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A new acoustic imaging process clearly identifies defects in bonded wafers.

One obscure, but most important detail in the acoustic imaging of bonded wafers is the way ultrasound behaves at various material interfaces. If two materials—say, silicon and an epoxy—are well bonded to each other, the percentage of the energy in the ultrasonic pulse that is reflected back to the transducer and used for imaging can be calculated from the properties of the two materials. But that energy percentage is likely to be in the mid-range of possible reflectivities; somewhere between 30% and 70%.

But if a gap exists between the two wafers, the pulsed ultrasound encounters an interface between a solid (such as silicon) and a non-solid (which might be a gas such as air or a vacuum). The acoustic properties of a solid and a gas (or vacuum) are so different that nearly all of the energy is reflected.

If the acoustic microscope is imaging two direct-bonded silicon wafers, the two solids may be identical. If they are truly bonded and there is no SOI layer, no interface may exist at all, and therefore no reflected energy to create pixels. But a gap between the two identical materials will still reflect virtually all of the ultrasound.

This detail of physics matters in the imaging of bonded wafers because the gaps (delaminations, disbands, voids and cracks) that can exist between two wafers are almost never harmless. They can be opened or expanded by later processing and destroy the wafers. During polishing, they can react so violently that both the wafers and the polishing plate are destroyed. Even if they are not exposed by processing, gaps are such powerful thermal barriers that they can easily cause circuitry to overheat and burn out.

In a MEMS device, gaps may exist anywhere within the thickness of the seal material surrounding the cavity, where they can cause leakage through the window seal and loss of the desired hermeticity in the cavity. If an SOI layer is underlying the MEMS device, gaps may also occur in the bond between the bottom silicon wafer and the sacrificial wafer.

The delaminations or non-bonded regions between wafer pairs can be exceedingly thin; much thinner than the types of gaps typically found, for example, in plastic IC packages. Fortunately for the imaging of bonded wafers, more than 99.99% of pulsed energy is reflected from a gap even where the gap's z-dimension is 0.01 micron (100 nanometers). Very likely, the
minimum z dimension is actually less than this.

Typically, bonded wafers are imaged acoustically after bonding but before later processing. At the wafer level, imaging at this point permits the removal of bonded wafer pairs that are too flawed to be economically processed beyond this step. At the device level, imaging identifies devices that should be discarded after dicing. Engineers engaged in new product development often use acoustic imaging to bring bonding processes from early stages where flaws are plentiful to mature stages where adequate yield is achievable.

After early development, the device level is more significant, because production may involve bonded wafer pairs in which a relatively small number of devices suffer from gap-type defects. These wafer pairs can be imaged manually, but the process is likely to be somewhat inefficient because the data obtained—the identity of defective devices—must somehow be retained and applied in the dicing process.

For this reason, new software has been developed that divides the acoustic image into numbered square ID cells. In many applications, the cell is identical to one die or one device. But where devices are not yet present on the wafer (as when imaging unpatterned direct-bonded silicon wafers), the cell grid may be arbitrary and will be used only in the acoustic image. Cell analysis can be used with laboratory C-SAM systems or during production with fully automated wafer C-SAM systems.

**Figure 1** is the acoustic image of a bonded pair of silicon wafers that have no patterning. The white features are voids between the wafers. They are bright white because of their very high ultrasonic reflectivity. Voids of various sizes are visible in the figure. But additional smaller voids exist, which are too small to be seen without greater magnification, but still capable of causing reliability problems.

**Figure 2** shows the grid that can be electronically overlaid onto the acoustic data in Figure 1. Because there is no patterning on the wafers, the cells are arbitrary.

**Figure 3** shows the overlay of the grid onto the acoustic image. Identified defects can now be located by cell number. The size of each defect can also be measured as a percentage of the area of the cell. The full range of defect sizes can be seen here. Cells 001/1 and 002/1 at the upper left share a large edge delamination. The void near the wafer edge at right lies outside any cell. A small but potentially significant defect is in cell 009/1. This defect is only visible (circle) in the inset at upper right.

The percentage of each cell area not covered by a defect is shown in **Figure 4**. The defect in cell 009/1 covers only 0.3% of the cell area, but the location of this defect could be critical.

**Figure 5** is the cell pattern used for a MEMS wafer pair, where each cell covers one MEMS device. The area of interest is typically the seal surrounding each device. The cavity itself is hermetically sealed and contains a vacuum or a gas. When ultrasound is focused on the interface between the overlying wafer and the cavity, the cavity is bright white, just like a void or other defect, because it is an empty gap.

The chief target when imaging MEMS devices is the window seal around each cavity. Seals can be formed of various materials, but they must be well bonded to both the substrate wafer and the cover wafer, and they must be free from internal gaps such as voids. If there are no defects in the window seal, the acoustic image will reveal a medium-gray feature whose width is constant. Each cell in the pattern used for MEMS devices matches a single device in the wafer pair.
Figure 4. Percent area of good bonding for some cells in Figure 3.

Figure 6 shows the results when the grid pattern is used with a MEMS wafer pair. In this portion of the total area, intact window seals are gray. The device indicated by 078/1 (circled) has a defect in the seal at the upper part of the device. This defect extends through the entire thickness of the seal. There are also defects in 079/1 and 070/9 to the left of the circle, where the width of the seal is compromised.

Figure 7 is the acoustic image of two direct-bonded wafers where the top wafer has been patterned. No cell grid was used during imaging, in part because the wafers were in an early stage of development. The two large red circles are voids between the two wafers, perhaps caused by particles. (The color map used here displayed high-reflectivity defects in red.) Because the voids are below the patterned top surface, the patterning is visible in front of the voids.

**Conclusion**

Numerous small red areas are also scattered across the image. These may be small cracks in the fragile, porous low-k dielectric material underlying the traces. Some locations appear to be free from cracks, but the numerous apparent defects suggest that the processing of the low-k dielectric material may need refinement.

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