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A Highly Stable Al-Si Contact to Mo-Silicided Shallow Junctions

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Highly stable (up to 550°C) contacts have been realized in an Al-2%Si contact to n^+-p and p^+-n shallow junctions (X_j~0.16µm) covered by a 0.1µm thick uniform $MoSi_2$ layer, which was formed by the ITM (Ion Implantation Through Metal) technique. Low contact resistance was maintained, at submicron (0.5µm square) Al-Si/$MoSi_2$ contacts, after 550°C sintering for 30 minutes.

I. INTRODUCTION

Refractory metal silicided Si structures have attracted much attention as ohmic and Schottky contacts and interconnections for VLSI. Since Al and Al-Si alloy films are most widely used for ohmic contacts and interconnections in both bipolar and MOSICs, thermal stability for Al or Al-Si alloy/silicided-Si structures is a problem of great concern. Furthermore, in future submicron devices with multilevel interconnections, higher thermal stability (>500°C) shall be necessary for annealing out damages, induced by beam-processing, such as electron or Xray lithography and ion-assisted processing. From this viewpoint, several structures, including TiN or TiW between an Al metallization and silicides as an additional barrier layer were proposed and have been shown to be effective for thermal stability improvement.[1] These structures, however, exhibited demerits in regard to high contact resistance and process complexity.

This paper reports that low resistance and highly stable (up to 550°C) ohmic contacts, in an Al-Si metallization contact to silicided shallow junctions, have been achieved for the first time in a simple structure, i.e., without any additional barrier layer, such as TiN, between Al-Si and silicide. In the present contacts, a uniform Mo-silicide layer, formed by the ITM (Ion Implantation Through Metal) technique[2], was utilized as a barrier layer to prevent junction short as well as a low resistance layer for reducing resistance in the shallow doped-Si layer.

II. EXPERIMENTAL

1) Mo-silicided junction formation

Mo-silicided junctions were formed by the ITM technique, which consists of ion implantation through metal to induce the metal-Si interface and subsequent thermal annealing. A double ion implantation method in the ITM technique, using non-dopant ion (Si) implantation for Mo-Si interface mixing and dopant ion (As or B) implantation for doping, was used to make Mo-silicided shallow junctions.[3] This technique is particularly effective to make p^+-n shallow junctions. For an Al/$MoSi_2$ sample, mere As implantation was used, to form a deeper junction. Uniform Mo-silicide was obtained by the mere As implantation as well as a double ion implantation. Si substrates used in these experiments, ion implantation conditions and the resultant junction depth (including 0.1µm thick Mo-silicide) are presented in Table 1.

2) Contact formation to Mo-silicide layer

Contact holes, larger than several tens of micron square, were fabricated by usual photolithography. Submicron contacts holes were formed by electron-beam direct writing. Figure 1 shows a cross sectional SEM micrograph for the sample after submicron contact hole formation. 0.5µm square contact holes were fabricated with nearly vertical sidewalls.

3) Metallization

Al and Al-Si (1%Si and 2%Si) films were deposited by magnetron sputtering. After patterning Al and Al-Si films by usual photoetching process, sintering at a 450~550°C temperature range was performed in a hydrogen ambient for 30 minutes.

4) Electrical properties measurements

Thermal stability of the barrier against sintering was evaluated by diode leakage current and Al metallization/Mo-silicide contact resistance measurements. Figure 2 shows (a) cross-sectional and (b) plane diagrams used in leakage current measurements. The Mo-silicided diode area is 300µm×300µm. The contact size is 250µm×40µm. Contact resistance was measured using the Kelvin pattern.

Ⅲ. RESULTS AND DISCUSSION

1) $Al/MoSi_2$ Contacts

Figure 3 shows leakage current characteristics for n^+-p diodes with a deep junction (X_j~0.41µm) and a large contact hole, sintered at 450°C for 30 minutes. Leakage current level at lower reverse bias voltage (V_R<10V) was several tens of picoamperes, which was about one order of magnitude higher than that for the Al-2%Si case (Fig. 5). At higher reverse bias voltage, several junctions showed sharp leakage current increase. Figure 4 shows an SEM micrograph for the $Al/MoSi_2$ sample surface after Al etching with phosphoric acid. Si growths were observed at the Mo-silicide surface. Leakage current increase cause is considered to be local Si transport from Si substrate through the Mo-silicide layer to Al. Therefore, Mo-silicide was ineffective as a barrier against Al metallization for 450°C sintering.

2) $Al-2\%/Si/MoSi_2$ contacts

Figure 5 shows leakage current characteristics for n^+-p and p^+-n diodes with a shallow junction (X_j~0.16µm) and a large contact hole, sintered at 550°C for 30 minutes. Leakage current level was less than several picoamperes (~1×10^{-8} A/cm^2) at a reverse bias voltage lower than 10 V for n^+-p and p^+-n diodes. This leakage current level was comparable to that for a non-silicided conventional As implanted diode with a deeper junction (X_j~0.25µm), sintered at 450°C.

Figure 6 shows an SEM micrograph after Al etching for the sample sintered at 500°C. Si nodules, less than 1µm and larger than a few microns in size, were observed at the ~10^7/cm^2 density on both Mo-silicide and SiO_2 surfaces. Figure 7 shows Si nodules formation dependence on sintering temperature for a constant sintering time (30 minutes). Si nodules were observed even at 450°C

Such high density Si nodules may cause a contact resistance increase for contact holes with comparable or smaller than Si nodules size. Figure 8 shows SEM micrographs after Al etching for samples, having 0.5µm square contact hole, sintered at 550°C. (a) The case where the Si nodules do not hit the contact hole. (b) The case where the Si nodule was formed at half of the contact hole. (c) The case where the Si nodule covered almost the entire contact hole. Contact resistivity between Al-2%Si and $MoSi_2$ for cases (b) and (c) was adequately low value (~4×10^{-8} Ω·cm^2), which was comparable to that for case (a). This forms a clear contrast to an Al-Si/Si contact, i.e., without a silicide barrier layer, where Si precipitation is enhanced in contact holes to induce a severe contact resistance increase.[4]

The difference in the Si nodule or precipitate effect on contact resistance between the present $Al-Si/MoSi_2$ contact and the Al-Si/n^+-Si contact seems to be due to the difference in the Si precipitate morphology. In the Al-Si/n^+-Si contact, Si precipitates on Si tend to grow into a uniform layer. Thus, the entire contact area for small dimensional contacts is easily covered by a precipitated p-type (Al-doped) Si layer, which forms a p-n junction to n^+-Si.[4] On the other hand, in the present Mo-silicided contact, Si precipitates on $MoSi_2$ tend to form nodules, i.e., grow vertically rather than laterally on the $MoSi_2$ surface. Therefore, contact area reduction, i.e., contact resistance increase, seems to be mostly negligible.

3) Al-1%Si/$MoSi_2$ contacts

Leakage current level for 31 samples among 35 measured Al-1%Si samples was mostly the same as that for Al-2%Si at 550°C sintering for 30 minutes. However, 4 samples showed leakage current increases. The cause for the leakage current increase has not been clarified.

Si nodules, formed in the Al-1%Si case, were 0.1~0.3µm in size, which is much smaller than that for the Al-2%Si case, although the nodule density was almost the same (~10^7/cm^2). The smaller nodules are less detrimental to resistivity and device reliability. Further work is needed to conclude whether the Al-1%Si/$MoSi_2$ contact is effective or ineffective.

Ⅳ. CONCLUSION

Stability upon sintering was investigated for Al and Al-Si metallization to Mo-silicided shallow junctions, formed by the ITM technique, which provides a uniform silicide formation, self-aligned to exposed Si areas. The following conclusions were obtained.

(1) Highly stable (up to 550°C) contacts have been realized in Al-2%/Si contact to Mo-silicided p^+-n and n^+-p shallow junctions (X_j~0.16µm).

(2) Low contact resistance, between Al-Si and Mo-silicide, was maintained, at submicron (0.5µm square) Al-Si/Mo-silicide contacts after 550°C sintering.

(3) Failure mechanism for Al/Mo-silicide junctions was local Si transport from Si substrate through the $MoSi_2$ layer to Al.

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METAL	JUNCTION TYPE	JUNCTION DEPTH (µm)	Si SUBSTRATE (Ω·cm)	ION IMPLANTATION INTERFACE MIXING	ION IMPLANTATION DOPING
Al-Si	n^+-p	0.16	40	Si: 80keV $5\times10^{15}cm^{-2}$	As: 140keV $1\times10^{15}cm^{-2}$
Al-Si	p^+-n	0.16	10		B : 30keV $1\times10^{15}cm^{-2}$
Al	n^+-p	0.41	40	As : 180keV $5\times10^{15}cm^{-2}$	

Table 1. Contact fabrication parameters.

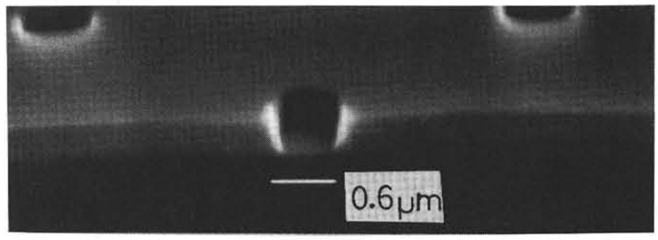
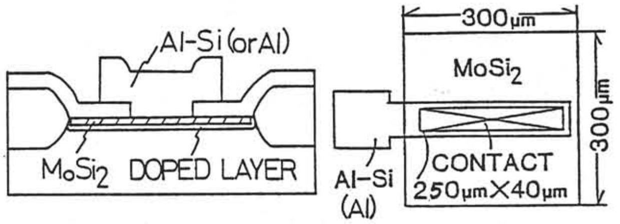


Fig. 1 A cross-sectional SEM micrograph for a sample with 0.5µm square contact holes, formed by electron beam direct writing.



(a) (b)

Fig. 2 A sample for leakage current measurement. (a) A cross-sectional diagram. (b) A plane diagram.

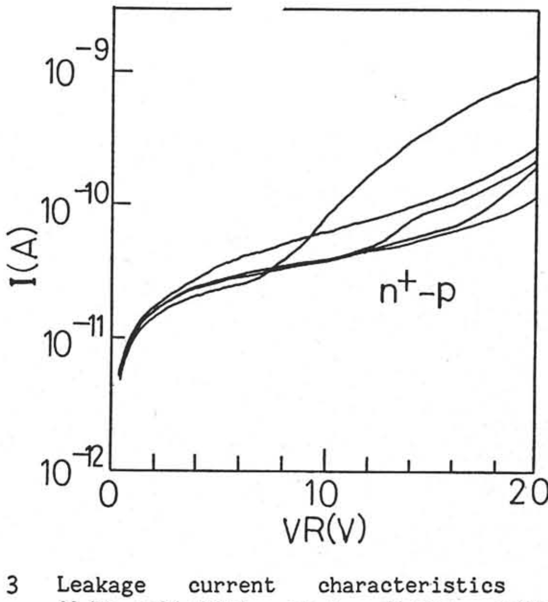


Fig. 3 Leakage current characteristics for Al/Mo-silicided n^+-p diodes with a ~0.41µm thick junction and a 250µm×40µm contact hole, sintered at 450°C for 30 minutes.

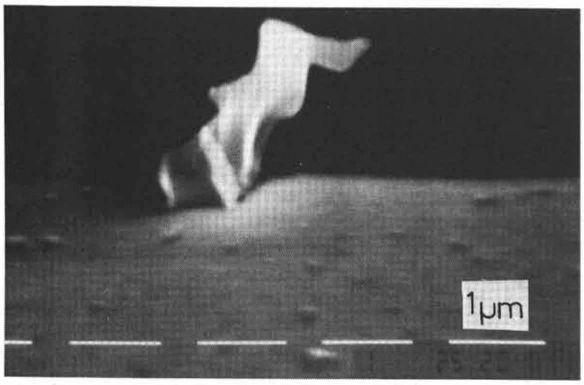


Fig. 4 An SEM micrograph for an Al/$MoSi_2$ sample surface after Al etching.

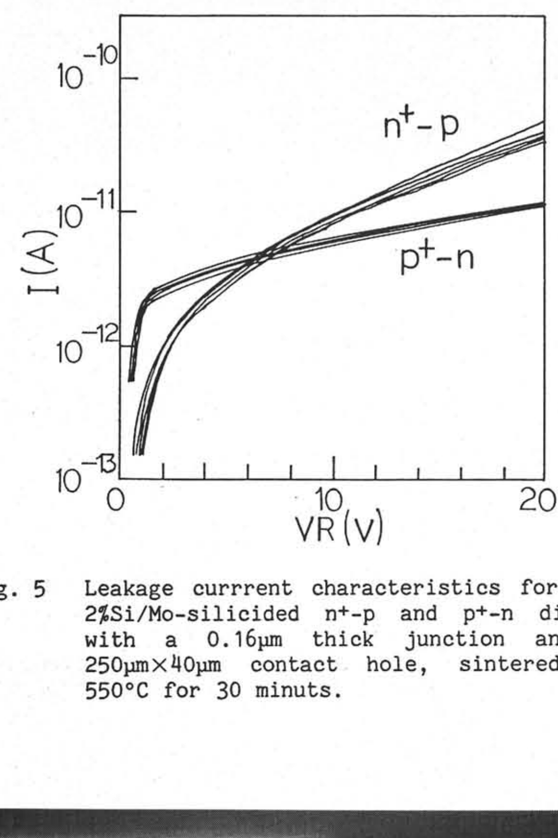


Fig. 5 Leakage currrent characteristics for Al-2%Si/Mo-silicided n^+-p and p^+-n diodes with a 0.16μm thick junction and a 250μm×40μm contact hole, sintered at 550°C for 30 minuts.

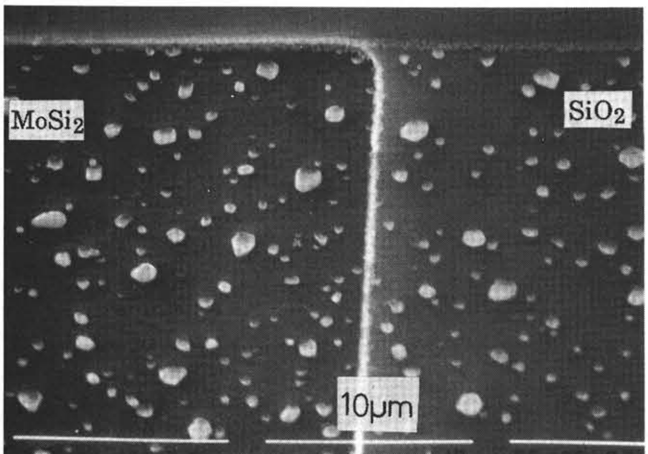


Fig. 6 An SEM micrograph for an Al-2%Si/$MoSi_2$ sample surface after Al etching.

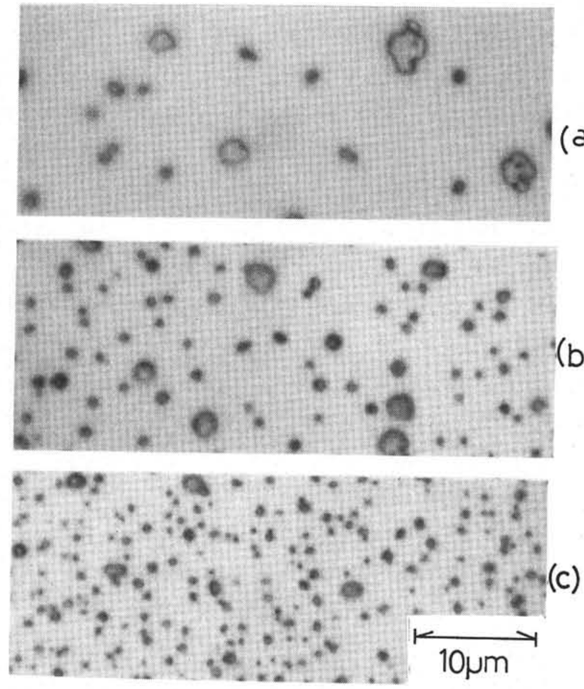


Fig. 7 Optical micrographs for $MoSi_2$ surfaces after Al etching in Al-2%Si/$MoSi_2$ samples, sintered for 30 minutes at (a) 550°C, (b) 500°C and (c) 450°C.

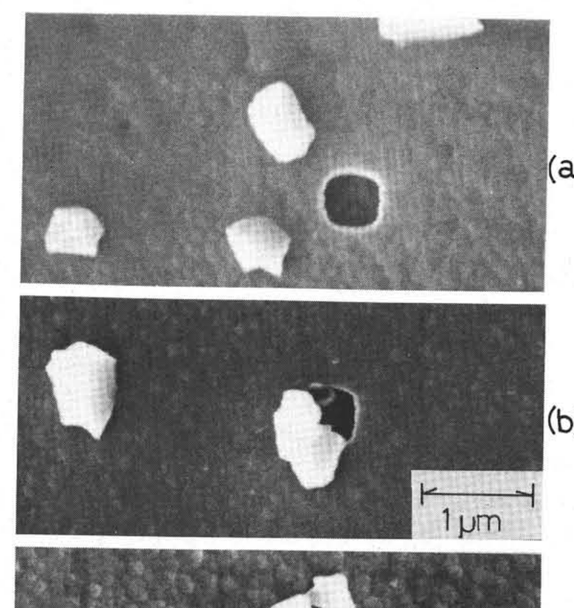


Fig. 8 SEM micrographs after Al etching for Al-2%Si/$MoSi_2$ samples sintered at 550°C for 30 minutes. Contact hole size: 0.5μm square.