A New Oxidation-Resistant Self-Aligned $TiSi_2$ Process

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Abstract—**This paper presents a thin amorphous Si (a-Si) on Ti as an oxidation-resistant material for a self-aligned $TiSi_2$ process. It is shown that a thin a-Si over Ti film will greatly suppress the interaction between Ti and ambient gases (N_2 and O_2) during the thermal $TiSi_2$ formation cycle in conventional N_2 furnance while maintaining satisfactory self-aligned property after silicidation at a temperature below 630°C.**

I. Introduction

Among all refractory silicides, $TiSi_2$ is probably the most promising material for the self-aligned silicidation because of its comparatively low resistivity [1]–[3]. But due to its high reactivity with N_2, O_2, and H_2O in the ambient gas, the process control for obtaining homogeneity and reproducibility of a self-aligned $TiSi_2$ process has been a crucial problem in practice. Recently, several techniques [4]–[6] have been proposed to minimize the undesirable oxidation in conventional N_2 gas ambient. However, the Ti losses due to surface oxidation and/or nitridation still cannot be completely prevented using any of these methods, which make the precise control of Ti silicidation process problematic especially when the initial thickness of Ti film is very thin (< 500 Å) for typical SALICIDE applications [4], [6].

In this paper, a simple approach using a thin amorphous Si (a-Si) over Ti film as a protective layer is presented. Compared with the silicidation behavior of Mo/Ti bilayer in oxygen-contaminated N_2 ambient, it is found by both the sheet resistance measurements and AES depth analysis that the addition of 30–50-Å a-Si overlayer will effectively prevent Ti from reacting with N_2 and O_2 in the ambient gas during the thermal silicidation cycle. Moreover, due to a Ti-rich silicide (Ti_3Si) phase formed over SiO_2 region, a satisfactory self-aligned property of Ti silicidation can still be maintained using standard $NH_4OH + H_2O_2 + 4H_2O$ selective etching step when the annealing temperature is kept below 630°C in N_2 ambient.

II. Experimental Procedure

The (100) P-type Si wafers with the resistivity of 7 Ω·cm were used as the substrates. The Mo/Ti and a-Si/Ti metallizations were carried out using the e-beam evaporation method.

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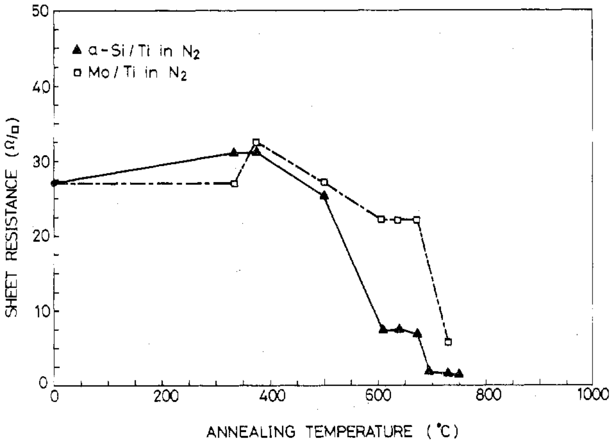

Fig. 1. The measured sheet resistances as a function of annealing temperature for Mo/Ti and a-Si/Ti bilayer structures in N_2.

Typically, the Ti film with a thickness of 450 ± 20 Å was deposited followed by depositing either 30–50-Å a-Si or 250-Å Mo layer without breaking the chamber vacuum which was pumped below 2×10^{-6} torr prior to deposition. The thicknesses of as-deposited Ti film and grown $TiSi_2$ for different structures are monitored by a SLOAN DEKTEK II step profiler on steps prepared by selective chemical etching. To investigate the self-aligned property, a standard two-step annealing process was used. First, the $TiSi_2$ was selectively grown on the patterned SiO_2 on Si substrate at 630°C for 40 min in N_2. Then, the sample was annealed at 750°C for 40 min in N_2 after selective removal of the unreacted portion by conventional NHH solution.

III. Results and Discussions

The sheet resistances for both a-Si/Ti and Mo/Ti bilayers as a function of annealing temperature after annealing in N_2 for 40 min are shown in Fig. 1. It is demonstrated that for annealing temperature above 600°C, the sheet resistance after silicidation for a-Si/Ti bilayer is much lower than that of its Mo/Ti counterpart. When the thickness of the grown $TiSi_2$ is measured after a two-step annealing process in N_2, it is found that the $TiSi_2$ grown from a-Si/Ti bilayer is almost double the thickness of that from Mo/Ti bilayer which has been claimed to be oxidation resistant in forming gas (N_2 + 10-percent H_2) ambient [4]. The measured thickness ratios of the grown $TiSi_2$ to as-deposited Ti for these two structures are listed in Table I. The AES depth profiles of a-Si/Ti bilayer before and after annealing in N_2 at 630°C are shown in Fig. 2(a) and (b), respectively. Compared with that of simultaneously processed

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TABLE I
THE MEASURED THICKNESS RATIO OF GROWN $TiSi_2$ TO DEPOSITED Ti FILM AND THE SHEET RESISTANCE AFTER A TWO-STEP ANNEALING PROCESS FOR TWO DIFFERENT BILAYER STRUCTURES

Process Condition	Measured $TiSi_2$/Ti Ratio	Measured Sheet Resistance
250 Å Mo/450 Å Ti in N_2	∿ 1.0	4.2 ± 0.2 Ω/□
40 Å a-Si/450 Å Ti in N_2	∿ 2.2	1.6 ± 0.2 Ω/□

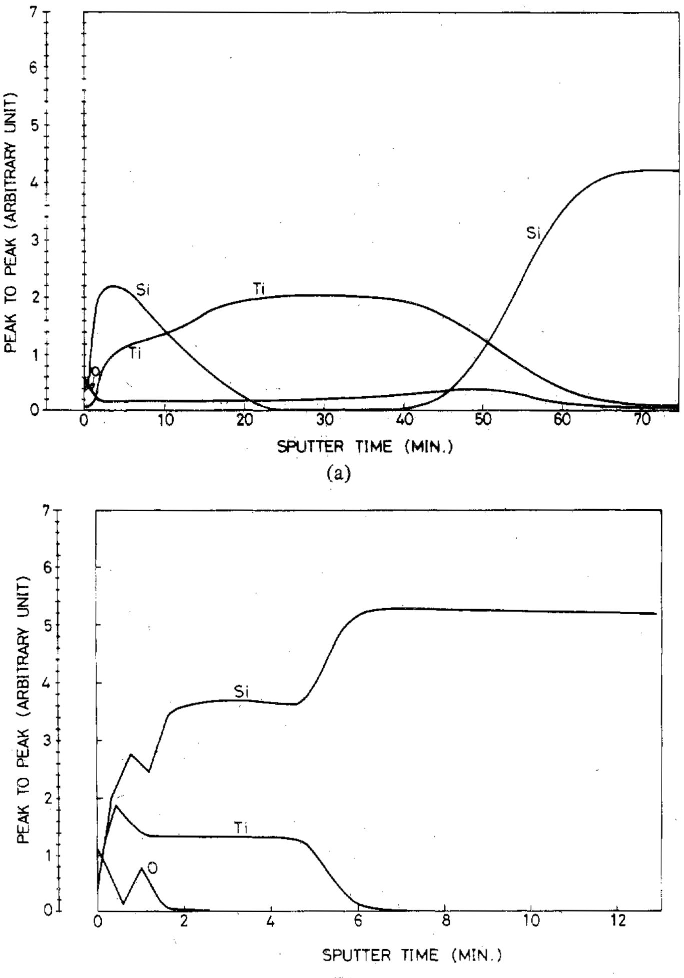

Fig. 2. The AES depth profiles for a-Si/Ti structure: (a) as-deposited, and (b) after annealing in N_2 at 630°C for 40 min.

Mo/Ti bilayer shown in Fig. 3, both oxidation and nitridation of Ti film at the surface are almost completely suppressed for a-Si/Ti bilayer structure. From both Table I and Fig. 2 we may conclude that the extremely low sheet resistance achieved by a-Si/Ti bilayer can be mostly attributed to almost complete transformation of Ti into $TiSi_2$ despite serious oxygen contamination in the N_2 ambient during the annealing cycle. The reaction between a-Si and Ti over SiO_2 has also been analyzed in this study. It is found that due to much thinner a-Si, as compared with that of Ti film in this region, only thin Ti-rich phase silicide can be formed over SiO_2 and can be easily removed by a standard NHH etching step. Detailed studies on this topic will be presented elsewhere. The self-aligned growth

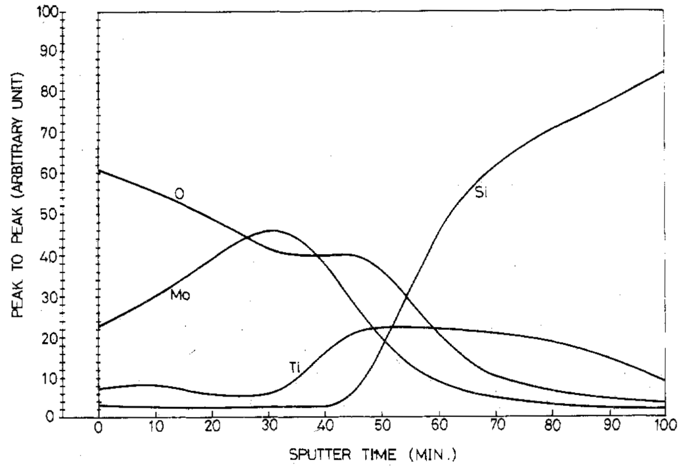

Fig. 3. The AES depth profile for Mo/Ti bilayer simultaneously processed with a-Si/Ti bilayer at 630°C for 40 min in N_2.

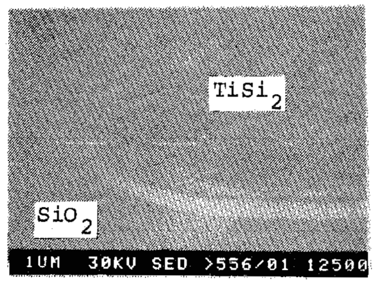

Fig. 4. The SEM micrograph (× 12500) shows no lateral growth of $TiSi_2$ after annealing at 630°C in N_2 for a-Si/Ti bilayer.

of $TiSi_2$ can be justified by observing the well-defined edge between the $TiSi_2$-grown region and the SiO_2 region from the SEM micrograph shown in Fig. 4.

IV. Conclusion

A new and simple technique which can effectively isolate the active Ti underlayer from reacting with N_2 and O_2 in conventional N_2 furnance has been introduced. The effectiveness of a-Si layer over Ti as an oxidation and nitridation barrier is believed to be due to the stabilization of Ti surface by thin silicide formation between a-Si and Ti. Using this technique, neither a specially designed annealing system nor procedure is needed for tighter control of the self-aligned $TiSi_2$ process.

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