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Suppression of Resistance Increase in Al/W Interconnects by N_2 Plasma Treatment

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The suppression of resistance increase in annealed Al/W interconnects has been achieved by exposing the W surface to N_2 plasma before Al deposition. This process forms thin WN_x layer at the interface between Al and W layer. The WN_x layer prevents alloy formation between Al and W during annealing at 450°C. With N_2 plasma treatment, the resistance increase after annealing at 450°C is suppressed to be only 10% in contrast with 140-180% in the case without N_2 plasma treatment.

1. INTRODUCTION

The Al/CVD-W bilayer interconnects (1-4) is one of the promising candidates for marginless contacts in future quarter-micron ULSIs, because a use of *blanket CVD-W without etchback* provides good step coverage without a recess in vicinity of contacts, which is in remarkable contrast to the popular *blanket CVD-W with etchback* (5,6) as shown in Fig.1, because no etchback process is needed in this structure. Reaction between Al and W during annealing at 450°C , however, results in undesirable resistance increase in Al/W structure (1). An Al/TiN/W structure (7) and SiH_4 treatment of W surface (8) were reported to solve this problem. The Al/TiN/W structure, however, shows slight resistance increase because of Ti diffusion from TiN layer. In SiH_4 treatment, the mechanism of suppression of resistance increase is not well understood.

Recently, WN_x diffusion barrier , which was formed by ECR plasma nitridation on W surface, was reported to prevent the reaction between Cu and Si substrate during annealing (9). This paper reports the suppression of resistance increase in annealed Al/W lines by N_2 plasma exposure of W surface. This approach is found to be effective to prevent Al-W reaction during annealing at 450°C. In our experiments, WN_x layer is formed by N_2 plasma generated in a capacitively coupled parallel-plate reactor. This WN_x layer is found to be thicker and more N-rich compared with the WN_x layer previously reported (9).

2. EXPERIMENTAL

The detailed structure of Al/W lines is shown in Fig.2. Following sputter-deposition of a TiN/Ti adhesion layer of 30/10nm thickness on BPSG deposited Si wafers, a W layer of 130nm thickness was formed by the blanket CVD method. After CVD-W deposition, specimens were exposed to air. To form WN_x layer, W surface was exposed to N_2 plasma generated in conventional capacitively coupled parallel-plate reactor. The condition of N_2 plasma treatment was as follows; RF power: 300W, V_{DC}: 230V, pressure: 80mTorr, substrate temperature: 50°C, and exposure time: 60sec. After N_2 plasma treatment, specimens were exposed to air again, and moved into sputtering apparatus. Then, Al-1%Si-0.5%Cu of 200nm thickness was sputter-deposited. As an anti-reflective layer for fine patterning in lithography, TiN layer of 40nm thickness was deposited by a reactive sputtering from Ti target using Ar and N_2 gas mixture. Fine-lines of various widths (0.3-3.0μm wide) were patterned by KrF excimer laser lithography. Finally, these lines were passivated with plasma enhanced CVD silicon oxide of 500nm thickness.

The sheet resistance was measured as a function of the line width after annealing at 450°C for 30min. To investigate the reaction between Al and W during annealing, XRD analysis using Cu Kα radiation was carried out for both specimens with and without N_2 plasma treatment of planar (unpatterned) structures after annealing at 450°C for 30min. To characterize the surface of W with N_2 plasma treatment, the surface of W layer just after N_2 plasma treatment was analyzed by XPS. The reaction between Al and W was also observed by cross-sectional TEM in 0.3μm wide Al/W lines with and without N_2 plasma treatment.

3. RESULTS AND DISCUSSIONS

As shown in Fig.3, the interconnect sheet resistance is almost same in both Al/W lines with and without N_2 plasma treatment before annealing. The N_2 plasma treatment does not affect the interconnect resistance before annealing. After annealing at 450°C, the sheet resistance of Al/W lines without N_2 plasma treatment is much larger than the one with N_2 plasma treatment. Fig.4 shows that the resistance increase ratio is about 140-180% without N_2 plasma treatment. On the other hand, It is suppressed to be only 10% with N_2 plasma treatment. The anomalous sheet resistance increase, which shows the larger resistance increase at the narrower line width (7), is not found in Al/W lines without N_2 plasma treatment, because the experimental conditions are different. In this experiment, native oxide on W surface was not removed. This may be the reason for little line width dependence of sheet resistance increase. This phenomenon, however, will be discussed elsewhere.

In Fig.5(a), XRD analysis of the Al/W structure without N_2 plasma treatment showed the existence of WAl_{12}, WAl_5 and $Al_2(WO_4)_3$ formed by the reaction of Al and W during the annealing. As these products are considered to have high resistivity, WAl_{12}, WAl_5 and $Al_2(WO_4)_3$ formation during annealing causes resistance increase in Al/W lines without N_2 plasma treatment. On the other hand, the Al/W structure with N_2 plasma treatment showed no existence of reaction product after annealing, as shown in Fig.5(b).

In Fig.6, XPS analysis of W surfaces showed there are WN_x and WO_3 in the specimen with N_2 plasma treatment, in contrast to W and WO_3 in the one without N_2 plasma treatment. It is found that WN_x layer is formed on the W surface by the N_2 plasma exposure before Al layer deposition. Diffusion barrier property of high resistive WN_x layer, which was prepared by reactive sputtering from W target using Ar and N_2 gas mixture, was reported to prevent the reaction between Al and Si substrate (10). It is clear that the WN_x layer also prevents reaction between Al and W layer during annealing. In Fig.7, the cross-sectional TEM observation shows that there is no reaction product between Al and W in the Al/W lines with N_2 plasma treatment.

From peak analysis of XPS data, N/W ratio was calculated to be 1.6 for the W which was combined with N. The thickness of the WN_x layer was estimated to be about 6nm. The following assumption was used to calculate WN_x layer thickness; The WN_x layer was assumed to be formed under WO_3 layer. The electron escape depths of WO_3 and WN_x were estimated to be 2.27 and 1.62nm, respectively. These values were derived from the physical constants of the materials which have same property with that of WO_3 or WN_x.

Thin WN_x layer as in this experiment can not be detected by XRD. Though this WN_x layer is considered to have high resistivity (10), it is so thin that interconnect resistance before annealing is not increased by the WN_x formation after N_2 plasma treatment.

Using AES analysis, Ono et al. showed that the WN_x layer formed by ECR N_2 plasma exposure has the thickness of 1-2nm and N/W ratio of about 2/3 (9) for the same exposure time in this work. The WN_x layer formed in this experiment is thicker and more N-rich compared with their results. The RF plasma used in this experiment has self bias voltage of 230V. This bias voltage is considered to be larger than the bias voltage in the ECR N_2 plasma used by Ono et al. This large bias voltage may result in the thicker and more N-rich WN_x layer compared with the one reported by Ono et al.

4. CONCLUSIONS

The suppression of resistance increase in annealed Al/W interconnects has been achieved by N_2 plasma exposure of W surface before Al deposition. This process forms thin WN_x layer at the interface between Al and W layer. About 6nm WN_x layer was formed by exposing to N_2 plasma generated in the conventional capacitively coupled parallel-plate system for 60sec. This WN_x layer prevents alloy formation between Al and W during annealing at 450°C. With N_2 plasma treatment, the resistance increase after annealing at 450°C is suppressed to be only 10% in contrast with 140-180% in the case without N_2 plasma treatment. This technology will be useful to realize Al/W interconnects with low sheet resistance for marginless contacts in future ULSIs.

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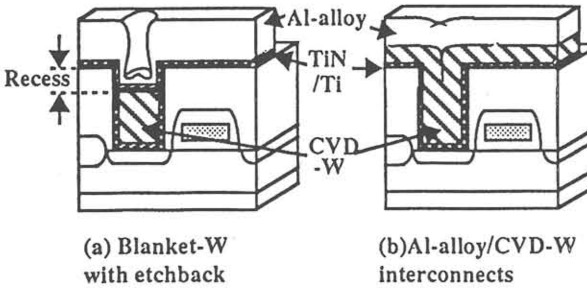

Fig.1 The step coverage of interconnects by two process of contact filling

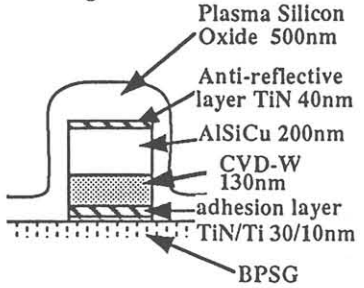

Fig.2 Cross-sectional view of Al/W interconnect structures

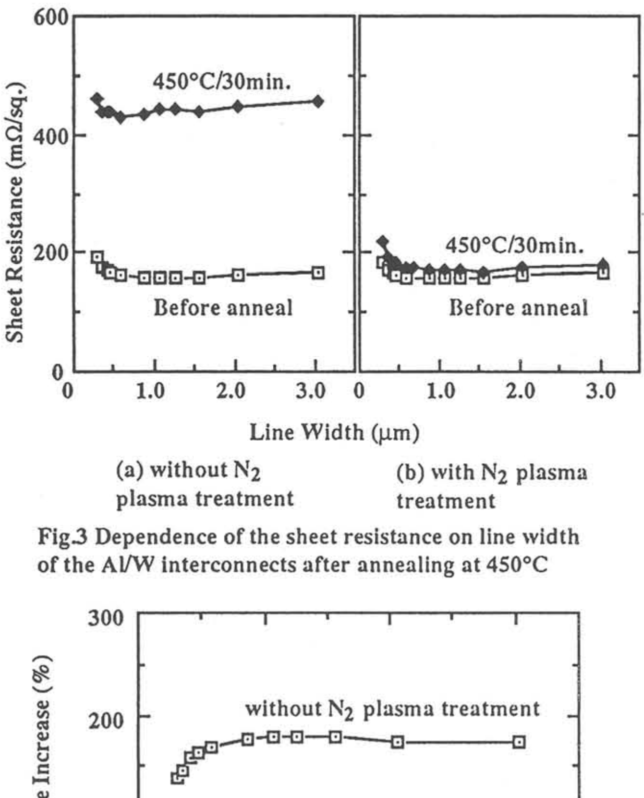

Fig.3 Dependence of the sheet resistance on line width of the Al/W interconnects after annealing at 450°C

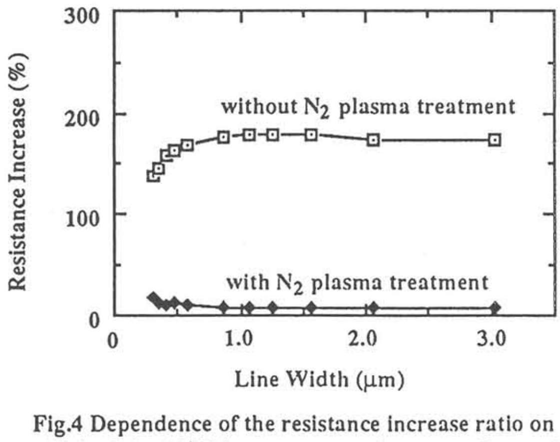

Fig.4 Dependence of the resistance increase ratio on line width of the Al/W interconnects after annealing at 450°C for 30min.

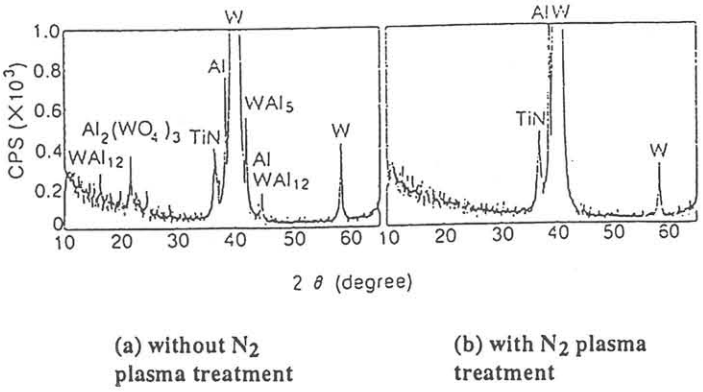

Fig.5 The θ-2θ XRD spectra of two planar structures after annealing at 450°C

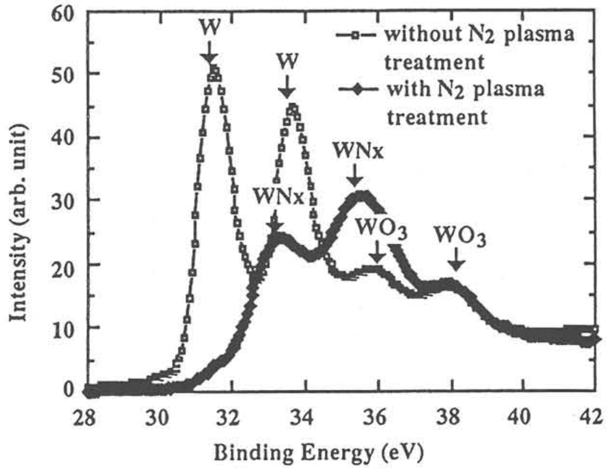

Fig.6 The XPS spectra of W surfaces of two planar structures

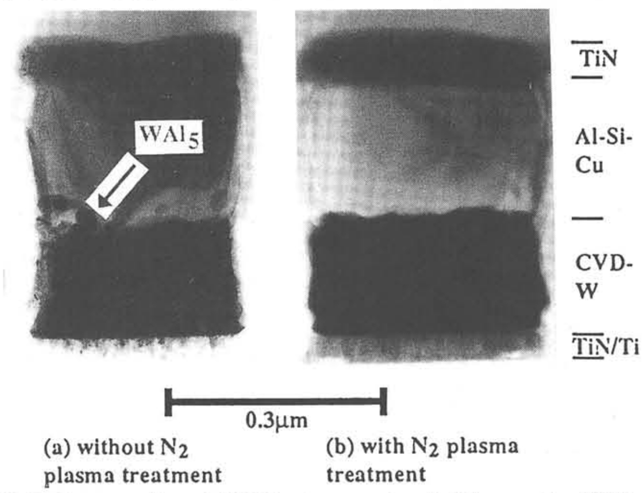

Fig.7 Cross-sectional TEM micrographs of 0.3μm-wide Al/W interconnects after annealing at 450°C for 30min.