Arsenic 도즈 량에 따른 코발트 실리사이드 표면 위의 이상 산화

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Effect of As Dose on Abnormal Growth of Oxide on $CoSi_2$

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서론

In order to obtain high-speed logic devices and to minimize chip size without shrinking contact size, cobalt silicide and borderless contact (BLC) have been extensively investigated [1]. Silicon nitride is generally used as an etch-stop barrier in BLC. The direct deposition of silicon nitride on $CoSi_2$ films and Si-substrates can degrade device reliability such as hot carrier lifetime because of the defects generated in Si by constrain stress [5]. In order to avoid degradation of device reliability, silicon oxide is chemically deposited on $CoSi_2$ and Si, prior to deposition of silicon nitride.

We found that the contact resistance (R_c) of $CoSi_2$ formed on n^+ doped Si was more degraded than that on p^+ doped Si, as shown in Fig. 1, when an Si oxide and nitride double layer structure on cobalt silicide is used as an etch barrier. The thick oxide on $CoSi_2$ films grew in the n^+ doped Si region rather than in the p^+ region, as shown in Fig. 2. Thus the contact hole for the n^+ region was not well defined, resulting in an increase in the contact resistance. As and P were used for n^+ dopants. Enhancements of oxide growth rate on highly n^+ doped Si under exposure by boiling deionized water and increased deposition rates of silicon dioxide films on phosphorous-doped Si have been reported [2]. Thus we assumed that the dopants influence the oxide growth on $CoSi_2$ films. The oxidation kinetics of $CoSi_2$ on (111) Si by transmission electron microscopy (TEM) have been investigated [3]. However, no research on As concentration dependence of LPCVD oxide growth behavior on $CoSi_2$ has been reported. In this study, we investigated the effect of arsenic doping level on LPCVD of SiO_2 growth on $CoSi_2$ films and discussed the origin of abnormal growth of SiO_2.

본론

The effect of As concentration on $CoSi_2$ formation is shown in Fig. 3, where the XRD patterns and sheet resistances of $CoSi_2$ films with As dose are presented. $CoSi_2$ (220) peaks were observed only for the samples with As dose up to 1×10^{15} cm^{-2}, but no peaks appeared at a dose of 1×10^{16} cm^{-2}. The $CoSi_2$ (220) peak showed maximum intensity at the As dose of 1×10^{15}, suggesting that the formation of $CoSi_2$ significantly depends on As concentration in Si substrates. On the other hand, no peaks corresponding to a $CoSi_2$ phase were observed for the As dose of 1×10^{16}, which indicates that $CoSi_2$ formation was prevented by the high dose As in Si. Similar behavior was reported for $TiSi_2$ silicide systems: $TiSi_2$ formation was suppressed by high dose As-implanted Si substrates [4]. The sheet resistance of samples with As dose below 5×10^{15} cm^{-2} was as low as 6 ohm/☐, but it abruptly increased to about 50 ohm/☐ at a dose of 1×10^{16} cm^{-2}. This abnormal increase in sheet resistance is probably caused by the formation of thin $CoSi_2$ or a different phase from $CoSi_2$. As mentioned above with the XRD results, this finding also supports that the heavily As-doped Si blocks the formation of uniform $CoSi_2$ crystallites.

Figs. 4(a)-4(b) show cross-sectional TEM images of LPCVD SiO_2/$CoSi_2$ films with As dose. For the As dose up to 1×10^{15} cm^{-2}, uniform $CoSi_2$ films of 40 nm in thickness were obtained, and the silicon oxide thickness slightly increased with increasing dose. At a dose of 1×10^{16} cm^{-2}, however, non-uniform $CoSi_2$ layers below 10 nm in thickness and thick SiO_2 were observed. This result indicates that the highly doped As in Si suppressed the formation of uniform $CoSi_2$ resulting in high sheet resistance of $CoSi_2$ for the As dose of 10^{16} cm^{-2}. In addition, the formation of a layer silicon oxide of about 60 nm-thickness on $CoSi_2$ is unexpected, as approximately 15 nm-thick silicon oxide should be deposited on bare Si wafer according to our deposition rate.

Figs. 5(a)-5(b) show the SIMS depth profiles of the same samples used for TEM analysis. The depth profiles of Co and Si atoms show an uniform $CoSi_2$ phase for As dose up to 1×10^{15} cm^{-2}, which is consistent with the TEM results. As shown in Fig. 5(b), for As dose of 10^{16} cm^{-2}, the uniform $CoSi_2$ layer disappeared, and a thick SiO_2 layer larger than 60 nm in thickness was observed. The Co depth profiles extended to the oxide film and its depth profile shows similar behavior with As, rather than with Si, in the whole range, suggesting the formation of a Co-As compound for the As dose of 1×10^{16} cm^{-2}. Since the formation energy is comparable between CoAs and $CoSi_2$ [5], some reaction of As with Co might take place for the As dose of 10^{16} cm^{-2}, resulting in the formation of a Co-As compound during the silicidation. The limited solid solubility of As in Si also encourages Co-As compound formation. A stable tie line exists between $CoSi_2$ and the Co-As compound according to the phase diagram; thus the Co-As compound is stable with respect to an overlaying $CoSi_2$ film. However, there is no experimental evidence for any Co-As compound formation.

As shown in Figs. 5(a), the As depth profiles change at the interface of $CoSi_2/SiO_2$ with As dose, which may result from the usual matrix effect; i.e., the degree of ionization and sputtering yield of As dopants increase at the interface. For the As dose of 1×10^{16} cm^{-2} (Fig. 5(b)), some As dopant diffused out into the cobalt silicide films and even into the SiO_2 layer from the Si-substrates. Out-diffusion of As into silicide was also revealed by X-ray photoelectron spectroscopy (XPS) (not shown in this paper). According to the phase diagram of $CoSi_2$ and As in Si, no tie line exists between $CoSi_2$ and As. Thus As doped Si is unstable with respect to an overlaying $CoSi_2$ film. During the $CoSi_2$ formation and SiO_2 deposition by LPCVD, the small amount of As in the Si-substrates diffused into silicide and oxide.

Fig. 6 shows the thickness of SiO_2 grown on both $CoSi_2$ film and bare Si as a function of As dose. The oxide thicknesses on $CoSi_2$ rapidly increased with As dose, while the thickness on bare Si increased negligibly. This result suggests that As on the $CoSi_2$ films accelerates the decomposition of TEOS and then increases the deposition rate of SiO_2. As-doped Si was reported to enhance oxide growth in steam oxidation [2]. Thus, we can conclude that As on the $CoSi_2$ surface increased the decomposition rate of TEOS, resulting in abnormal oxide growth, especially for high As doses.

결론

The abnormal growth of SiO_2 on $CoSi_2$ films was mainly caused by highly doped As in Si. In addition, the highly doped As in Si interrupted the formation of $CoSi_2$ and increased contact resistance. Thus, we have carefully to control the As concentration in Si to prevent abnormal oxide growth on $CoSi_2$ and to obtain low contact resistivity for the interconnection lines to Si substrates when we use a oxide and nitride layered structure as a etch barrier. For stable process control, the suppression of rapid growth of oxides on $CoSi_2$ is essential. This point will be addressed in future work.

참고문헌

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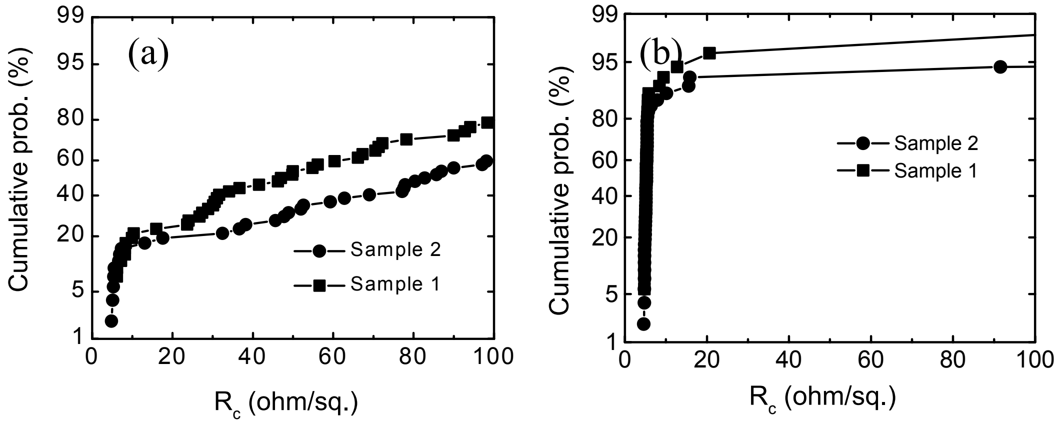

Fig.1. Cumulative plot for contact resistances for two samples of (a) n+ and (b) p+ doped Si with a Si_3N_4/SiO_2 etch stop layer.

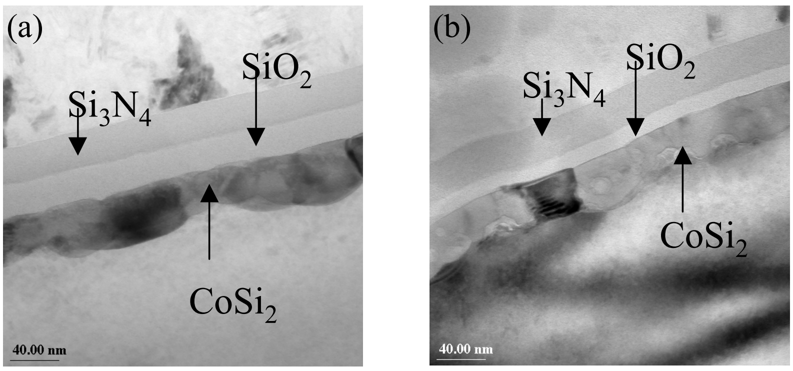

Fig. 2. Cross-sectional TEM images of $Si_3N_4/SiO_2/CoSi_2$ structures on (a) n^+ and (b) p^+ doped Si. The nitride (30 nm) and oxide (10 nm) films were deposited by low-pressure chemical vapor deposition method

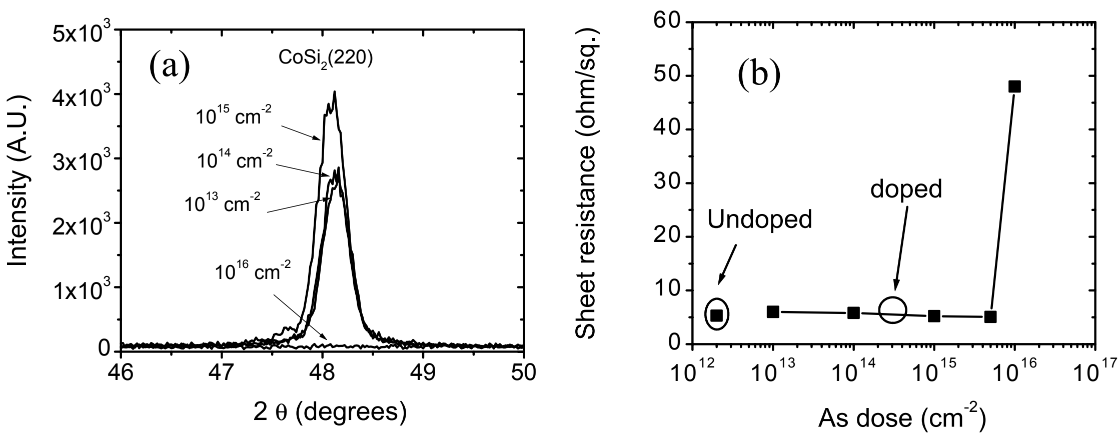

Fig. 3. (a) XRD patterns and (b) sheet resistances of $CoSi_2$ films as a function of As dose in Si.

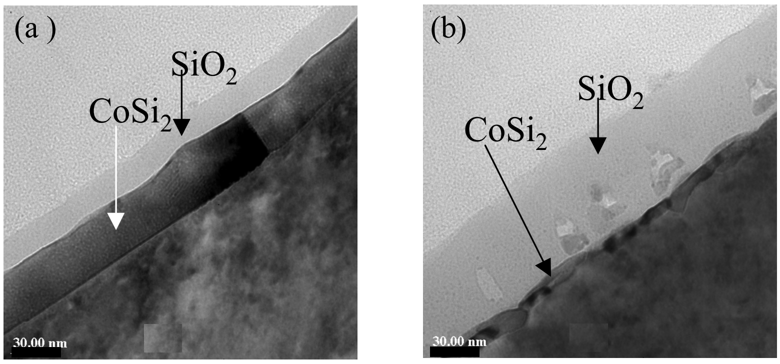

Fig. 4. Cross-sectional TEM micrographs of LPCVD $SiO_2/CoSi_2$ at As dose of (a) 1×10^{15}, and (b) 1×10^{16} cm^{-2}.

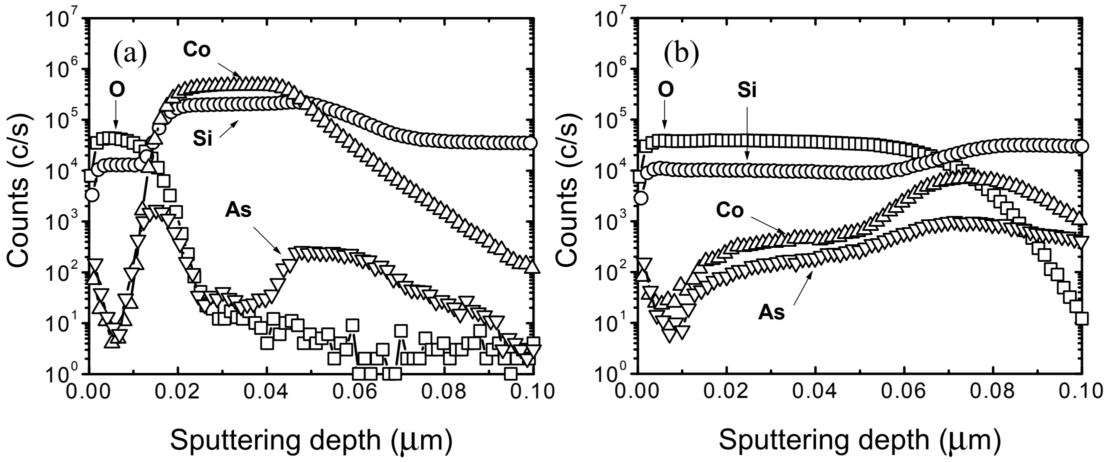

Fig. 5. SIMS depth profiles for LPCVD SiO_2 and $CoSi_2$ films at As dose of (a)1×10^{15}, and (b) 1×10^{16} cm^{-2} .

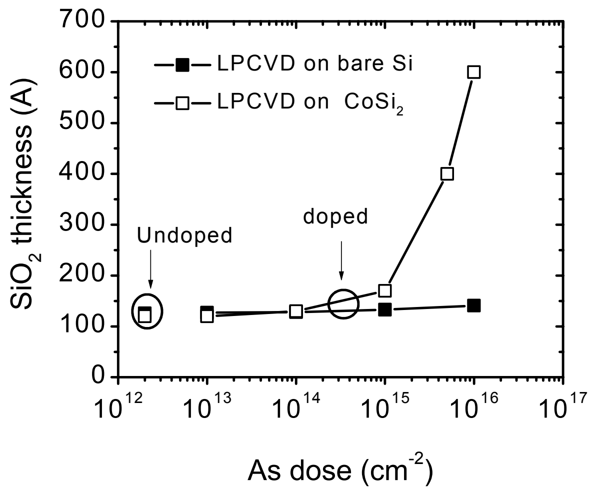

Fig. 6. The thickness of SiO_2 grown by LPCVD at 680°C for 150 s as a function of As dose. The oxide thickness was obtained by TEM.