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Al-Reflow Process with a "Cap-Clamp" for Sub-Micron Contact Holes

G. H. Choi, C. S. Park, I. S. Park, S. I. Lee and S. T. Ahn
Y. K. Kim* and R. Reynolds*
Semiconductor R & D Center
Samsung Electronics, KOREA
* Varian Associates, Palo Alto, CA., U. S. A.

The use of "Cap-clamp" has been demonstrated for extending the process margin of Al-reflow process. For evaluating the process window of Al-reflow with and without a "Cap-clamp", the two major factors of in-situ annealing temperature and time were varied between 500 ~ 560°C and 40 ~ 90sec, respectively. Sub-micron contact holes were completely filled by heating at 500°C or higher temperatures with the cap-clamp. The effect of the cap-clamp comes from the improved heating efficiency of the wafer by introducing the hot Ar gas into the cap-clamp, resulting in faster ramp-up as well as more effective heating of the frontside of the wafer. Al-reflow with the cap-clamp gives wider process window than the conventionally used heating method.

Introduction

In order to fill up high-aspect-ratio contact holes and vias with vertical sidewalls in the deep submicron level, various techniques, such as selective- and blanket-W[1),2)], laser reflow[3)], and high temperature sputtering[4)] have been attempted. However, there remain some problems to be solved in terms of manufacturing yield and reliability issues.

In the previous work[5)], we reported contact filling technology utilizing the Al-reflow process, which consists of deposition and in-situ annealing at high temperature in a row. It is generally accepted that Al-reflow process is effective for mass production due to its relative simplicity and low cost-of-ownership. In another study[6)], better resistances of Al-reflow processed films against electro- and stressmigration were reported by measuring the reliability and comparing the characteristics of the films to those of conventional Al films.

In this study, a modified backside Ar conduction heating with the use of the cap-clamp is introduced to improve the wafer heating method. The cap-clamp widens the window of Al-reflow process to lower temperatures and shorter annealing time.

Experimental

The Al-Si-Cu film was deposited to a thickness of 600 nm onto a contact-patterned wafer at temperatures below 100°C in a vacuum-isolated modular sputtering system. The wafer was in-situ annealed in the reflow module without being exposed to air at temperatures between 500 ~ 560°C, in order to induce the migration of Al atoms deposited at low temperature by thermal activation. The annealing time for Al-reflow was varied from 40 to 90 seconds, as well.

Fig. 1 shows the schematics of the reflow module installed to a typical modular sputtering system, in which conduction heating is mainly done by introducing Ar gas from the backside of the wafer. In addition, two kinds of cap-clamps, called type-I and type-II were mounted on the regular clamp to improve the efficiency of wafer heating. The difference between two kinds of cap-clamps was the height; 5 mm and 25 mm for type-I and type-II, respectively. The major parameters for Al-reflow such as temperature and time were evaluated for comparing the filling characteristics of contact holes with those of the conventional heating method.

The wafer temperature was monitored by two different methods; a conventionally used thermocouple connected directly to the heater under the susceptor, and a fiber-optic temperature measurement system. In the latter case, the optical fiber is positioned just under the wafer through the susceptor. The fiber-like sapphire crystal transmits the energy to a remote optical detector, and then converts the radiant energy into an electrical signal. This signal is linearly amplified and digitized, and finally converted into a temperature read-out. With this system, the temperature can be measured from 200 to 4000°C with the accuracy of 2°C. Hence, the real temperature at the backside of the wafer can be monitored more accurately than the conventional method.

Results and Discussion

The purpose of the cap-clamp is to improve the efficiency of the heating of wafer upon Al-reflow, by introducing the hot Ar gas toward the frontside. In the conventionally used method, however, the wafer is only heated from the backside by the heated Ar gas, so that the frontside of the wafer can not be heated efficiently. This type of heating method, therefore, requires higher annealing temperature for Al-reflow, which may not be beneficial for the junction integrity.

Before evaluating the window of Al-reflow process with and without the cap-clamp, the wafer temperature was monitored using the fiber-optic system, to compare the ramp-up speeds of the reflow module with and without the cap-clamp. Fig. 2 shows the temperature curves measured just below the backside of wafers as a function of reflow time. It is clear that the cap-clamp gives faster ramp-up speed than that of conventional heating system at a constant temperature of 560°C. This figure implies that the reflow time required for contact planarization can be shortened at a given temperature. Fig. 3 shows the process window of Al-reflow carried out in the standard reflow module, with the heating time from 40 to 90 seconds at the given temperatures. Complete planarization was obtained over 0.8 μm contact by annealing at temperatures higher than 520°C. Improved filling characteristics at lower temperature than 520°C is observed in Fig. 4, which is the case of using the type-II cap-clamp. Further improvement using the type-I cap-clamp can be seen in Fig. 5, in which all of the contacts are planarized completely with Al except for the condition of 500°C and 40 sec. For the three kinds of wafer heating method, the process margin of Al-reflow is plotted in Fig. 6 with respect to temperature and time. It is clearly shown that the process window for contact planarization can be extended using cap-clamp, especially type-I. The improved process margin of Al-reflow comes mainly from the increased efficiency of the wafer heating, since the hot Ar gas can be introduced toward the frontside of the wafer.

Conclusion

The use of the cap-clamp has been demonstrated in conjunction with Al-reflow process for extending the process margin. As a result, using the cap-clamp, especially type-I gives wider process window than a conventionally used heating method, in which the time and temperature for Al-reflow process can be reduced while the filling characteristics of contact holes are maintained. This is mainly due to the improved heating efficiency of the frontside of the wafer by introducing the heated Ar gas into the the cap-clamp.

References

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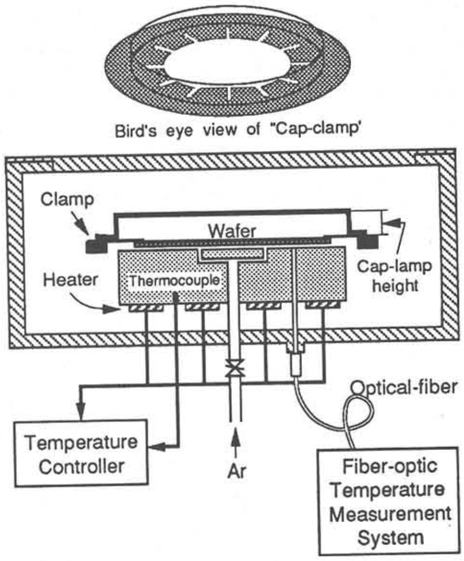

Figure 1. Schematic diagram of Al-reflow module.

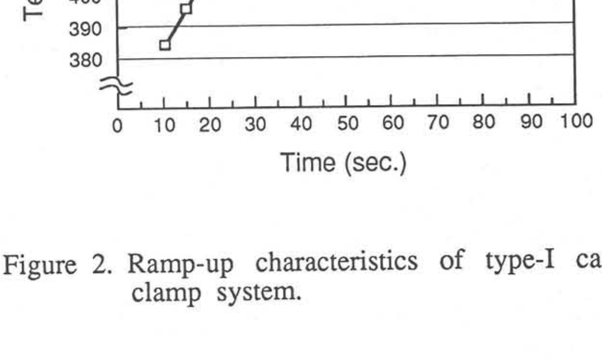

Figure 2. Ramp-up characteristics of type-I cap-clamp system.

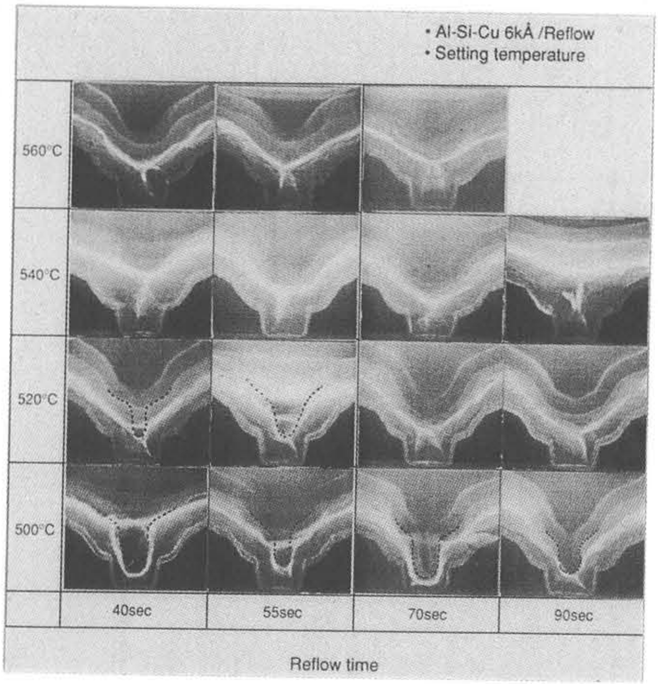

Figure 3. Filling characteristics of contact holes in standard reflow module **without cap-clamp.**

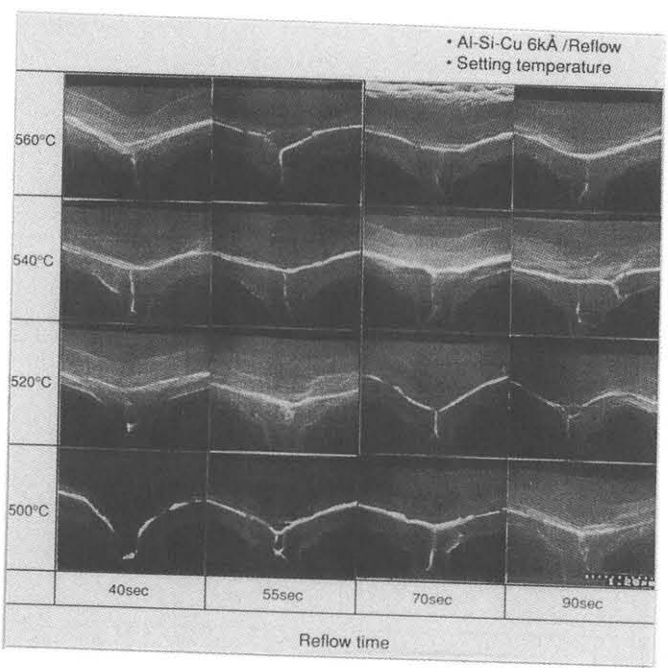

Figure 4. Filling characteristics of contact holes in standard reflow module **with type-II cap-clamp.**

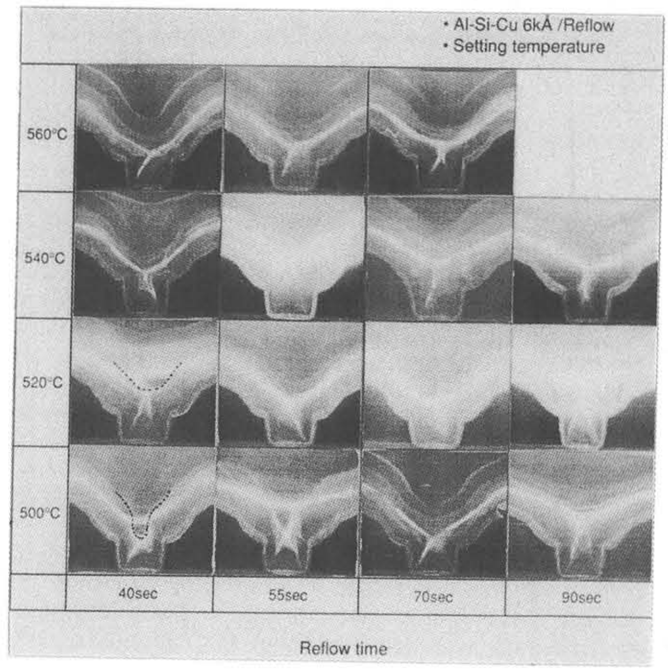

Figure 5. Filling characteristics of contact holes in standard reflow module **with type-I cap-clamp.**

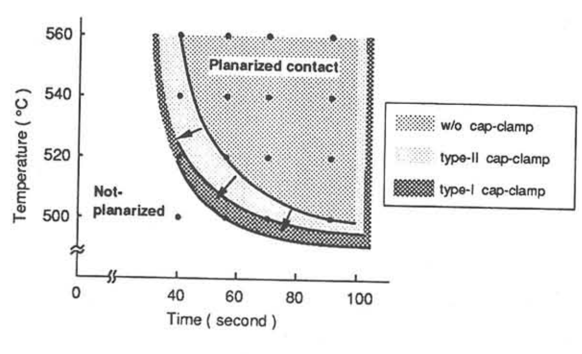

Figure 6. Process margin of Al-reflow with a cap-clamp.