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## Aluminum Chemical Vapor Deposition Technology for High Deposition Rate and Surface Morphology Improvement

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### 1. Introduction

In sub-0.1 $\mu\text{m}$  ULSI interconnection, Cu metallization is recently developed. However, Cu metallization has an issue on filling capability to sub-0.1 $\mu\text{m}$  holes. This is because the sidewall barrier is required to prevent Cu diffusion into interlayer dielectrics. One should recognize that, in sub-0.1 $\mu\text{m}$  hole-filling, the resistance of Al without sidewall barrier is much less than that of Cu with sidewall barrier. In this scene, Al is continued to be employed in sub-0.1 $\mu\text{m}$  era instead of Cu. Al sputtering method cannot be applied to sub-0.1 $\mu\text{m}$  hole-filling because of its poor step coverage. Aluminum chemical vapor deposition (Al CVD) is a promising method for filling plugs with a high aspect ratio. We have investigated the Al CVD technology using dimethylaluminumhydride [(CH<sub>3</sub>)<sub>2</sub>AlH, DMAH] and H<sub>2</sub> [1]. The features are (1) filling capability of 0.3 $\mu\text{m}/1\mu\text{m}$ -deep contact holes, (2) selective deposition on conductive materials, and (3) single crystal Al growth on H-terminated Si surface. However, its main issues are its low growth rate of 0.02 $\mu\text{m}/\text{min}$  and its poor morphology of thick film of over 0.3 $\mu\text{m}$ . Although high deposition rate of 1 $\mu\text{m}/\text{min}$  using a liquid mass flow controller is reported [2], small-diameter tube in the liquid mass flow controller is choked up by high viscosity liquid DMAH.

In this work, we report the Al CVD with high deposition rate using direct liquid injection (DLI) system and Al surface morphology improvement by Cu doping.

### 2. High deposition rate

For the high growth rate of 1 $\mu\text{m}/\text{min}$  on 12inch-diam. wafer, the required delivering flow rate of liquid DMAH is 2.1cc/min. In this work, we have employed direct liquid injection (DLI) system (Fig. 1). The features are liquid delivering by forced pumping and controllability of liquid flow rate from 0.006 to 2.5cc/min. In the CVD system configuration using DLI, the requirements are that the liquid DMAH is fully vaporized in the vaporizer, and the vaporized DMAH is delivered from the vaporizer to the deposition chamber without re-liquefying. For this purpose, the distance between the vaporizer and the chamber should be as short as possible; in our apparatus, the vaporizer and the chamber are connected with a 1/2-inch $\phi$  10cm-long tube. Furthermore, the DMAH partial pressure in reaction chamber should be high because the Al is deposited with the surface reaction limited condition regime.

Figure 2 shows Al deposition rate as a function of DMAH partial pressure. The deposition rate (DR) increases with increase in DMAH partial pressure ( $P_{\text{DMAH}}$ );  $\text{DR} = P_{\text{DMAH}}^{0.7}$ . It is noted that deposition rate can be controlled by the DMAH partial pressure.

Figure 3 shows Arrhenius plots of Al deposition rate. The flow rate of liquid DMAH and the partial pressure of DMAH are kept at 2.5cc/min and 3.0Torr, respectively. The total pressure of reaction chamber is 4.0Torr. The growth rate of Al exceeds 1 $\mu\text{m}/\text{min}$  over 240°C. The activation energy has been found to be 0.35eV, which is coincides with that obtained by the bubbling method. This means that DLI and bubbling methods have the same surface reaction model. The high deposition rate of

1 $\mu\text{m}/\text{min}$  has been obtained with the control of DMAH partial pressure using DLI.

### 3. Surface morphology improvement

An addition of a small amount of Cu is known to be greatly effective for improving electromigration (EM) endurance [3]. The Cu addition to CVD Al has become one of the major concerns. In this work, we have found that the Cu addition improves the surface morphology of Al film. CpCuTEP [( $\eta^3$ -C<sub>5</sub>H<sub>5</sub>)Cu P(C<sub>2</sub>H<sub>5</sub>)<sub>3</sub>] is used as Cu precursor without oxygen. DMAH, CpCuTEP and H<sub>2</sub> are delivered into the reaction chamber at the same time. DMAH is vaporized by the conventional bubbling method.

Figure 4 shows the XPS spectra on TiN surface with Cu-doped Al. The growth duration is 20sec. The Cu peak is clearly observed on the TiN surface, while the Al peak is not observed on the TiN surface. This means that, before formation of Al, Cu nuclei or layer is formed on the TiN surface.

Figure 5 shows the surface micrographs of (a) pure-Al and (b) Cu-doped Al. The growth duration is 40sec. For pure-Al growth, Al islands are formed. On the other hand, the continuous film is formed for Cu-doped Al. Cu layer formed prior to Al formation has enhanced the continuous Al film formation.

Figure 6 shows the surface and cross-sectional micrographs of (a) pure-Al and (b) Cu-doped Al films. The growth duration is 20min. The thickness is 0.5 $\mu\text{m}$ . The incorporated Cu concentration in the Cu-doped Al is 0.1wt%. The surface morphology of 0.5 $\mu\text{m}$ -thick pure-Al films is poor. The Cu-doped Al films have superior surface morphology. The reflectivity of 0.5 $\mu\text{m}$ -thick Cu-doped Al films is found to be over 225% at wavelengths of 300–600nm when the reflectivity of Si is 100%. The Cu layer formed prior to Al film formation is effective to deposit 0.5 $\mu\text{m}$ -thick Al with mirror-like surface morphology on TiN surface.

### 4. Conclusion

We have discussed the Al CVD technology for high deposition rate using the direct liquid injection (DLI) system and surface morphology improvement with Cu doping. It has been experimentally confirmed that high deposition rate of 1 $\mu\text{m}/\text{min}$  is obtained with the control of DMAH partial pressure, and that the Cu layer formed before the formation of Al greatly improves the surface morphology of thick Al film. The combination of high deposition rate technology and Cu addition is promising for Al CVD technology in ULSI multilevel metallization.

### References

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- [2] Y. Matsumiya, N. Ohtsuka, S. Yamazaki and K. Nakajima, *Proceeding of Advanced Metallization And Interconnect Systems for ULSI Applications in 1996*, (Materials Research Society, Boston, 1996) p. 201.
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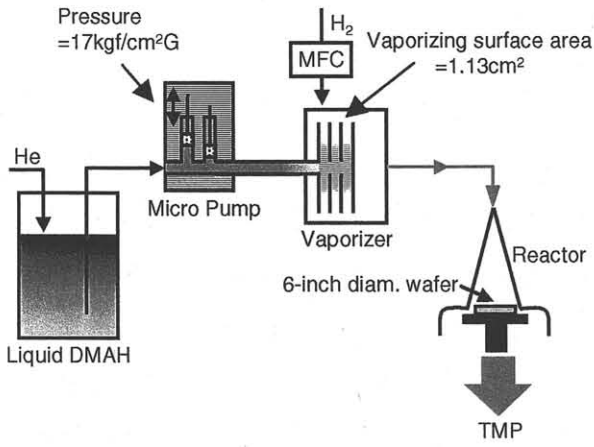


Fig. 1 Schematic of direct liquid injection system.

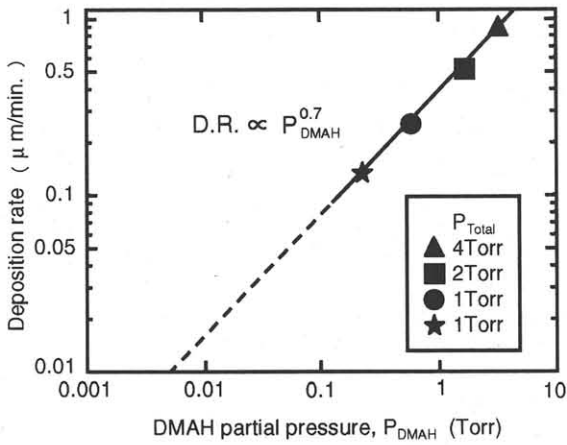


Fig. 2 Al deposition rate vs. DMAH partial pressure.

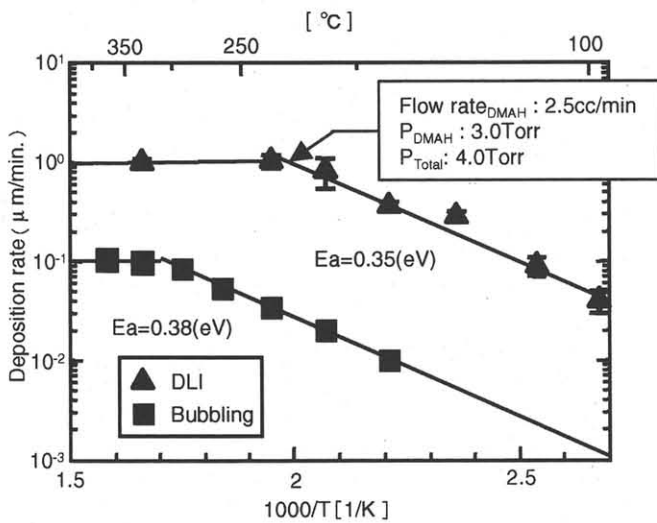


Fig. 3 Temperature dependence of Al deposition rate.

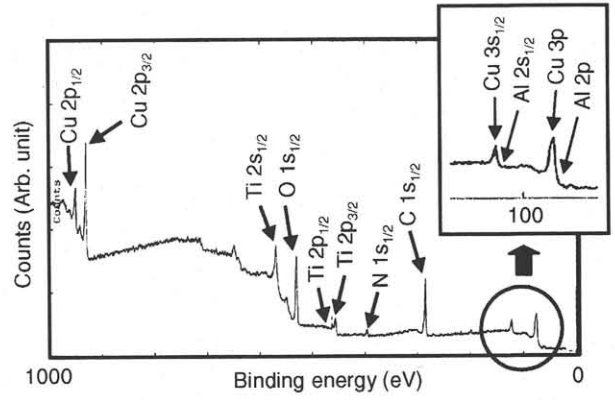


Fig. 4 XPS spectra on TiN surface with Cu-doped Al. 20sec growth. ( $P_{Total}$ : 1 Torr,  $P_{DMAH}$ : 12mTorr,  $P_{CuTEP}$ : 0.1mTorr,  $T_{dep}$ : 210°C)

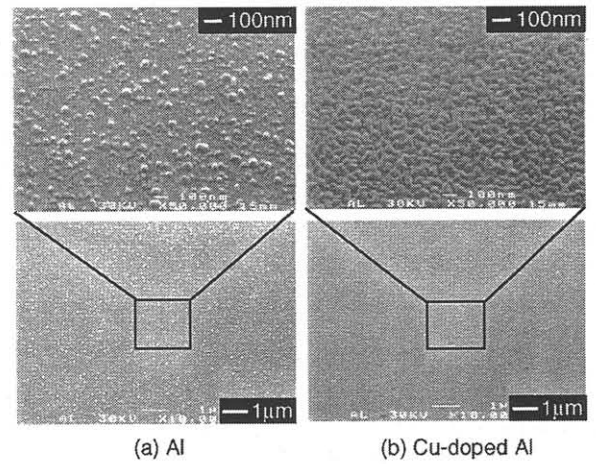


Fig. 5 Surface micrographs of (a) pure-Al and (b) Cu-doped Al. 40sec growth. ( $P_{Total}$ : 1 Torr,  $P_{DMAH}$ : 12mTorr,  $P_{CuTEP}$ : 0.1mTorr,  $T_{dep}$ : 210°C)

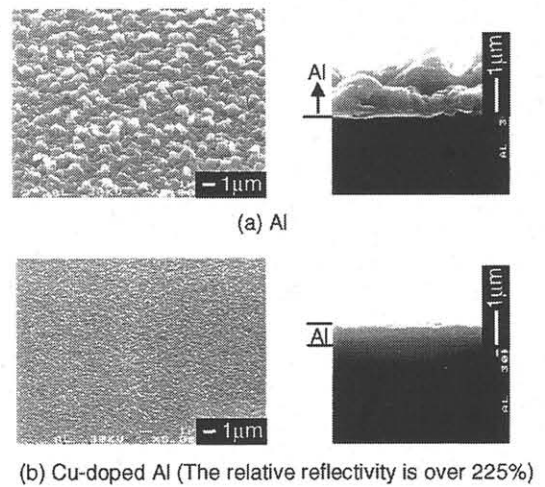


Fig. 6 Surface and cross-sectional micrographs of (a) pure-Al and (b) Cu-doped Al. 20min growth. ( $P_{Total}$ : 1 Torr,  $P_{DMAH}$ : 12mTorr,  $P_{CuTEP}$ : 0.1mTorr,  $T_{dep}$ : 210°C)