistance decreases with the increase of flow rate. Due to NiSi formation earlier than the complete diffusion of nickel into silicon, Ni diffusion can be effectively reduced and can even result in Ni residues. Thus, the final thickness of the Ni-silicide film decreases and the final sheet resistance increases. The process sequences for the Ni-silicide used in this experiment can be schematically presented using a unified scheme as shown in Fig. 5.

4. Summary

We developed the two-step Ni-silicide process and studied the influence of the different process conditions. The two-step Ni-silicide process can exactly control NiSi phase and NiSi film thickness. The TiN/Ni/Si stack is of benefit to uniform NiSi thickness and a smooth interface between NiSi and Si. The flow rate of N_2 protective gas has a remarkable effect on the real reactive temperature for Ni to Si, so it should take the optimum value.

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