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Self-Aligned Titanium Silicidation by Lamp Annealing

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Silicidation reaction of sputter-deposited titanium (Ti) thin films on silicon (Si) are performed by lamp annealing. A rapid thermal processing with halogen lamp heating is found to be quite effective to form oxide-free $TiSi_2$. Rutherford backscattering analyses and X-ray diffraction studys show that the lamp annealing above 650°C results in stoichiometric $TiSi_2$ within as short as 30 sec. A self-aligned titanium silicidation is successfully applied to source/drain and gate of MOS transistors by 2-step lamp annealing.

1. INTRODUCTION

Refractory metal silicides have been used to lower the resistance of gate level interconnects in MOS-VLSI [1]. Recently a self-aligned silicidation of source/drain and gate has been investigated for scaled MOS transistor [2]. $TiSi_2$ is the most promising material for self-aligned silicidation because of its lowest resistivity among various silicides. Ti is, however, known to be quite active metal easily to form titanium oxide during silicidation by a conventional furnace annealing. We have developed a rapid thermal processing with halogen lamp heating for self-aligned titanium silicidation. This paper describes characteristics of silicidation reaction of Ti and Si by the lamp annealing, and self-aligned titanium silicidation of source/drain and gate of MOS transistors.

2. SILICIDATION REACTION OF TI AND SI BY LAMP ANNEALING

Ti is deposited onto (100) Si substrates or poly Si films of 300-500 nm thickness by dc magnetron sputtering. Silicidation reactions are performed with the lamp annealing system at the temperature range of 450-900 °C for 15-240 sec. The lamp annealing system has an Ar-purged quartz annealing chamber equipped with halogen heating lamps. Annealing temperature is monitored in

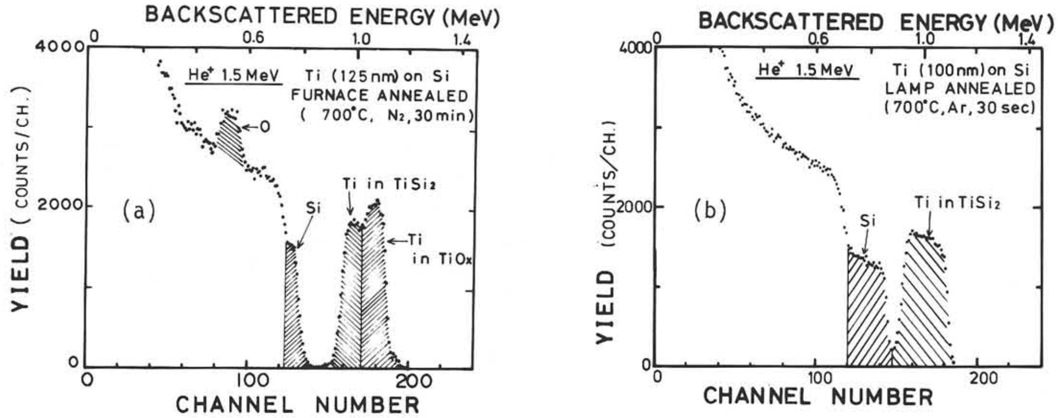

Fig.1 RBS spectra of $TiSi_2$ formed by (a) furnace annealing, and (b) lamp annealing.

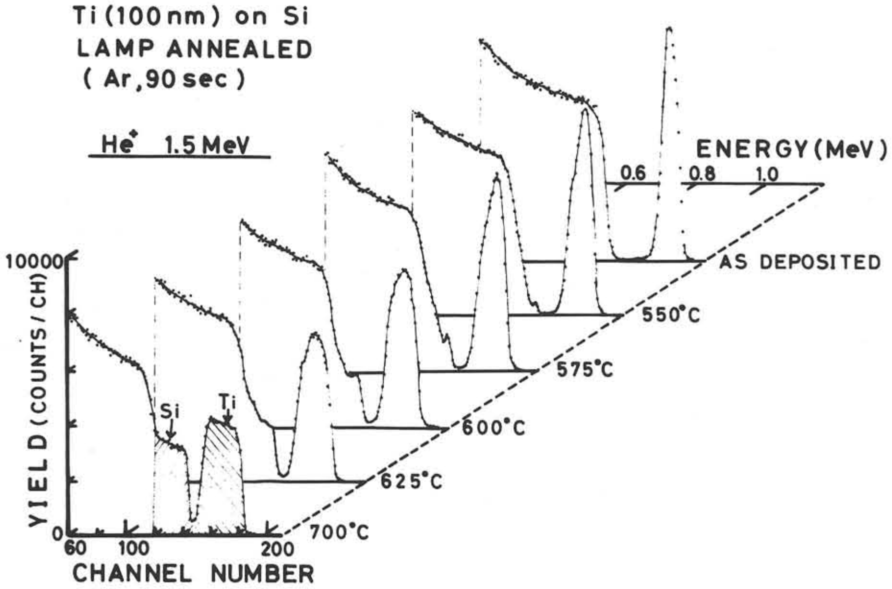

Fig.2
RBS analysis of silicidation reaction of Ti and Si by lamp annealing at 550-700°C for 90 sec.

situ, and controlled with a closed loop feedback. The rise time of wafer temperature to a presetted value is typically 10 sec.

Ti is known to be quite active metal easily to form titanium oxide during silicidation by a conventional furnace annealing, as is shown in the Rutherford backscattering (RBS) spectrum of Fig.1(a). This is caused by residual oxygen gas in a furnace during the heat treatment. A rapid thermal processing with the halogen lamp annealing system is found to be quite effective to form oxide-free $TiSi_2$, as is shown in Fig.1(b). This is due to the oxygen-free ambient during the annealing in the Ar-purged quartz annealing chamber. A thin layer of titanium nitride is observed by RBS at the surface of the samples silicided by the lamp annealing in N_2 atmosphere.

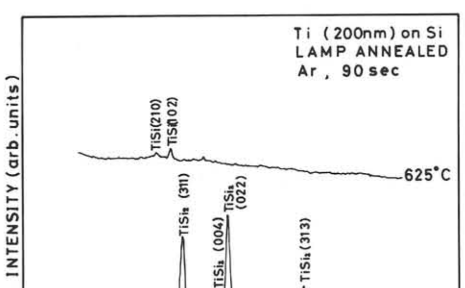

Fig.3 X-ray diffraction peaks from $TiSi_2$ films formed by lamp annealing at 625°C and 700 C.

Characteristics of silicidation reaction as a function of annealing temperature are investigated by RBS. Figure 2 shows RBS spectra from Ti thin films silicided at 550-700 °C for 90 sec. Intermixing of Ti and Si is clearly seen in the samples annealed at 550-625°C. Si atoms appear at the Ti surface even at the lowest temperature, i.e. 550 °C, which might be a result of Si diffusion in a Ti film to the surface. Up to 625 °C annealing temperature, no homogeneous titanium silicide films are formed. While an annealing at 700 °C, a homogeneous titanium silicide film is formed, a stoichiometry of which is estimated to be Ti:Si=1:2 by RBS. To identify the phase of titatium silicides, X-ray diffraction study is performed. Figure 3 shows X - ray diffraction peaks from the samples annealed at 625°C and 700 °C. From the sample annealed at 625°C, X-ray diffraction peaks from TiSi can be observed, though the intensities are weak. From the sample annealed at 700°C, intense peaks from $TiSi_2$ are observed. This result combined with the RBS analysis indicates that the homogeneous and stoichiometric $TiSi_2$ film is formed by the lamp annealing at 700°C for 90 sec.

Figure 4(a) shows the sheet resistance of 60 nm Ti silicided by the lamp annealing at various temperatures. The sheet resistance increases by the annealing below 550°C up to two times of the as-deposited film, the resistivity of which is 75-90 μΩ·cm. Around 650°C, the resistivity reduces

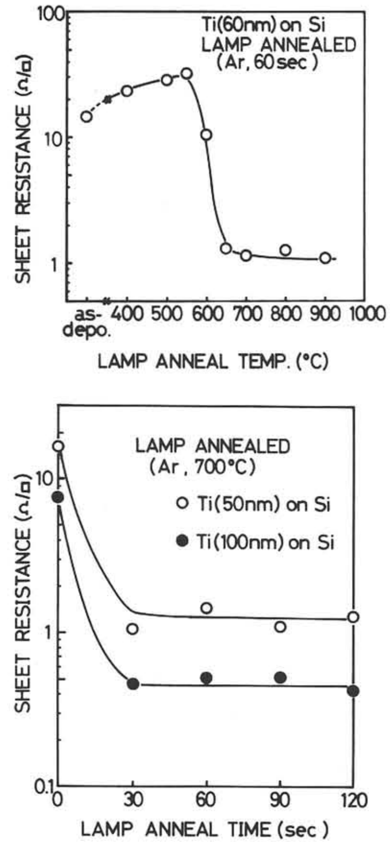

Fig.4 Sheet resistance of $TiSi_x$ films formed by lamp annealing, (a) temperature dependence, (b) annealing time dependence.

drastically to 14-16μΩcm, which is almost the same as that of bulk $TiSi_2$. The change of the sheet resistance with the annealing time at 700 °C is shown in Fig.4(b). The lowering of the sheet resistance is saturated over 30 sec annealing with 50 - 100 nm Ti films on Si. Silicidation reaction is completed within as short as 30 sec at this temperature range, which is more than 10 times faster than the reported silicidation speeds with furnace annealing[3].

3. SELF-ALIGNED TITANIUM SILICIDATION FOR MOS TRANSISTORS

In order to form $TiSi_2$ at source/drain and gate of MOS transistors, we have developed self-aligned titanium silicidation technique.

Ti is sputter-deposited onto silicon wafers which have exposed Si and poly-Si portions, and then annealed to form $TiSi_2$ in a self-aligned manner by the lamp annealing. Unreacted Ti films on top of SiO_2 are etched off by wet chemicals. At elevated silicidation temperature, e.g. 700°C, self-aligned titanium silicidation cannot be obtained. Figure 5 shows that $TiSi_2$ is undesirably formed beyond SiO_2 openings. A SEM observation reveals that silicon is hollowed out at the edge of SiO_2 openings. The length of $TiSi_2$ laterally grown over SiO_2 is proportional to square root of the annealing time, as is shown in Fig.6. This clearly indicates that the formation reaction of $TiSi_2$ is diffusion limited process, and the predominant diffusing species is Si. The diffusion length of Si is about 5 μm with lamp annealing at 700°C for 240 sec.

Self-aligned titanium silicidation can be successfully obtained by 2-step annealing: (1) annealing below 600 °C followed by removal of

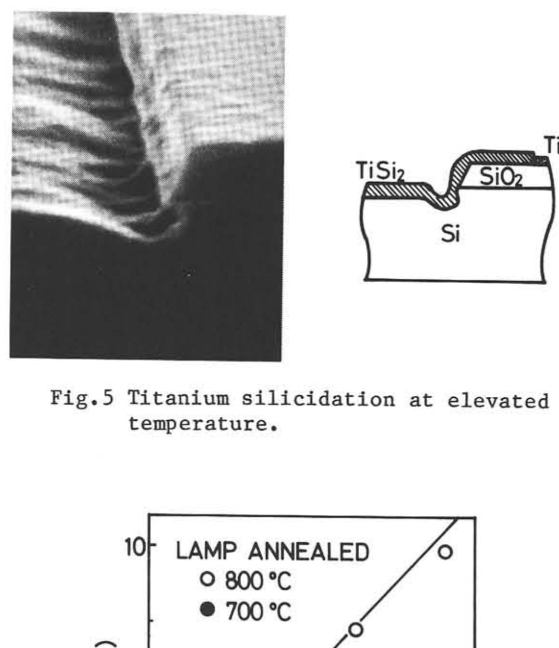

Fig.5 Titanium silicidation at elevated temperature.

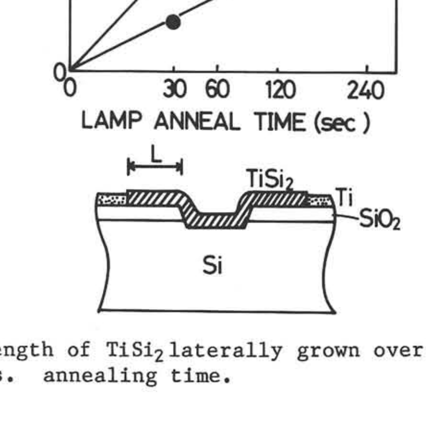

Fig.6 Length of $TiSi_2$ laterally grown over SiO_2 vs. annealing time.

unreacted Ti on top of SiO_2 by wet chemicals, (2) annealing above 650 °C to complete $TiSi_2$ formation. RBS analyses show that with the optimized annealing temperature and time of the 1-st stage annealing, the film composition on exposed Si portions is not altered by succeeding etching of unreacted Ti on top of of SiO_2. After the 2-nd stage annealing, the silicide formed is stoichiometric $TiSi_2$ with 14-16 $\mu\Omega \cdot$ cm of resistivity.

The self-aligned silicidation technique is applied to form $TiSi_2$ at source/ drain and gate of MOS transistors. To separate source/drain from gate, SiO_2 side walls are formed at the side of the poly-Si gate electrodes by using reactive ion etching. Thses SiO_2 side walls are also used to construct LDD (Lightly Doped Drain) structures with phosphorus and arsenic implants for lightly and heavily doped drain, respectively. Figure 7 shows the SEM photograph of the self-aligned titanium silicidation of source/drain and gate of MOS transistor. A transistor characteristics fabricated with the self-aligned titanium silicidation technique by using lamp annealing is shown in Fig.8. The gate length is 0.8 µm and the gate oxide is 25 nm thick. With the optimization of Ti thickness and lamp annealing temperature, the junction integrity and the gate dielectric integrity are preserved. Sub-threshold characteristics are typically 75 mV/decade.

4. CONCLUSION

Silicidation reaction of Ti and Si is performed by rapid thernmal processing with halogen lamp heating. A lamp annealing is found to be quite effective to form oxide-free $TiSi_2$. RBS and X-ray diffraction study show that with the lamp annealing of Ti on Si below 625 °C, intermixing of Ti and Si occurs and only TiSi phase is identified at this temperature range. The lamp annealing above 650 °C results in stoichiometric $TiSi_2$ within as short as 30 sec. The formation reaction of $TiSi_2$ is diffusion limited with the predominant diffusing species of Si. Resultant resistivity of $TiSi_2$ is 14-16 $\mu\Omega$ cm. A self-aligned titanium silicidation is successfully applied to source/drain and gate of MOS transistors by 2-step lamp annealing.

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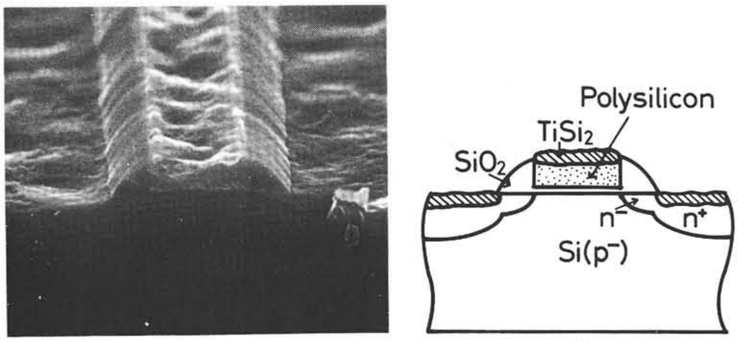

Fig.7 SEM photograph of self-aligned titanium silicidation of source/drain and gate of MOS transistor.

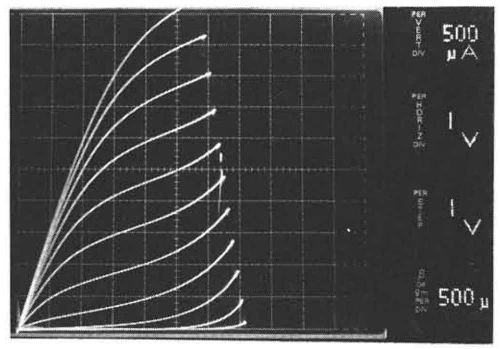

Fig.8 MOS trnsistor characteristics fabricated with self-aligned titanium silicidation technique by using lamp annealing.