A Study of Tungsten Metallization for the Advanced BEOL Interconnections

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ABSTRACT

In this paper, a study of tungsten metallization in advanced BEOL interconnects is presented. A mature 10 nm process is used for comparison between the tungsten and conventional copper metallization. Wafers were processed together till M1 dual-damascene etch then separated for different metallization. Tungsten metal line of 24 nm width is showing a 1.6X wire resistance comparing to the copper metal line. Comparable opens/shorts yield were obtained on a 0.8 M comb serpentine, Kelvin-via and 4K via chains. Similar physical profile were also achieved. This study has demonstrated the feasibility of replacing the copper by tungsten at BEOL using the conventional tungsten metallization tools and processes. This could be a cost-effective solution for the low-power products.

INTRODUCTION

Tungsten is a refractory metal with high resistance to electromigration and it has good gap fill capability with chemical-vapor deposition (CVD) technology [1-2]. Meanwhile, not only the dry etch of tungsten [3], but the chemical-mechanical polish of Tungsten [4] are both mature processes. Therefore, tungsten metallization has been a simple and reliable high volume manufacturing technique at contact level of the CMOS technology for many years. Unfortunately, due to its high resistivity, tungsten is not a good candidate for the BEOL interconnects. However, due to the surface scattering effect when the metal width is approaching the mean free path of 39 nm of copper, the resistivity of copper is increased dramatically [5]. Also, the gap-fill capability and reliability of copper metallization are all hurdles for the extendibility of copper [6] at the advanced technology node, such as 10 nm node. On the other hand, tungsten has a smaller mean-free path of 19 nm [7], as a result, the resistivity of tungsten will be close to copper at small dimension by many predictions [8-9]. Therefore, there is an interest to understand the feasibility of replacing copper with tungsten at the BEOL of 10 nm node as a cost-effective solution. This could be a significant benefit for the low power products where the interconnect resistance is not a major concern [10]. The metal resistance, via resistance, metal opens/shorts and nest via chain continuity are important criteria for the success of tungsten.

EXPERIMENTAL

In order to demonstrate the feasible of tungsten metallization at the BEOL interconnects, a mature 10 nm process is used as the test vehicle [11] where the mask set is designed for immersion-DUV lithography. This process starts from the tungsten contact level followed by the double patterned V0 and triple patterned M1. Wafers were built to the M1 dual-damascene etch to ensure the same initial metal trench profile, then, followed by the different metallization, respectively, as shown in Fig. 1. Tungsten metallization was conducted by using the conventional tungsten-CVD and tungsten-CMP to fill in the M1 dual-damascene structure. All the tools and processes are the similar to contact. The wire resistance was measured from a 1000 µm long line. A 0.8 M long comb-serpentine pattern was used for the metal opens and shorts measurement. Four point Kelvin-via was used for via resistance measurement. Finally, the continuity of M1-V0-Contact was determined from a 4K nest via chain. Electrical test and cross section were performed to compare the performance of both the copper and tungsten metallization.

RESULTS and DISCUSSION

Wire resistance and via resistance

The wire resistance of tungsten metallization on a 24 nm wide, 1000 µm long line was 1.6X to that of copper metallization as shown in Fig. 2. Via resistance as plotted in Fig. 3 was showing a 1.37X Kelvin-via resistance. Even though the wire resistance of tungsten is 60% higher than that if copper, it is interesting that the difference is smaller for via resistance. This is indicating the resistivity of copper in the confined via hole could be much higher than the prediction.

Metal opens/shorts and Via Chain continuity

As shown in Fig. 4 (a) and (b), the opens and shorts yield of tungsten wires on a 0.8 M comb-serpentine structure was comparable to that of copper. The leakage current of tungsten was one order of magnitude smaller than that of copper.

In addition, Fig. 5 (a) and (b) were showing a good continuity on 4K via-chains. Again, the leakage current of tungsten metallization was better.

This result which implies tungsten metallization could have a benefit on the surface leakage control due to its noble property.

Physical Structure

The TEM micrographs in Fig. 6 (a) and (b) showed the comparison of copper and tungsten via chain profile.
Tungsten wire width was about 1.5 nm larger than the copper wire. On the other hand, Copper metallization blew up via bottom CD quite a lot where the tungsten metallization retained a conventional via bottom profile. This is an indication the damage during the copper metallization.

CONCLUSION

Electromigration and gap-fill capability are challenges for the extendibility of copper metallization at the most advanced technology node. The barrier metal for copper has becoming more and more complicated. As a result, Tungsten is a good candidate for replacing copper with its proven high volume manufacturability and good resistance to electromigration. The trade-off is the high wire resistance of tungsten. However, the resistivity between copper and tungsten is expected to become closer as the dimension shrunk. Therefore, tungsten could be a good option at the BEOL for low-power products which have a higher tolerance to the interconnect resistance.

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REFERENCE


Fig. 3 Via resistance of tungsten versus copper. Tungsten wire resistance is 1.37X higher than that of copper.

Fig. 4 (a) and (b) Comb-serpentine opens and shorts current. The leakage current of tungsten is one order of magnitude smaller than that of copper.

Fig. 5 (a) and (b) 4K via chain opens and shorts current. Tungsten is showing a better control on leakage current other than the copper.

Fig. 6 (a) and (b) TEM cross sectional micrographs show the via chain profile of copper (a) and tungsten (b). Copper metallization blows up the via bottom CD where the tungsten metallization retains a typical via bottom profile.