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Impurity and Ambient Effects on Self-Aligned Titanium Silicidation by Rapid Lamp Annealing

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Impurity and ambient effects on lateral growth in the self-aligned titanium silicidation by the halogen lamp annealing were investigated. In the case of titanium (Ti) with arsenic (As), As was swept toward the unreacted Ti side and formed an accumulated layer, as lateral growth proceeded. The As-accumulated layer had an effect to suppress progress of lateral growth. The halogen lamp annealing in nitrogen (N_2) was found to be quite effective in forming self-aligned silicidation without lateral growth, which was due to rapid nitridation of Ti on silicon dioxide (SiO_2). The silicidation in N_2 was also effective for improvement of surface roughness.

1. INTRODUCTION

According to an increase of packing density of VLSI circuits, refractory metal silicide technology is increasingly getting important. Especially, the self-aligned silicidation of gate and source/drain is the most interesting application. Among various silicide, titanium silicide ($TiSi_2$) is the most promising material for the self-aligned silicidation because of its lowest resistivity. However, titanium (Ti) is highly active and tends to oxidize easily during annealing. Previously, we reported that the short time annealing process with halogen lamps was quite effective in forming oxide-free $TiSi_2$[1]. In order to form self-aligned $TiSi_2$, it is important to prevent not only oxidation of Ti but also lateral growth of silicide. This paper describes impurity and ambient effects on lateral growth in the self-aligned Ti silicidation process by the halogen lamp annealing method.

2. EXPERIMENTAL PROCEDURE

Ti was sputter-deposited onto silicon (Si) substrates, silicon dioxide (SiO_2) or patterned SiO_2 films on Si to a thickness of 40-175 nm. Then, the halogen lamp annealings were carried out in argon (Ar) or nitrogen (N_2) ambient at 650-850 °C for 15-240 sec. In order to investigate impurity effects, arsenic (As) was implanted into surface of some Ti films; $1x10^{16}/cm^2$ at 35-50KeV. Impurity and ambient effects were investigated by an optical microscope, scanning electron microscope (SEM), Rutherford backscattering spectroscopy (RBS), secondary ion mass spectroscopy (SIMS), scanning auger analysis and fluorescent X-ray spectrometer measurements.

3. RESULTS AND DISCUSSIONS

3.1 Effects and Behaviour of As during Silicidation

Figures 1(a) and (b) are optical microscope photographs showing lateral growth of silicide formed by annealing at 800°C for 240 sec in Ar; (a) un-implanted Ti and (b) As-implanted Ti. In

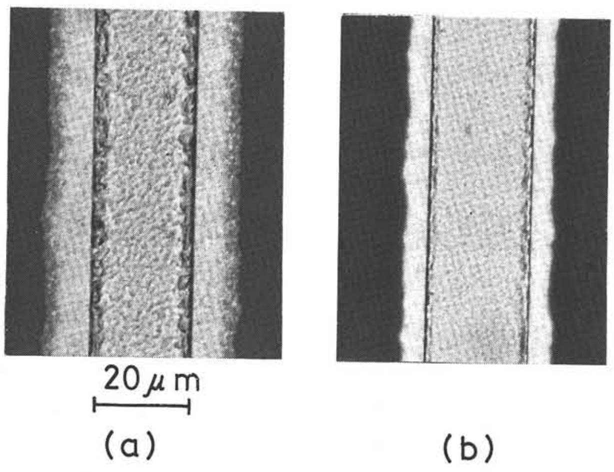
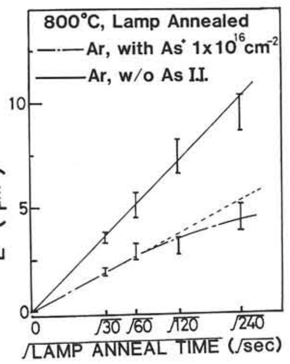


Fig. 1 Optical microscope photographs indicating lateral growth of silicide formed by annealing at 800°C for 240 sec in Ar; (a) un-implanted Ti, (b) As-implanted Ti.



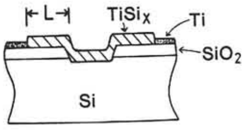


Fig. 2

Length of lateral growth over SiO_2 as a function of square root of annealing time.

the case of Ti without As, lateral growh over SiO_2 reached more than 9 μm. On the other hand, when As was implanted into a surface of Ti, lateral growth was suppressed to less than half of the un-implanted sample. In Fig.2, length of lateral growth (L) over SiO_2 as a function of square root of annealing time ($\sqrt{t}$) is shown. In the case without As implantation, L was proportional to $\sqrt{t}$, which indicated that silicidation reaction was a process limited by Si diffusion. Lateral silicidation of Ti containing As was suppressed as the annealing time became longer. In order to make clear the mechanism of the above phenomena, an effect and behaviour of As during Ti silicidation on Si were investigated by RBS. Figures 3(a) and (b) show RBS spectra from un-implanted and As-implanted sample, respectively. Ti without As formed homogeneous $TiSi_2$ by the halogen lamp annealing at 700 °C for 90 sec in Ar, while in the case of As-implanted Ti, silicidation was not completed on the same annealing condition. This result clearly shows that As in Ti has an effect to retard silicidation reaction. Figures 4(a) and (b) show RBS spectra from Ti on Si annealed at 650°C for 15-240 sec in Ar and enlarged RBS spectra of As, respectively.

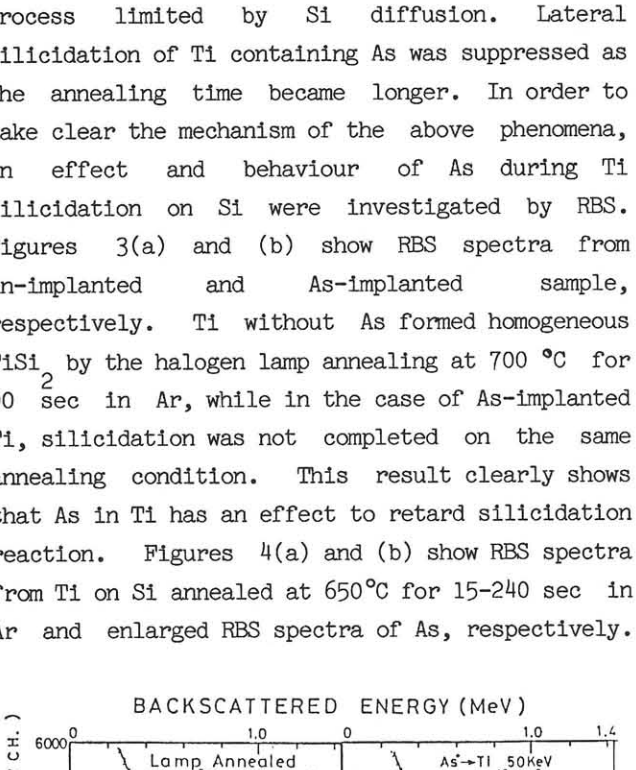


Fig. 3 Influence of As implanted into Ti on silicidation.

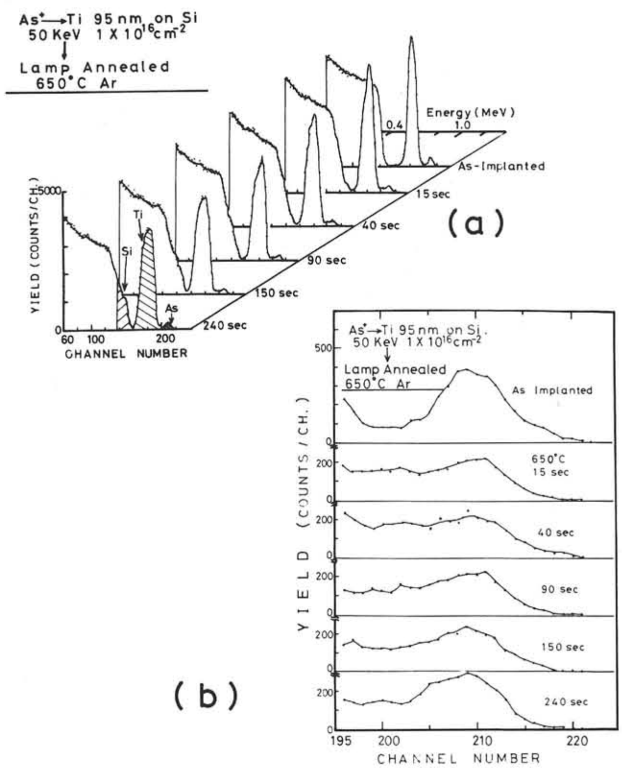
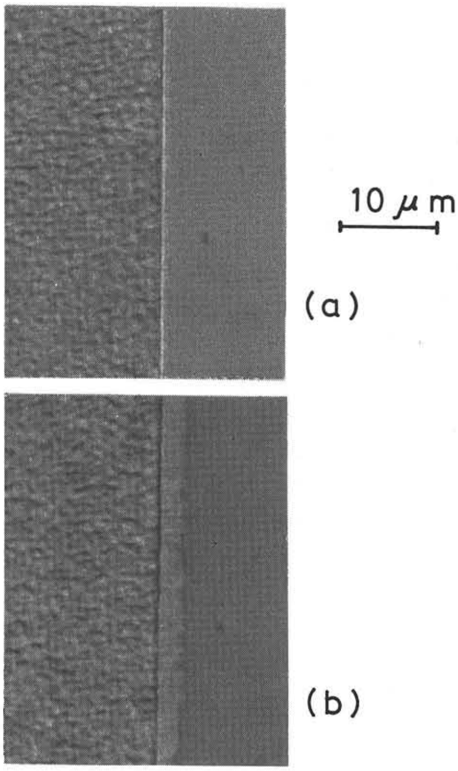
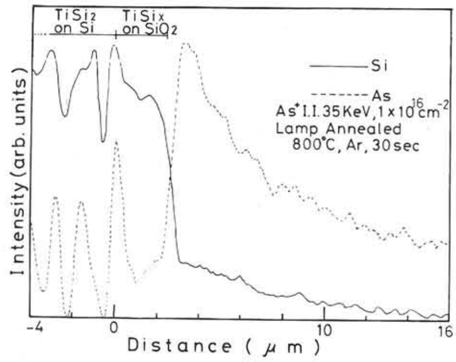


Fig. 4 (a) RBS spectra showing redistribution of As in Ti by annealing at 650°C for 15-240 sec, (b) enlarged spectra from As.

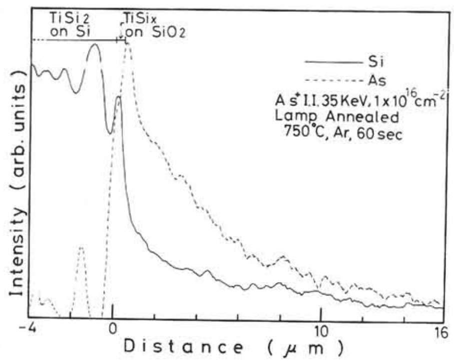
It was found that As at the surface diffused within the Ti film at the initial stage of silicidation (15,40 sec). By the annealing longer than 90 sec, As began to form a surface peak again in the spectra. This indicates that As, which initially spread within Ti, was swept toward the surface as silicidation proceeded. In order to confirm the behaviour of As during actual lateral growth of titanium silicide over SiO_2, lateral distribution of As was measured by a scanning auger analysis. In Figs.5 (a)-(d), optical microscope photographs and line distributions of As and Si in a sample annealed at 750°C for 60 sec (a),(c) and 800 °C for 30 sec (b),(d) in Ar are shown. These figures show that As was swept toward the unreacted Ti side and formed an accumulated layer. The As accumulated layer became wider as lateral growth proceeded. From these results it was concluded that the retardation of lateral growth with the increase of annealing time was caused by the formation of the As accumulated layer and its suppression effect on silicidation.





(c)

Fig. 5 Optical microscope photographs and AES line distributions of As on Si in a sample annealed at 750°C for 60 sec (a),(c) and at 800°C for 30 sec (b),(d) in Ar.



(d)

3.2 Ambient Effects on Self-Aligned Silicidation.

Ambient effects (Ar or N_2) on the self-aligned silicidation were also investigated. Ti on patterned SiO_2 was annealed in N_2 at 850 °C for 240 sec. As shown in Fig. 1(a) previously, lateral growth over SiO_2 was clearly observed in the case of annealing in Ar. On the other hand, it was found that the halogen lamp annealing in N_2 resulted in self-aligned silicidation without lateral growth in spite of annealing at relatively high temperature, as shown in Fig.6. In Fig.7, a RBS spectrum from Ti (70nm) on Si lamp-annealed in N_2 at 800°C for 60 sec is shown. It was observed that a thin titanium nitride (TiN) layer (~ 20nm) was formed at the surface. By fluorescent X-ray spectrometer measurements for this sample before/after selective removal of TiN, it was found that about one forth of Ti was consumed in the surface nitride layer, and remaining Ti formed $TiSi_2$. Ti films (175nm) on SiO_2 were annealed in N_2 at 700°C and depth profiles of N were measured by SIMS. As shown in Fig.8, it was found that N diffused into Ti rapidly and nitrided Ti. It is known that TiN is not converted into silicide [2)-4)]. Successful self-aligned silicidation in N_2 is due to rapid nitridation of Ti on SiO_2 and its barrier effect for lateral growth of silicide. Submicron MOS devices were fabricated with self-aligned silicidation of both source/drain and

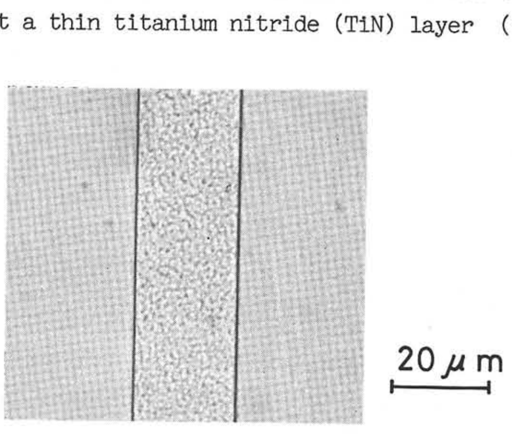


Fig. 6 An optical microscope photograph of self-aligned silicide formed by annealing in N_2 at 850°C for 240 sec.

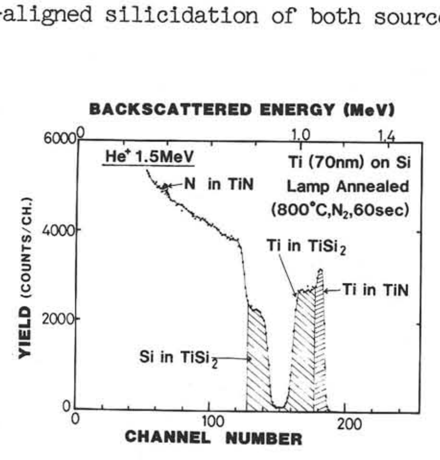


Fig. 7 A RBS spectrum from Ti on Si annealed in N_2 at 800°C for 60 sec.

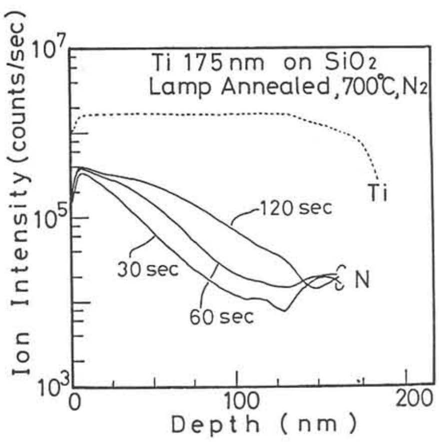


Fig. 8 Depth profile of N in Ti on SiO2 annealed in N_2 at 700°C for 30-120 sec.

gate regions. Figures 9 show SEM photographs of MOS devices; silicidation was carried out in (a) Ar and (b) N_2, respectively. In both cases, self-aligned silicide with thickness of ~100nm was successfully obtained without lateral growth. However, in the case of Ar, formed silicide had a considerably rough surface, and the annealing condition for preventing a bridging between source/drain and gate was very severe especially in annealing temperature. On the other hand, annealing in N_2 resulted in homogeneous silicidation. And the very wide tolerance of annealing condition could be obtained compared with Ar. It was concluded that annealing in N_2 was quite effective to not only prevent lateral growth over SiO_2 but also improve surface roughness.

4. CONCLUSIONS.

Impurity and ambient effects on lateral growth in the self-aligned Ti silicidation by the halogen lamp annealing were investigated. It was found that As in Ti had an effect to retard silicidation reaction, and lateral growth over SiO_2 was suppressed. From RBS and scanning AES measurements, following results were obtained: As was swept toward the unreacted Ti side and formed an accumulated layer; retardation of lateral growth was caused by a suppression effect of accumulated As on silicidation. The halogen lamp annealing in N_2 was found to be quite effective in forming self-aligned silicidation without lateral growth. By annealing in N_2 , about one forth of

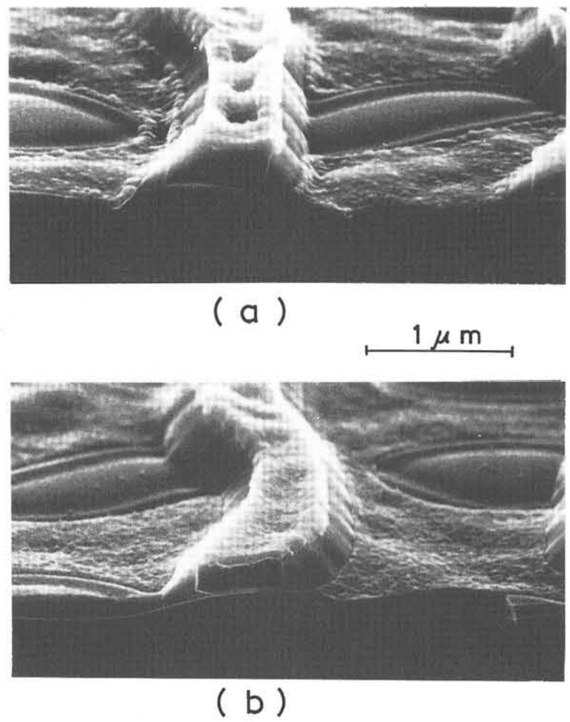


Fig. 9 SEM photographs of submicron MOS devices with self-aligned silicidation performed in (a) Ar and (b) N_2.

Ti on Si was converted into nitride, while whole Ti on SiO_2 was nitrided rapidly. This rapid nitridation of Ti on SiO_2 prevented lateral growth. It was also found that annealing in N_2 ambient was effective for improvement of surface roughness.

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