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 Ω · 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, EDX, XRD and SEM. Diodes were formed by plasma implantation [5] of BF$_3$ (14 KeV, 1x$10^{15}$ / 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
Table I. Identified phase by XRD for Co samples with and without Ti annealed at several temperatures for 30 min.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>without Ti</th>
<th>with 2nm Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>Co</td>
<td>Co</td>
</tr>
<tr>
<td>375</td>
<td>Co, CoSi</td>
<td>Co</td>
</tr>
<tr>
<td>400</td>
<td></td>
<td>Co, CoSi2</td>
</tr>
<tr>
<td>425</td>
<td>CoSi</td>
<td>Co, CoSi2</td>
</tr>
<tr>
<td>450</td>
<td>CoSi, CoSi2</td>
<td>Co, CoSi2, CoSi (?)</td>
</tr>
<tr>
<td>500</td>
<td>CoSi, CoSi2</td>
<td>Co, CoSi2, CoSi (?)</td>
</tr>
<tr>
<td>550</td>
<td>CoSi, CoSi2</td>
<td>Co, CoSi2</td>
</tr>
<tr>
<td>600</td>
<td>CoSi2</td>
<td>Co, CoSi2</td>
</tr>
<tr>
<td>800</td>
<td>CoSi2</td>
<td>Co, CoSi2</td>
</tr>
<tr>
<td>900</td>
<td>CoSi2</td>
<td>CoSi2</td>
</tr>
</tbody>
</table>

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 CoSi2 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 SiO2 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 CoSi2 formed with 2 nm Ti shows reverse leakage current two orders of magnitude lower and higher forward current than was obtained for polycrystalline CoSi2 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 CoSi₂ 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 SiO₂ patterns has been obtained by a single 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 CoSi₂ layer.

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REFERENCES