Testing of a MEMS-based IC Probe with NANO INDENTER G200 and NanoSuite EXPLORER

Application Note

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Introduction

The Nano Indenter G200 is a versatile instrument capable of measurements beyond the scope of traditional or even advanced depth-sensing indentation tests. NanoSuite Explorer software's user-friendly environment for developing novel test *methods* turns the Nano Indenter G200 into a multi-functional tool capable of several different types of small-scale mechanical tests. Each NanoSuite *method* is a customizable prescription for driving the instrument hardware and for collecting, conditioning, and analyzing the resulting measurement data.

This application note describes the development of a novel *method* for testing an element in a micro-electro-mechanical system (MEMS) device. The MEMS device that is the subject of this testing is itself used to test integrated circuits (IC).

MEMS-based Arrays for the IC Industry

The top five IC probe card manufacturers sold nearly $1b in products, service, support, and spare parts in 2008.[1] The hardware in IC probe cards is gradually migrating from the traditional needle type and vertical type to the more modern MEMS-based varieties.

To test IC's at the wafer level, manufacturers are increasingly relying on arrays of MEMS devices, each device including one or more probes. An array of probes makes it possible to address multiple IC devices on separate sites, thus dispensing with the need to repeatedly translate an individual probe from one location (usually a bond pad) to another. Although probe arrays have long been in use, MEMS-based arrays offer distinct advantages over their classical counterparts. For example, in addition to miniaturization, individual MEMS probes retain their in-plane (x,y) alignment within an array much better after repeated measurements, and also offer better co-planarity.

[1] Source: VLSI Research. Report summary (29 April 2009) at http://www.fabtech.org

The Test Subject

This application note concerns the measuring of the mechanical strength of the probe in a MEMS device that is used to test IC's. (See Figure 1).

In testing an IC device, the probe of the MEMS device usually makes mechanical contact with the wafer. The mechanical integrity of the probe after it comes into and breaks contact with the IC wafer is critical and must be maintained in order that the probe can be used again reliably and repeatedly.

In particular, for the MEMS device whose side-view schematic is shown in Figure 1, it must be assessed how strongly the "probe" is attached to the rest of the structure. This probe comes into direct contact with the IC device that it tests, and while in contact, it may experience a shear force perpendicular to it long axis. We are interested in the magnitude of the shear force that the probe can withstand without breaking off its support structure.

In order to assess this strength, an independent testing method is required. A combination of hardware and software products from Agilent Technologies addresses this task, as we review in the rest of this Application Note.

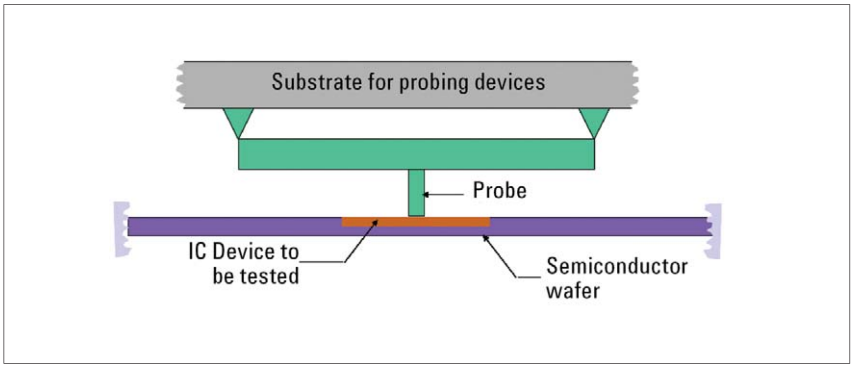


Figure 1. Schematic of a MEM device in use.

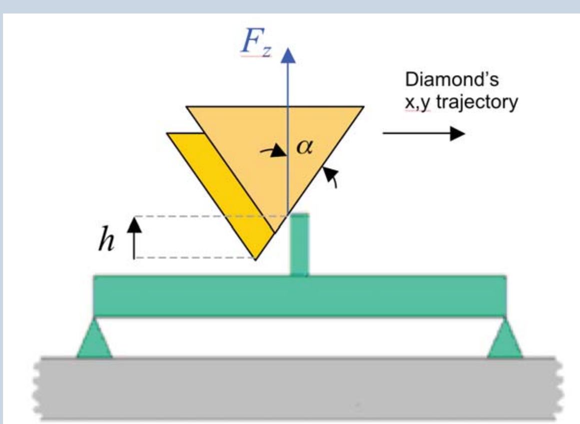
The Tools

Hardware

These tests used both the vertical-force-measurement and the lateral-force-measurement (LFM) options of the G200 Nano Indenter and the Nano Suite Explorer Software. The vertical-force method is indirect, as described in the sidebar. The LFM option directly measures the lateral force on the indenter diamond, frequently during a scratching experiment. In this work, however, the LFM measured the lateral force between the indenter diamond and the MEMS probe. The G200 Nano Indenter can exert on the test object a maximum lateral force of at least 250 milli-Newtons (250 mN). The LFM force sensor can measure the lateral force with a resolution better than 2 micro-Newtowns (2 µN). The data from the force sensors in the Nano Indenter G200 are collected at 12.5 kHz, then averaged, in this test at 500 Hz, and recorded.[2]

Software

In this work, NanoSuite Explorer software was used to define a custom test, detailing the controlled movement of the MEMS probe relative to the Nano Indenter G200's indenting diamond, and measuring the lateral contact force between the diamond and the MEMS probe that was required to break off the probe from the rest of the MEMS structure.



Measuring the Lateral Force Indirectly

In this technique, the Nano Indenter G200's vertical measurement capabilities are used to extract the lateral force. The instrument measures the vertical displacement, h, of the diamond as a result of the relative motion of the diamond and the MEMS probe in contact. From this measurement, it is possible to compute the force, Fz, (the vertical force) that would give rise to h. Then, with the knowledge of the diamond's geometry (the angle, α, of the diamond's facet relative to the vertical) and the trajectory of the motion, it is possible to compute the corresponding the lateral force, FL, assuming that the contact between the diamond and the MEMS probe is frictionless.

[2] The rate of averaging is flexible, configurable in the software.

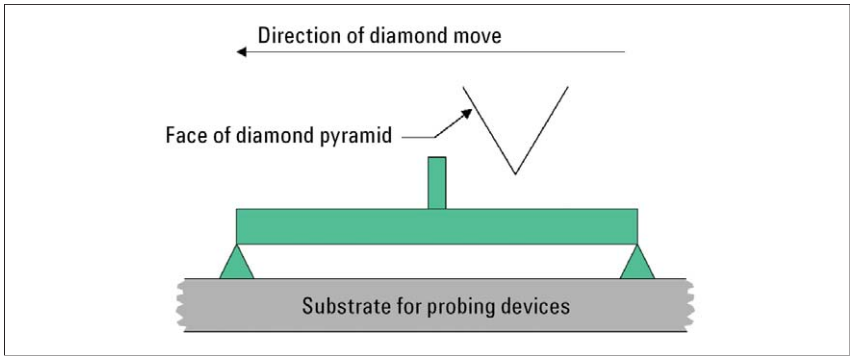


Figure 2. Schematic of test. Cube-corner face shows through probe tip.

In the NanoSuite Explorer, the user defines the parameters that define the move trajectory, that is, the starting point, the vector (direction and length), and the speed. The vector may be as short as a few micrometers and as long as 100 mm; the speed as slow as 100 nm/sec and as fast as 2 mm/sec. An optically magnified field of view from the sample surface is incorporated into the NanoSuite software, facilitating this process for the user.

Measuring the Lateral Force with the Nano Indenter G200: A Case Study in MEMS

In the Nano Indenter G200, the indenter diamond remains fixed while the sample moves. However, descriptions may be made more intuitive if we envision the indenter diamond moving, and the sample fixed; we adopt this perspective in the illustration artwork.

In this application, there was no intention to indent or scratch the test sample surface. Instead, the diamond traveled close enough but free of contact with the surface of the MEMS device substrate in order to "catch" only protrusions and asperities above a certain height. Here, the target was the MEMS probe (See Figure 2).

In each test cycle, the diamond's trajectory was deliberately set to collide with the MEMS probe visible in the optical image. As the moving diamond made contact with the MEMS probe and continued on its trajectory forward, the MEMS probe experienced a lateral force at the area of contact with the diamond; this force changed with the time and the advance of the diamond. By Newton's third law of motion, the diamond experienced the same time-dependent force, which the instrument measured (see Figure 3).

Test Results and Discussion

Figure 3 shows the data collected in a typical LFM measurement as performed in this test. The lateral force is plotted against the distance that the diamond traveled (in the x,y plane). This measurement was performed on 25 separate probes, and the data was analyzed with the NanoSuite software. The average value of the lateral force at which the MEMS probe broke ("abrupt failure of probe tip" in Figure 3) measured 0.49 mN ± 0.04 mN (1σ error).

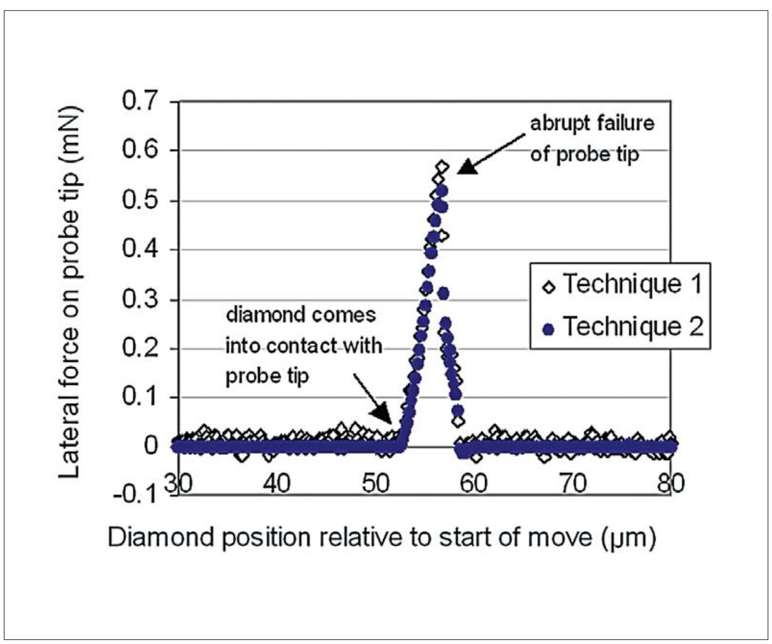


Figure 3. An LFM measurement plot shows the profile of the lateral force and the "failure" of the test subject. Here, the failure is the initial breaking and the subsequent detachment of the probe from the rest of the MEMS structure. The plot shows that as the diamond traversed its trajectory, after the initial contact, the lateral force first increased, then decreased abruptly (when the probe failed). The plot also shows a second abrupt drop in the force nearer the baseline. The overall sequence of events appears to have been 1) diamond contacted the probe; 2) diamond (and probe) experienced a gradually increasing lateral force with the diamond's advance; 3) the probe fractured but was not completely detached from the rest of the MEMS device; 4) therefore the probe continued to resist the movement of the diamond, though with decreasing force; 5) diamond eventually passed by the probe, and the lateral force vanished.

Figure 4 shows a MEMS device before and after a lateral force measurement. The probe is broken and removed from the device during the measurement. The micrographs are recorded using the camera attached to the G200 Nano Indenter's optical microscope, which features 10x and 40x objective lenses.

Summary

The Nano Indenter G200 can accurately measure forces and record individual mechanical events, such as an abrupt mechanical failure, not only in the direction perpendicular to the sample surface, but also parallel. Here, this capability was used to test cantilever-type MEMS probes for the strength of their attachment to their supporting structures—IC test devices in a MEMS array. The test scheme requires highly accurate, low-noise force measurements, and precise positioning with respect to the Nano Indenter's diamond. It also requires easy-to-use software that facilitates human interface with the hardware, and customizes definitions of the test parameters without having to write the entire computer code from scratch. The NanoSuite Explorer software enables these tasks. An extension of Agilent's NanoSuite, the Explorer allows customizing a test by making available to the user numerous built-in functions that can easily be modified. The combination of the Nano Indenter G200 and the NanoSuite Explorer software may be used to develop other test methods with applications to other MEMS devices.

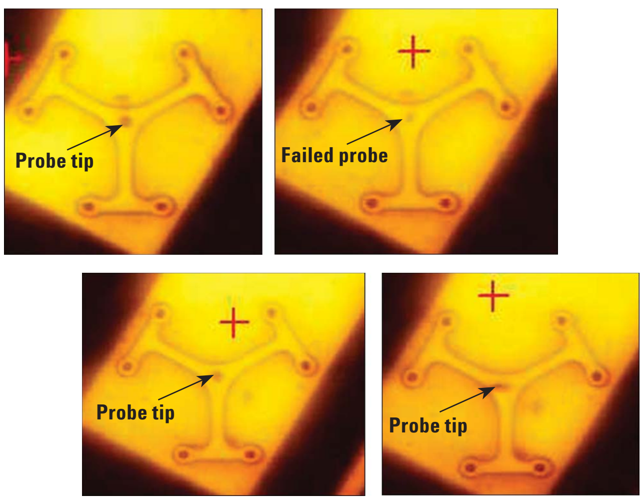


Figure 4. MEM structure before (left) and after (right) shear test. Failed probe is still visible.

Inspired Science

Characterizing surfaces at the nanometer scale has become increasingly important in manufacturing and research. Nano-scale properties of constituent materials surfaces affect the performance of manufactured products. Nano Indenter Systems from Agilent technologies use some of the most advanced technology to acquire fast, accurate mechanical data on materials surfaces.

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