

High Current Reliability of Carbon Nanotube Via Interconnects

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Abstract

We have investigated the high current reliability of carbon nanotube (CNT) via interconnects for future LSI. Our CMP process, which could improve the contact to the upper metal line, had not only lowered via resistance but also effectively improved the current tolerance. In the same way, improvement of the lower metal contact, a TaN barrier layer which was deposited on the bottom of the via hole, also improved durability. Moreover, several improvements of the contact to both the upper and the lower metal line could withstand a high current density of $1.7 \times 10^8 \text{ A/cm}^2$ per tube of a CNT's via.

1. Introduction

With shrinking dimensions in LSI circuits, the resistivity and electromigration (EM) reliability of Cu interconnects deteriorates as the line width decreases. Carbon nanotubes have been studied as candidates of emerging research materials. CNTs exhibit excellent electrical properties, a tolerance of current densities exceeding 10^9 A/cm^2 [1] and a ballistic transport up to several micrometers [2]. Because of these factors, CNT via interconnects are expected to have a large current tolerance and are estimated to have low electrical resistance compared with those of Cu via. In our previous results [3], we reported that the electrical resistances of a CNT via fabricated using CMP decreased about 25% because of the improved contact to the upper metal line.

In this paper, we report the improvements to the high current reliability of CNT via interconnects for future LSI.

2. Experimental

Figure 1 is a schematic cross-sectional structure of a CNT via. We integrated a CNT via with the upper (M2) and the lower (M1) Cu lines. The CNT via was fabricated as follows. A 15 nm TaN barrier layer/5 nm TiN contact layer was deposited by PVD on the surface of M1 Cu in a via hole. Co particles with an average diameter of about 4 nm were deposited on the bottom of the via using a pulsed laser deposition system. CNTs were grown by using a thermal CVD system. The source gas was a mixture of C_2H_2 and Ar at 1 kPa. The growth temperature was 450°C . The CNTs density was $3 \times 10^{11} \text{ tubes/cm}^2$. The CMP process we used was as follows: Spin-on glass (SOG) was coated on the samples in order to hold the CNT bundles during the CMP process. The sample was polished with a conventional IC1000 pad and silica slurry under pressures of about 2 psi. As the M2 Cu line, a 15 nm Ta barrier

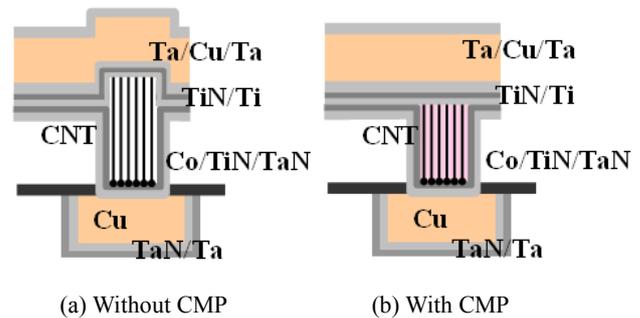


Fig. 1 Schematic cross-section of a CNT via

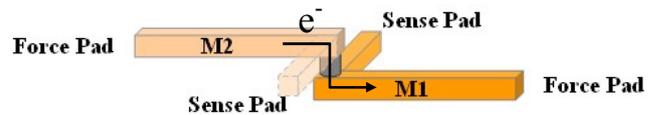


Fig. 2 Schematic diagram of Kelvin pattern for reliability test of a CNT via. The current was applied in the electron downstream direction



Fig. 3 SEM image of top surface of a CNT via after CNT growth process. The CNT via had a diameter of 160 nm. The CNT density was $3 \times 10^{11} \text{ tubes/cm}^2$. There were 60 tubes of CNTs with a diameter of 10 nm in a via.

layer/300 nm Cu/15 nm Ta barrier layer/5 nm TiN/10 nm Ti contact layer was connected to the CNT via by PVD.

Figure 2 is a schematic diagram of the Kelvin pattern for the reliability test of a CNT via. The tested CNT via had a diameter of 160 nm, a length of 275 nm, and there were about 60 tubes with a diameter of 10 nm, as shown in Fig. 3. The test conditions were as follows. The current densities per via ranged from 5×10^6 to $4 \times 10^7 \text{ A/cm}^2$, i.e. the average current densities per CNT ranged from 2.1×10^7 to $1.7 \times 10^8 \text{ A/cm}^2$ in the electron downstream direction at room temperature. Resistance increasing to infinity was taken as the fail criterion.

3. Results and Discussion

Figure 4 shows the cumulative lifetime plots. Plot (A) describes the pre-improvement samples without CMP. Plot (B) shows the TaN-improvement samples, which had a TaN barrier layer deposited on the bottom of the via hole using the other PVD equipment. Plot (C) shows the samples with CMP without TaN-improvement. (B) and (C) had a longer lifetime than (A). In the case of (B), it was considered that the electrical contact of the via-TaN/Cu-line interface was improved. In the case of (C), the electrical contact of M2-metal/CNTs interface was improved. As a result, the current density through a CNT decreased because the number of CNTs contributing to the current flow increased. It was considered that the current density per CNT of (A) was up to several times that of (B) and (C).

Figure 5 shows a cross-sectional TEM image of sample (A) after the reliability test. It seems that CNTs were cut from the surroundings of the via in the first stage because the majority of current passed the surrounding CNT of a via and the outer layer of the CNT, which was easy to connect to the metal line.

Figure 6 shows the lifetime vs. current density plots. (D) had undergone several improvements of electrical contact to both the upper and the lower metal line. (D) was tested under a higher current density from 1×10^7 to 4×10^7 A/cm² per via, i.e. from 4.2×10^7 to 1.7×10^8 A/cm² per CNT. (D) had a much better lifetime than (A), (B), and (C). Furthermore, (D) did not have any failures during the plotted test time. In the case of (D), it was considered that the current density through a CNT dropped substantially to the average current density of each test condition. And also, in the test of (A), (B), and (C), it was considered that the current density per CNT was up to about 10 times the average current density of 2.1×10^7 A/cm².

4. Conclusions

The improvement of the contact to both the upper and the lower metal line, such as the improved performance of the CMP process and the improvement of the TaN barrier layer, results in a high current reliability because the current density per tube decreases.

Acknowledgements

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References

- [1] B. Q. Wei, R. Vajtai, and P. M. Ajayan, Appl. Phys. Lett., 79, 1172 (2001).
- [2] J. Kong, E. Yenilmez, T. W. Tomblor, W. Kim, and H. Dai, Phys. Rev. Lett., 87, 106801(2001).
- [3] M. Nihei, et al., SSDM 140, (2006).

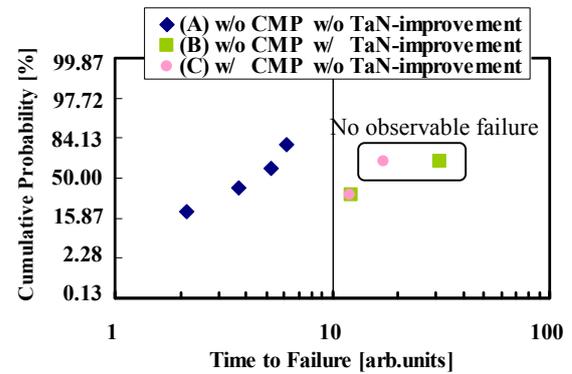


Fig. 4 Cumulative lifetime plots. The current density was 5×10^6 A/cm² per via, i.e. the average current density of 2.1×10^7 A/cm² per CNT.

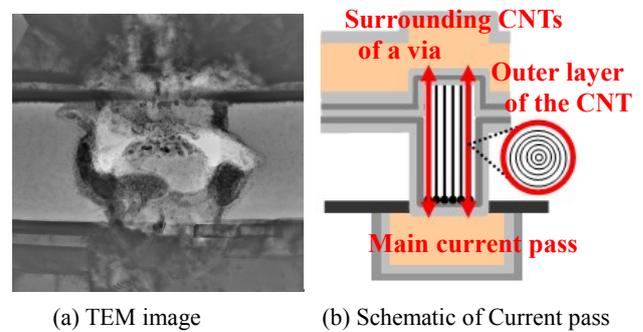


Fig. 5 (a) Cross-sectional TEM image of sample (A) after the reliability test. It seems that CNTs were cut from the surroundings of the via. (b) Schematic of main current pass. The surrounding CNTs of a via and the outer layer of the CNT were easy to connect to the metal line.

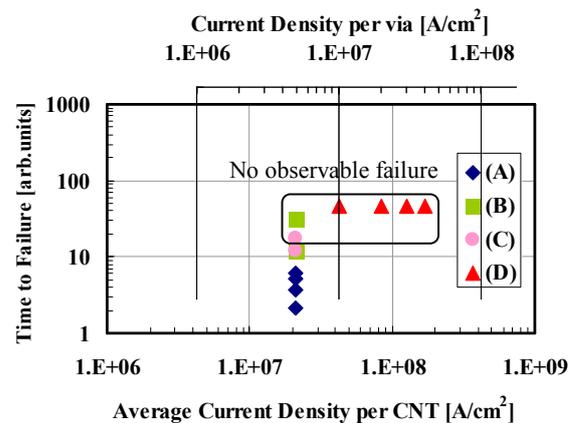


Fig. 6 Lifetime vs. current density plots. Plots of (A), (B), and (C) are equal to those of Fig. 4. Plot (D) shows several improvement samples.