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To cite this version:


HAL Id: jpa-00223150

https://hal.archives-ouvertes.fr/jpa-00223150

Submitted on 1 Jan 1983

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THERMAL PULSE ANNEALING OF TITANIUM AND TANTALUM SILICIDES

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RÉSUMÉ

Des couches de titane et de tantale ont été aspergées avec du silicium. La possibilité d'utilisation de techniques de trempage par impulsions pour la formation de disilicides à basse résistivité a été indiquée.

ABSTRACT

Titanium and tantalum films were cosputtered with silicon. The feasibility of using pulse anneal techniques to form the low resistivity disilicides is shown.

INTRODUCTION

The reduction of device geometries necessary for the realisation of VLSI circuits requires a reduction in the resistivity of high temperature compatible interconnect materials, and to this end refractory metal disilicides are increasingly being adopted as promising alternatives to polysilicon. A general reduction of process temperatures or times is also desirable in order to minimise redistribution of dopants and interdiffusion of adjacent layers. Clearly the 30–40 minute anneals at present used1) for annealing titanium and silicon layers to form titanium disilicide are the cause of some concern. It has been shown1) that anneal times can be reduced, but only if a reduction in the film's conductivity can be accepted. It has also been shown that a short high temperature anneal at the end of a process is highly beneficial in terms of activating2) or reactivating3) dopants. We report here experiments which show that it is possible to achieve the desired high conductivity in titanium and tantalum disilicide films using only very short high temperature anneals.

EXPERIMENTAL DETAILS

In our experiments the substrates used were silicon wafers on which 80 nm of thermal oxide had been grown in a wet oxidation process. Metal (titanium or tantalum) and silicon layers 7 nm and 14 nm thick respectively were alternately sputtered to a total film thickness of approximately 200 nm. The films had a metallic silver appearance and exhibited sheet resistances of 15–25 Ω/□. A dc magnetron sputtering source was used for the titanium and tantalum, but because of the higher resistivity of the polycrystalline silicon target, an rf magnetron sputtering source was employed. Targets were specified pure to 99.99%. The chamber was evacuated to 10⁻⁵ torr before back filling with argon to a pressure of 8 x 10⁻³ torr. The thickness and composition of the film were calculated from deposition rates, which were checked by etching a step in the film and measuring its height using a Talystep height monitor, and also by measuring the weight increase of the wafers after deposition.

The wafers were scribed into 2 centimetre squares before annealing. The squares were then annealed in the pulse anneal apparatus shown schematically in Figure 12).
The anneal chamber was first evacuated to $5 \times 10^{-6}$ torr and then back filled with nitrogen to a pressure slightly above atmospheric. Current was then passed through the graphite heater and the temperature monitored using the infra-red pyrometer. The required temperature was reached in times varying from 8 seconds to 700°C to 12 seconds for 1100°C. The squares were left in the chamber to cool for 10-15 minutes, taking under 30 seconds to cool below 600°C. A four point probe was used to measure the sheet resistance of the annealed films.

RESULTS AND DISCUSSION

Titanium
As can be seen in Figure 2, the sheet resistance dropped rapidly from the 'as deposited' value of 25 $\Omega$/\text{sq} to 6 $\Omega$/\text{sq}, but only at temperatures in excess of 900°C did it drop further to 1.3 $\Omega$/\text{sq}.

The completion of two processes is required to achieve low resistivity films; the film constituents must interdiffuse in order to form a homogeneous layer, and they must react in order to form the silicide. It is likely\textsuperscript{11}) that sufficient interdiffusion to form the monosilicide occurs very rapidly at temperatures above 750°C, but that temperatures in excess of 900°C are required - given the short pulse - to form the lower resistivity disilicide throughout the film. The sheet resistivity of the films annealed at about 900°C is directly comparable with that obtained from films annealed in a conventional furnace for 30 minutes, indicating that the interdiffusion and reaction of titanium and silicon are complete. Also, the post anneal film thickness of the 1100°C sample was estimated by Auger profiling to be 175 nm. This, and the measured sheet resistance of 1.3 $\Omega$/\text{sq}, shows that the bulk resistivity of the annealed film is close to 23 $\mu\Omega$ cm, in good agreement with that reported elsewhere for titanium disilicide\textsuperscript{4,5}).
Figure 3 shows sheet resistivities after repeated pulses, and their effectiveness compared with a full furnace anneal. As noted earlier, for pulse anneals at temperatures in excess of 900°C the interaction appears to be complete, with subsequent pulses yielding no further improvement. The sample pulse annealed at 870°C shows a dramatic drop in sheet resistance after only a few pulses, whereas the sample pulse annealed at 770°C does not show a similar change after twice as many pulses. It is hoped that by decreasing the thickness of the individual titanium and silicon layers, the peak temperatures of the pulse anneal required to obtain high conductivity films will drop. The 770°C trace on Figure 3 would then be expected to approximate more to the 870°C trace, or even the 1000°C. The limiting temperature is about 600°C, which is the lowest temperature at which titanium disilicide is the favoured phase for formation. Even with a pulse of some 950°C, the equilibrium diffusion of dopants is predicted to be negligible, and the short high temperature anneal used to activate or reactivate dopants at the end of a process could also be used to anneal the silicide gate electrode and interconnects.
**Tantalum**

As can be seen in Figure 4, the sheet resistance dropped from the 'as deposited' value of 20 $\Omega/\square$ to the fully annealed value of 3.1 $\Omega/\square$ without the intermediate anneal regime observed in the case of titanium. This suggests that tantalum disilicide is the only silicide formed during the anneal. The sheet resistivity of films annealed above 1000°C is comparable with the lowest resistivities obtained by furnace annealing, indicating that the interdiffusion and reaction of tantalum and silicon are complete. Also, the post anneal thickness of the 1150°C sample was estimated by Auger profiling to be 180 nm. This and the measured sheet resistance of 3.1 $\Omega/\square$ show that the bulk resistivity of the annealed film is close to 55 $\mu \Omega \text{cm}$, in good agreement with that reported elsewhere\(^4\)\(^5\) for tantalum disilicide.

![Figure 4: Sheet resistance of tantalum silicide as a function of anneal temperature](image)

**CONCLUSIONS**

This work shows that it is possible to fully anneal cosputtered refractory metal silicides to form low resistivity layers without the need for long heat treatments which would be undesirable at such a late stage in the process.

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