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Epitaxial $CoSi_2$ Layer Formation Technology on (100) Si and Its Application for Reduced Leakage, Ultra Shallow p^+/n Junction

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Thermally stable, epitaxial $CoSi_2$ / (100)Si with smooth surfaces has been developed by a sputter deposition of Co / 2 nm Ti on Si substrates followed by a 900°C anneal. An amorphous 2 nm thick layer, which was formed between the Co and Si during a Co / 2 nm Ti deposition on Si, worked as a diffusion controlling layer to form the epitaxial $CoSi_2$ without any overgrowth at the SiO_2 / Si edge. Reduced leakage, p^+/n junctions have been obtained by impurity diffusion from an epitaxial $CoSi_2$ layer.

1. INTRODUCTION

An epitaxial $CoSi_2$ layer formation on (100) Si substrate by sputter deposition of Co / Ti bilayer on a Si substrate followed by N_2 annealing has been reported[1-4]. In those studies, however, a significant amount of non-uniformly thick (0 ~ a few 10 nm) TiN covered the surface of the $CoSi_2$ layer. The $CoSi_2$ surface is rough after the wet etch removal of the unreacted Co, Ti and TiN layer that is formed during a typical SALICIDE process which could affect subsequent shallow junction formation.

This paper describes a thermally stable, epitaxial $CoSi_2$ / (100)Si formation technology with smooth surface and without any TiN layer formation on top, employing thinner Ti, discusses the reaction process, and shows an advantage of usage of the epitaxial $CoSi_2$ layer for an ultra shallow junction formation.

2. EXPERIMENTS

Ti (0 - 5 nm thick) and Co (15 nm thick) films were sputter deposited with collimation sequentially on N (100) Si, 5 - 10 $\Omega \cdot$ cm, wafers with a patterned oxide mask. The samples were annealed in N_2 for 20 sec - 30 min. Reactions were evaluated by sheet resistance, reflectivity, AES, TEM, EDS, XRD and SEM. Diodes were formed by plasma implantation [5] of BF_3 (14 KeV, 1×10^{15} / cm^2) followed by a 600°C 30 sec anneal. p^+/n junction characteristics were then measured.

3. RESULTS AND DISCUSSION

3.1 Structure and Reactions

A Ti thickness of 1 - 2 nm brought about the lowest sheet resistance of 3.1 Ω. Fig. 1 shows cross section TEM photographs of the samples after annealing at 900°C with 5 nm or 2 nm Ti layer under the Co layer. A non-uniform and thick (20 nm) TiN layer on $CoSi_2$ is formed when 5 nm of Ti is used (Fig. 1(a)). When a 2 nm Ti layer is used an epitaxial, 50 nm thick $CoSi_2$ layer with smooth interfaces and no definable TiN upper layer is formed (Fig.1(b)). Uniform fine coherent Ti-N-O-Co-Si (by AES and EDS) precipitates are observed inside the epitaxial $CoSi_2$ layer near the surface. In the 1 nm Ti case, a resulting polycrystalline $CoSi_2$ film with rough interfaces was highly <100> oriented. The small amount of Ti (2 nm) seems to be sufficient for reducing any native oxide that might be present without the formation of a large TiN layer on top of the epitaxial $CoSi_2$. High melting point N containing precipitates near the top of the silicide might also be the cause of the excellent thermal stability observed when the silicide is annealed at 900°C for 30 min, while an epitaxial $CoSi_2$ is thermally unstable [6]. A similar improved thermal stability due to N containing precipitates has been previously observed for $TiSi_2$ [7].

Fig.2 shows a dependence of reflectivity for samples during annealing with or without Ti. In both cases, the reflectivity began to decrease at 400°C, however without Ti, there is one step between 450°C

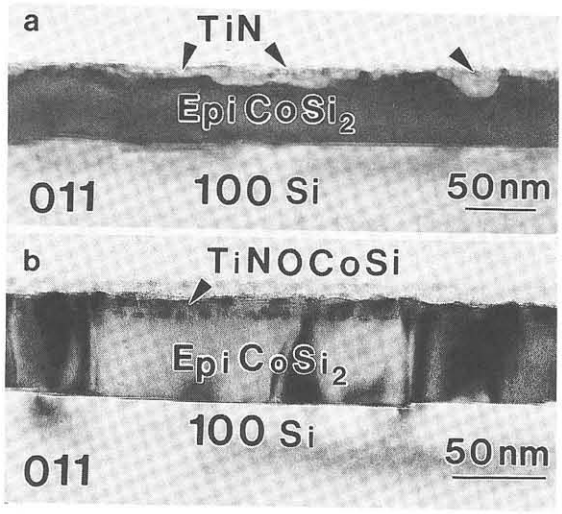

Fig. 1. Cross section TEM photographs of the samples after anneal at 900°C in N_2 with (a) 5 nm (20 sec anneal), (b) 2 nm (30 min anneal) Ti layer under the 15 nm Co layer.

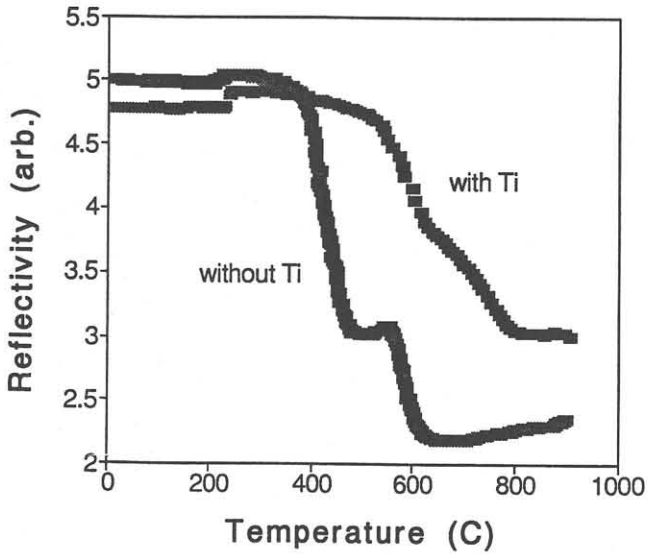

Fig. 2. Dependence of reflectivity (670 nm, diode laser) for Co samples with and without Ti film during the anneal.

and 560°C, on the other hand, with Ti of 1 - 5 nm thick, the reflectivity decreased gradually without any significant change. XRD analysis results after annealing at several temperatures for 30 min are summarized in Table I. Without Ti, CoSi appeared at 375°C and $CoSi_2$ with CoSi at 450°C, and $CoSi_2$ at 600°C, and all of them are polycrystalline. On the other hand, with Ti, $CoSi_2$ starts to form at 400°C. A non-uniform, epitaxial reaction at 400°C is observed by TEM underneath a thin amorphous layer. The thin (~ 2 nm) amorphous layer exists between Co and the epitaxial $CoSi_2$ layer even after anneal at 800°C as shown in Fig.3. Fig.4 shows EDS spectra from layers 1, 2, and 3 in Fig.3 using a 2 nm electron beam probe.

Table I. Identified phase by XRD for Co samples with and without Ti annealed at several temperatures for 30 min.

Temperature (°C)	without Ti	with 2nm Ti
300	Co	Co
375	Co, CoSi	Co
400	-	Co, $CoSi_2$
425	CoSi	Co, $CoSi_2$ CoSi (?)
450	CoSi, $CoSi_2$	Co, $CoSi_2$ CoSi (?)
500	CoSi, $CoSi_2$	Co, $CoSi_2$, CoSi (?)
550	CoSi, $CoSi_2$	Co, $CoSi_2$
600	$CoSi_2$	Co, $CoSi_2$
800	$CoSi_2$	Co, $CoSi_2$
900	$CoSi_2$	$CoSi_2$

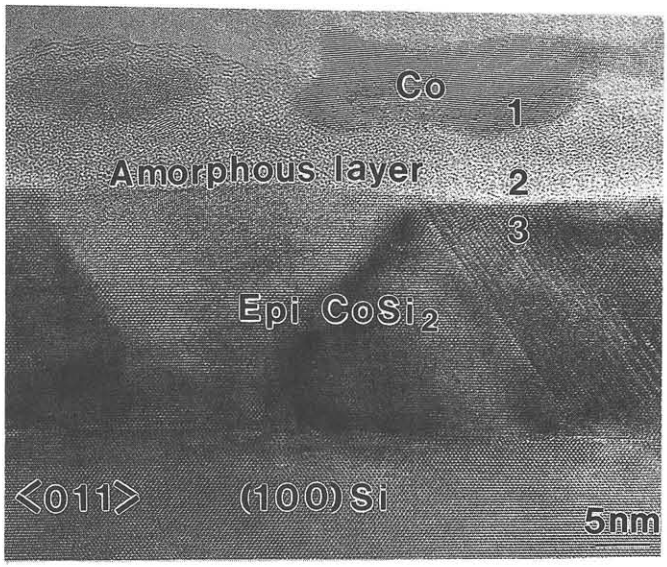

Fig. 3. Cross section TEM photograph of the sample after 800°C, 30 min anneal. A starting structure is 15 nm Co / 2 nm Ti / (100) Si.

The intermediate thin amorphous Ti-Si-O-Co layer (layer 2) which originates during Ti film deposition on Si [8] appears to reduce diffusion of Co into the Si from the Co layer thereby, reducing the growth rate of epitaxial $CoSi_2$ which forms at temperatures as low as 400°C. As shown in Fig.5, no encroachment, overgrowth, or crystal defects were observed at the edge of SiO_2 patterns on Si after a single step, 900°C, 30 min anneal. The thin amorphous layer appears to suppress diffusion of Si into the Co during the anneal.

3.2 Junction Properties

A p^+/n junction under epitaxial $CoSi_2$ formed with 2 nm Ti shows reverse leakage current two orders of magnitude lower and higher forward current than was obtained for polycrystalline $CoSi_2$ formed without Ti

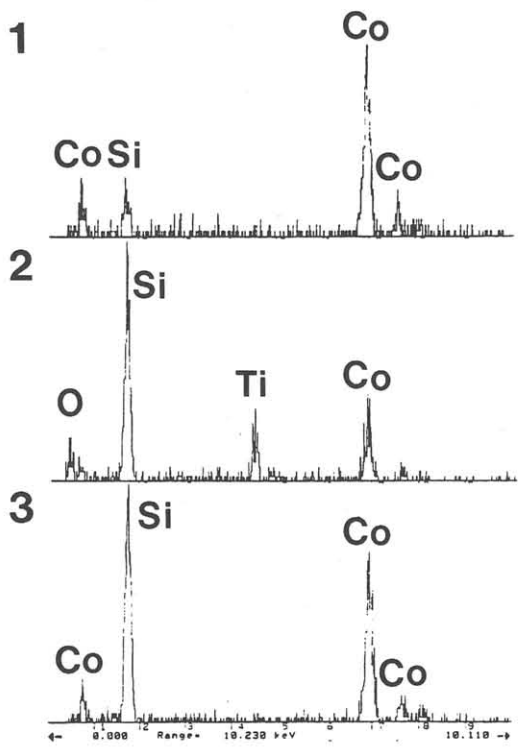

Fig. 4. EDS spectra from layers 1, 2, and 3 in Fig. 3. using 2 nm probe.

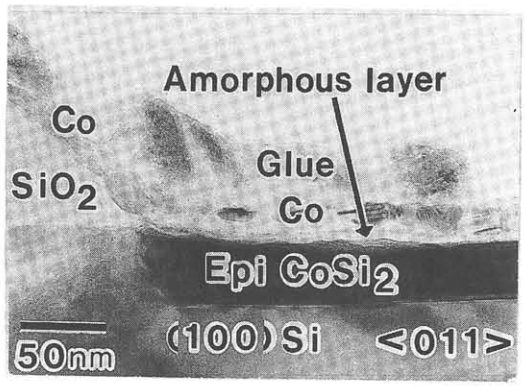

Fig. 5. Cross section TEM photograph of the sample at a pattern edge after a single step 900°C, 30 min anneal.

as shown in Fig.6. In this experiment, the leakage current includes both area and edge contributions. An area intensive structure without edge compensation was used. The p^+/n junction depth is estimated to be a few 10 nm based on the plasma implantation energy.

4. SUMMARY

Fully epitaxial $CoSi_2$ films with smooth morphology at both top surface and silicide / Si interface with nominal TiN formation on top without any encroachment, overgrowth, or crystal defects at the edge of SiO_2 patterns has been obtained by a single

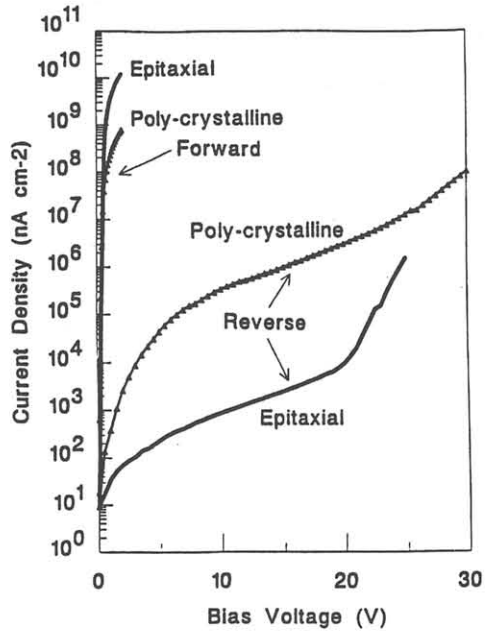

Fig. 6. I-V properties of p^+/n junctions under epitaxial and polycrystalline $CoSi_2$ layers after annealing at 600°C, 20 sec.

step anneal employing thin Ti, and reactions were analyzed. Reduced leakage, ultra shallow p^+/n junctions have been obtained by impurity diffusion from an epitaxial $CoSi_2$ layer.

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