Management of Voids in Processing of Bonded Wafers

Dr. Shari Farrens, Chief Scientist, EV Group Inc.
Dr. Lawrence W. Kessler, President, Sonoscan, Inc.

Abstract

This paper discusses the origination and detection of bonding voids in silicon wafer pairs.

Contact information:

Sonoscan, Inc.
2149 E. Pratt Boulevard
Elk Grove Village, IL USA 60007
Phone: 847 437-6400
Fax: 847 437-1550
E-mail: info@sonosan.com
www.sonoscan.com

EV Group
1210 Pontiac Avenue
Cranston, RI USA 02920
Phone: 401 784-0008
Fax: 401 784-9933
E-mail: sales@evgroup.com
www.evgroup.com

(Submitted for publication.)

The projected growth of the MEMS market to 60 billion US$ by 2005 makes Microsystems one of the fastest growth markets in the semiconductor sector. To quote Marc Madou from "Fundamentals of Microfabrications," "Hardly any microdevice has been fabricated without making use of some type of wafer bonding or cavity sealing." Hence, high volume manufacturing equipment must meet and exceed the exacting specifications of the present market. Most important is the prevention of voids (unbonded regions) at the interface since voids lead to product failure.

Void prevention is accomplished with sophisticated point-of-use cleaning stations, controlled bond chamber environments, and Class 1 mini-environments. In-process monitoring of voids is critical to identifying and eliminating the source of voids. Most voids are caused by issues upstream from the bonding process. These include particles from etching systems, implantations, and CVD steps. Failed photolithography steps can also lead to surface features that are not bondable. Understanding of the void morphologies and consequences can help to eliminate voids and achieve high yields. A diagram illustrating typical voids shown in Figure 1.

Once voids have been removed from the entire process flow, acoustic imaging of critical areas such as trench corners in bulk micromachined parts or joints in surface micromachined parts can be very useful for improvements to corner compensation design and hinge designs.

Particles of Si or SiO_2 are probably the most frequent causes of voids. The diameter of the void can be quite large. One rule of thumb is that the diameter of the void is about 40 times the effective diameter of the particle. Particle-derived voids are thought to be circular or nearly circular in x-y profile. Contamination-related voids are caused by the residue of various fluids, probably originally deposited as aerosols. The profiles of these voids tend to be irregular. Voids caused by warping or bowing of a wafer are often very large and have a shape determined by the pattern of distortion.

In BGSOI (Bond and Grind Back SOI) processing, one wafer is thinned by chemical-mechanical polishing (CMP) after annealing has permanently bonded the wafers. Voids between the annealed wafers usually go unnoticed unless they are detected by infrared (IR) microscopy or by acoustic microscopy. As CMP grinding proceeds, the material covering the void is broken through and removed. Quite often shear forces also remove material surrounding the void as

well, because bonding in the areas immediately surrounding the void may be weak. Uncovering a void in this fashion also produces an abrupt change in the in situ monitoring of wafer thickness, and causes grinding to stop prematurely.

During the polishing stage of CMP, the material covering a void will be broken through by the shear forces of the polishing pad. The slurry used in polishing is designed to soften the surface of the wafer, and enhances the break-through process. Delamination and flaking of the material covering the void, and of material adjacent to the void, quickly contaminates the polishing pad. If the pad is not replaced - a time-consuming operation - debris from the void will scratch and contaminate subsequent wafers.

A void remaining after CMP may cause failures during subsequent processing steps. A void that has not yet been broken through may be exposed by the creation of a via or a trench. Both dry and wet etches are most active against a weak interface, with the result that undercutting of the void wall - the original wafer-to-wafer interface - can begin as soon as the void is exposed.

Voids are particularly dangerous during oxidation of the thinned wafer. A void at this stage may already have been broken through, or is opened during the oxidation process. The insidious consequence is that oxide grows both on the device layer and at the interface exposed by the void. As a result the device layer is typically forced upward and forward to form a "bird's beak." These unwanted structures have a tendency to fracture and flake into the oxidation tube, causing severe particle contamination. A single bird's beak can cause the tube to be shut down for cleaning or replacement. Flaking of voids sometimes occurs as well during megasonic cleaning baths and, though less frequently, during ultrasonic cleaning.

In some instances a void may not be broken through, but its thin top layer may bulge upward. The bulge can cause resolution distortion during contact or proximity photolithography, and can also impact spin-on processes such as applying SOG or photoresist.
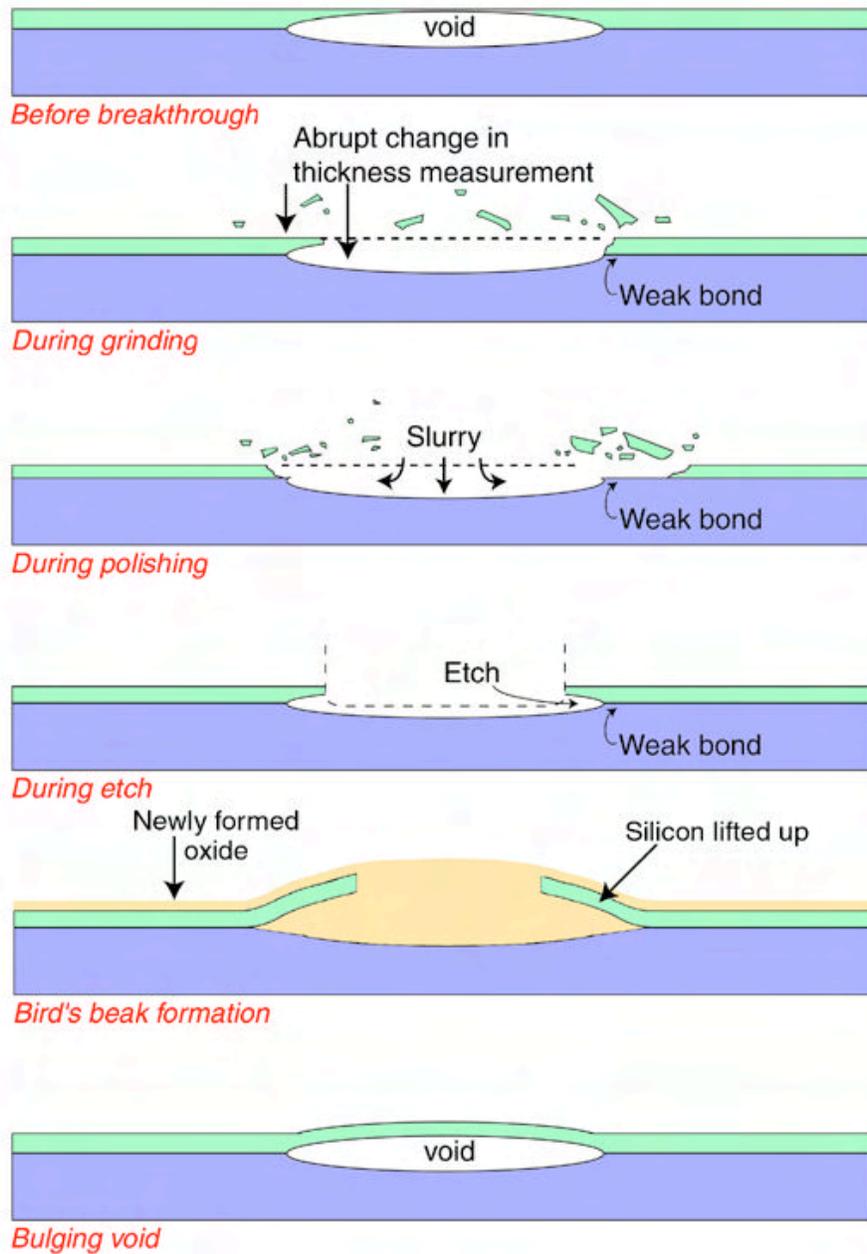
Figure 1 - Entrapment of a void during wafer bonding causes various failures in later processing, depending on the stage at which the void is broken through. A void which survives until oxide formation may cause growth of oxide both on the intended surface and within the void, causing lifting of the silicon layer. A void that survives beyond this point may bulge upward and interfere with photolithography or spin-on processes.

The thickness of a void is defined as the vertical dimension of the gap created between the two wafers. Although thickness is seldom measured, it has some impact on the subsequent history of the void (i.e., thicker voids are uncovered more quickly during grinding), and has considerable impact on methods used to detect voids. Infrared microscopy takes advantage of silicon's transparency to wavelengths around 1070 nm, and reveals voids by the interference of diffracted light at the interface. The resulting visible light and dark rings occur only when the void is at least 0.5 micron thick. Such a void would display a single ring; a void 1.5 microns thick would display a triple ring. Voids less than 0.5 micron thick are not imaged by IR microscopy. IR imaging is further hampered by the presence of metallization layers, and by the resistivity of the material, which must not be lower than approximately 0.01 ohm/cm.

Void measurement is far more sensitive when voids are detected by acoustic micro imaging. In acoustic terms, a void represents a layer of material whose acoustic impedance differs very sharply from the values of the overlying and underlying materials. This sharp difference means that a pulsed beam of ultrasound is reflected at near 100% intensity. No one has detected the lower limit of the gap thickness that will produce this degree of reflection, but recent research has shown that this value is less than 100 nm and is likely closer to 100Å, or even less. Silicon itself is virtually transparent to the ultra-high frequency ultrasound (typically 230 MHz or higher) used to image bonded wafers. The result of the high transparency of silicon and the high reflectivity even of extremely thin voids translates into high contrast in the acoustic imaging of voids as shown in Figure 2. Since voids may be formed by particles of varying diameters as well as by the residue of fluid contamination, void thicknesses cover a wide range, but all voids appear to have a thickness above the minimum thickness for maximum ultrasonic reflectivity. The high transparency of silicon means that a silicon-silicon interface has very little or no reflectivity because the two components of the interface are identical and are in intimate contact. One consequence of this phenomenon is that bonded stacks of more than two wafers (six wafers, in one case) can also be imaged acoustically.

The value of void detection is twofold: defective wafer pairs are removed from further processing,

Figure 2 - Nondestructive acoustic imaging of voids between two bonded wafers. Void size varies greatly, depending on the cuase of the void and, if caused by a particle, the diameter of the particle. (Acoustic image courtesy of Sonoscan, Inc.)

and monitoring of voids reveals problems (particle dispersal, wafer bowing) that may require corrective action. In most instances, wafer pairs are imaged after bonding is completed; i.e., after annealing or another irreversible bonding process. Direct bonding, however, is initiated by light bonding of the wafers, which are temporarily held together only by weaker van der Waals forces. Automated acoustic imaging has been used after initial light bonding, and before annealing, to identify voids. At this stage wafer pairs having voids can be separated and re-cleaned to remove the particles or residue causing the voids, and can be re-bonded. Figure 3 shows a void free wafer pair.
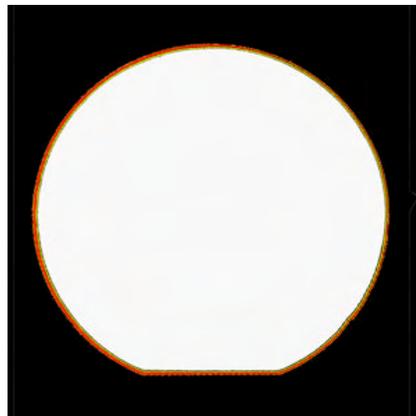

Figure 3 - Acoustic imaging is useful in monitoring the success of cleaning and bonding operations. This wafer is free from voids. (Acoustic image courtesy of Sonoscan, Inc.)

Automated acoustic imaging is basically a high-resolution, high-throughput operation, but is adjustable within a range of frequencies and resolutions. Normal production screening typically uses moderate resolution that will image voids having diameters of roughly 50 microns or more. For occasional process monitoring, the highest resolution is used. Resolution at this level images voids as small as 5 microns in diameter, but takes somewhat longer. Although voids of 5 microns might not in themselves be significant, their presence may point to processes that are drifting out of control and will produce much larger voids.

High volume production yields are obtained by monitoring the void size, void distribution, and frequency of void occurrence within the process flow.

Production bonding tools that are designed to work in concert with other tools in the fabrication steps help to eliminate void yield loss by removing contamination and particles that may remain after previous batch processing such as etching, implantation, or wet cleaning. These tools include brush cleaning stations (Figure 4) that can be used to scrub wafer surfaces prior to bonding. For best results the cleaning station is equipped with up to two dilute chemical dispense systems, hot or cold DI ringing, and megasonic point of use cleaning (Figure 5).

A complete automated production wafer bonder is shown in Figure 6.
.
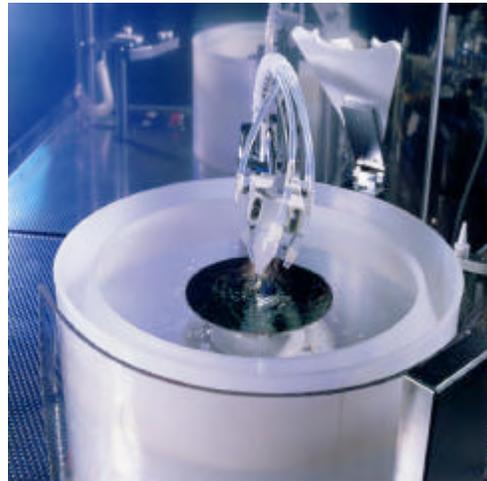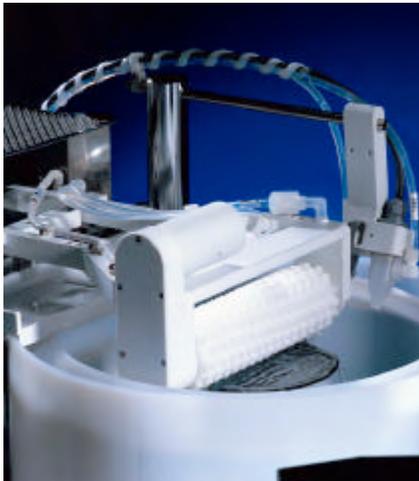
Figures 4 and 5 -   Point-of-use cleaning stations remove last-minute particles and contamination that might impair bond yields. Left: PVA brush unit. Right: Megasonic rinse and chemical dispense arm. [Photos courtesy EV Group, Inc.)

Figure 6 - EVG Gemini automated production wafer bonder. Alignment capabilities include options for bottom side, IR, and Smart View (face to face) alignment. Bonding options range from anodic and thermal compression to SOI. [Photo courtesy EV Group Inc.]

###