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Nucleation and Growth Control of Al-CVD for Dual-Damascene Application

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1.Introduction

The multi-level interconnects made of all-aluminum lines may have lower resistivity and higher reliability than conventional Al-line/W-plug scheme. Dual damascene process is a promising technology for reducing process steps and costs, but it requires conformal deposition of metal lines in high aspect ratio. Thus Al-CVD is the most required process but surface roughness of CVD-Al prevent the realization of dual-damascene. Enhancing the initial nucleation density and suppressing the roughing after coalescence of initial nuclei are the effective prescriptions [1]. The key for high initial nucleation density may be the pre-treatment of initial surface. In this study, we examined the effect of HF treatment on TiN surface for Al-CVD substrate and found a suitable condition. The better condition to suppress the surface roughing after the coalescence of initial nuclei was also investigated.

2.Experimental

Figure 1 shows the cold-wall CVD reactor with load-lock chamber employed in this study. The surface roughening of aluminum surface was monitored in-situ using the laser light reflectivity measurement [2]. We used TiN as the underlayer for Al-CVD. The TiN was prepared by conventional PVD technology on top of thermally oxidized Si substrate and preserved for about 1 year in the atmosphere. Dimethyl-aluminum-hydride(DMAH) was used for Al precursor and it was introduced to the CVD chamber using H_2 as carrier gas. Deposition runs were performed at heater temperature of 285°C. The actual surface temperature is about 20°C lower than heater temperature. The surface composition of TiN layer was investigated using XPS.

3.Results and discussion

Figure 2 shows examples of reflectivity measurement. The reflectivity change of non-treated sample shows the major issues in Al-CVD. At the initial nucleation stage of the deposition, because the nuclei scattered the incident light, the reflectivity dropped. As the nuclei coalesced, the surface became flat and the reflectivity increased. After the coalescence, the surface became rougher as the film thickness increased. However when TiN was dipped into HF solution (5wt%) for 3 min prior to the deposition, the initial drop of the reflectivity was not observed and the maximum reflectivity was larger as shown in fig.2. SEM observations of initial stage of film growth proved that the change was caused by the enhancement of nucleation density as depicted in fig.3. The higher nucleation density results in smoother film and higher reflectivity. In order to clarify the mechanism of HF treatment, the effect of HF concentration of the solution was investigated. Figure 4 summarizes the results. With HF concentration of 0.05wt%, the initial drop of the reflectivity was observed although it was smaller than the case of untreated TiN. With 0.5wt% HF solution, this drop disappeared indicating enhanced nucleation of Al. The use of 5wt% HF solution led to slightly larger value and higher rate of reaching maximum reflectivity. Figure 5 shows surface compositions of these samples. The contamination on surface of non-treated TiN were mainly carbon and oxides. Oxides were well-removed by 0.5wt%HF and more, but carbon contamination cannot be removed effectively with 0.5wt%HF. From these facts, it was estimated that carbon contamination affected on nucleation stage. Figure 6 shows the change of chemical status of Ti by these HF treatments. The suppression of TiO related peak and increase of TiF, TiN related peaks were observed. The reduced state of Ti and surface Ti-F bonds may be the other cause of nucleation enhancement. The surface roughening after coalescence of initial nuclei can be suppressed by decreasing the total pressure as shown in fig.7. This phenomena suggests that the surface roughening derives from surface oxidation by small amount of impurities in H_2 carrier gas. Therefore, high partial pressure of DMAH and low total pressure may be the solution to get smooth surface morphology in Al-CVD.

4.Conclusinos

The effect of HF pretreatment on TiN surface was examined to get better surface morphology of CVD-Al films. HF treatment with suitable concentration effectively removes surface contamination and enhances Al nucleation. The HF pretreatment and adequate deposition condition enables the Al-CVD to full fill the dual damascene structure.

References

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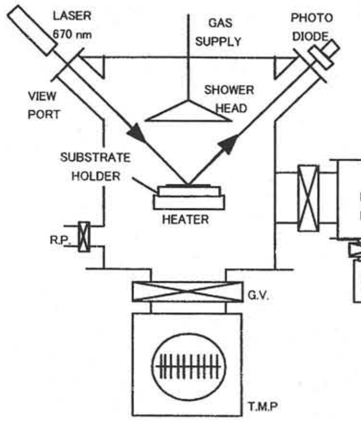

Fig.1 Experimental setup of Al-CVD and reflectivity measurements.

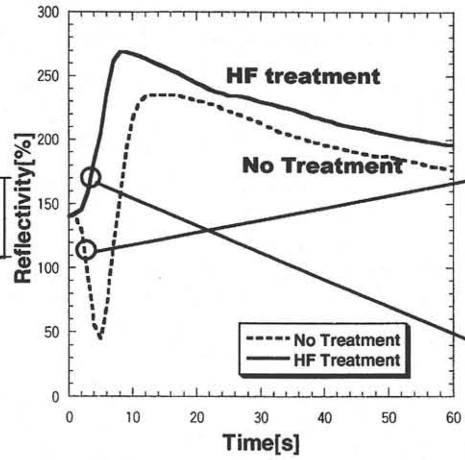

Fig.2 Reflectivity behavior of Al-CVD with and without HF treatment (5 wt% HF solution). Reflectivity of 100% corresponds to that of Si(100) surface.

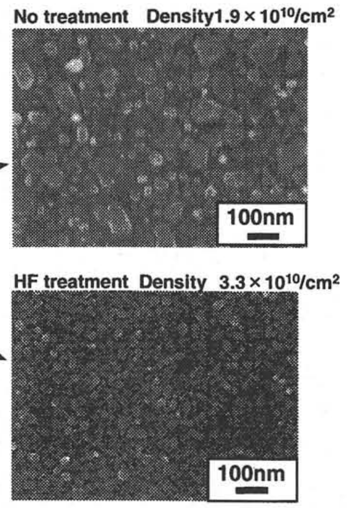

Fig.3 SEM images of the Al surface (top view) at the initial nucleation stage with and without HF treatment.

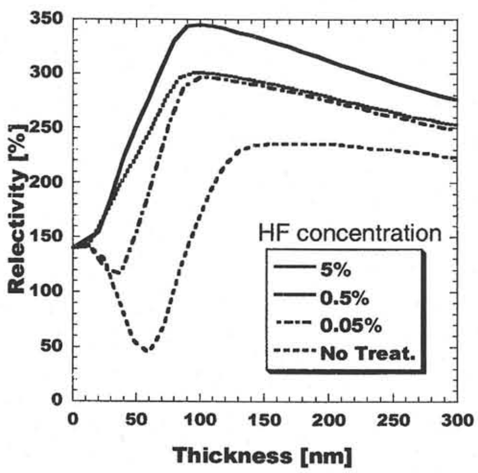

Fig.4 Reflectivity behavior of Al-CVD with various HF treatments.

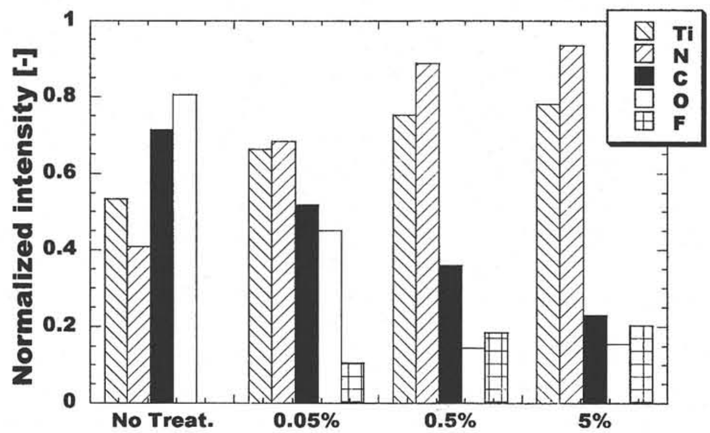

Fig.5 TiN surface compositions after various HF treatments. The intensity is normalized by the peak area of Ti after 3 min Ar etching.

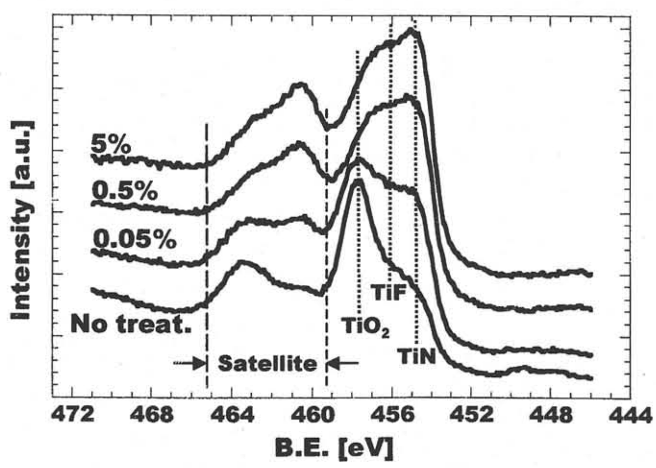

Fig.6 Ti(2p) peaks observed by XPS after various HF treatments.

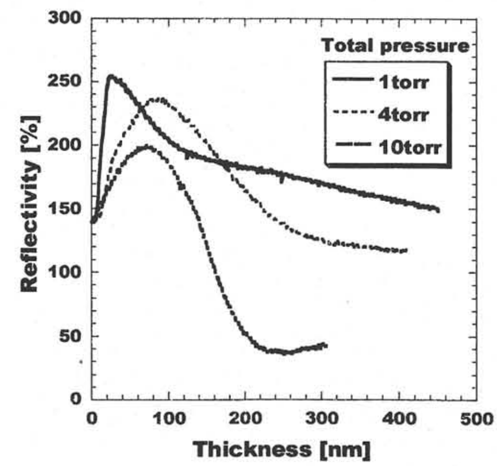

Fig.7 Reflectivity change during Al-CVD by variations total pressure. Partial pressure of DMAH was 0.15tor,temperature was 285°C.