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FormFactor Springs Into Action

New Chip-Interconnect Technology Cuts Packaging, Testing Costs

By Peter N. Glaskowsky {2/21/00-01}

The fabrication of an integrated circuit is only one of many steps in the progression from sand to system. Chips are tested while still part of the wafer, then diced, packaged, and tested again. These subsequent steps are costly and time-consuming, especially when a packaged device is scrapped—the expensive package must be scrapped as well. New technology from FormFactor offers several ways to reduce the time and money spent testing and packaging chips, all based on a common idea—the simple spring.

What FormFactor calls MicroSpring contacts begin as gold bond wires, bonded at one end to the chip or substrate using a conventional wire-bonding machine that also forms the wire into the desired shape. Wires are cut by a small electric arc, and an application-specific contact is formed on the free end of the wire. Because gold wire makes a poor spring, the wires are then plated with a more resilient nickel alloy. The choice of alloy and the size and shape of the spring determine the finished contact's mechanical properties, which vary according to the intended application.

The springs, though small, are surprisingly robust. An array of springs feels bristly to the touch, like a few days' growth of beard, and is not damaged by casual contact. Figure 1 shows a typical MicroSpring designed for a land-grid-array (LGA) socket application.

Probe Heads First to Benefit

The first commercial application of FormFactor's MicroSpring technology was in probe heads for semiconductor wafer-test systems. FormFactor's retrofit probe heads improve the electrical characteristics of the probes they replace and offer improved parallelism to reduce test time and cost. FormFactor offers probe heads that contact up to 64 DRAMs in parallel, twice the capacity of its competition.

While most competing probes rely on sharp tungsten-needle contacts that pierce the surface of the device, causing damage that may limit the number of test cycles, FormFactor's springs cause essentially no damage at all—to the device or to the MicroSpring probe head. FormFactor says there is no known limit to the number of test cycles that can be performed using a single probe head, or on a single device. One customer reports over two million touchdown

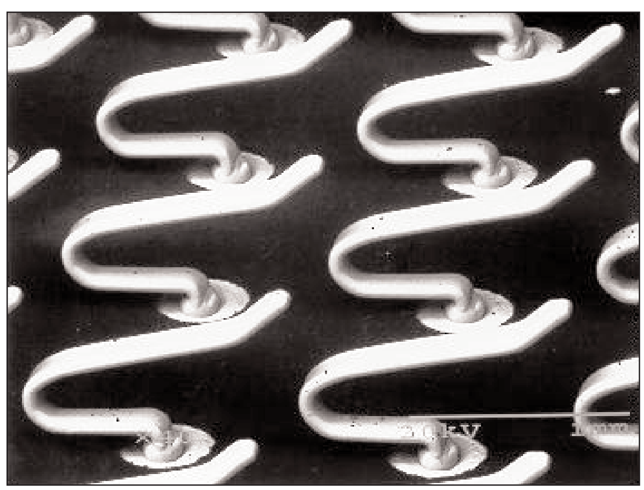

Figure 1. MicroSpring contacts are small and strong. The shape and size of the spring and the contact at the spring's tip vary according to the intended application. These springs are used in an LGA socket.

cycles (so far) from a single probe head, with no maintenance or cleaning.

FormFactor says the longer life of its probe heads offsets their higher initial price, though the company will not disclose specific pricing comparisons. The MicroSpring heads also take longer to deliver than competing test heads. For these reasons, FormFactor's probe heads are typically used in production rather than for prototyping. FormFactor says it has over 20 DRAM makers using its probe heads today, though only IBM and Infineon have gone public with their use of the new heads.

The small spring contacts may be used to create very dense contact arrays. FormFactor has shipped probe heads with over 3,000 contacts on a 9-mil (225-micron) pitch, and says its current contact design allows pitches as tight as 7 mils. Such a probe, as Figure 2 shows, is suitable for testing microprocessors built with IBM's C4 (controlled-collapse chip connect) technology.

More advanced probe heads can be created with the actual test electronics built into the probe-head substrate. These probes can perform high-speed testing of chips on intact wafers. Teradyne recently announced a new test head based on FormFactor technology that can perform wafer-level testing with data-transfer rates up to 500 MHz, with double-data-rate (DDR) signaling for one billion transfers per second. FormFactor says this speed is roughly an order of magnitude faster than the next-best wafer-test technology.

Sockets Bring Springs to Boards

A simple extension of the probe-head application involves spring contacts attached to a small PC board, along with a chip-alignment frame and lid. Such an assembly, equipped with solder balls on the bottom of the PC board for soldering to a motherboard, acts as a socket for standard ball-grid-array (BGA) or leadless-grid-array (LGA) packages. The socket footprint is almost the same as the device footprint, though some extra space is required around the pads for the socket frame.

Figure 3 shows such a socket. Clamping forces (applied by closing the lid) are low, about 10 grams per contact. This slight force causes the springs to bend slightly, wiping the spring tip across its contact pad to ensure a good electrical connection. A 475-pin MicroSpring socket supplied by Tyco Electronics has been approved by Transmeta for use with its Crusoe microprocessor.

FormFactor has also developed extremely low profile sockets for LGA devices. The contacts in Figure 1 are from such a socket. The substrate in these sockets is a single-sided flex circuit with small holes behind each contact pad. The MicroSpring contacts are bonded through these holes to one side of the contact pad, while the other side of the pad is soldered to the motherboard using a thin film of solder paste. The socket height is thus reduced to about 27 mils—about 2 mils taller than the spring itself and shorter than the typical 34-mil height of a BGA solder ball after soldering.

Even with their lower height, these sockets are better at accommodating the differing thermal coefficients of expansion of chip packages and PC boards than soldered connections. As a result, FormFactor believes these sockets will deliver better long-term reliability than soldering.

Chip-Scale Packages Show Biggest Benefits

Though its probe heads and sockets represent large markets, FormFactor has even bigger plans for its smallest application—chip-scale packaging. By attaching spring contacts directly to wafers as the last step in the chip-fabrication process, FormFactor eliminates the need for any further packaging in many applications. The new

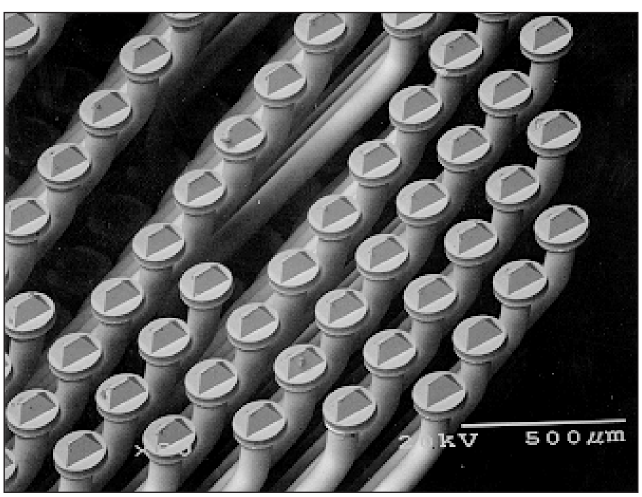

Figure 2. FormFactor has built probe heads suitable for testing microprocessors with C4 solder balls on a 9-mil pitch. Shown here is an array of MicroSpring tips with pyramidal contact surfaces designed for C4-ball connections.

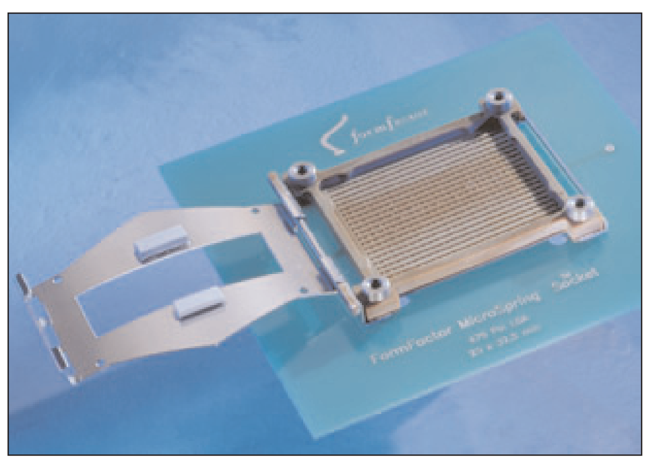

Figure 3. This low-insertion-force LGA socket uses MicroSpring contacts. Clamping force, applied by closing the lid, is typically about 10 grams per contact.

approach promises to solve many of the problems with existing packaging technology (see *MPR 12/27/99-03*, "Processors Put Pressure on Packages") and will first be fielded in memory modules.

Existing chip designs can be adapted to MicroSpring contact arrays by means of a redistribution layer that consists of metal traces printed on top of the finished chips to give perimeter-bond chips a more regular array of bond pads, suitable for spring attachment. Figure 4 shows a redistribution layer on a DRAM. Chips designed for C4 bonding or specifically for MicroSpring contacts may not need the redistribution layer.

Once the bond pads are prepared, bond wires are attached to all the pads on all the chips on a wafer—about 25,000 wires on today's DRAM wafers. The wires, about 3 mils in diameter, are then plated to create springs. The tips of the wires typically stand about 25 mils above the surface of the board and within +/– 2 mils of their nominal position in all three dimensions.

Testing may be performed using probe heads with flat contact surfaces. Probe heads may be made to emulate the electrical environment of the chips' target application—a DRAM module on an FR4 fiberglass PC board, for example. At-speed testing of the wafer thus requires only a small guard band to accommodate differences between the probe and the final environment in which chips will be used, boosting yield. As with the MicroSpring-equipped probe heads, many chips may be tested in parallel.

Once tested, the wafer may be diced and bad chips discarded. Those that remain need no further packaging; they are ready for delivery to the customer. Total packaging costs amount to under a penny per pin, according to FormFactor—as low as 0.3 cents per pin in high volumes compared with about 1.5 cents per pin for competing high-performance chip-scale packaging solutions. The time saved by eliminating a trip to a packaging and testing facility also allows quicker design and fab-optimization cycles.

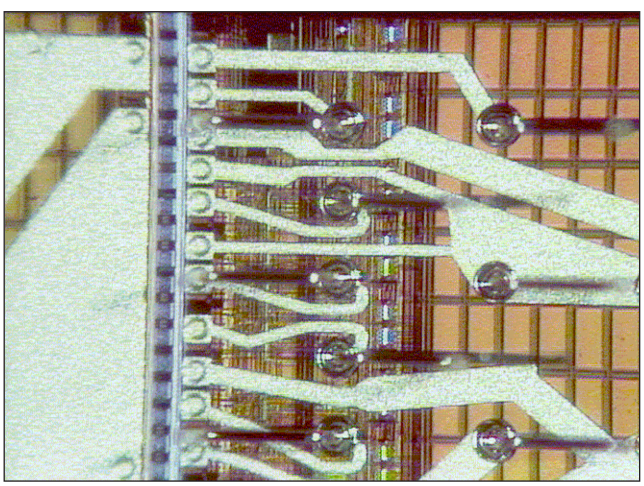

Figure 4. Perimeter bond pads may be adapted to an array of MicroSpring contacts using a metal redistribution layer on top of the chip. A DRAM is shown here.

There are several options for attaching spring-equipped chips to boards. As Figure 5 shows, the spring tips may be reflow-soldered to conventional surface-mount pads. This approach provides substantial mechanical strength without increasing the footprint of the chip. Shinko has qualified this process and is looking for customers. Conductive epoxy may be used in place of solder.

A mechanical socket assembly may be used to hold the chip to the board, allowing the spring tips to contact the board pads directly, or this mechanical hold-down function may be performed by an epoxy bridge between the PC board and the edges of the chip. Chips attached in these ways may be removed more easily than soldered devices, making repair work faster and cheaper.

According to FormFactor, the electrical characteristics of the MicroSpring contacts are superior to all known alternatives, except for chip-on-board techniques, which have almost no effective wire length but introduce thermal-mismatch problems. FormFactor's springs make the assembly essentially immune to these problems.

It is somewhat more difficult to remove heat from MicroSpring-contacted chips than from conventionally packaged devices, however. The mechanical connection between the board and MicroSpring chips is not strong enough to support a large heat sink. Also, relatively little thermal energy passes from the chip into the board below. There is some risk of conductive particles being trapped under these chips, so some form of shroud may be required, especially for products such as memory modules that may be handled by end users. The shroud may serve as a heat sink or heat spreader.

FormFactor expects its chip-connection technology to be adopted first by high-performance DRAM makers. The company says the higher yields and lower costs for test and packaging of its technology can save DRAM makers as much as $1 per chip (up to $18 per module).

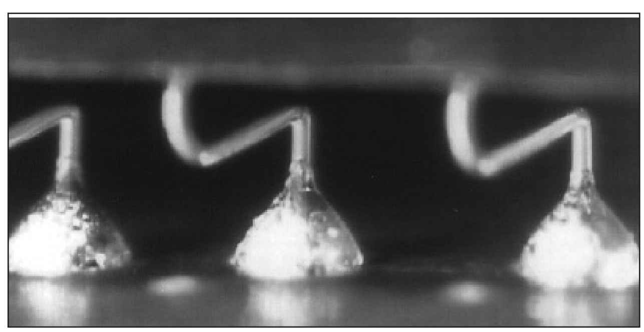

Figure 5. Bare die with attached MicroSpring contacts may be reflow-soldered to PC boards, as shown here. Chips may also be held against the board by a socket or epoxy.

For More Information

FormFactor's Web site at *www.formfactor.com* offers additional information on its MicroSpring contacts, including white papers and more pictures.

FormFactor also expects its customers to ship DRAM products later this year. It is competing with many well-established technologies, some of which offer advantages over the spring-contact approach, but FormFactor's superior cost structure seems likely to earn it a large share of this important market. ◊