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Characterization of Direct-Contact Via Plug Formed by Use of Selective Al-CVD

N. Takeyasu, Y. Kawano, T. Katagiri, E. Kondoh, H. Yamamoto and T. Ohta

LSI Research Center, Kawasaki Steel Co., Ltd.
1, Kawasaki-cho, Chu-oh-ku, Chiba City, Chiba, 260, Japan
Tel: 043-262-2468, Fax: 043-262-2619

Filling via plug with Al directly on underlayer Al interconnection by selective Al-CVD has developed, for the first time. A key solution for the technique is to carry out the whole three processes in a high vacuum cluster tool: surface cleaning by RIE, selective Al-CVD and Al sputtering. The via structure has no interface with hetero-materials perpendicular to the direction of current. Electronic properties were compared with the conventional W-plug: via chain resistance (0.25Ω/via for 0.5μm) was 1/3 of that of W-filled plug, and EM resistance was better than that of W-plug. Our data demonstrated that the process can be effected at lower cost than the blanket W-CVD/etchback process and that the process and structure are very suitable for current and future ULSI.

1. Introduction

Contact/Via filling technique for ULSI/VLSI metallization is very important. Blanket or selective W- and Al-CVD have been studied for this technique. In half-micron devices, the blanket W-CVD/etchback process has been widely used. However,W plug formed by this process has Al/W and W/TiN/Al interfaces at the upper and lower sides of the plug, as shown Figure 1. Such interfaces have potentiality to cause many problems, e.g., increase of resistance, degradation of electromigration (EM) characteristics[1], corrosion because of forming a galvanic couple[2], etc. Futhermore, the existence of TiN adhesion layer causes the degradation of yield. It is afraid that these problems is striking, especially, as LSI's dimension is scale down.

In order to solve these problems, the via structure which has no interface with hetero-materials is needed. Al-CVD is an expected technique to form this structure. In the previous work using selective Al-CVD, Al plug was formed on Ti underlayers capped on the lower Al interconnects[3], because the Al surface is easily oxidized.

In this study, the direct-contact via structure could be formed by a simple process using selective aluminum CVD (Al-CVD) at lower cost, because no additional step such as adhesion layer formation and etchback is needed.

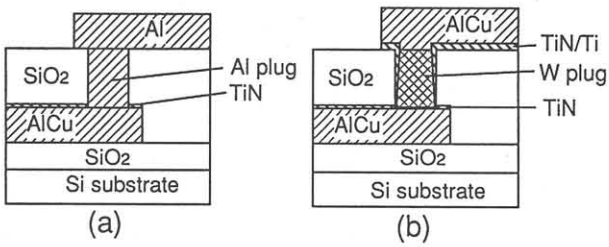

Figure 1. Two different via structures; (a) the direct-contact via plug proposed in this paper, (b) conventional W plug.

2. Experimental

The substrates used in this work were prepared as follows: the 1μm thick PECVD SiO_2 film and the 0.05μm thick TiN anti-reflection layer on the lower Al alloy interconnect were etched by conventional RIE to make via holes with 0.3-0.8μm in diameter. In a cluster tool, RIE cleaning using BCl_3, selective Al-CVD at 210°C using dimethylaluminumhydride (DMAH) as a source gas, and sputter deposition of upper level Al film were made continuously in a same vacuum with the base pressure of less than $1x10^{-5}$Pa (Figure 2).

In order to confirm selective Al-CVD deposition on the pre-cleaned Al , the samples before sputter deposition were observed by SEM. Finally, to evaluate electrical and EM characteristics, the upper

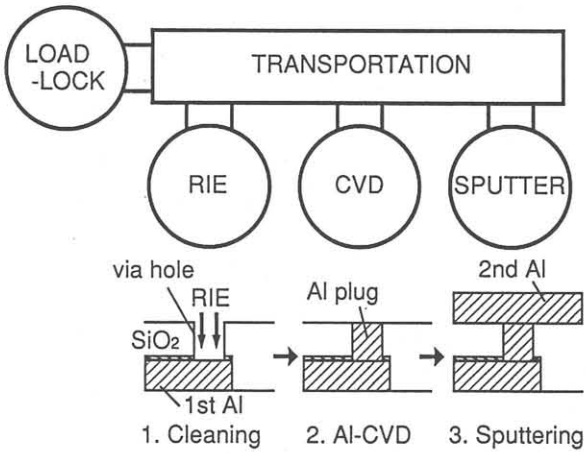

Figure 2. Schematic diagram of the cluster tool used in the work. The process steps to fabricate direct-contact via plug are also shown.

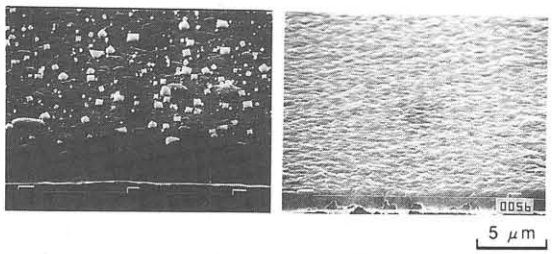

Figure 3. SEM micrographs showing blanket Al-CVD on the Al film substrates without (left) and with (right) in-situ RIE pre-cleaning.

level Al interconnect was patterned and the sample was annealed at 400°C for 60min. Conventional blanket W plug sample was also made for comparison.

3. Results and Discussion

Figure 3 shows the SEM micrographs of the blanket Al-CVD deposition on the Al film substrates. It was found that smooth Al-CVD films can be deposited with in-situ RIE cleaning step, while no continuous film can be deposited without the cleaning step. This indicates that, by the RIE cleaning, the oxidized Al on the Al film substrates was removed and the cleaned Al surface was exposed. Figure 4 shows cross-sectional SEM micrographs of Al plugs in 0.6μm via holes at 3 different deposition times. It was found that the Al plug deposited selectively on Al surface and the selectivity was maintained even after the time when the holes were overfilled (15min). The selectivity was also confirmed by the SEM micrograph of the Al plugs formed in 0.45μm via holes, as shown in Figure 5. The in-situ RIE

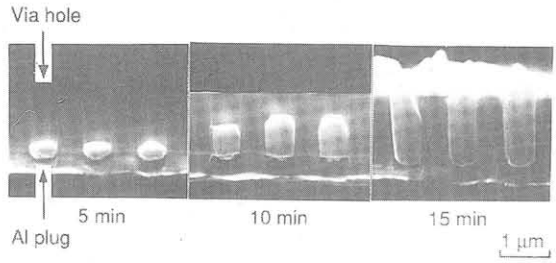

Figure 4. Cross-section SEM micrographs of the Al plugs in 0.6μm via holes at 3 different deposition times.

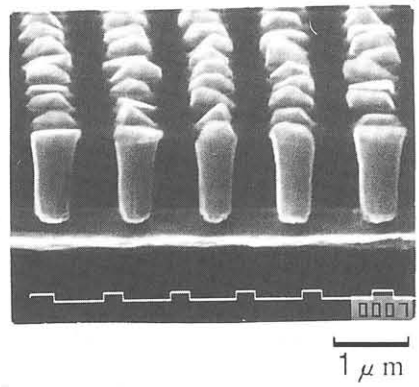

Figure 5. SEM micrograph of the Al plugs formed in 0.45μm via holes.

cleaning was found to be essential to realize selective Al deposition in the via hole. The deposition rate did not change even at the 0.3μm hole. The cross-section TEM observation indicated that the via holes are fully filled with Al plugs and that the plugs contact to both the lower and upper interconnects with no intermediate layers.

Figure 6 shows via chain resistance as a function of via holes size for the direct-contact plug fabricated in this work and W plug as shown Figure 1. The resistance for the direct-contact plug was lower than that for W plug, and the difference of these was larger as the via hole size was smaller. The 0.5μm via chain resistance of the new structure was 0.25Ω/via, which was about 1/3 of that of W plug. This indicates that the difference of the via resistance was partially due to the difference of the resistivity of the plug material, mainly due to the difference of the resistance at the interface, and that the new structure does not have the resistance at the interface. In fact, the via resistance of the Al plug with the Al/Ti/Al interfaces was reported to be higher than that of the present work[3].

The interface resistance; R_i was calculated by decreasing the upper and lower line resistances; R_u and R_l, and the

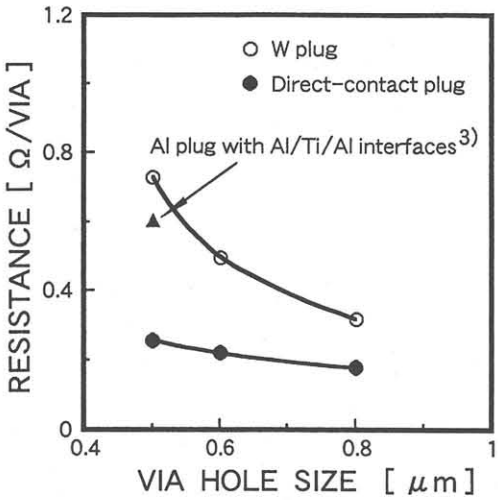

Figure 6. Via chain resistance as a function of via hole size for the direct-contact and W plugs. Also shown is the value for the Al plug with Al/Ti/Al interfaces previously reported[3].

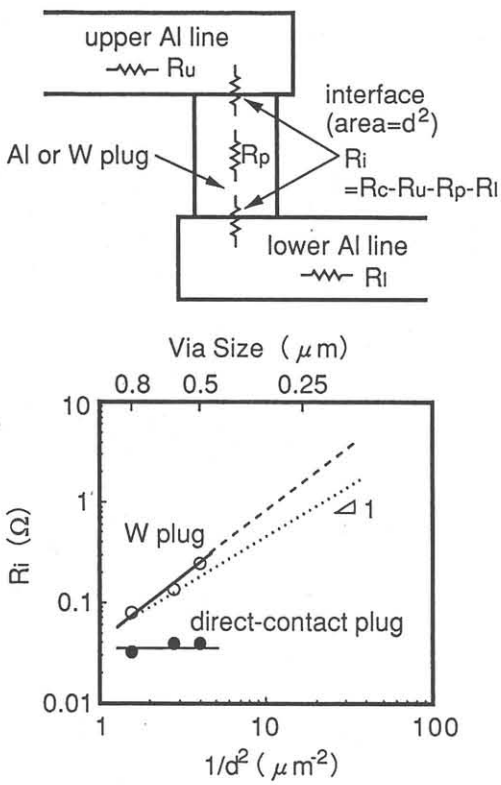

Figure 7. Calculated interface resistance; R_i ($=R_c-R_u-R_p-R_l$) as a function of the reciprocal of via hole area; d^{-2} for the direct-contact and W plugs.

plug resistance; R_p from the via chain resistance; R_c as a function of reciprocal via hole area; d^{-2} for the direct-contact and W plugs, as shown figure 7. Note that, the interface resistance for W plug will increase rapidly with decreasing via size. On the other hand, the interface resistance for the direct-contact plug will be about 0.03Ω, and it is considered to be within calculation error.

Electromigration reliability was tested at 200°C with 1×10^7A/cm^2 stress for Kelvin pattern of the new structure. It showed, in 0.5μm diameter, the change of resistance was not observed even when stressed for more than 300 hours. It was also found that the new structure has somewhat superior EM resistance than that of the W plug. The high reliability of the new structure may be caused by, not only that it has no interface between different materials, but also that it consists of a single crystal. Furthermore, the characteristics may be improved by applying AlCu alloy CVD[4].

4. Conclusions

We succeeded in forming direct-contact via plug by use of in-situ RIE cleaning and selective Al-CVD in a cluster tool. The in-situ RIE cleaning was found to be essential to realize selective Al deposition in the via hole. The new structure was found to have lower via resistance than that of W plug, to have superior EM characteristics, in order to have no interface with hetero-materials. The new process requires less than half the steps of blanket W-CVD/etchback process and can be effected at lower cost. The new structure is considered very suitable to halfmicron and subhalfmicron ULSIs.

Acknowledgement

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