Probe card considerations when migrating to new testers

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Introduction

For on-wafer automatic parametric testers, the probe card is the interface between the test head and the device pads on the wafer, so it is key to achieving a successful electrical measurement. The probe cards specified by each of the two dominant parametric tester companies, Agilent and Keithley Instruments, are incompatible with the other's testers. Therefore, when fabs change to a new tester type, such as from an Agilent 4000 Series tester to a Keithley S600 Series tester, they must also migrate to new probe card types.

To ensure good (i.e., correlated) parametric tests, a minimal, repeatable, and reliable pin-to-pad contact resistance is a necessary prerequisite. Test system specifiers must select a suitable probe card to fulfill these requirements. This White Paper addresses two major considerations: 1) how to select and specify a suitable probe card, and 2) how to use the probe card properly. Many measurement results are presented. For the sake of simplicity, we will assume that the new tester will be used to probe the same wafer types with the same tests as the old one was.

Probe card selection

Obviously, the new card's probe pin count, pad pitch, leakage current, test temperature, and frequency limit specifications should be the same as those of the previous probe card. In addition to these basic aspects, the following list of parameters should be considered. All the listed parameters affect contact resistance, current handling capability, and bond pad scrub characteristics. Card

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specifiers should specify the same parameters for the new card as the old probe card to ensure proper correlation of old and new tester results.

1. *Needle material.* The needle metallurgy must be compatible with the device pad metallurgy. Is long needle life more desirable than lower contact resistance? Is probe pad damage an issue with multiple probing touchdowns at a site (i.e., is a softer needle material required for a given prober Z over-drive)? For example, rhenium-tungsten (ReW) material is hard and durable, but its contact resistance is higher than beryllium-copper (BeCu), which is soft and wears out more easily but has lower contact resistance. It may be advisable to contact probe card manufacturers for expert advice on needle and pad metallurgy.
2. *Tip shape.* Flat or semi-radius (hemispherical)? Flat needle tips are low cost and offer good performance. The semi-radius tip is a little more expensive, but it provides better performance in terms of contact resistance and pad damage.
3. *Tip diameter.* What dimension? Larger diameter tips offer better contact resistance, but have more difficulty in breaking through pad oxide. Conversely, it's easier for smaller tip diameters to break through pad oxide, but they have poorer contact resistance. Also, the larger the tip diameter, the more difficult it becomes to keep the tip completely within the (steadily shrinking) pad area as the needle scrubs the pad surface. (This is a requirement for maintaining measurement repeatability, as well as to preventing any possible device damage.)
4. *Alignment accuracy.* This measures the distance of the probe tip at over-drive with respect to the center of the bond pad.
5. *Planarity.* This parameter defines the difference in vertical distance between the highest and the lowest probe tips in the Z dimension. Planarity is the most important needle placement parameter.
6. *Over-drive.* The wafer prober pushes the wafer up against the probe tips at a test site. The initial probe-pad contact Z height is the zero level, and the prober then moves higher by a specified distance called over-drive. This action scrubs the needles on the probe pad, breaking through pad oxide and ensuring good contact between the needle tip and the device pad. Probe card vendors' specification sheets define the over-drive used to qualify the probe card. Vendors also refer to this term as overtravel.

7. *Probe-force rate*. This parameter is also called “probe-spring rate” or “probe-force” for short. This is the rate of downward tip force per unit over-drive distance, defined as grams/mil of over-drive. If the probe-force rate is too low, it needs larger over-drive to obtain a good contact; however, this increases the risk of the probe tip sliding out of the bond pad laterally. On the other hand, if probe-force rate is too high, it can damage the bond pad and increase the tip’s wearout. Needle material and construction directly affect the spring constant of the needle, and therefore the probe-force rate as well.

Probe card application

Contact resistance behavior

To speed and simplify the tester migration process, probe card specifiers should understand the basics of probe card contact. This section discusses how contact resistance works and what an acceptable contact condition is. The following equation describes the relationship between probe-force and over-drive. Probe-force is linearly proportional to over-drive in normal range and it follows Hooke’s Law.

$$F_{probe} = K \times D$$

where F_{probe} = probe-force

K = spring constant (probe-force rate)

D = over-drive

Because probe force dominates contact resistance, then according to above equation, probe-force rate and over-drive mainly determine contact resistance. Additionally, needle material, tip shape, tip diameter, and bond pad features also affect contact resistance. ***Figure 1*** illustrates a theoretical curve of contact resistance versus over-drive. In the first region in ***Figure 1***, the probe tips first land on the bond pad. Initial contact occurs after the probe tips touch the bond pad surface and contact the oxide layer on the pad metal. Contact resistance is high in this region. In the second region, contact resistance decreases dramatically while probe-force increases and the needle tip starts scrubbing through the pad oxide. Contact resistance decreases linearly in region 3 as the needle tip reaches bare new metal, and in region 4, contact resistance stays constant at a minimum level even though probe-force increases. (In reality, at some point excessive over-drive in region 4 will result in pad damage and/or the tip sliding off the pad, and the contact resistance will increase.) From the curve, we can see that excessive over-drive is not necessary for good contact resistance. More than that, excessive over-drive increases probe tip lateral slide, makes for poor alignment, or can cause a failure of alignment in the worst case. It can also damage the bond pad and increase tip wear-out rate. Therefore, excessive over-drive is harmful and should be avoided.

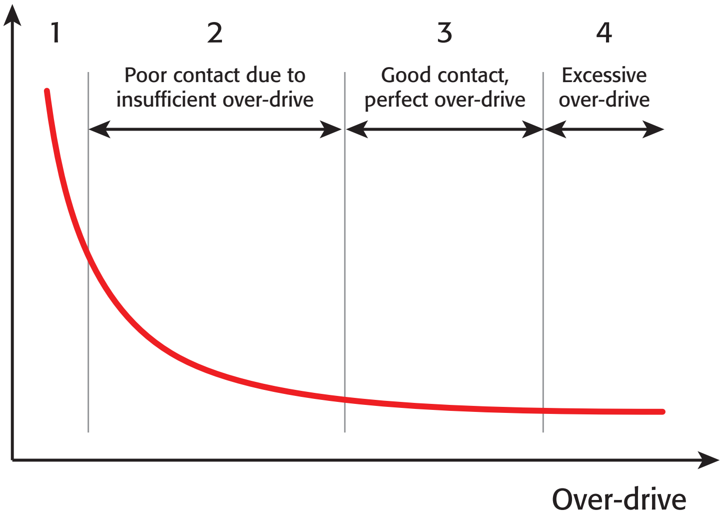


Figure 1. Relationship between contact resistance and over-drive

Figure 2 is an actual measured curve of contact resistance versus over-drive. ***Figure 3*** is the test pad layout diagram. Twelve bond pads were shorted to adjacent pads by a metal line. In order to evaluate the contact resistance, resistance between adjacent pads was measured while increasing over-drive in discrete steps. For example, at each over-drive point in the R12 graph line, resistance between pad 1 and pad 2 is measured and returned as R12 correspondingly, and plotted in ***Figure*** 2.

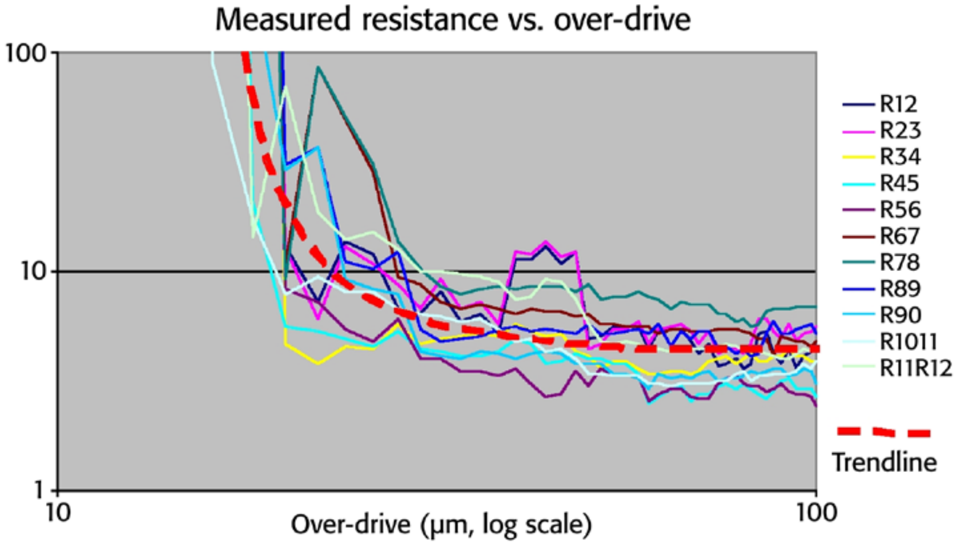


Figure 2. Measured contact resistance versus over-drive

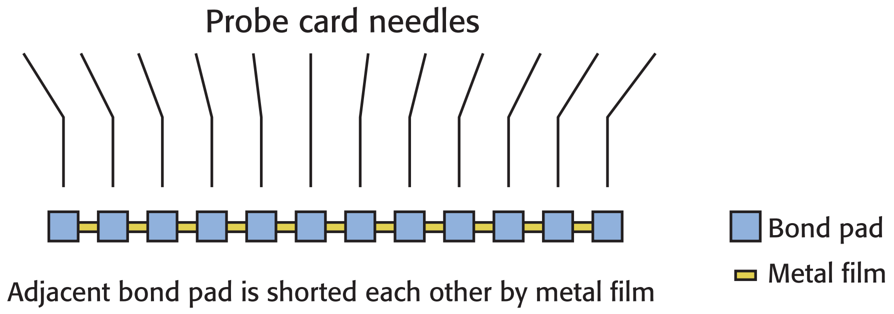


Figure 3. Contact resistance test diagram

The importance of planarity

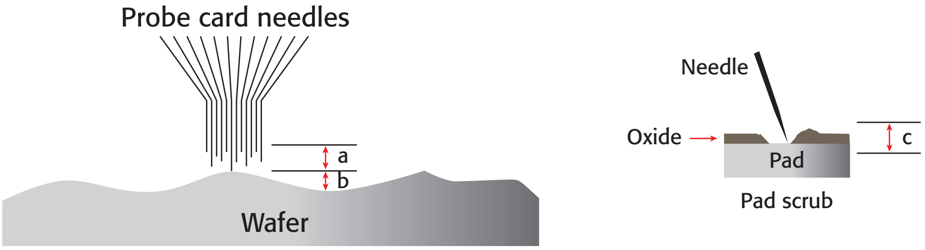
Two aspects of planarity impact contact resistance. Tip planarity is the difference in vertical height between the highest and the lowest probe tips in the Z dimension. It varies from card to card, and vendor to vendor, but it is usually within the 0.5–0.7 mil or 12–18nm range. The second, wafer planarity, is the distance between the highest point and the lowest point of wafer surface in the Z dimension. Usually, wafer planarity is within 0.1–0.4 mil or 2–10nm range.

A native oxide layer forms on the top surface of aluminum bond pads. On gold or other non-oxidizing pad materials, a contamination layer typically adheres to the bond pad surface. Over-drive causes the needle tip to scrub through the oxide (or contamination) layer mechanically, ensuring a good pin-to-pad contact. Wafer and tip planarity together determine when the probe needles first make contact with the pad surface at a test site (region 1 of ***Figure 1***). Wide variations in that first Z contact point can drastically affect the contact resistance, as over-drive must allow the needle tips to scrub through the pad oxide or contamination. The amount of over-drive required for scrubbing depends on tip features and pad surface features. Normally, it is determined through experimentation in a few steps. Usually, the initial over-drive is set from 10µm to 20µm, followed by a verification step. If this amount of over-drive is insufficient, then an increment is added, followed by another verification step. This cycle should be repeated until good contact is achieved.

This paragraph introduces a practical method of determining the amount of over-drive needed to ensure the needles are within the good contact resistance region. The sum of tip planarity, wafer planarity, and pad scrub establishes the lower limit of over-drive. The upper over-drive limit is governed by the excessive over-drive region of the contact resistance curve. To reveal the over-drive value required through experimentation, just repeat the tests described in ***Figures 2*** and ***3***. Start from no contact, increase over-drive gradually while monitoring the measured contact resistance between pins, and then stop at the excessive contact region where resistance changes flatten out at some minimum value. Finally, plot the resulting curve and find the excessive over-drive region. The over-drive amount corresponding to excessive over-drive sets the over-drive upper limit. The perfect contact region is found between the over-drive lower limit and the upper limit. (See the formula that follows.) ***Figure 4*** illustrates the effects of planarity and pad scrub.

Perfect contact region formula:

(tip planarity + wafer planarity + pad scrub) < Correct over-drive < Excessive over-drive start point



Good contact condition:
Excessive > Over Drive > (a + b + c)
where:
a = tip planarity (12~18μm)
b = wafer planarity (2~10μm)
c = pad scrub (10~20μm)

Figure 4. Planarity and pad scrub

The graph in ***Figure 5*** plots the measured contact resistance versus pin position and reflects the importance of tip planarity. From the blue line (square marker) in ***Figure 5***, we can see that four pairs of pins contact well with their pads because their contact resistance is less than 3.2Ω. Others do not. We can see that pin-pair 2–3, represented by R23, has the highest contact resistance at 6.25Ω. We can also see that pin-pair 6–7 makes the best contact because R67 has the lowest resistance at 2.55Ω. If over-drive is insufficient, contact resistance uniformity across pin positions is poor. Tip pin planarity is a major contributor to this uniformity. After increasing over-drive by an additional 15μm, pin-pair contact resistance was measured again, producing the results described by the pink line (triangle marker) in ***Figure 5***. All pins contacted well with the pad because all contact resistance was less than 3.2Ω. Accordingly, we can conclude that:

1. Even when a few pins have good contact with the pad, it does not guarantee others are well contacted if the over-drive is insufficient.
2. Sufficient over-drive can resolve poor contact due to poor tip planarity, within limits. If over-drive is too large, tips slide laterally out of the pad contact area, which can result in contact failure and possible tip or wafer damage. Lateral slide can be significant,

especially in high temperature (>100°C) testing. Therefore, select special high temperature probe cards for high temperature testing applications.

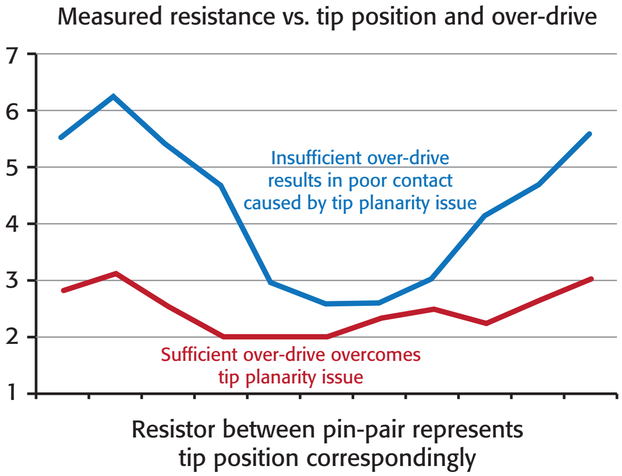


Figure 5. Measured resistance versus tip position

Contact resistance uniformity across wafer

The preceding paragraph discusses contact resistance uniformity across pin positions within a single die only. ***Figure 6*** shows contact resistance uniformity both within one die and across the full wafer range. Again, insufficient over-drive results in poor contact uniformity across the wafer, but sufficient over-drive ensures all pins are well contacted with pads across the full wafer range. The family of curves with 100µm over-drive is a successful test example in full wafer range.

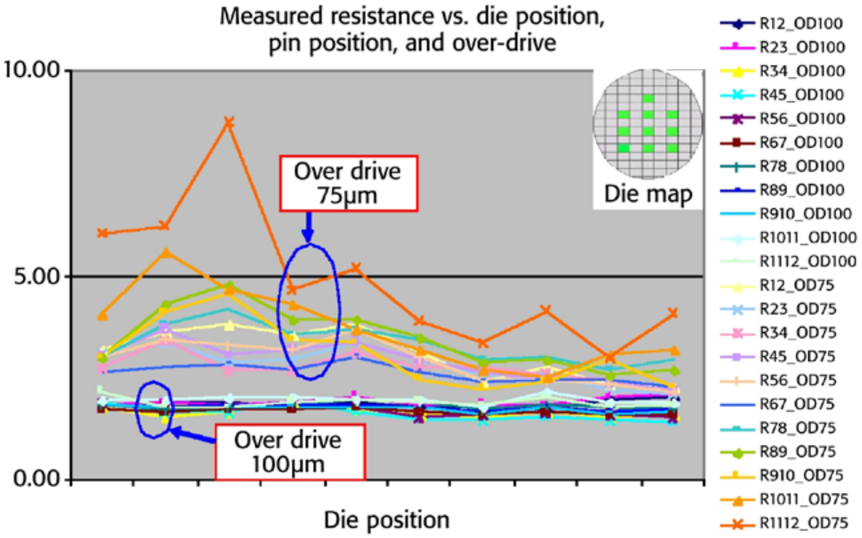


Figure 6. Measured resistance across full wafer

Summary

New probe card selection and application issues are inevitable when migrating to a new tester. This White Paper discusses how to select a suitable probe card and how to use it properly. Needle material, tip shape, tip diameter, alignment accuracy, planarity, over-drive, and probe-force rate should be all carefully considered. The relationship between contact resistance and over-drive is discussed thoroughly, supported by actual measurement data. Poor tip planarity results in poor contact, but it can be overcome by over-drive if the tip planarity is not too large. Although sufficient over-drive is necessary, excessive over-drive is harmful. A practical method to determine the perfect contact region (and therefore, the correct over-drive value) is introduced. Finally, a successful test example across full wafer range is presented. These considerations can help the fabs shorten tester migration time and reduce costs by avoiding expensive and time-consuming experimentation with card parameters and test conditions.

Reference

[1] "Probe Card Tutorial," Otto Weeden, Keithley Instruments, Inc.

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