

Investigation on Suppression of Nickel-Silicide Formation By Fluorocarbon Reactive Ion Etch (RIE) and Plasma-Enhanced Deposition

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Abstract—Detailed study on how the plasma process during the sidewall spacer formation suppresses the formation of silicide is done. In non-patterned wafer test, it is found that both fluorocarbon reactive ion etch (RIE) and TEOS plasma-enhanced deposition processes modify the Si surface so that the silicide reaction is chemically inhibited or suppressed. In order to investigate the cause of the chemical modification, we analyze the elements on the silicon surface through Auger Electron Spectroscopy (AES). From the AES result, it is found that the carbon induces chemical modification which blocks the reaction between silicon and nickel. Thus, protecting the surface from the carbon-containing plasma process prior to nickel deposition appears critical in successful silicide formation.

Index Terms—Nickel silicide, plasma-enhanced deposition, reactive ion etch, sidewall spacer

I. INTRODUCTION

As the logic CMOS technology goes to deep-submicron nodes beyond 100-nm, nickel silicide has attracted attention as an alternative for future nodes due

to low resistivity, good sheet resistance in narrow line-width and low Si consumption [1-8]. And, not like its precedents such as titanium and cobalt, nickel forms the least resistive silicide phase at low temperature below 500°C, which makes nickel silicide formation more sensitive to the pre-treatment and the surface defects before the silicide process [9, 10]. Especially, the control of “plasma damage” during sidewall spacer formation is known to be critical to successful growth of silicide. However, whether the physical damage on the silicon lattice or the chemical effect plays a role in suppressing the silicide formation hasn’t been yet clarified.

In this work, we try to analyze the details of the process by reproducing the situation that “plasma damage” suppresses silicide formation and investigating it with step-by-step non-patterned wafer test.

II. EXPERIMENTAL

For nickel silicide formation, the following processes were done in the fabrication facilities of Inter-University Semiconductor Research Center located in Seoul National University. Right after 100:1 diluted HF cleaning removed residual or native oxide from 6 inch p-type Si (100) prime wafers, 200 Å nickel was deposited using Applied Materials Endura™ Sputter System. Silicidation anneal was performed for 60 sec at 450°C in N₂ ambient using KVR-3006T RTP System of Korea Vacuum Tech. Remaining or un-reacted metal after anneal was stripped with 4:1 mixture of 98% H₂SO₄ and 30% H₂O₂ at 80°C. After nickel silicide process, analysis was done by using sheet resistance, SEM and TEM image.

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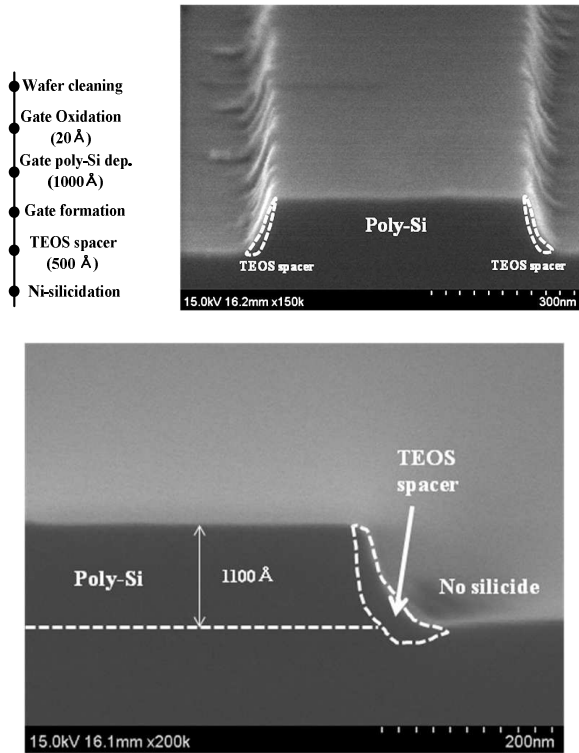


Fig. 1. Cross-sectional SEM image of the gate and sidewall after silicidation (No silicide is seen).

III. RESULTS AND DISCUSSION

First, a situation that silicide does not properly grow after sidewall spacer formation is reproduced following the sequence shown in Fig. 1. Wafer cleaning, gate oxidation and gate poly-Si deposition are sequentially performed. Then, gate patterning is done using hydrogen bromide (HBr) gas, and sidewall spacer is formed using plasma-enhanced deposition and fluorocarbon reactive ion etch (RIE). After that, silicidation process is performed. As expected, the measured sheet resistance is unacceptably high and no nickel silicide is seen from the cross-sectional image (Fig. 1).

In order to understand the physics behind this phenomenon, non-patterned wafer test is designed as shown in Fig. 2. Fig. 3 shows the sheet resistances measured from each experimental group. The control nickel silicide (T1) formed on a bare wafer without any RIE or dielectric deposition steps as a reference shows sheet resistance as low as 4 ohm/sq., which indicates successful formation of silicide as shown in Fig. 4.

However, once TEOS deposition and RIE processes are performed before silicide formation (T2), no silicide

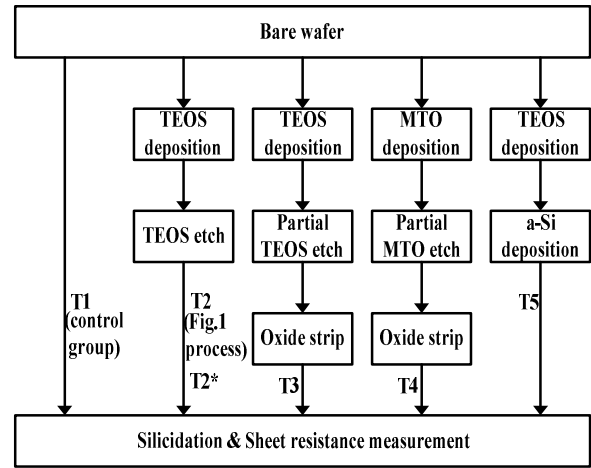


Fig. 2. Design of non-pattern wafer test (T2*: O₂-plasma treatment).

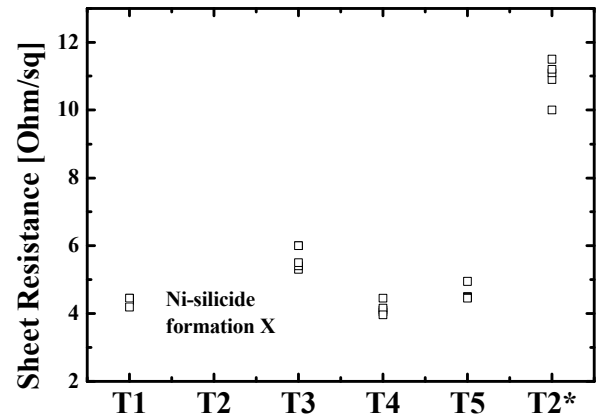


Fig. 3. Sheet resistances measured from each experimental group.

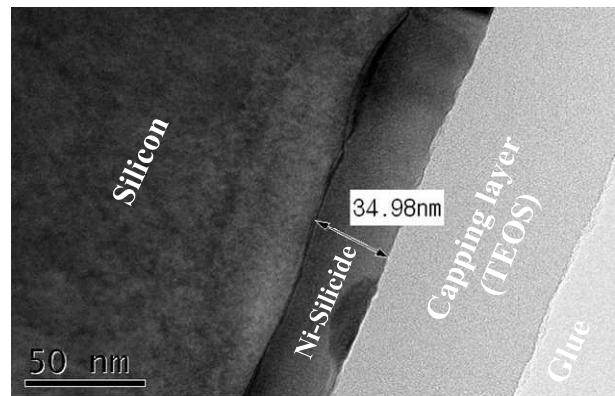


Fig. 4. TEM image of nickel silicide on control group (T1).

is observed from the cross-section and the sheet resistance is measured very high.

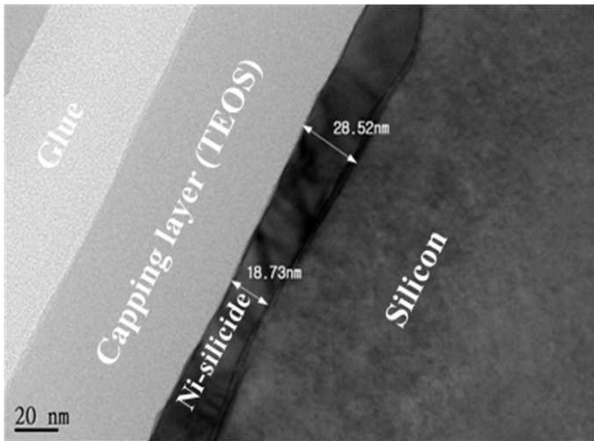


Fig. 5. TEM image of nickel silicide after partial TEOS etching and oxide wet strip process (T3).

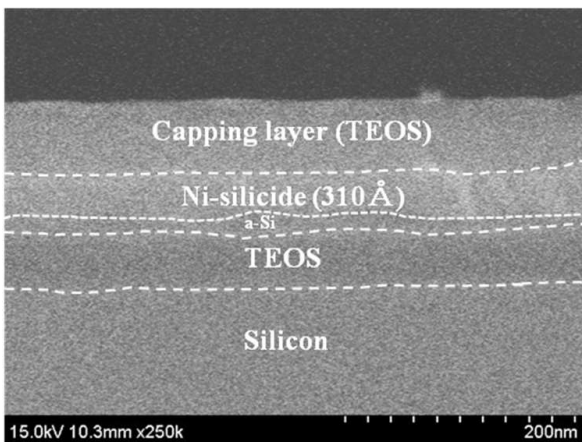
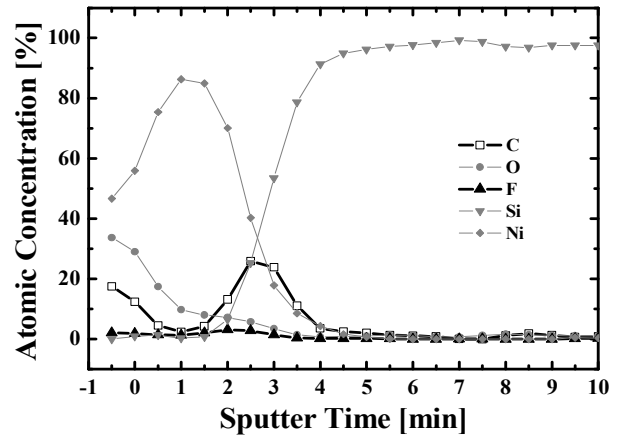
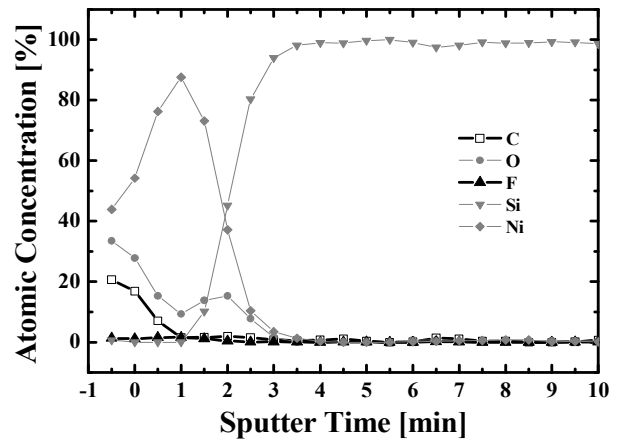


Fig. 6. SEM image of nickel silicide on amorphous silicon (T5).

To find out whether this occurs by RIE or deposition processes, a partial RIE sample (T3) is prepared. After the deposited TEOS is partially etched by RIE, the residual oxide is stripped off using the diluted HF solution. The reason why the residual oxide is removed using wet chemical is to only consider deposition effect without RIE effect. Sheet resistance value in Fig. 3 and TEM image in Fig. 5 show that silicide is formed on this sample. In order to understand whether the suppression of silicide formation is induced by the physical damage or chemical alteration of the surface, silicide process is done on amorphous silicon film (T5). Again, this sample shows low sheet resistance (Fig. 3) and successful silicide formation as in Fig. 6 (T5). Thus, the physical damage has no effect on silicide process. To sum up these results, the chemical modification of silicon surface by carbon-containing RIE plasma appears to be the root



(a)



(b)

Fig. 7. Atomic concentration of each element in the depth direction from silicon surface (a) before O_2 -plasma treatment, (b) after O_2 -plasma treatment.

cause of the suppression mechanism. To investigate the cause of this chemical modification, we analyze the elements on the silicon surface that went through TEOS deposition and RIE processes, using PHI 700Xi Scanning Auger Nanoprobe of Physical Electronics Inc. Fig. 7 shows the atomic concentration of each element in the depth direction from silicon surface. Five elements are detected; carbon, oxygen, fluorine, silicon and nickel.

Nickel on silicon surface is used as a capping layer. By carbon-containing RIE plasma process, there is a significant amount of carbon combined with silicon on surface as shown in Fig. 7(a). From this result, carbon seems to be introduced into the silicon during RIE process, similarly to dopants of plasma doping process [11]. In nickel silicide process, it is known that the formation temperature increases as an amount of incorporated carbon increases. This is because the carbon

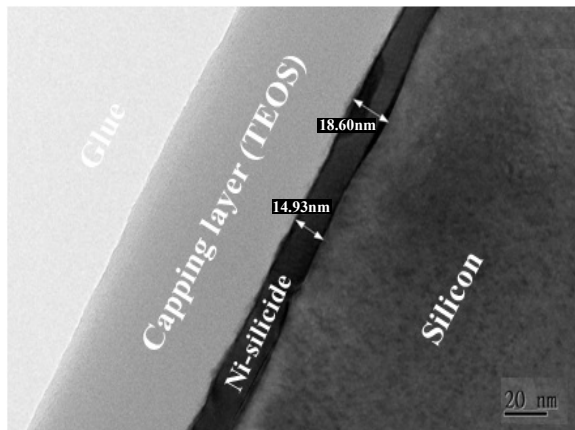


Fig. 8. TEM image of nickel silicide after fluorocarbon plasma etching and O₂-plasma treatment process (T2*).

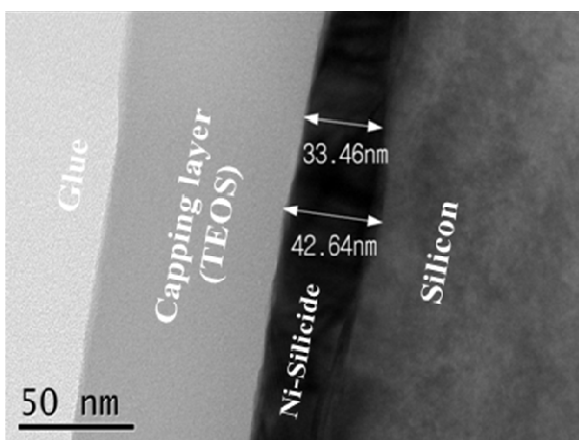


Fig. 9. TEM image of nickel silicide after partial MTO etching and oxide wet strip process (T4).

in the Si system suppresses the nickel mono-silicide formation by making the texture of mono-silicide on the substrate unstable [12, 13]. After O₂-plasma treatment is done, these carbon elements can be removed as shown in Fig. 7(b). Thus, we can confirm that the carbon induces the chemical modification which suppresses the reaction between silicon and nickel. From this result, nickel silicide can be formed by using O₂-plasma treatment (T2*) after TEOS deposition and RIE processes (Fig. 8).

Finally, Medium-Temperature Oxide (MTO) deposition instead of TEOS is tried to understand the effect of plasma during TEOS deposition process (T4). While the sheet resistance of TEOS group (T3) is slightly higher than that of the control group, the value of MTO group is similar to that of control group. And nickel silicide is formed well as shown in Fig. 9. This means that plasma-assisted surface modification occurs during TEOS

deposition although it is not as severe as in the case of RIE.

III. CONCLUSIONS

We have investigated how plasma process during sidewall formation can influence the formation of nickel silicide. Plasma-assisted surface modification is the key mechanism to suppress the reaction between nickel and silicon. From this study, we can understand either protecting the silicon surface from carbon-containing plasma or removing the plasma-modified surface is crucial to successful future silicide technology.

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