Hot Stage Probing Techniques

Application Note

Abstract

When using a hot stage for elevated temperature probing or CV measurement, there will be movement of a device under the probe and the probe point due to thermal expansion. This uncontrolled movement may be enough to cause the probe to slide or jump off its contact. On a six or eight-inch wafer, the expansion can result in a movement of up to one mil at any location, in some unpredictable direction, for every 100° C temperature change.

This Application Note discusses the causes and effects of this problem and offers an equipment solution.

The Key

A high compliance probe point, like our model 7F, will follow a target device as it moves in the X,Y,Z axes. The 7F probe has a very fine wire tip that flexes. When using it with a small amount of flexure on the tip and at a near vertical angle of about 80° ± 5°, it is steep enough for this application, while it remains visible under a microscope.

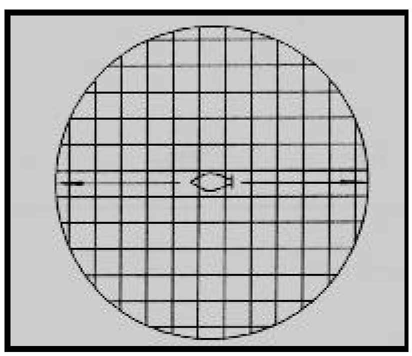
At The Micromanipulator Company, we take pride in manufacturing the finest equipment available for probing small geometries. We also spend considerable energy trying to solve application problems. Here is an extensively researched solution to a relatively common probing dilemma:

> *Maintaining probe contact during temperature stressing of wafers can compound the natural difficulties already associated with probing.*

This is due mostly to the relative motion between the fixed probe connected to the manipulator and the desired probe site on the wafer. The relative motion is due to the effects of thermal expansion of materials when heated and/or converse contraction when cooled. Since these motions occur in all dimensional axes, operators may encounter different perspectives on different probing problems.

Let's first discuss the coefficient of thermal expansion for silicon which is 2.8 uin/ in. °F.(1) This equation can be permuted into several easier to work with equations by using dimensional analysis (conversion factors). Here are several permutations that allow us to determine relative motion based on the most convenient units available for consideration:(2)

1. 2.8 uin/in. °F or 0.071 µm/in. °F
2. 2.8 uin/2.54 cm °F or 0.071 µm/ 2.54 cm °F
3. (1.8) 2.8 uin/in (Δ°C) or (1.8) 0.071 µm/in. (Δ°C)
4. (1.8) 2.8 uin/2.54 cm (Δ°C) or (1.8) 0.071 µm/2.54 cm (Δ°C)



a = 5 inches
D°C = 275° C

(1.8) 2.8 uin/in. DC) or (1.8) 0.071 mm/in. (D°C) x 5 in. 275 DC [(1.8) 0.071 mm] x 5 x 275 = 175.73

With this information, let's determine the anticipated expansion between two points on opposite edges of a five-inch diameter wafer that is heated from 25°C to 300°C.

We can expect a 176 micron expansion of this entire wafer's diameter. Since materials tend to expand linearly from the center and if the heating effect is homogeneous and the material unrestrained, we could say that from the center of this same wafer to either point, we should expect approximately 88 microns of expansion. This alone will establish us with our relative motion between the fixed probe and the probe site. Experience suggests that this movement occurs but not always in a predictable direction due to other influences such as stage vacuum (or lack of it), back side contact, special friction points and the thermal effects of the stage itself.

Silicon has a considerably smaller coefficient of thermal expansion than most pure metals and metal alloys. Consequently, heat stage design, construction and wear can result in even greater apparent motions than the effect of the silicon itself.

Stage planarity, thickness and construction can also create great problems with motions in the Z-dimension as well as X and Y-axes of travel.

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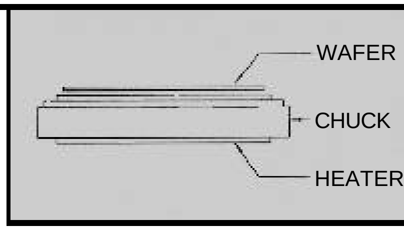
Take, for example, a heat stage design which is a quarter of an inch thick slice of aluminum sitting on top of a heater.



Place your wafer on this hot stage and heat it from 25°C to 300°C. Disregarding the wafer thickness and assuming perfect planarity of the stage surface, how much motion upwards (Z) would you expect the wafer to travel? The coefficient of thermal expansion for aluminum is 14 uin/ in. °F [3] or (1.8) 0.356 µm/in. (Δ°C).

Since the aluminum sits on the heater, the aluminum will push the wafer up (0.250 in. x 275°C) or a minimum of 44 microns toward or into the probe contact area. [1.8 (.356 µm/ in (Δ°C) x .250 in x 275 Δ°C = 44.055 µm].

It should be apparent that the Z-motion effects of the stage, if not compensated for, have a greater consequence with respect to relative motion of the wafer and the probe point than the XY motion. If the hot stage planarity with respect to the probing plane was skewed, then the effects of thermal expansion would even further exacerbate this problem.

Hysteresis, which can be described as the retardation of the effect when the forces acting on a body are changed[4], can make it impossible to predict where probe sites might end up after the completion of a cycle of heating and cooling. Therefore realignment of probes could be required when simply raising the probes during a heat cycle to avoid all the aforementioned motion problems.

Ignoring the obvious desire to compare our hot stage construction with other manufacturers' designs, it is believed that the problem is best solved by the use of an extremely compliant probe tip.

What is meant by compliant probe tip is one that will flex as a spring flexes when a very small force is applied. Naturally, the least force required for this spring action would minimize the possibility of damage to the wafer.

The requirements for qualifying such a probe or probe tip can be first determined empirically using formulas for establishing the stability of elastic columns. Although these engineering formulas are normally used to qualify parameters of design opposite to this concern, they produce valid data for these purposes.

Using Euler's formula for pin-ended columns, we can qualify the criteria that makes one probe tip better than another. Euler's formula for pin-ended columns is

$$P_{cr} = \frac{\pi^2 EI}{L_e^2} \quad (5)$$

where

P_{cr} = the critical load that will cause bending.

E = modules of elasticity; for tungsten is $50X10^6$ PSI. [6]

I = moment of inertia; moment of inertia for a solid round-section column is

$$I = \frac{\pi d^4}{64} \quad (7)$$

d = diameter of a circle.

L = length of column.

L_e = effective length of column.

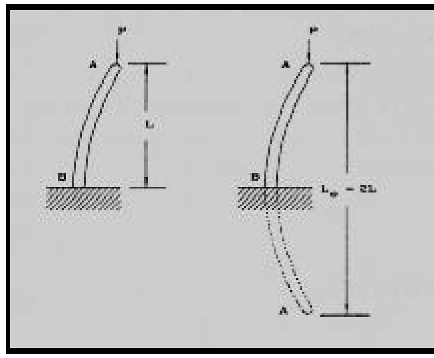
Thus, our working Euler's formula is:

$$P_{cr} = \frac{(\pi^2)\, E\, \left(\frac{\pi d^4}{64}\right)}{L_e^2}$$

or

$$\frac{\pi^2\ (50X10^6 \text{lbs/ins.})\ \left(\frac{\pi d^4}{64}\right)}{L_e^2}$$

The similarities should be readily apparent in this example. Our probe tip on a wafer is actually closer to an extension of Euler's formula for the column with one fixed end and one free end.

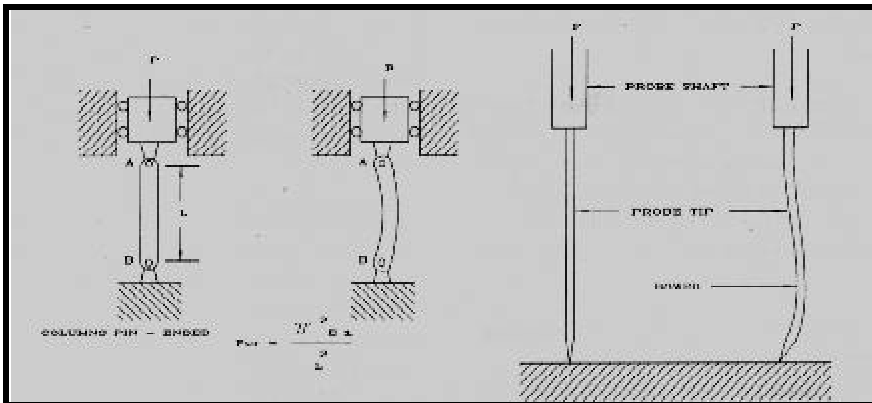


In this condition, the column will behave as the upper half of a pin-connected column and therefore the effective length (L_e) is equal to twice the length of the column, that is, $L_e = 2L$. This permutes Euler's equation for our probe to be:

$$P_{cr} = \frac{(\pi^2)\, EI}{(2L)^2} \quad (8)$$

$$P_{cr} = \frac{\pi^2\ (50X10^6 \text{lb/in}^2)\ \left(\frac{\pi d^4}{64}\right)}{(2L)^2}$$

This equation further illustrates that the criteria of the columns that we are interested in are its length and diameter. P_{cr} is directly proportional to the diameter of the column/probe and indirectly proportional to its length, that is $P_{cr} \propto \frac{d}{L}$.



Here are illustrations of the theoretical pinned-end column and of a theoretical probe on a wafer:

In the previous illustration, the tips have been scaled 50 times larger than normal so that two distinct (if not three) features can be rapidly distinguished, that is, length and diameter. When we fit these numbers in the Euler equations, we can see that maximum forces might be applied when bending or bowing these probe tips. Remember, the pressure exerted on the wafer rapidly drops after bowing occurs and that the probe tip operates like a spring.

Again we repeat the formula:

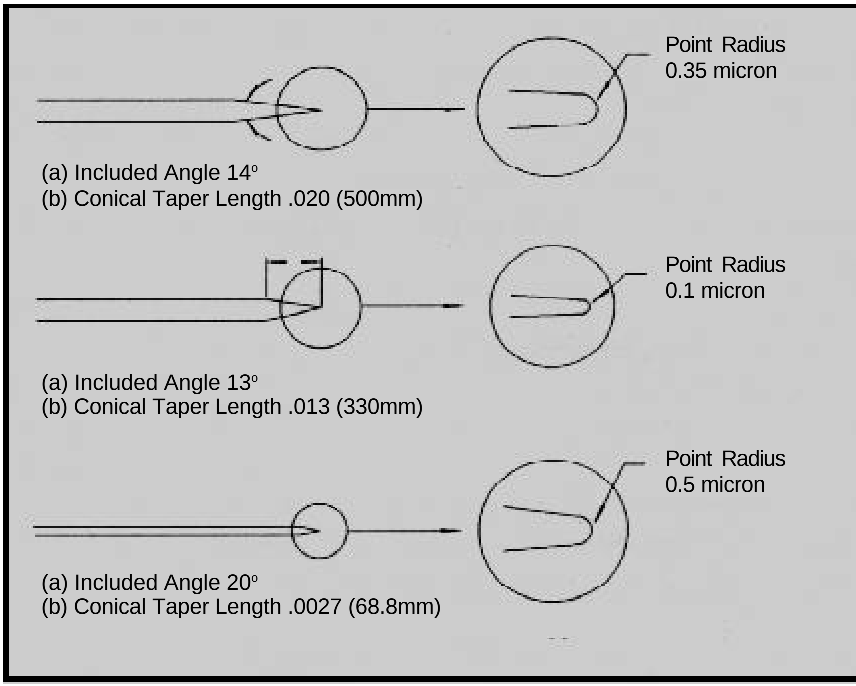
$$P_{cr} = \frac{(\pi^2)\ EI}{(2L)^2} \quad (8)$$

$$P_{cr} = \frac{\pi^2\ (50X10^6 lb/in^2)\ \frac{(\pi d^4)}{64}}{(2L)^2}$$

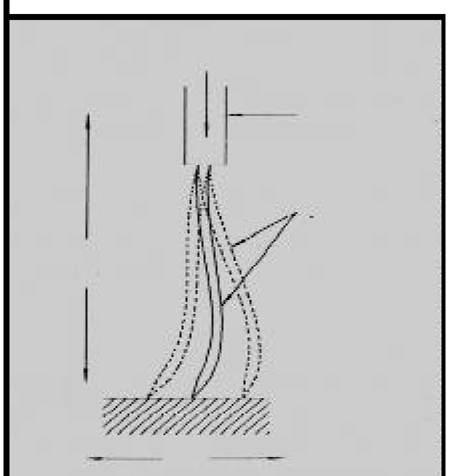
When we solve P_{cr} for the 7A probe whose L=.130 in. and d=0.005 in. we find that a maximum of 0.224 lbs (101.6 gr) force may be applied prior to its bowing.

The 7X whose L=0.130 and d=0.003 in. may require a maximum for of 0.029 lbs x (13.17 gr) to initiate bowing.

This flexible probe concept has been found to be one of the safest ways to probe on very thin oxide sites regardless of thermal cycling. Experience with certain thin oxides has demonstrated that no damage occurs when vertically probing with the model 7F. Other probes invariably damaged the oxide. CV measurements of inversion can be used to verify our findings concerning oxide damage, etc.



Note: the 7F probe has the largest radius for probe contact and the shortest conical taper length. These features minimize the skating or slipping effect of the probe tip may have on the wafer site



Lastly, the 7F probe whose L=.150 in and d=.001 in. may require a maximum force of 0.000269 lbs (0.12 gr) to initiate its bowing.

We recommend the 7F probe for use in thermal cycling situations. Since it requires only a small amount of force to initiate bowing (approximately 1/10 of a gram), X, Y, or Z-motion of the wafer probe site can be easily compensated for by maintaining constant probe contact during a heat cycle.

The third feature of the earlier illustration that may have gone unnoticed is the conical taper length of the three different probe tips. The next illustration magnifies those portions of the probe tips for further comparison.

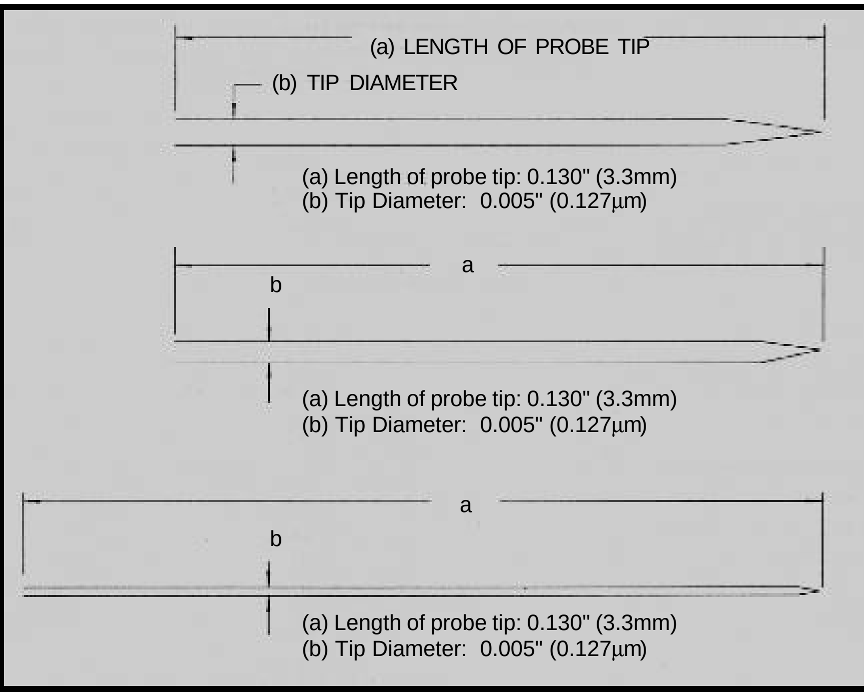
A probe angle of about 80° plus or minus 5° is sufficient to produce a good probe point contact and flexure. While the more vertical the probe point flexes more easily, many people will desire this slight angle for ease in viewing under a microscope.

As with all forms of probing small geometries, a little technique can go a long way and each operator will find the most suitable probing angle and/ or technique if these simple guidelines are followed:

1. Probe as close to vertical as possible.
2. Use of 7F style probe tip. (Very small diameter with as long a length as possible.)
3. When making probe contact, continue lowering the probe until bowing or flexure of probe tip is seen.
4. Verify bowing by using a little X or Y-motion of manipulator or stage and insure probe contact follows the motion and stays on target site.
5. Practice makes better.

The following provides guidelines for using a Model 79 (coaxial probe holder) with a 7F probe and an open style manipulator. The basics to note are:

1. All probe holders use a Model 5 collet for probe to manipulator electrical isolation.
2. Cable strain reliefs are recommended with probe holders that use large or bulky cables. Strain reliefs for both open and closed style manipulators are part of an accessories package that can be purchased from the Micromanipulator Co., Inc. (Part #19107017).
3. Placement of probe tip into probe holder. We recommend as vertical a probing arrangement as practical for the operator.



Illustrations to compare three different probe tips available in our Model 7 series of disposable probes. Shown here are 7A, 7X and 7F probe tips.

4. When using a Model 79 probe holder as illustrated, we recommend rolling the extra length of probe shank around the tip of the holder to prevent any probe rotation in the pin jack.

The newer Model 79-02 probe holders are equipped with a higher spring force pin jack and Model 79-03 probe holders use a small locking screw to prevent probe rotation.

End Notes

[1]Ray E. Bolz and George L. Tuve, ed., CRC Handbook of Tables for Applied Engineering Science, 2nd ed. (Boca Raton, Fl.: CRC Press, Inc., 1970-73) pp. 117.

[2]Ibid, pp. 817-847.

Conversions for dimension analysis used;

1 m = 39.370079 in

1 in = 0.0254 m

1 in = 2.54 cm

1 mm = 10^{-6} m

Absolute zero:

on Celsius scale is -273.15^{o}C

on Fahrenheit scale is -459.67^{o}F

^{o}C = 5/9 (^{o}F - 32) ^{o}F = 9/5 (^{o}C) +32

[3]Ibid, pp. 117.

[4]Webster's New Collegiate Dictionary, 1961 ed.

[5]Ferdinand P. Beer and E. Russell Johnston Sr., Mechanics of Materials (New York: McGraw-Hill Book Co., 1981), pp. 526-534.

[6]Bolz, CRC Handbook of Tables, pp. 117.

[7]Joseph Edward Shigley and Larry D. Mitchell, Mechanical Engineering Design, 4th ed. (New York: McGraw-Hill Book Co., 1983), pp. 148-154.

[8]Beer, Mechanics of Materials, pp. 531.