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The Noble Contact

DERINGER-NEY INC.

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Our Past Issue...

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As we all know, "chips" - pieces of highly refined semiconducting material etched with many circuits and billions of components, make our 21st century lifestyle possible. Integrated circuit manufacturing is a complex process with many steps that not only include the fabrication of the ICs themselves, but also the bonding, packaging, and testing to make a complete component used to transmit input and output signals. They're found performing data processing, data storage, timing, illumination, and countless other functions in smart phones, computers, televisions, medical devices, autos, and other devices we use on a daily basis. Many are in server farms where data processing and retention occurs for our web searches and data storage. Others can be found in everyday items like common household appliances thanks to the recent expansion of "Internet of Things" (IoT) device engineering. Due to the sheer number of devices produced and the need to supply them at an affordable price, testing is a critical part of the process flow on both the "front end" and "back end" of the integrated circuit manufacturing process.

The Need for Extensive IC Testing

Due to the complexity of the manufacturing processes used in IC production, 100% of all ICs, both logic and memory, are tested to eliminate less-than-acceptable performing units. Defects can have many causes thanks to the numerous steps required to build a finished IC from a bare wafer of semiconducting material. One example is the possibility of gaps in the resistive layers produced via photolithography or electron beam lithography that may create electrical short circuits in the device's circuitry. Likewise, errors due to dust or debris on an in-process wafer may prevent a trace from being completed during the deposition of conductive materials using vacuum sputtering or electrochemical deposition (ECD) processes.

Although the IC manufacturing environment is closely monitored and controlled to maximize yield and eliminate defects, even a nano-sized dust particle can result in a defective IC. As a result, 100% testing and inspection is necessary.

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A dedicated industry has emerged to make the complex equipment needed to test these ICs at high speeds and throughput. The equipment consists of test tools called “probers” and the “probe cards” that reside within them. Probers are machines which transfer individual ICs, or full wafers with many ICs into the test fixture. The IC is known in the industry as the “device under test” (DUT). The prober contains sophisticated electronics and programming to power the ICs, deliver input signals, and collect output data with the goal of testing the proper function of each DUT. This communication is performed through the probe cards, which contain an array of test needles. The test needles, commonly called “probes”, make contact with pads on the DUT. All the input power and data required to perform the test is transmitted through the probes, and feedback is similarly routed through the probe card back into the prober electronics. Since the probes operate in very close proximity, the bulk of the probe length is typically coated with an insulating polymer layer to avoid shorting through adjacent channels.

Application-specific test algorithms identify and record defective devices and note the actual portion of the ICs that are malfunctioning. They also record the location on the wafer where the defective IC originated. The data collected helps troubleshoot and correct potential process issues. All this is done in a very short time, necessitated by the high production rate of these devices.

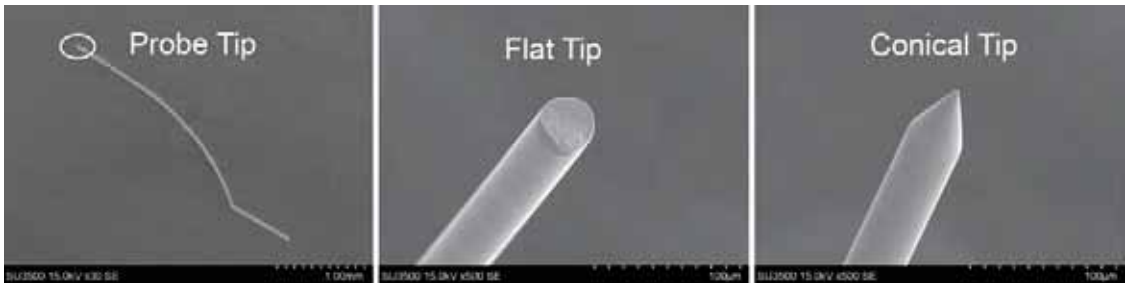
Test Probe Needle Configurations

There are a number of technologies used to produce the test needles mounted in the probe card that vary by test level (pre- or post-packaging) and IC function. Many wafer- and die-level test needles are produced from metallic wires fabricated with alloys which were developed by Deringer-Ney. Common types of wire needle configurations include cobra probes, cantilever probes, vertical probes, and LED probes. Other common, non-wire probes include so-called MEMS probes and pogo pins.

Cobra Probes

Cobra Probes are formed pins manufactured with starting wire diameters of approximately 0.001-0.004 in (25-100 µm) and are typically used for small-pitch logic testing.This type of probe is named for its self-contained ribbon-shaped spring that gives it a “snake-like” appearance as shown in Figure 1. The working tip may be found in a flat configuration or as conical points. Force exerted by the tip of the cobra probe on the test pad is a combination of beam bending and beam buckling. The forerunner to today’s cobra probes were so-called “buckling beam probes”, developed by IBM in the 1970s. In fact, Deringer-Ney’s Paliney® family of alloys was named in the original inventions as materials suitable for this application [1]. The cobra probes are typically the IC-facing surface of the probe card, backed by complex electronics that route and condition the signal to and from the prober.

Figure 1 - Typical cobra probe (left) and high magnification views of the surface configurations that would interface with the test pads on a chip (middle) (right)



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ertical Probes

ertical probes, as well as other straight wire needles, are often used in a manner consistent with cobra probes. A key difference is that probe card design utili es clever guiding with multiple perforated plates to offset the tip and tail of the probe, thus controlling the buckling of the probe. This simplifies probe manufacture relative to cobra probes. As with cobra probes, typical starting wire diameters are approximately 0.001-0.004 in (25-100 µm).

Cantilever Probes

Cantilever probes, more typically used for testing memory, are fabricated from wire approximately 0.00 in (75 µm) starting diameter, with lengths of 2-5 in (50-125 mm). enerally, the cantilever probes are held at an acute angle relative to the DUT, and their pointed tips make contact with the IC test pads. Force exerted by this probe design is that of a simple bending beam, as the name would imply. Most of the overall length of the probe is used as a connection to route signals to and from the supporting PCB and associated electronics. Flexibility of the wire is a key characteristic to ensure consistent board attachment for each probe.

Probes

LED probes, as the name implies, are used primarily for verifying the function of light emitting diodes (LEDs). This style of probe has a larger cross-section than the others discussed above, typically 0.014-0.020 in (50-500 µm). hen testing LEDs, particular attention is needed to the surface finish of the probe such that detected illumination values do not vary from probe to probe.

Probes

MEMS probes are typically wafer-level test needles and are manufactured using techniques similar to those used in the fabrication of ICs, but reimagined to produce freestanding structures. This is referred to in the industry as “microelectromechanical systems”, or “MEMS” technology. A typical method for MEMS needle production includes photolithographic patterning of a shape over a sputtered seed layer, plating using ECD, perhaps over the core of a different metal, and release of the MEMS needles from the substrate.

Pogo Pin Probes

Pogo pins, unlike the other probe types discussed, are usually designed to contact balls of soft solder alloys at the die- and packaging-level test during wafer bumping and die attachment respectively. These pins are micro-assemblies typically consisting of 4 parts the probe tip is the working surface that contacts the DUT the spring, which dictates load-displacement behavior for the pin the plunger that compresses the spring and transmits the signal back through the probe card and the barrel that houses all of these components. The probe tip will have a major diameter of about 0.010-0.020 in (250-500 µm), making it quite a bit larger than most wire probes.

Figure 2 on the following page illustrates the details of a pogo pin probe using both SEM and optical microscopy techniques.

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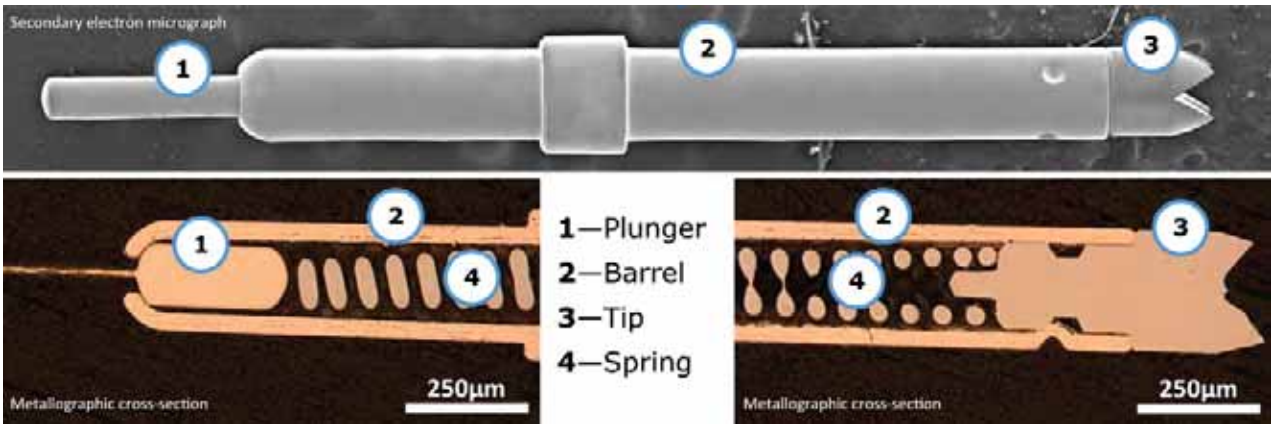

Figure - overview (top) and optical micrographs of a metallographic cross section (bottom) of a pogo pin probe illustratingits primary components labeled (1) plunger ( ) barrel ( ) tip and ( ) spring

ncreasing emands on Test Probes

Over the years, as IC technology advanced across the entire fabrication environment, the physical si e of the transistor had become smaller and smaller. hile Moore's Law may not continue indefinitely [2], the march toward IC si e reduction and higher component density still continues. This means that the available pad si e for signal and power delivery has decreased over time, and the number of test sites per unit area has increased. As test site density increases, the distance between adjacent probes - their "pitch" - decreases, necessitating the use of smaller diameter probe designs.

Current Carrying Capacity (CCC)

Compounding the difficulty of manufacturing these tiny probes is that they must also support current levels similar to larger, previous generation wire probes. This means that current density increases quickly, inversely proportional to the square of the diameter. For example, if the diameter of the probe decreases by half, all other things remaining equal, the current density in the probe increases by a factor of 4x. This presents challenges in both the mechanical and electrical aspects of the design. The ability to simultaneously support amperage and a mechanical load is termed "current carrying capacity" (CCC).

Semiconductor test engineers use CCC values as an approximation of how much current they can pass through a needle or probe card for a specified duty cycle. The two most common methods for measuring CCC are the International Sematech Manufacturing Initiative (ISMI) method, and the Maximum Allowable Current (MAC) method.

CCC Testing

ISMI CCC testing measures the spring force exerted by a probe at increasing current densities, as described by Daniels [ ]. Typically, the test needle is compressed to a manufacturer-specified overdrive, and the compression force in the absense of applied current is measured. Constant current is then applied for 2 minutes, stopped, and after a cooling cycle of 10 seconds the remaining force is measured. This cycle is

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repeated with stepwise current increases until a substantial drop in force is observed. The CCC limit is conventionally defined as **the current at which the remaining force is reduced y 20 .**

ingle Probe C CCC Testing

Single probe MAC CCC testing looks for permanent deformation of a probe at levels of appled current, as opposed to measuring the force exerted. A description by a mi *et al.* [4] characteri es this approach as "[CCC is the] maximum current a probe can handle without permanently deforming (stresses remain below the yield strength) at its fully loaded state for a repeated number of cycles." In the simplest embodiment, a test needle is compressed per manufacturer-specified overdrive, current cycled, force removed, and the probe height measured. The CCC of a single probe is thus defined as **the current at which the needle does not return to its original osition once the current and com ression are withdrawn.**

ultiple Probe C CCC Testing

Multiple probe MAC CCC testing was offered as a somewhat more complex approach by Cassier *et al.* [5], where a small array of 10 probes was used. Each probe experienced a unique current level and duty cycle before its free height was measured. The change in probe planarity was examined as a function of current on a log-log scale. MAC was defined as **the current at which the line of est fit coincided with some allowa le change in lanarity** (0.1 µm in this case). et more sophisticated approaches designed to gather both MAC and ISMI CCC data from multiple probes have been proposed as well [ ].

ther emands on Test Needles

In addition to CCC requirements, the probe needles must have high tarnish resistance to minimi e contact resistance (C) variation and ensure signal integrity for the lifetime of the probe. In some cases, adhesive transfer from the DUT to the probe tip can raise the C to unacceptable levels. In these cases, abrasive mechanical cleaning treatments are often used periodically to remove the transferred material and prolong the useful life of the probe. Typical needle life is in the millions of touchdowns.

Precious etal lloys for C Testing

Deringer-Ney has been supplying high performance wire to the probe industry since the 1970s. Most of the needle probe alloys we provide are heat-treatable Pd-Ag-Cu alloys. The alloy compositions have evolved over time to balance the demands of smaller pad si es (resulting in the need for decreased wire diameter) and increased CCC. Although we cannot yet accurately predict CCC or MAC from just the physical and mechanical wire properties, there are a number of properties that do allow a reasonable trend analysis of a probe's performance. Following is a list of the Deringer-Ney alloys that had been used for many years for IC test probes and a comparison of their relevant properties.

Paliney 7 was used in the original cobra probe development by IBM in the 1970s and is still used today for cantilever probes, straight probes, and cobra probes.

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The demand for smaller diameter probes created two challenges for the probe designers. The reduced cross-section created a rapid temperature rise with the applied current. These higher operating temperatures resulted in a loss of mechanical properties and a concern about increased C due to oxidation. These concerns led to the development of **Paliney 3C**. This alloy was designed specifically for igh ardness and igh Conductivity (C) and has the benefits of both a 2x reduction in bulk resistivity and an increase in mechanical properties relative to Paliney 7. It has been used for cobra probes, cantilever probes, and other vertical needles. Due to C's higher hardness, it is also used for long life pogo pin tips.

Paliney C was introduced to offer slightly higher conductivity and improved formability. It is used mostly for cobra probes and straight needles. Our latest alloy, **Paliney 25** (US patent 10, 5,424), has the highest CCC of Deringer-Ney's family of age-hardenable Pd alloys. It nearly doubles the bulk conductivity of C and still maintains the mechanical properties equivalent to Paliney 7 or Paliney C.

Deringer-Ney Semiconductor Alloys
Nominal Pro erties Age ardened

Pro erties	Paliney 7 (Pd-Ag-Cu-Pt-Au)	Paliney 3C (Pd-Ag-Cu)	Paliney C (Pd-Ag-Cu)	Paliney 25 (Pd-Ag-Cu)
Conductivity IACS micro-ohm cm	5.5 1. 4	14.5 11. 9	1 .5 10.45	27.0 .25
UTS si	1 0	250	190	190
ardness	0	450	5	0
longation	1-10	1-	1-4	-12

ther Considerations

Contact Force

In addition to these characteristics, there are other properties that affect overall test probe performance. For example, it is important to establish and maintain good metal-to-metal contact during the mating of the probe with the DUT. ery light contact force will result in unstable contact resistance and false negatives resulting in a low process yield. ery high contact forces will produce stable C values but can produce excessive wear scars and in the extreme case, can actually crack the wafer during the test.

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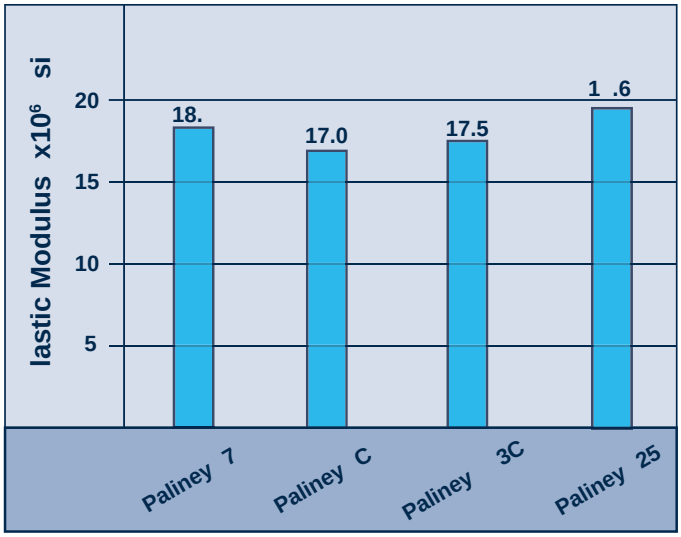
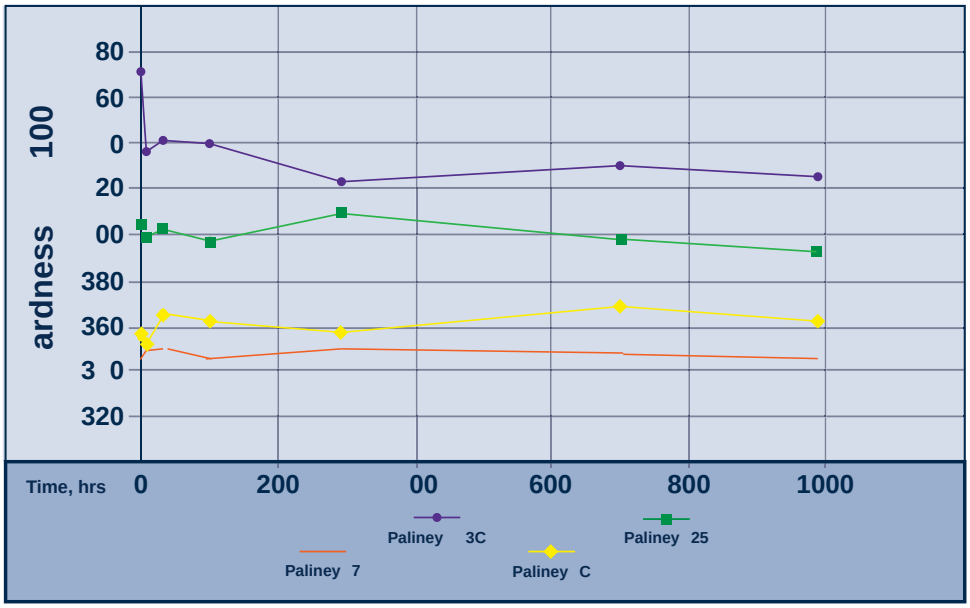
The typical contact force for IC probes is on the order of 1- g_f with a typical overdrive (deflection after initial contact) in the range of 50-250 µm. Some of the newer D configurations (Cu pillars or solder balls) require even tighter tolerances. The spring rate of a typical vertical probe is related to the physical geometry and elastic modulus of the probe material. The oung modulus of the Deringer-Ney probe alloys are similar and fall within a range of 17 to 19. x 10 psi (115 to 1 5 Pa).



lastic modulus of eringer-Ney semiconductor alloys

Temperature

IC probes must maintain stable properties at elevated temperatures. In addition to the anticipated I heating of the probe caused by the test currents, some wafer test protocols require heated chucks using temperatures in excess of 125 C. As noted earlier, IC manufacturers are on a never ending path to shrink the IC and reduce the pitch of the various features. This produces very tightly packed test arrays on the wafer, resulting in probe cards that can exceed 10,000 individual test probes. The heat generated by these tightly packed probes is challenging to dissipate and acts to raise the localised temperatures under test conditions. As a consequence, it's important to maintain the mechanical strength of the test probes at temperatures significantly above the ambient temperature. As shown in the graph below, the Deringer-Ney semiconductor alloys are mechanically stable at temperatures above 250 C.



ardness of various eringer-Ney semiconductor test alloys - noop hardness change over time C

High Performance Materials for Semiconductor Test Applications and Beyond (continued...)

Summary

The semiconductor manufacturing process is complex and continues to be refined over time. It's been made possible and developed over many years by the fields of material science, quantum physics, optics, chemistry, engineering, and many other scientific disciplines. Due to the ubiquity of the integrated circuit, little to no thought is given to these amazing devices by the average consumer as they find their way into everything from sophisticated smartphones to simple devices such as a $15 light dimmer switch. Worldwide, the end-product market using ICs exceeds $300B and will continue to grow for the foreseeable future.

Taking into account the market size, the demand for a low per-unit price, and the expensive infrastructure required to make these devices, high production yield is essential in order for a manufacturer to survive. As a consequence, every silicon die on every wafer will be tested as part of the fabrication process, followed by a final test performed after the die is mounted on a leadframe and packaged. The earlier in the process a defective IC can be detected, the better.

During wafer testing, the only thing seperating the dies from the prober circuitry is the vast array of test probes. When designing contact probes for this type of application, many things need to be considered including probe material bulk resistance, contact force, number of test "touchdowns", and current carrying capacity to name a few. Deringer-Ney has years of experience in developing the materials and manufacturing the parts for this highly specialized application. To learn more, contact one of our material scientists or application engineers. Visit our materials page at www.DeringerNey.com.

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