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Elevated Polycide Source / Drain Shallow Junctions with Advanced Silicidation Processing and Al Plug / Collimated PVD-Ti/TiN/Ti / Polycide (APPOCIDE) Contact for Submicron CMOS

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Low resistive elevated polycide source/drain shallow junction and contact processes have been developed using advanced silicidation processes called "AAS and BAS" and Al plug / collimated PVD-Ti/TiN/Ti / Ti-polycide (APPOCIDE) structure contact. Sheet resistances of n^+-Ti-polycide and p^+-Ti-polycide were reached at the same level as that of undoped-Ti-polycide. Contact resistivities were 2~3x10^{-9} Ωcm^2 for contact on both n^+ and p^+. These contact resistivities were two orders of magnitude lower than the conventional case of Al / TiN /Ti / n^+ or p^+-Si structure. Furthermore, we propose unique consideration for the relative difficulty in achieving silicidation with low sheet resistance of $TiSi_2$ layer on n^+-Si (or n^+-poly-Si) as compared to that on p^+-Si or undoped-Si.

1. INTRODUCTION

With decreasing dimensions in ULSI designs, the need for shallow junctions is increasingly important because of suppression for transistor short channel effect. However, as the junction depth and device size shrink, serious problems such as increases in sheet resistances of transistor source / drain, contact resistances and junction leakage current occur, which limit device performance. For these problems, elevated polycide S/D structures were proposed[1~3]. However, silicidation on n^+-Si or -poly-Si layer with low sheet resistance was difficult as compared with undoped-Si or -poly-Si.[4,5] The actual mechanism of this obstruction is not fully understood. In order to overcome these problems, we proposed elevated polycide S/D shallow junctions formed by the advanced silicidation processing called "AAS[6] and BAS ($^{75}As^+$ or $^{11}B^+$ doped into the silicide layer after silicidation)" processes, and then discussed the difficulty in silicidation with low sheet resistance on n^+-Si (or n^+-poly-Si). Furthermore, Al plug / collimated PVD-Ti/TiN/Ti / Ti-polycide (APPOCIDE) structure was demonstrated to realize a low contact resistance on n^+ and p^+.

2. EXPERIMENT

The polycide samples used in this experiment were formed by the AAS (n^+), BAS (p^+), ABS (n^+) and BBS (p^+) processes on a poly-Si layer using two-step rapid thermal annealing (2 step RTA) with halogen lamp heating in a N_2 atmosphere[7]. The process flows are shown in Fig.1. The ABS and BBS ($^{75}As^+$ or $^{11}B^+$ doped into the poly-Si layer before silicidation) processes are the conventional processes of silicidation for poly-Si layers instead of the Si-substrates. Dosage of As^+ or B^+ implantation was fixed at 5E15/cm^2 for all processes. The first RTA was performed in a temperature range from 575 to 625°C for 20sec in a N_2 atmosphere without atmospheric exposure after Ti deposition by multi-chamber system, of which the base pressure was lower than 1x10^{-8} Torr. After the first RTA, the TiN and unreacted Ti were etched off by a H_2SO_4 based solution. The second RTA condition was fixed at a temperature of 850°C for 20sec in a N_2 atmosphere. The Ti-polycide film properties were estimated using a four-point probe method, scanning electron microscopy (SEM), transmission electron microscopy (TEM), secondary ion mass spectroscopy (SIMS) and X-ray photoelectron spectroscopy (XPS).

The APPOCIDE contacts were formed using optimized AAS and BAS processes on n^+ and p^+. After the silicidation process, CVD-SiO_2 deposition and contact hole definition, the multilayered metallization process was performed. Collimated-Ti (50nm), -TiN(100nm) -Ti (20nm), and high-temperature-flow-Al (500nm) were sequentially sputtered by the same multi-chamber sputtering system without atmospheric exposure. The contact resistances were estimated by the Kelvin method.

3. RESULTS AND DISCUSSION

Figure 2 shows the dependence of the final sheet resistances of the $TiSi_2$ films on the first RTA temperature. The effect of the n^+ and p^+ doping into the polycide layer was studied by comparing the AAS, ABS, BAS and BBS processes with the silicidation of undoped-Si and undoped-poly-Si processes. Under the condition of first RTA temperature of 625°C, the sheet resistances of polycide layers by AAS, BAS and BBS processes were all about 2.0~2.1 Ω/square. On the other hand, the ABS process was essentially larger than the others. From TEM and SEM observations, the resistivities of $TiSi_2$ films formed by ABS and the other processes were estimated as about 26 μΩcm (5.1Ω/sq. at 50nm) and 16 μΩcm (2.1Ω/sq. at 75nm), respectively. From SIMS analysis, the tail of an oxygen peak extended throughout the silicide layer in the sample formed by the ABS process, as shown in Fig.3. So, it is considered that the oxygen in the silicide layer affects the sheet resistance of silicide layer.

Figure 4 shows final sheet resistances of the $TiSi_2$ films formed by two kinds of ABS as a function of first RTA temperature. One method was a direct implantation of As^+ ions into the poly-Si layer and subsequent annealing before silicidation. The other was implantation of As^+ ions through an oxide layer of 20 nm into the poly-Si layer and the same annealing. Even in the ABS process, it was confirmed that the sheet resistance of Ti-polycide film was decreased to that of the AAS-polycide level by direct implantation, except for the problem of contamination. Figure 5 shows XPS spectra of poly-Si surface before Ti sputtering for the above-mentioned two ABS methods. HF treatment of two samples was performed just before analysis. In the sample formed by As^+ implantation through a SiO_2 layer, the peak assigned to Si $2P_{3/2}$ of Si-O bond was observed. By TEM micrographs, a titanium silicide layer formed by the reaction between sputtered-Ti and poly-Si was observed in the direct implantation without annealing sample. On the other hand, in the As^+ implantation through SiO_2 layer sample, no titanium silicide layer was observed, as shown in Fig.6. From these results (Fig.3.~6.), it is considered that the difficulty in silicidarion on n^+-Si (n^+-poly-Si) was caused by a knocked-on-oxygen and not an arsenic itself. If this consideration was appropriate, low sheet resistance of BBS polycide as the same level of the BAS and undoped polycide could be explained self-consistently, because of little knocking of oxygen at the implantation for small mass of B^+ ion.

Figure 7 shows the SEM micrograph of the APPOCIDE contact. The $TiSi_2$ film plays two important roles in the APPOCIDE contact. One is to act as a barrier layer against the diffusion of Al and Si. The other is to form a contact with low resistance. In the sample using collimated PVD-Ti/TiN/Ti as a barrier layer, an alloy spike was observed. On the other hand, using the APPOCIDE structure, no alloy spike was observed. It was confirmed that the barrier effect could be enhanced by the addition of a $TiSi_2$ layer. Figure 8(a) and 8(b) show the dependence of the contact resistance on contact diameter in APPOCIDE contacts on n^+ and p^+ source / drain regions as compared with the conventional Al-based metal/TiN/Ti structure contacts, respectively. In the APPOCIDE structure, contact resistances two orders of magnitude lower than the conventional case were obtained for both n^+ and p^+.

The average contact resistance of 0.35 μm diameter contacts on n^+ was about 2.5Ω and that on p^+ was about 3.0Ω. From those results, the contact resistivities on n^+ and p^+-polycide were about 2.4×10^{-9} and 2.9×10^{-9} Ωcm^2, respectively. Furthermore, the leakage current of elevated polycide source / drain with APPOCIDE contact for n^+/p and p^+/n junctions, which extended polysilicon / silicon interface area, were the same level as conventional (non-silicidation) 0.2 μm deep junctions with conventional contact, as shown in table 1.

4. CONCLUSION

Low resistive elevated polycide S/D shallow junction and contact processes have been demonstrated. Also, we suggest that the relative difficulty in achieving silicidation with low sheet resistance of the $TiSi_2$ layer on n^+-Si (or n^+-poly-Si) as compared to that on p^+- or undoped-Si can be attributed to an knocked-on-oxygen in As^+ implantation and not an arsenic itself. By using the AAS and BAS processes, low-resistive and low leakage shallow junctions were achieved. The resistivities for n^+-polycide and p^+-polycide resulted in 16 μΩcm that was the same level as that for undoped-polycide (or undoped-silicide). Al plug / collimated PVD-Ti/TiN/Ti / Ti-polycide (APPOCIDE) structure contact has low enough contact resistances. The average contact resistances of 0.35 μm diameter contact on n^+ and p^+ were about 2.5Ω and 3.0Ω, respectively. These contact resistances were two orders of magnitude lower than the conventional Al / TiN /Ti / n^+- or p^+-Si structure. Furthermore, the leakage current of elevated polycide source / drain with APPOCIDE contact for n^+/p and p^+/n junctions were the same level as conventional (non-silicidation) 0.2 μm deep junctions with conventional contacts. This technology is expected to be important for the development of future deep submicron devices.

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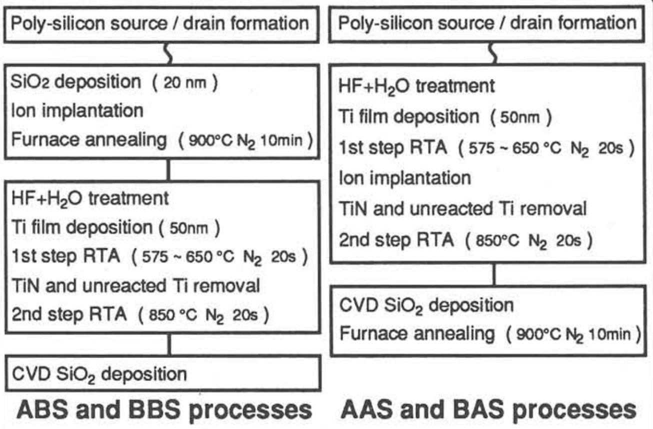

Fig.1 AAS, ABS, BAS, and BBS processes.
AAS: As^+ doped into the polycide layer after silicidation.
ABS: As^+ doped into the poly-Si layer before silicidation.
BAS: B^+ doped into the polycide layer after silicidation.
BBS: B^+ doped into the poly-Si layer before silicidation.

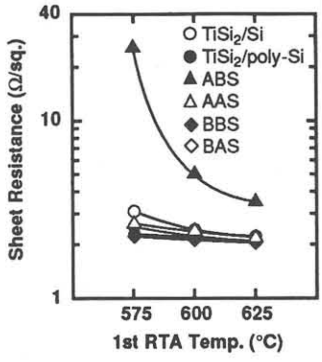

Fig. 2 Dependence of the final sheet resistances of the Ti-polycide films.

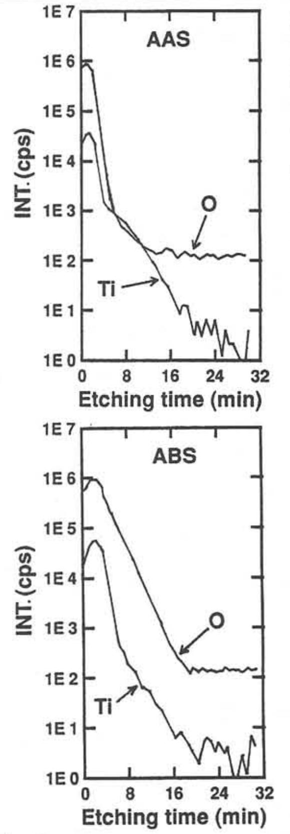

Fig. 3 SIMS profiles of "Ti" and "O" in the Ti-polycide layer formed by the AAS and ABS processes.

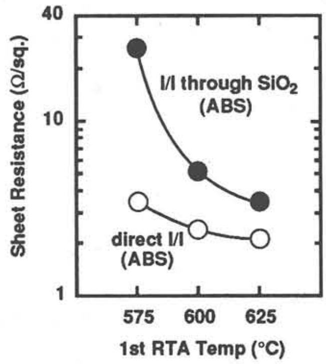

Fig. 4 Dependence of the final sheet resistances of the Ti-polycide films formed by two methods.

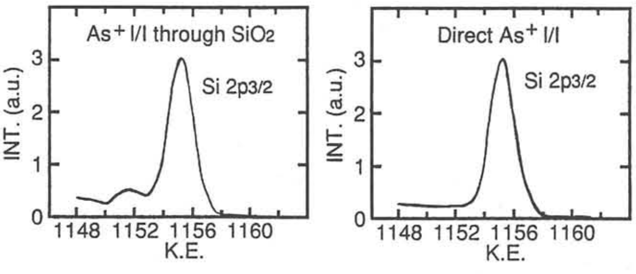

Fig. 5 XPS spectra of Poly-Si surface before Ti sputtering.

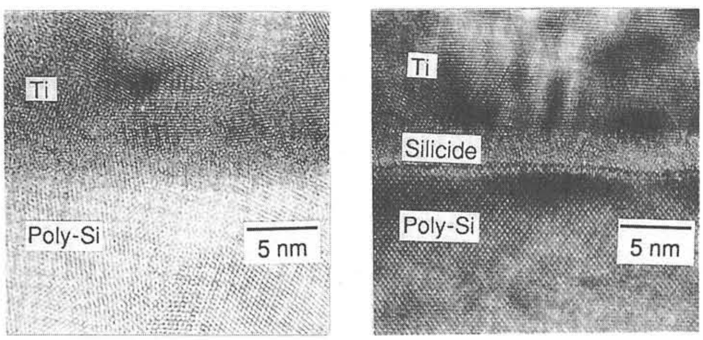

Fig. 6 TEM micrographs of Ti/Poly-Si interface region after Ti sputtering.

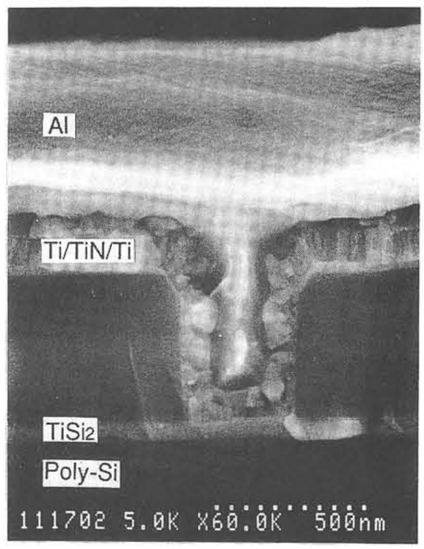

Fig. 7 SEM micrograph of Al plug / Ti/ TiN/Ti/ polycide (APPOCIDE) contact.

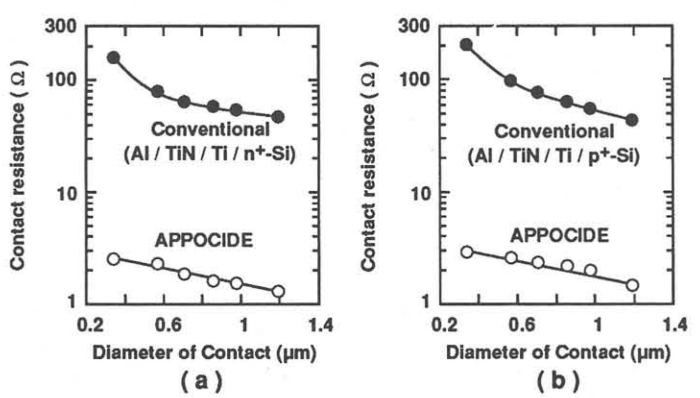

Fig. 8 Dependence of the contact resistances on (a) n^+ layer and (b) p^+ layer in the APPOCIDE structure and conventional Al/TiN/Ti structure.

Table 1 Contact resistivity and junction leakage current.

		0.35μm contact resistivity	Junction leakage current VR=5.0V
n^+/p	Polycide (AAS)	2.4E-9 Ωcm²	11~14 pA
	Ref.	1.5E-7 Ωcm²	11~13 pA
p^+/n	Polycide (BAS)	2.8E-9 Ωcm²	2~3 pA
	Ref.	1.9E-7 Ωcm²	2~3 pA