BASICS OF THERMAL STABILITY IN WLR TESTING

Application Note

Abstract

This application note addresses the basics of thermal instability* in Wafer Level Reliability (WLR) testing. Thermal instability is defined and its causes are identified. Proper test system setup is discussed. Micromanipulator products are recommended which help the user overcome thermal instability issues in WLR testing.

Introduction

WLR tests are becoming more and more crucial in the overall device reliability evaluation of semiconductor products. The best practice is to test devices while still in wafer form. This allows for yield and defect problems to be identified early on before the time consuming and costly packaging processes take place. Additionally, process problems are resolved more quickly resulting in fewer defective wafers, and thus fewer dollars are wasted.

Generally, WLR tests require extended test times and non-ambient temperatures to accelerate failures. While most WLR tests such as TDDB, NBTI/PBTI and Electromigration require above ambient test temperatures, Hot Carrier Injection (HCI) sometimes requires colder than ambient test conditions.

Whichever the case, thermal effects on probe contact need to be minimized. This can be done through an understanding of the causes of thermal instability, proper setup of WLR test stations, and using probe stations and accessories designed to minimize the effects of thermal instability.

Thermal Instability Defined*

The term "Thermal Instability" as it pertains to WLR testing and the discussion of this application note is defined by the following statement:

"Thermal instability is the unintended movement of analytical probe station components, accessories, and/or target wafers as a result of variation in temperature. Thermal Instability is relative to the physical positions of the station, manipulators, probe holders, probe tips and device under test (DUT) at a selected reference time where initial expansion of the station, manipulators, probe holders, probe tips and test sample due to thermal ramp-up has ceased."

Thermal Instability Causes

Whenever change of environmental conditions is required for device testing, the user needs to anticipate the effects of this change within the context of the test environment and relative to the hardware used. The amount of thermal expansion in solids is based upon a material's Thermal Coefficient of Expansion (TCE). Thus, whenever two dissimilar materials are simultaneously subjected to a change in temperature their physical dimensions and relative positioning will change.

In the case of WLR testing the two dissimilar materials of interest are probe tips and target wafers. Each material will expand at different rates and possibly different directions.

For example, the TCE of Tungsten, a typical probe material, is 4.5 X 10-6 mm/mm/ºC while Silicon Dioxide (SiO2) has a TCE of 0.5 X 10-6 mm/mm/ºC. In this example, the probe would expand nine times faster than the target material. Additionally, the shapes of materials play a role in how a material physically expands. A block of a material would expand differently than would a curved probe of the same material. Furthermore, the movement of a material may also be affected by the growth or contraction of some other material in contact with it.

For instance, a wafer may grow to some small degree in the "Z" direction, but it also could be pushed up into the "Z" direction by the supporting chuck underneath the wafer. Needless to say, predicting how a heated probe and target material duo would behave in their relative positioning can be difficult.

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Beyond probe tips and test wafers, thermal expansion can also occur in your probe station and test accessories. Probe stations may be viewed as large pieces of interconnected metal. One might not think of, or simply dismiss, the physical variances that can arise in these large mechanical systems when they are subjected to varying temperatures.

In fact, unless they are properly designed, thermal effects are quite prevalent within probe stations. Some key components that can contribute to thermal instability are the manipulators, the probe holders, the stage/chuck assembly and the platen. The design and method of use of each of these will determine whether or not the wafer sample or the probe tip move after the tip is brought in contact with the test pad.

Proper Setup to Avoid Thermal Instability

Successful WLR testing requires many hours of uninterrupted data collection. Uniform electrical contact must be maintained in order to collect meaningful data. Thus the probe should not lift off of or slide on the test pad. What can be done in the test setup to help prevent this from happening?

The best strategy is to allow the entire test setup to rest or "soak" at the desired test temperature before initiating any tests. Before making contact between probe tips and test wafers, it is advised that the entire test setup be ramped to the test temperature as a group. This will allow all components to reach the test temperature at the same time. During this operation, the probe tips should be positioned just above the test wafer where they can adjust to the heat radiated from the wafer and underlying chuck.
After the test setup has reached the desired test temperature it is important to allow the test setup to "soak" at the test temperature for a period of time. This technique will allow the test setup to come to thermal equilibrium and reach a static physical position. The amount of time necessary for a test setup to reach thermal equilibrium will vary based upon the design of the equipment used.

Once thermal equilibrium has been reached the probe tips and test wafer can be brought into contact. This allows thermal expansion to occur without interfering with test results. After contact has been made, the test setup should be soaked for an additional period of time. During this secondary soaking period, the probe tips will complete their settling and reach thermal equilibrium with the rest of the test setup.

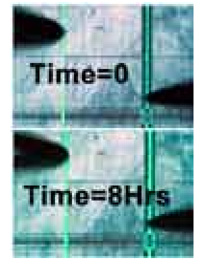

Figure 1

The user can expect the probe tips to show some visible movement during this process. Once the probe tips have settled into a fixed position, testing can begin. Figure 1 demonstrates stable probe tips (in X-Y direction). An example of stable probe contact (in Z direction) based on contact resistance, is shown in Figure 2.

Another key strategy in proper test setup is to use overdrive when positioning measurement probes. The use of overdrive provides some assurance that thermal expansion/contraction will not lift a probe from the contact pad. It is important to remember that a probe need not lift completely off a contact pad in order to interfere with a measurement.
If a probe lifts only partially, an element of random noise may be introduced into test data due to variations in contact resistance. Using proper overdrive will decrease variations in contact resistance.

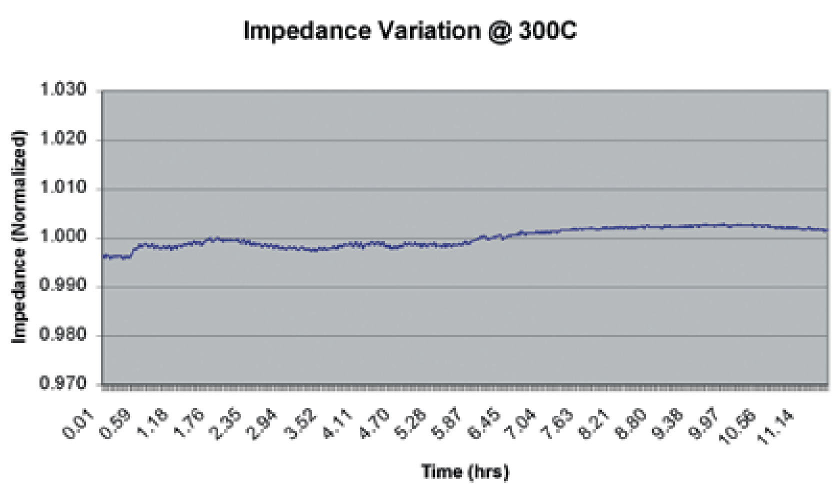

Figure 2
Stable probe contact

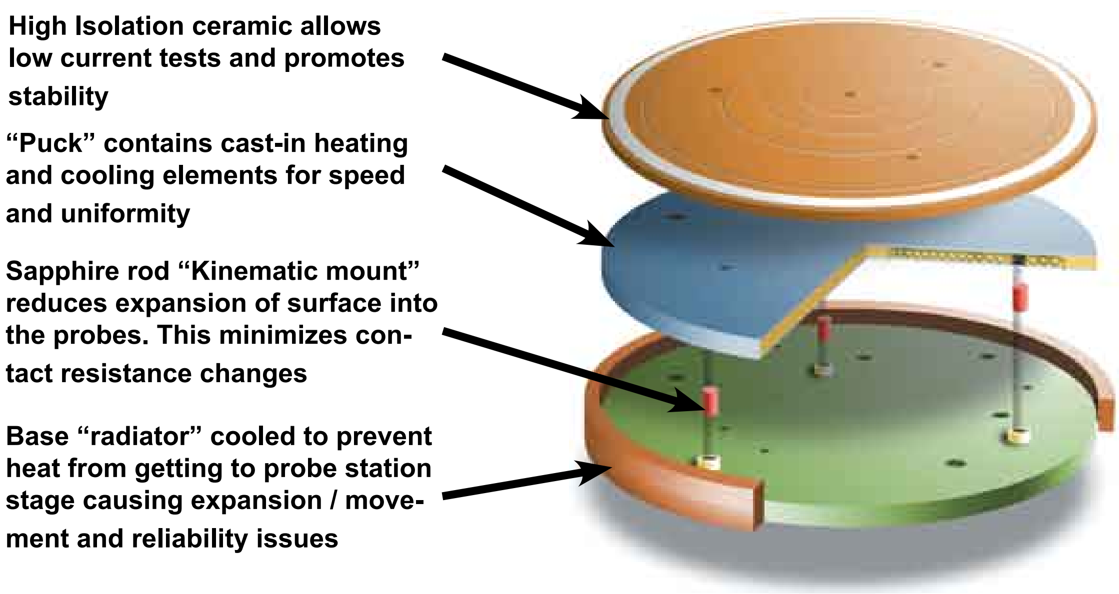

Figure 3
A Thermal Chuck dissected

Proper probe station design can minimize the impact of thermal effects on measurements. First, consider the design of the thermal chuck. Typical commercially available thermal chucks are specified to expand up to 400µm in the "Z" direction. This amount of instability is clearly unacceptable for WLR applications.

A good chuck design is one where motion in all directions is anticipated, minimized, and limited. Micromanipulator's H1000 chuck accomplishes this through the following:

First use of kinematic mounts reduces expansion of the chuck into the probes by mounting the chuck surface on supports which have very low coefficients of thermal expansion. These supports are recessed into the chuck so Z expansion is away from the probes.

Second, a chuck's surface material should have a low coefficient of thermal expansion to reduce movement of the chuck under the test wafer.

Third, the chuck is equipped with an integrated cooling shield. This shield is designed to block heat transfer from the chuck to the station stage assembly. By blocking heat transfer from the chuck to the station stage assembly, thermal expansion of the mechanism holding the chuck will be minimized resulting in a more stable system.

An example of a properly designed thermal chuck where Z expansion is limited to 50µm over a 300°C range can be found in figure 3.

Another way to minimize the impacts of thermal effects is to select materials for probe holders which have low coefficients of thermal expansion.

Remember that after a chuck is initially heated to a test temperature it will be periodically heated in order to maintain the desired test temperature. This will produce cycles of radiated heat above the chuck. These slight variations in temperature will affect all devices on or around the chuck. For this reason, individual probe holders, multiple tip wedge cards, and probe cards need to be made of materials which are thermally stable.

Lastly, in any probe station where the stage and platen are closely situated it is important to have a cooled platen. Without a cooled platen, heat radiated from the chuck will increase the temperature of the platen. The change in temperature will be variable, depending on the location of the chuck. This change in platen temperature could force the platen to expand and thus move any attached manipulators or probe card holders.

Micromanipulator Products for WLR Testing

Probe Stations

The probe stations best suited for WLR testing and minimized thermal instability are the 9000 series probe stations and the 2200-WLR probe station. While the 2200-WLR station is a more economical solution, both stations feature 300mm capability, digitally controlled thermal chucks, and optional environmental control enclosures. All are available with optional cooled platen and platen shielding hardware. See figures 4 and 5.

Figure 4
9000 Series Probe Station shown with platen shielding hardware inside an LTE

Thermal Chucks

The H1000 chuck design is shown in figure 3. It features a radiator style cooling system to protect station/stage assemblies, kinematic mounts to reduce expansion, and a high isolation ceramic surface that has a best in class flatness specification.

Figure 5
A 2200-WLR Probe Station

Discrete Probe Holders with Replaceable Tips

The 79-8000-HCT-03 Triaxial Ceramic probe holder (Figure 6) is suitable for WLR measurements at above ambient temperatures. This probe holder incorporates a ceramic shaft that minimizes expansion effects. Additionally, it uses triaxial cabling that allows for low current measurements.

Probe tips should be chosen based upon factors such as type of measurement and test pad size. Micromanipulator offers a large selection of probe tips to fit various WLR testing needs. Suitable probe tips, numbered from least compliant to most compliant are:

1. 7B
2. 7X
3. 7C
4. 7F
5. 7F-C
6. 7S

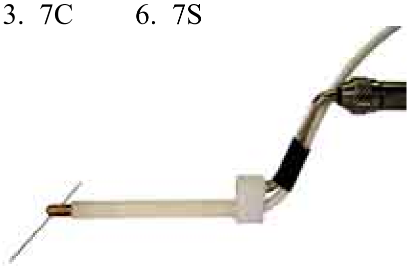

Figure 6
79-8000-HCT-03 Ceramic Probe Holder

Summary

In the course of WLR testing non-ambient temperatures will be used. The challenge for the test engineer will be to collect the best data as quickly as possible. This can be done by:

- understanding how thermal instability impacts a test setup
- knowing the causes and identifying the likely sources of thermal instability
- using probing equipment that is designed to minimize the effects of thermal instability to proactively counteract thermal instability

Lastly, use a consistent set up procedure designed to minimize the effects of thermal expansion from a test station.