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Drastic Leakage Suppression by Through-Oxide Arsenic Pre-SALICIDE Implantation for $CoSi_2$ Formation on Shallow n+/p Junctions

M. Tsuchiaki[1], A. Murakoshi[2] and C. Hongo[1]

[1] Corporate Research & Development Center, Toshiba Corporation.
[2]Process & Manufacturing Engineering Center, Toshiba Semiconductor Company
c/o 8 Shinsugita-Cho, Isogo-Ku, Yokohama, 235-8522, Japan
Phone:+81-45-770-3667 Fax:+81-45-770-3578 E-mail:masakatsu.tsuchiaki@toshiba.co.jp

Abstract

Using simple and damage-free n+/p junctions, a sensitive and comparative investigation is conducted on leakage suppression by pre-SALICIDE ion implantation (PSII) for $CoSi_2$ formation. As-PSII is found to be greatly superior to Ge-PSII. Moreover, it is discovered that the presence of O facilitates this advantage of As. Combining these two factors, i.e., by As-PSII through an oxide, leakage suppression up to 4 orders of magnitude is attained.

1. Introduction

Among various concerns regarding $CoSi_2$ technology, leakage generation with the shallowing of S/D depth x_j, especially for n+/p junctions, is crucial. Recently, using damage-free n+/p junctions, it has been revealed that a substantial Co in-diffusion and resultant GR center formation is the primary cause of the leakage[1]. Because the inward migration is inherent to the Co reaction[1,2], an extra way must be devised to suppress the leakage. Although several means have been proposed[3,4], the most practical is PSII just prior to the silicidation[5]. Therefore, it is highly desirable to have a systematic examination of PSII's efficiency in leakage suppression. For $CoSi_2$, however, the available study[5] reports only a sketchy profile of Ge-PSII. Especially, dependence of PSII effects on bombarding ions, their impacts on leakage-x_j relationship and correlation with Co in-diffusion have never been studied. Thus, for a fair and clear evaluation of these critical PSII characteristics, the present paper reports a sensitive and comparative study of PSII's intrinsic ability to suppress $CoSi_2$ leakage. Using n+/p junctions formed by solid phase diffusion, a clear focus is put on the leakage without any distraction arising from other process damages. The most effective way of leakage suppression is readily identified through a direct correlation between leakage and Co in-diffusion.

2. Junction Formation and PSII

Fig.1 illustrates the procedure for damage-free junction formation employed in this study. The details of the fabrication will be found in ref. [1]. After formation of virtually flat p-well of $2x10^{17}cm^{-3}$ concentration, a junction region is delineated by RIE-etching a SiN film and wet-etching an underlying TEOS film, avoiding plasma damage on the substrate (Fig.1-a). Subsequently, AsSG film is deposited and annealed to form an n+ region by solid phase diffusion into the opening defined above (Fig.1-b). By adjusting the annealing time and temperature, n+/p junctions with various depths can be readily obtained[1]. After AsSG removal by wet etching, a 20-nm-thick pad TEOS layer and a SiN film are applied. The following SiN RIE stops at the pad TEOS and leaves sidewalls to guard the periphery (Fig.1-c). Then, to assess PSII's effects, As and Ge are implanted. The dose, Φ, is varied up to $1x10^{14}cm^{-2}$, so that S/D profiles will not be disrupted severely (i.e., retaining applicability to p+ S/D). The energy, E_I, is set to be 50keV, so that a resultant damaged layer (up to 30nm thick) is completely consumed by the following silicidation. Because As and Ge have similar atomic weights, this experiment can also contrast chemical difference due to PSII ions, while maintaining almost the same physical damage. Next, after wet etching the pad TEOS, 15nm of Co, 20nm of Ti and 20nm of TiN are sequentially sputtered and the 1st RTA at 475 °C for 30s promotes 20nm CoSi formation. Then, unreacted metals are removed and the 2nd RTA at 815 °C for 30s transforms CoSi into $CoSi_2$ about 35nm thick to realize the final junction structure (Fig.1-d).

3. Leakage Suppression by PSII : As vs. Ge

First, effects of PSII on leakage is monitored for various doses, Φ. Leakage levels (I_R at V_R=4V, x_j=106nm i.e., the depth below silicide is only 70nm) are plotted as a function of Φ for As (Fig.2-a) and Ge (Fig.2-b). Leakage at different V_R shows almost the same behavior. On some of the samples, a recrystallization RTA (690 °C, 30s) is applied prior to silicidation (dotted line). Comparing the leakage with and without recrystallization RTA, effects of amorphization can be easily gauged. Although some effects of residual damage are also visible at small dosage ($\Phi<5x10^{13}cm^{-2}$), significant leakage suppression takes effect after formation of amorphous layer ($\Phi>7.5x10^{13}cm^{-2}$). For both ion species, leakage decreases exponentially with Φ. Notably, however, the amorphization effects strongly depend on the bombarding ions, i.e., As being greatly superior to Ge. Measuring As SIMS profile, it is also confirmed that x_j is not deepened by As-PSII and As superiority is genuine. The suppression becomes even more appealing when its statistical behavior is revealed. Fig. 3 is the Weibull plot for each PSII dose. The leakage suppression proceeds without causing any high leakage events. Fig.4 demonstrates correlation between Co backside SIMS and leakage-depth profiles. Apparently, Co inward migration is efficiently blocked by PSII, especially by As. Because Co inward migration is the intrinsic cause of the leakage[1], these tight statistics and Co SIMS data suggest that the PSII works properly by reducing Co in-diffusion without forming any additional defects such as silicide spikes. As-PSII allows x_j reduction of about 50nm compared with the PSII-less sample. Finally, to shed light on the advantage of As over Ge, their depth profiles in the $CoSi_2$ are measured by SIMS after silicidation (Fig.5). While Ge is simply ousted by silicidation, a portion of As remains in the vicinity of where CoSi/Si interface was once located. Arsenic may have formed some type of compound with Co in the initial stage of CoSi-$CoSi_2$ phase transition. Since Co outburst is expected to take place at this phase transition[1,2], As incorporation at this critical CoSi/Si interface may have passivated the interface and prevented the Co outburst from the interface, resulting in the drastic leakage suppression.

4. O Involvement in PSII

The above-mentioned implantations are performed through a 20nm-thick oxide. With due caution, involvement of knock-on O is a concern. In order to check O effects on the leakage, PSII without an oxide is compared with PSII through the oxide. E_I of oxide-less PSII is adjusted to 30keV, so that a similar implantation range can be obtained. Fig.6 exhibits the resulting leakage levels for each PSII condition. Although, the presence of O has virtually no effects on Ge-PSII, the existence of O is clearly beneficial to As-PSII. In fact, SIMS profile shows significant O build-up near the CoSi/Si interface (Fig.7). It seems that O may have facilitated the formation of As-containing compound at the initial stage of the phase transition to block the Co in-diffusion. Now that O is proven to be an indispensable element for effective As-PSII, its impacts on other silicide characteristics must be monitored carefully. Fig.8 plots $CoSi_2$/Si(n+) contact resistance as a function of Φ for various contact sizes. Fig.9 shows sheet resistance of resultant $CoSi_2$ as a function of Φ. Fig.10 explains narrow line effects on thin n+poly-Si lines, where sheet resistance is plotted as a function of the line widths. Clearly, in all the above accounts, As-PSII and O-involvement have no adverse effects on these critical features.

5. Summary and Conclusion

As-PSII is found to be greatly superior to Ge-PSII in terms of the leakage suppression and the Co in-diffusion reduction. Moreover, this special advantage of As-PSII is assisted by the presence of O. By As-PSII through an oxide, leakage suppression up to 4 orders of magnitude is attainable. Furthermore, As-PSII through an oxide simply reduces the leakage without causing any other disturbances to critical $CoSi_2$ characteristics. It has been proven that As-PSII through an oxide is a viable option to counter the $CoSi_2$ leakage generation on sub-0.1μm shallow junctions.

Reference

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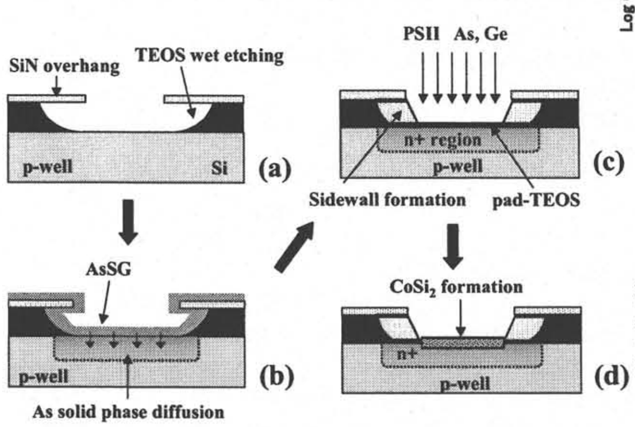

Fig.1 n+/p junction formation procedure to fabricate damage-free diodes. (a) Isolation is achieved by wet etching of TEOS. (b) Solid phase diffusion from AsSG is used for creating n+ region. (c) Sidewall is formed and PSII with As and Ge is applied. (d) $CoSi_2$ is formed.

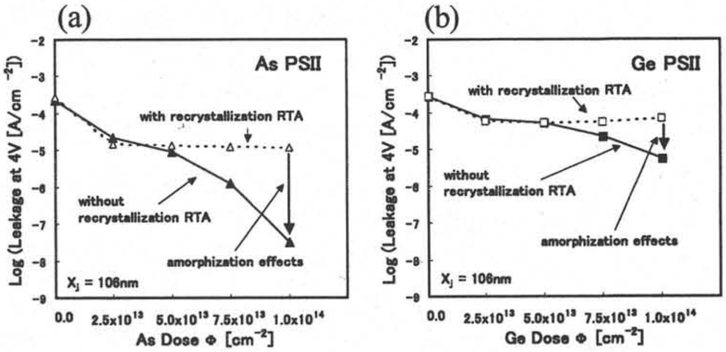

Fig.2 Leakage levels plotted as a function of PSII dose Φ, As (a) and Ge (b). Leakage levels of samples with recrystallization RTA are also plotted (dotted lines).

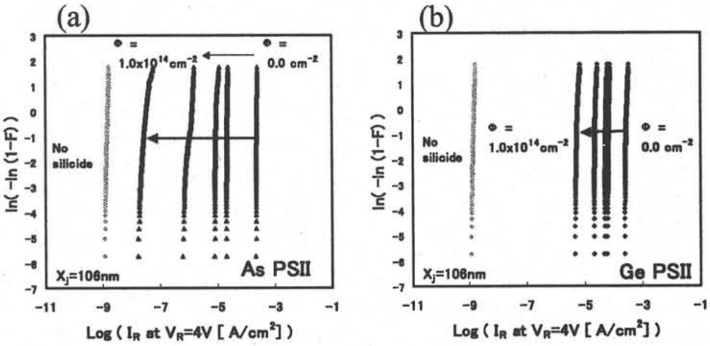

Fig.3 Weibull plots of leakage levels over 312 junctions for various Φ of As (a) and Ge (b). Leakages of silicide-less junctions are also plotted.

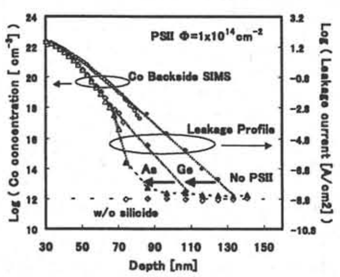

Fig.4 Comparison between Co SIMS profiles and leakage-depth profiles of no-PSII, As PSII and Ge PSII samples. 20nm stretch of depletion layer (V_R=4V) into n+ region is taken into account.

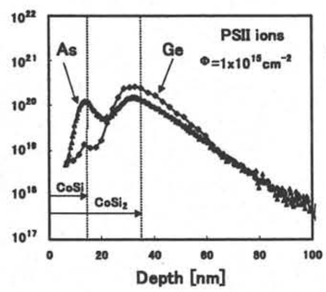

Fig.5 SIMS profiles of As and Ge inside $CoSi_2$ layer after silicidation. A portion of As remains in the vicinity of where CoSi/Si interface was once located.

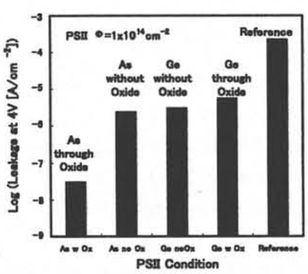

Fig.6 Leakage levels after various PSII conditions. As PSII through an oxide has a clear advantage over similar PSII conditions.

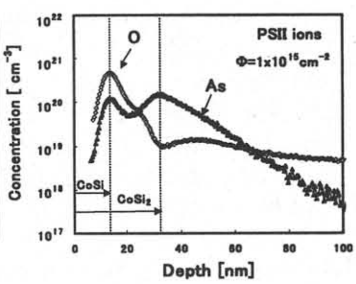

Fig.7 SIMS profile of knock-on O inside $CoSi_2$ layer after silicidation. As profile is also shown. O builds up near CoSi/Si interface

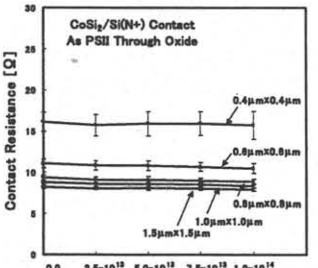

Fig.8 $CoSi_2/Si(n+)$ contact resistance for various opening sizes plotted as a function of Φ.

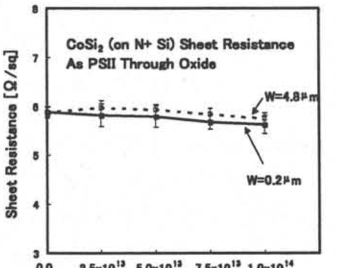

Fig9 Sheet resistance of $CoSi_2$ on n+ Si for narrow and wide lines plotted as a function of Φ.

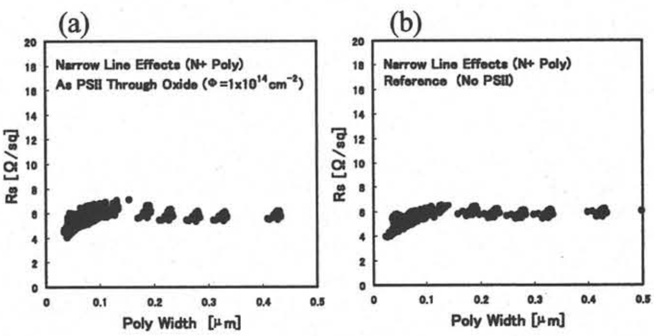

Fig.10 N+ poly narrow line effects of samples with As PSII (a) and without PSII (b). Roll-off near the narrowest lines is due to rather thick $CoSi_2$ layers formed around the corners of the gate lines. As PSII through oxide does not disturb narrow line effects.