Improved Electrical Characteristics of $CoSi_2$ Using HF-Vapor Pretreatment

Y. H. Wu, W. J. Chen, S. L. Chang, Albert Chin, *Senior Member, IEEE*, S. Gwo, and C. Tsai

***Abstract*— We have developed a simple process to form epitaxial $CoSi_2$ for shallow junction. Prior to metal deposition, the patterned wafers were treated with HF-vapor passivation. As observed by scanning tunneling microscopy (STM), this HF treatment drastically improves the native oxide-induced surface roughness. The epitaxial behavior was confirmed by cross-sectional transmission electron microscopy (TEM). Decreased sheet resistance and leakage current, and improved thermal stability are displayed by the HF treated samples, which is consistent with STM and TEM results.**

***Index Terms*—Epitaxial $CoSi_2$, HF pretreatment.**

I. Introduction

COBALT SILICIDE ($CoSi_2$) has become one of the most promising silicides for deep submicron technology [1]–[8], because of its linewidth-independent resistivity and minimum lateral growth. However, epitaxial $CoSi_2$ layers are more desirable because of better thermal stability and smoother interfaces than polycrystalline ones. There are many methods which can be used to grow epitaxial $CoSi_2$ [3], [9]–[12]:

1) molecular beam epitaxy (MBE) [10];
2) the use of Ti-interlayer mediate epitaxy (TIME) [11], [12];
3) the use of sputter cleaning before Co deposition [3].

Unfortunately, the MBE method needs Si deposition; therefore, it is not a self-aligned process. The TIME process is not desirable in certain process flows, and it causes large voids in the epitaxial $CoSi_2$ layers near the edges of field oxide. Finally, although the sputtering method results in improved performance for forming shallow junction, it might be limited by a small process window. The key factor to form epitaxial rather than polycrystalline $CoSi_2$ is the suppression of native oxide. This is because Co is thermodynamically stable on oxide [13], [14], so that a thin oxide between Si and Co not only blocks the silicidation but also limits the reaction to local weak spots; that roughens the $CoSi_2$ surface and creates a polycrystalline structure. The suppression of native oxide is also the most important factor to achieving an atomically smooth interface and good performance [15]. In this letter, we use HF-vapor passivation to suppress the native oxide. A similar process technique has been applied to Si epitaxy [16], [17], solid phase epitaxial SiGe [18], and thermal oxide growth [15].

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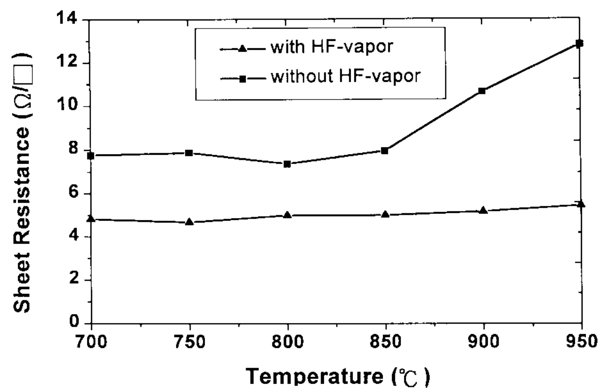


Fig. 1. Sheet resistance of $CoSi_2$ on p^+n junction with different surface treatment.

II. Experimental

In this study, (100), n-type Si wafers were used. P^+n junctions were formed using BF_2^+ implantation at the energy of 40 KeV with a dose of 5×10^{15} cm^{-2}. The active device areas are 2.25×10^{-4}, 9×10^{-4}, and 3.6×10^{-3} cm^2. A rapid-thermal-annealing (RTA) step at 960 °C for 30 s is used to activate the implanted species. Prior to metal deposition, the wafers were treated with HF-vapor to passivate the surface and suppress native oxide formation. For comparison, control samples were fabricated with the same recipe but did not receive the HF-vapor treatment. A Co layer 150 Å thick was then deposited by e-beam evaporation with a base pressure below 1×10^{-6} torr. A film of Mo, 200 Å thick, is used as a cap layer for Co. $CoSi_2$ is formed using two-step RTA. The first annealing was carried out at 550 °C for 45 s; then, selective etching was used to remove nonreacted metals. The second annealing was performed from 700 to 950 °C in the same N_2 environment. Sheet resistance and reverse current–voltage ($I-V$) leakage current are used to measure the electrical properties. STM and TEM are used to characterize the structural properties.

III. Results and Discussion

The sheet resistance as a function of the temperature of the second RTA treatment is displayed in Fig. 1. The epitaxial

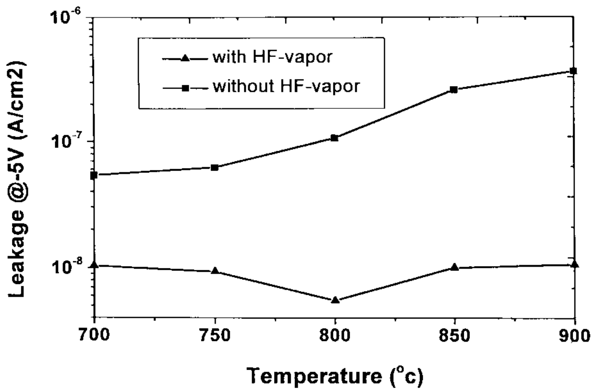
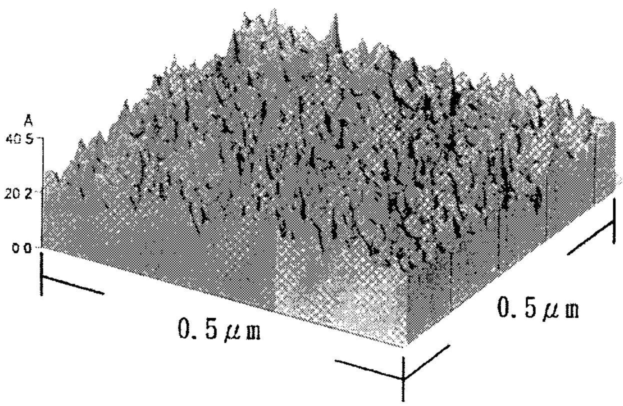
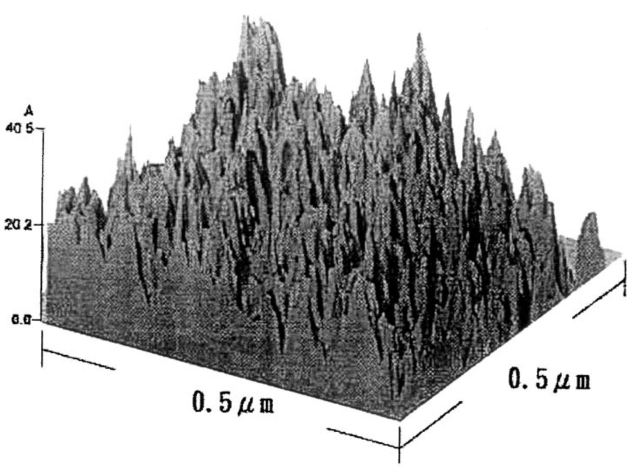


Fig. 2. Leakage current of $p^{+}n$ junction with different surface treatment.



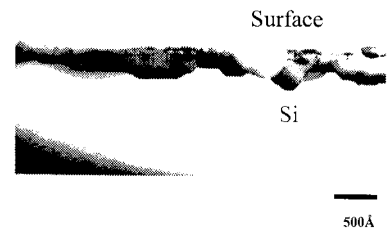
(a)



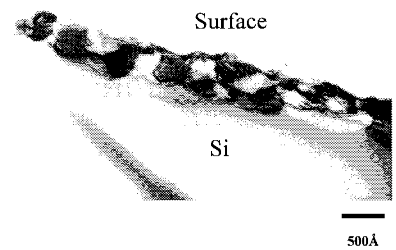
(b)

Fig. 3. STM images of (100) Si surface treated (a) with and (b) without HF-vapor before metal deposition.

$CoSi_2$ films formed with the HF treatment have excellent thermal stability; the sheet resistance is almost unchanged after the second RTA up to 950 °C. In contrast, the sheet resistance is higher in control samples over the whole temperature range, and becomes larger with increasing annealing temperatures above 850 °C. The higher sheet resistance is due to the thickness nonuniformity in $CoSi_2$; the silicide films agglomerated onto discrete islands that effectively increase the sheet resistance [19].



(a)



(b)

Fig. 4. Cross-sectional TEM images of $CoSi_2$ film treated (a) with and (b) without the HF-vapor before metal deposition.

The junction performance was evaluated by measuring the reverse leakage current, and the results are shown in Fig. 2. For HF treated samples annealed at 800 °C, the junction characteristics improved. The increased leakage current for more than 850 °C annealing is believed due to the out diffusion of boron at interface. For the control samples, the leakage current is nearly an order of magnitude higher, and the leakage current becomes larger at increasing annealing temperatures. A possible reason may also be agglomeration of the silicide films. The observed junction leakage current is consistent with the structure analysis discussed below.

Fig. 3(a) and (b) shows the STM images of samples with and without (the control samples) the HF treatment. In comparison to AFM, STM is converted from tunneling current that can directly image the thickness variations of the native oxide rather than the surface roughness. According to STM, the RMS roughness of 0.5-μm square surfaces was 4.5 and 7.4 Å for HF-vapor treated samples and control samples, respectively. Because exposure to HF-vapor is known to have a passivation effect which protects the surface from oxidation, better $CoSi_2$ structures can be expected by using that treatment.

We have further investigated the detailed $CoSi_2$ structure by cross-sectional TEM; the results are shown in Fig. 4. As observed from the dark field TEM in Fig. 4(a), the HF-treated silicide films show both uniform and epitaxial behavior. In sharp contrast, $CoSi_2$ from the control samples in Fig. 4(b) is polycrystalline with a rough interface. This is because silicidation process occurred at the weak spots of native oxide first and any presence of oxide will suppress the $CoSi_2$ formation. Therefore, uniform and epitaxial cobalt silicide films can only be grown on clean Si surfaces with little native oxide between Co and Si.

IV. Conclusions

We have demonstrated a simple HF-vapor treatment to form epitaxial $CoSi_2$. Much improved sheet resistance and leakage current are displayed by such HF-vapor treated samples. That is due to the suppression of native oxide formation, as confirmed by STM.

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