COMPARISON BETWEEN BERYLLIUM-COPPER AND TUNGSTEN HIGH FREQUENCY AIR COPLANAR PROBES

J.L. CARBONERO [1], G. MORIN [1] and B. CABON [2].

[1] SGS-THOMSON Microelectronics, Central R&D, 850 Rue Jean Monnet, BP 16, 38921 CROLLES Cedex, France.
[2] LEMO/ENSERG/INPG - URA CNRS 833, 23 Avenue des Martyrs, BP 257, 38016 GRENOBLE Cedex, France.

ABSTRACT

High frequency air coplanar probes using tungsten tips are now available for silicon wafer probing with aluminum pads. A comparative study of the beryllium-copper and tungsten behavior is presented in terms of contact resistance values, stability and reproducibility. Finally, tungsten is demonstrated to be the best material for breaking the aluminum oxide over the pad to enable accurate high frequency probing.

INTRODUCTION

On-wafer high frequency measurement is one of the major activities in microwave and radio frequency domain. HF measurements are performed in order to characterize many kinds of devices (transistors, passive elements, complex circuits ...) on different substrates (GaAs, Si ...). New silicon technologies (MOS and BICMOS), which work more and more quickly, are able to play an important role in the high frequency domain. As the size of advanced MOSFET's and BJT's shrinks, very high frequency measurements are required to enable accurate circuit simulation. Accurate measurements are obtained by using efficient calibration methods and de-embedding procedures. In addition, the equipment may have a great influence on result accuracy [1]. Variations of contact resistance is one of the major problems occurring in silicon wafer probing on aluminum pads. High frequency probing has been conducted for many years on dedicated HF substrate where metallization is made of gold. Beryllium-copper probes (also nickel probes) are used intensively and are certainly the best choice. For aluminum pad probing, the situation is very different as the aluminum pad is covered with 50 to 100Å of hard natural aluminum oxide [2]. For the first time, an HF probe supplier - Cascade Microtech - can provide specific HF probes, using tungsten material, for these kinds of applications in an industrial environment [3,4].

Tungsten and beryllium-copper material have been used intensively in DC and low frequency probing and tungsten is claimed to be specialized for non-critical applications in terms of contact resistance [5,6], this is not the case for accurate HF measurements. In this paper, the state of art in DC probing is summarized to obtain pertinent information for HF probing. Contact resistance measurement results on the two kinds of probes are presented to indicate the optimum material for HF probing on aluminum pads.

DC AND LOW FREQUENCY PROBING

Static and low frequency measurements at wafer level have been conducted for many years on silicon wafers with aluminum pads. Beryllium copper (BeCu), tungsten (W) and palladium (Pd) are the most widely used materials for these kinds of probes. Tungsten needles have been used for all non-critical applications where contact resistance values have no significant effect, whilst BeCu tips have been used for high speed and high power applications because they offer the lowest probe contact resistance. In addition, the contact resistance of tungsten probes degrades, that is increases, with use. These facts seem to suggest that tungsten is unsuitable for HF probing.

In fact, tungsten offers several advantages over BeCu. First of all, tungsten is the best material for breaking the aluminum oxide over the probe pad of the wafer. It exhibits an excellent fatigue resistance and produces very consistent contact pressure with repeated use. Moreover, its hardness provides long probe life. The contact resistance of clean tungsten needle is typically about 250 mΩ. Unfortunately, this value may increase and may exceed 5 Ω after several operations [5,6] (50 to 500 Ω has been often observed [6]). According to M. Schell and J. Sanders [5], this is due to the constitution of the tungsten needles, which are formed by compressing strands of tungsten together. They pick up aluminum and aluminum oxide from the probe pad, and aluminum oxide builds up on the probe tips. As a result, the contact resistance gradually increases.

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On the other hand, beryllium copper contact resistance is typically about 200 mΩ and remains stable thanks to a kind of "self cleaning action".

The most important parameter for probing is the contact pressure as this determines how well the electrical contact is established between probe and aluminum pad and how well the probe tip will punch through the aluminum oxide. Obviously, the contact pressure depends on the tip area and the tip force, which is related to the overdrive, the probe shape and the elasticity of the probe material. Contact pressure is much more important for tungsten probes, when considered against similar BeCu probes, due to the stiffness of tungsten being three times greater than that of BeCu.

Figure 1 presents typical variation of the contact resistance with time using clean BeCu and W probe cards on Al pads for long time probing. High values of contact resistance (1 to 15 Ohms), linked to strong unstable behavior with time, were found using BeCu probe cards due to either dirty or old probe cards, or even with new clean probe cards. Suchlike results, concerning W probe cards, were presented in previous publications [7].

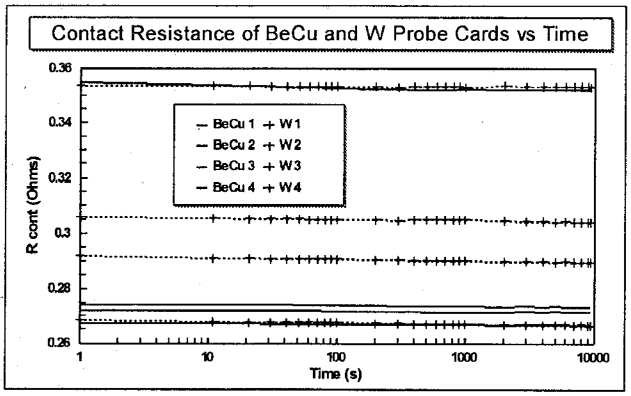

Fig.1 : Contact resistance versus time.

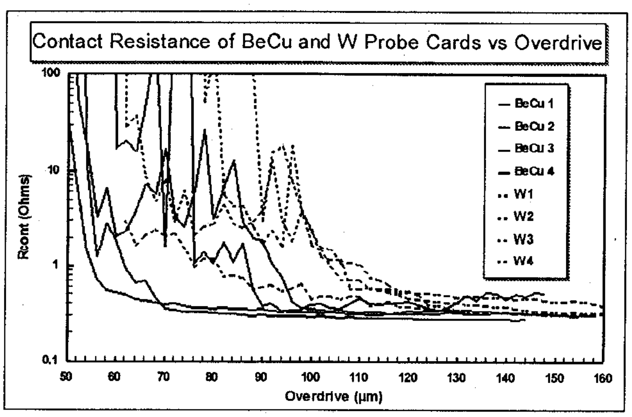

Fig.2 : Contact resistance versus overdrive.

The variation of the contact resistance with overdrive is presented in figure 2. At low overdrive, the resistance is highly unstable due to low penetration of the tips into the dirt and oxide layers above the pad [8].

SPECIFICITY OF HIGH FREQUENCY PROBING

The cross section of the HF air coplanar probe is given in figure 3. The tungsten and BeCu probes are made of the same body and only the air coplanar waveguide tips are replaced with the appropriate material. This material is gold plated to reduce the conductor loss (effects upon contact resistance occur only for the first few probing operations, due to tip wear). The main difference between the HF and DC probes concerns the tungsten material which, in HF probes, is not obtained by compressing strands of tungsten together. Consequently, evolution of contact resistance should remain of the same order for BeCu and tungsten.

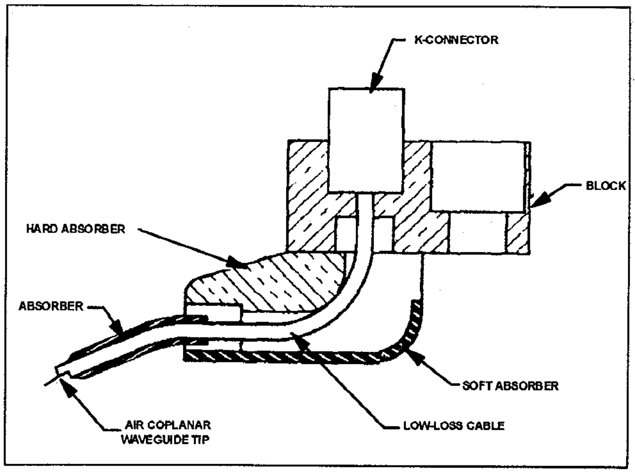

Fig.3 : Cross section of the probe (from [3]).

MEASUREMENT OF CONTACT RESISTANCE

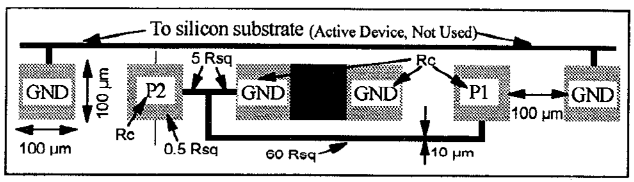

Fig.4 : Pattern used for contact resistance measurements.

The measurements are performed using the pattern depicted in figure 4. Since there is a difference between the resistance measured at port 1 (Rp1) and that measured at port 2 (Rp2), assuming the equality of all contact resistances, the value of contact resistance (Rc) may be extracted from global measurement by solving the linear equations:

RP1 = Rc + 60.5Rsq + (5Rsq + 0.5Rsq + Rc) / 2

RP2 = Rc + 0.5Rsq + 5Rsq + 0.8(5Rsq + 0.5Rsq + Rc)

The contact resistance of beryllium copper and tungsten probes on aluminum pads are given in figure 5. The square resistance (Rsq) of aluminum metallization is also reported to indicate the quality of our extraction procedure. Measurement of this parameter using Kelvin probes indicates 64 mΩ for this technology. The overdrive was of 150 µm for BeCu probes and 100 µm for tungsten probes. These values correspond to the optimum overdrive in order to obtain stable contact resistance for a long time contact. It was observed that BeCu probes do not have enough pressure to punch through the aluminum oxide and slide over the pad surface. Furthermore, aluminum oxidation can occur at the interfaces Al/BeCu and Al/W due to imperfect mechanical contact between the two materials.

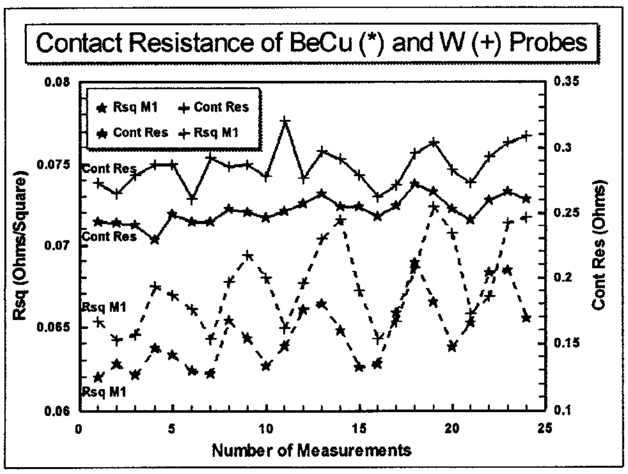

Fig. 5 : Contact resistance versus the number of probing.

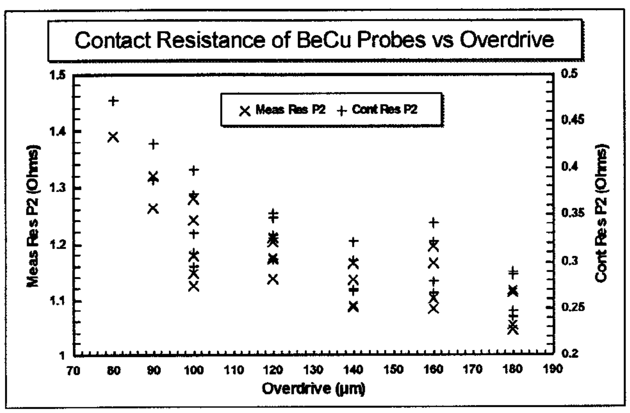

Fig. 6 : Contact resistance (BeCu) versus the overdrive.

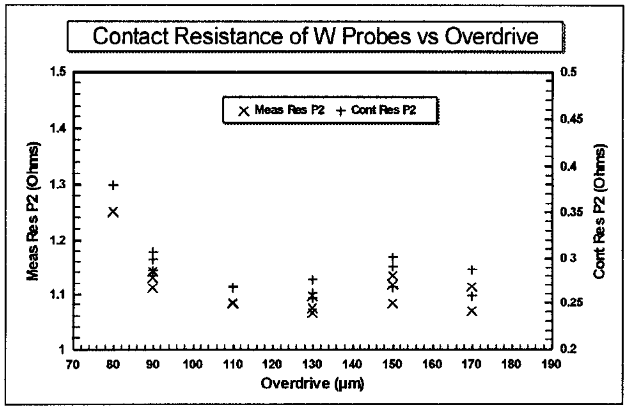

Fig. 7 : Contact resistance (W) versus the overdrive.

Figures 6 and 7 present the contact resistance (and also the total resistance at port 2) versus the overdrive for beryllium copper and tungsten probes respectively. For these measurements, as can be seen in Fig. 2 at low overdrive, the assumption of equality of all contact resistances is no longer valid [8]. The difference between the currently measured resistance and the minimum value at port 2 is corrected to provide an evaluation of the contact resistance.

The increase of the contact resistance at high overdrive is attributed to the fact that the tip surface in contact with the aluminum pad is the place where aluminum oxide builds up due to previous probing. BeCu and W probes exhibit similar behavior with the overdrive. The little difference in favor of W probes (W : 0.3 Ω @ 110 µm ; BeCu : 0.35 Ω @ 140 µm) was found not to be reproducible when making many measurements. Finally, overdrives of 80-90 µm are required to be beyond the "knee" of the curve and contact resistances reach 0.3 Ω for BeCu as well as for W probes. Differences in successive measurements are due to imperfect cleaning of the probes. Soft cleaning methods recommended by the manufacturer are not efficient when probing on Al pads. Hard cleaning methods like those presented by J.K. Logan [9] and N. Nandeau [10], or like the one inside the prober (ceramic wafer) were too hard to be done many times with HF probes. In order to obtain sufficiently small contact resistance, a semi-hard method was used which consists of increasing by 10 to 20 µm the overdrive before breaking the contact. Another method involves moving the probes on the ceramic surface of the calibration substrate while gently increasing the overdrive. Results are quite good, but this method requires calibration substrate loading which is very time-consuming. Returning to our own method, not only the reproducibility was improved, but also the time of good probing (5 times longer). The criterion of good probing time is defined as the time while the total resistance variation remains less than 0.01 Ω (i.e. : less than about 2% of contact resistance value).

Averaging of ten measurements at each overdrive indicates a better behavior of the W probes (Fig. 8).

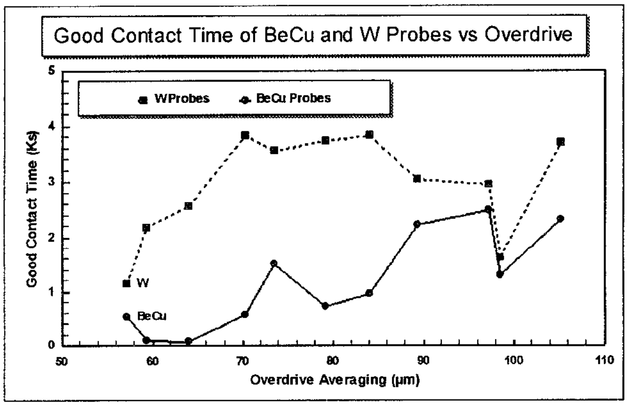

Fig. 8 : Time of good probing.

Finally, the contact resistance of the two probes on gold pads is presented in figure 9 to indicate the difficulty of probing on our Al pads.

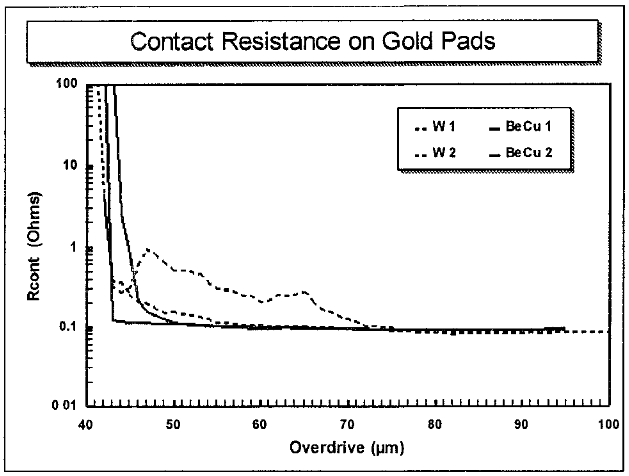

Fig. 9 : Contact resistance (gold) versus the overdrive.

CONCLUSION

An experimental study of beryllium copper and tungsten probes designed for high frequency measurement has been performed on the range of DC electrical contact quality. Tungsten material has been found to be the best tip material for HF probing wafers with aluminum pads covered with aluminum oxide.

The contact resistance of tungsten probes is not much higher than beryllium copper and lower overdrives are sufficient for tungsten probes. The life time of beryllium copper probes, which is shorter than that of tungsten probes, will be reduced by the use of the large overdrive to make good contact and by periodic cleaning of the tips where aluminum oxide builds up.

Long time probing can only be achieved with tungsten probes which offer sufficient contact pressure, but contact resistance evolution with repeated use seems to be a little more important than for BeCu probes and a shorter period between cleaning may be required.

ACKNOWLEDGMENTS

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