Checking for wafer-to-wafer bonding integrity

Detection of internal defects in bonded wafer pairs is vital to achieving anticipated yield and for long-term device reliability. Acoustic micro imaging provides you a non-destructive method for imaging and analyzing these defects.

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The use of wafer-to-wafer bonding, not only for silicon on insulator (SOI) applications but also for MEMS applications such as sensor building, is growing rapidly. With yield and device reliability issues a priority, you cannot afford to allow slips in the quality of the wafer-to-wafer bond.

Defects, which can exist between wafers, include voids and microvoids, as well as foreign particles and the voids or cracks associated with them. Owing to their thinness, and as the defects involve very little if any transport of material, they are difficult to detect with X-ray imaging. You could use infrared imaging, but the resolution of the image is limited by poor contrast, enabling only large defects to be seen. Acoustic micro-imaging is most suitable for two reasons:

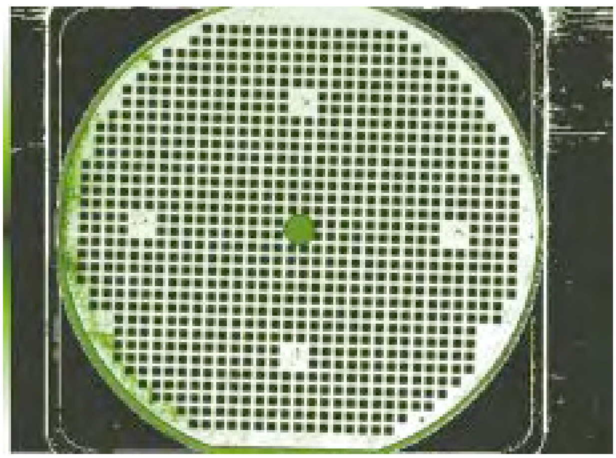

Figure 1: 50MHz acoustic image shows large number of microvoids (at left) between two wafers bonded by glass frit method.

- silicon wafers are nearly transparent to very high frequency ultrasound.
- the defects constitute "air gaps" which, whatever their thinness, have the property of reflecting all of the ultrasound which strikes them. They are acoustically opaque, while the silicon layers between which they lie are acoustically transparent.

Types of bonding

There are four general types of wafer-to-wafer bonding: direct wafer bonding (also called fusion bonding), eutectic bonding, glass-frit bonding, and anodic bonding. The last is used to bond glass to silicon. In direct wafer bonding, either hydrophobic or hydrophilic surfaces on the bulk wafers are pressed together and annealed at high temperature. Pressure at the center of one wafer creates a single bonding wave moving outward; multiple waves tend to create warpage and form voids. In eutectic bonding and glass-frit bonding a film of metal and glass, respectively, is applied before low-temperature treatment. Anodic bonding usually involves a silicon wafer and a glass wafer having a high percentage of alkali metals. Treatment creates electrostatic attraction between the two wafers, which are then bonded at temperatures ranging up to 500°C.

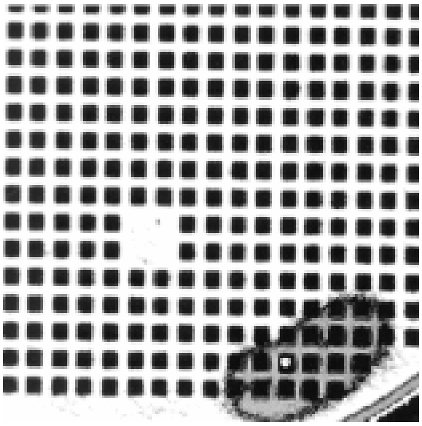

Figure 2: The dark oval in this 50MHz acoustic image is a large void between bonded wafers; the bright spot within the void is the particle, which created the void.

The reasons for bonding differ from application to application. SOI has as its goal the formation of a buried oxide layer that lowers the capacitance of transistors, and thus increases the speed of their operation while lowering power requirements. MEMs applications often involve the creation and protection of structural members such as accelerometers and turbines.

Types of defects

Where there is no intermediate layer such as metal or glass frit, a foreign particle can cause a void whose diameter is more or less in proportion to the height of the particle. In direct wafer bonding, a 1μm particle can result in a void as much as 1cm in diameter. However, in glass frit bonding, a similar particle might result in no void at all because the glass frit flows around the particle. If the dimensions of a foreign particle are large enough it can also cause a crack in one or both wafers.

Voids of widely varying sizes can also result from non-particulate surface contamination. In direct wafer bonding, contamination from ion implantation is a common source of contamination. Large voids may result from temperature variations during the bonding process. In SOI, voids can become direct electrical shorts to the substrate after the top wafer has been thinned. One inspection problem is that very small voids can be difficult to image optically.

Acoustic micro imaging of bonded wafers

The ultrasonic transducer used in acoustic micro imaging scans the area of the wafer in a grid. While scanning, the transducer switches several thousand times a second between its pulse and receive modes. In the pulse mode, it sends ultrasound ranging in frequency from 50MHz (generally the lowest frequency used for bonded wafers) to 230MHz into the wafer. The receive mode acquires the return echoes from the interior of the sample.

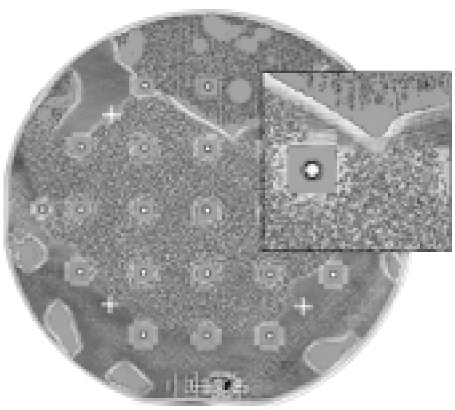

Figure 3: High-resolution 230MHz acoustic image of fusion-bonded wafers shows both large voids and areas of much smaller voids. Magnification of a portion of the image (inset) shows details of small voids.

Bulk silicon is transparent to ultrasound at these frequencies, with the result that essentially no echoes are returned from the bulk of the first wafer. However, when ultrasound encounters a well-bonded interface between two dissimilar materials, part of the ultrasound is reflected to the transducer, while the remainder travels deeper to be reflected by later interfaces. The intensity and polarity (positive or negative) of the reflection is governed by the acoustic impedance value of the two materials. Acoustic impedance is equal to the density of a material times its acoustic velocity. In successfully bonded wafers the interface between the two materials - which are, except in the case of anodic bonding, both silicon and therefore not dissimilar - may be nonexistent. Any defects that exist in the bonded wafers exist in an acoustically transparent medium.

Voids and similar defects are “gaps” filled with air or gas. Since very high frequency ultrasound will not travel through such gaps (the molecules are too far apart), the acoustic impedance of voids, cracks, delaminations and the like is always zero. This creates the strongest possible reflection. The thickness of the gap is unimportant; numerous comparisons of acoustic images and scanning electron micrographs have shown that gaps less than 0.1µm thick reflect all of the ultrasound. Total reflection of ultrasound from gaps, an important feature in imaging items such as IC packages, is even more important in imaging bonded wafers, where voids are by nature extremely thin.

Figure 1 is the 50MHz C-SAM acoustic image of a wafer pair bonded by the glass frit method. The purpose of bonding in this instance is to provide protection for the moving parts of a pressure sensor. Along the left edge of the wafers is a dense area of microvoids. The microvoids were probably caused by low temperatures during the bonding process. One of the dangers of microvoids in this application is that a microvoid may intersect and alter the controlled reference pressure on one side of the sensing diaphragm.

The action of a foreign particle is shown in the 50MHz image of a similar glass-frit wafer pair in **figure 2**. The particle (visible as a small bright spot) has created a void which is many times larger than the particle itself and which has interferred with the bonding of a fairly large number of devices.

Even in the same wafer pair, the size of voids can vary greatly. The recent introduction of higher resolution techniques in acoustic microimaging permits making acoustic images up to 8,000-by-8,000 pixels (the old standard was 512-by-512) while using the high-resolution 230MHz transducer. Although relatively large voids can comfortably be imaged at lower frequencies and at lower resolutions, the extra information provided by high resolution can be useful in diagnosis. **Figure 3** shows a fusion-bonded wafer pair with extensive defects. The bright red areas are voids. The finely mottled areas, however, are less easily diagnosed. Magnification of a portion of the image (inset) shows that the otherwise ambiguous mottled area actually consists of numerous, very small microvoids.

You can also choose to automate the acoustic imaging of bonded wafers. The unattended high-throughput production system developed by Sonoscan, whose first use was for JEDEC trays of packaged ICs, achieves its high speed in part by scanning each tray as though it were a single huge component. Image resolution for each component is maintained at laboratory-instrument levels, however. A similar tray holds two 6-inch bonded wafer pairs and images the bonding automatically.

It is vital that you identify internal defects in bonded wafer pairs to ensure long-term device reliability and to achieve anticipated yield. Acoustic micro imaging provides a nondestructive method for imaging and analyzing these defects. ●

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