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Material advancements

New acoustic tools for wafers

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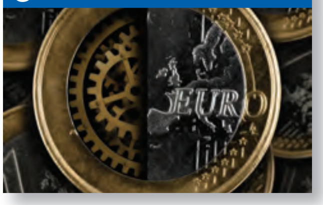
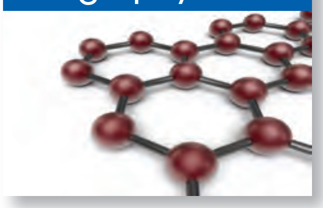


Revolutionising electronics

Nanoscale lithography



Cost-effective surface mounting of complex stacked die

Die and flip-chip bonding strive for ultra high precision

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AN ANGEL BUSINESS COMMUNICATIONS PUBLICATION

MUF and wafers get new acoustic tools

Modifications of production processes and changes in device dimensions require new non-destructive techniques to inspect for reliability. Tom Adams, consultant, Sonoscan, Inc. discusses recent advances in the acoustic microscope imaging of molded underfill flip chips and 200mm and 300mm silicon wafers.

BEFORE THE INTRODUCTION OF MOLDED UNDERFILL, the attachment of a flip chip to its substrate was imaged acoustically by a transducer that scanned the exposed silicon back side of the chip. The transducer pulsed ultrasound into the chip thousands of times a second as it scanned, and received the return echoes. Silicon is an excellent propagator of ultrasound; very little of the ultrasound is absorbed by the silicon during its fast passage to the underfill material and solder bumps that are the objects of interest.

Ultrasound is reflected at material interfaces - chip face to underfill, chip face to solder bump, and others. The most highly reflective interfaces are those between a solid (silicon, solder, underfill) and the air or vacuum in a gap. Some common gaps in flip chips are cracks within bumps, voids in the underfill, and non-bonding of bumps to their pads. These are the items that will determine whether a flip chip passes or fails.

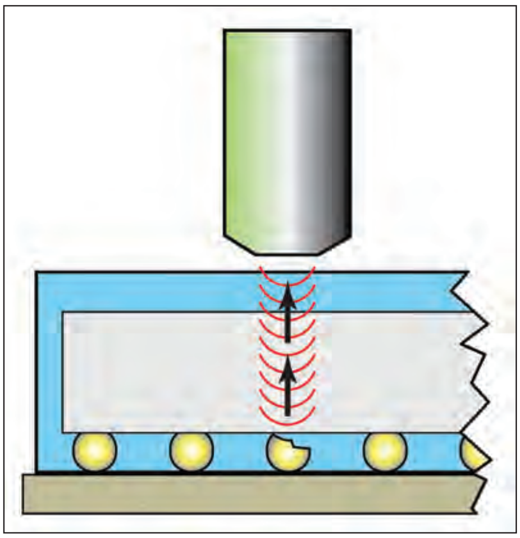

Figure 1. Ultrasound (red) pulsed into a molded underfill flip chip must travel through the attenuating underfill (blue) to image the solder bumps

When scanning the silicon back side of a flip chip, Sonoscan's personnel could use C-SAM® acoustic microscope systems equipped with very high frequency transducers because of the high acoustic transparency of silicon, and because some of the die were quite thin. Transducer frequencies could be 230, 300 or even 400 MHz. These transducers are all designed and manufactured by Sonoscan. Higher frequencies give better spatial resolution in the acoustic image. Higher frequencies are also absorbed more rapidly when traveling through materials, but silicon absorbs so little silicon that penetration of the pulse is only mildly affected.

The introduction of molded underfill gave manufacturers the ability to simplify production processes: instead of first underfilling the flip chip, and then later perhaps overmolding it, they could accomplish both functions in a single operation. But it also meant that overmolded flip chips could no longer be imaged at the high frequencies used on bare chips.

The problem is in the encapsulant material. The materials used in molded underfill are more absorbing of ultrasound than the overmold that is applied to bare-silicon flip chips as a separate process after acoustic imaging. The

Figure 2. Sonoscan's AW system can image 200mm and 300mm wafers and find defects down to 5 microns in size

MUF material contains a polymer matrix that absorbs ultrasound, and filler particles that scatter ultrasound. Typically a lower acoustic frequency having lower resolution must be used to image flip chips having MUF.

In a flip chip having molded underfill, the ultrasound must travel twice - as a downward-moving pulse, and later as an upward-moving echo - through the encapsulant material on top of the silicon [Figure 1]. (The encapsulant material in the attachment layer, changed by the capillary flow process, is less absorbing than this layer.)

Sonoscan's laboratories have seen hundreds of molded underfill samples. Most can be imaged acoustically, generally with a lower-resolution transducer, but with good results. A few flip chips are encapsulated with an underfill material that is especially attenuating, but these can usually still be imaged with meaningful results, and have been very useful in giving clues about transducer design changes that can provide both good penetration and good resolution. A few mold compounds have proved to be so attenuating that meaningful details may not be observed.

Broadly speaking, however, considerable success has been achieved in finding methods to image molded underfill flip chips. In part, success has been a matter of designing a new transducer with the right parameters to image a given molded flip chip design. Sonoscan routinely designs and manufactures customized transducers to meet the specific requirements of customer parts of all kinds that need something other than a standard transducer. The company develops and produces all of its transducers above 50 MHz. Knowing how to turn out a transducer to meet given parameters has been useful in imaging molded underfill samples; in turn, these samples have provided new insights into transducer design.

Inspecting diverse 200mm and 300mm wafers

As of mid-2013, 300mm wafers are used in producing chips for Silicon on Insulator (SOI), Chip-on-Wafer, and Backside Illumination (BSI), the latter for camera applications. There are numerous applications for 200mm wafers. The most exciting may be MEMS applications, many of which use the 200mm diameter. The versatile nature of MEMS devices is evident in their recent use in medical sensing applications, including DNA sequencers.

As die sizes and feature sizes shrink, the critical dimensions of the structural defects such as cracks and bubbles also shrink. For 200mm and 300mm wafers today, acoustic micro imaging tools need two chief capabilities: high spatial resolution in the acoustic data collection process, and high throughput rate to image large numbers of high-population wafers. (In roughly four years, when 450mm wafers come on line, these capabilities will be even more important.)

To meet this challenge, Sonoscan has developed a multi-diameter automated wafer inspection system having multiple ultrasonic transducers and multiple stages. The AW system, shown in Figure 2, handles both 200mm and 300mm wafers. A single machine can have stages for both 200mm and 300mm wafers, and can image two wafers simultaneously. The system has a library of recipes for the various wafer types it may be required to image. It can operate as a stand-alone unit, or can be controlled by the host computer through its SECS/GEM interface.

Two wafers are scanned simultaneously on the system's two stages. A robotic arm unloads the wafers from one or more loadports containing FOUPs or other carriers. During the scanning process, the robotic arm performs other pre- and post-scan functions on individual wafers. These functions are designed to achieve maximum overall throughput.

The accelerometers, pressure sensors and other sensors made with MEMS technology typically have an internal cavity as well as a bondline around the cavity to ensure its hermeticity. The key interest is in the bondline, which may contain voids or channels that could leak and destroy the cavity's hermeticity. Even though the bondline on some newer MEMS designs is as thin as 6 microns, discontinuities and interruptions in the bondline are still imaged.

Figure 3 is the acoustic image of a portion of a bonded MEMS wafer. The dark regions are the bondline surrounding and sealing the cavity.

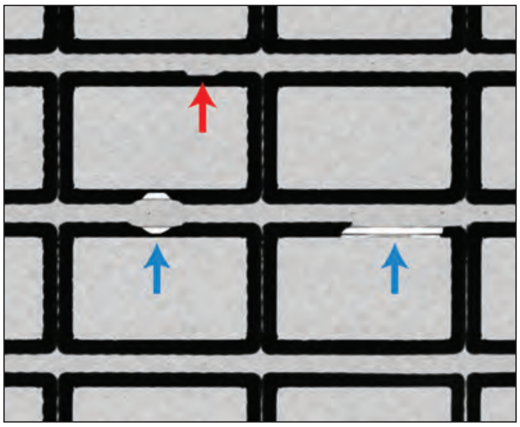

Figure 3. Acoustic image of a small area of a MEMS wafer. Blue arrows indicate separations of the bondline from the substrate; the red arrow points out thinning of the bondline

The blue arrows indicate areas where the seal is not bonded to one of its substrates - a condition that destroys the integrity of the cavity. The red arrows indicates an area where the bondline has been thinned laterally. There is no breach, but the bondline may be expected to be thinner and more vulnerable to stresses at this point.

Two new SEMI standards make it easier to evaluate the hermeticity of a MEMS bondline. SEMI MS8-0309 ("Guide to Evaluating Hermeticity of MEMS Packages") provides guidelines for evaluating bondline integrity with acoustic micro imaging. SEMI MS10-0912 ("Test Method to Measure Fluid Permeation Through MEMS Packaging Materials") describes how to measure the permeability of various bondline materials, and how to measure acoustically the thickness of a bondline to determine its long-term reliability.

Single wafers that will be used in SOI, BSI and other applications are sometimes imaged before bonding in order to spot surface cracks and subsurface damage. The ultrasound pulsed by the systems sends back return echoes from material interfaces. The strongest echoes are returned by the interface between a solid (silicon) and the air in a gap (meaning a crack, non-bond, void, bubble, etc.), even when the gap is as thin as 200Å. In a single polished wafer without metallization, such defects and anomalies are typically the only material interfaces within the bulk of the silicon.

Figure 4. Acoustic image of one portion of a direct bonded wafer pair shows size variation in the voids between the wafers

The defects most frequently imaged in wafers bonded for SOI and BSI applications are bubble-like voids, (Figure 4) contaminants or particles between the two wafers. A particle causes local upward curvature of one wafer; both bubbles and particles can cause the silicon above the defect to collapse during wafer thinning.

The contact bonding of these wafer pairs can also be evaluated earlier, after bonding but before annealing. Because the AW system uses a non-immersion system to couple the transducer to the wafer, there is reduced danger of water ingression between the wafers; unannealed wafers can thus be imaged and, if the contact bonding is not acceptable, separated and reprocessed.

300mm wafers for 2.5 D devices (including chip-on-wafer assemblies with interposers) are widely imaged on the AW system, and present their own challenges. The typical chip on wafer arrangement consists of a flip chip connected by its solder bumps to an interposer, which is in turn is connected by larger solder ball to the substrate.

The two layers of underfill tend to attenuate ultrasound, meaning that a lower frequency transducer is in order. Lower frequency means lower resolution, but the deeper solder balls are larger than the solder bumps above, and respond well to a lower frequency.

When an AW system has finished scanning a wafer, the output takes two forms: the quantitative data enumerating the anomaly/defect locations, and an acoustic image of the whole wafer. The acoustic image may be referred to, but it can hardly be viewed in its entirety because it displays defects down to 5 microns in size in a wafer that may be 300,000 microns in diameter.

Engineers may look at a specific region of the image because (for example) there is a history of the tool touching this region and causing contamination. If the quantitative data for a wafer type has previously proven to be reliable, that data alone is generally used as the guide for removal of defect die.