SEMI 3D13-0715
GUIDE FOR MEASURING VOIDS IN BONDED WAFER STACKS

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1 Purpose

1.1 This Guide will assist users in selection and use of bond-void metrology equipment and a protocol for performing bond-void measurements based on their application. New bonding processes and applications are sensitive to significantly smaller voids than bonding processes currently used for 3DS-IC package sealing.

2 Scope

2.1 This Guide is based on experimental data on 300-mm diameter silicon wafer pairs. The inspection and metrology tools covered include only commercial instruments available in the 2012–2014 time frame. The wafer bonding technique used was oxide bonding. The experimental data were provided by volunteer participants in this study and have not been independently verified.

2.2 This Guide covers the purpose and results of the experimental study. Detailed explanation of the principles of operation and construction of the instruments used is beyond the scope of this Guide.

2.3 The potential and actual effects of bond voids on the performance and reliability of fabricated devices are beyond the scope of this Guide.

2.4 The scope of this study does not extend to recommendations as to which techniques may be less or more appropriate for particular manufacturing processes, and no such recommendations are provided herein.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This Guide is directly relevant only to the specific materials studied, at the time frame of the experimental study, and to the instruments used by the contributors. As a result of the specimen production process, the bond voids in the specimens used here did not have strong stress fields surrounding them, as might be the case for voids occurring in the manufacture of production devices. Therefore, the present specimens are not appropriate for evaluating measurement techniques that rely on local stress fields. The voids used here were located in arrays of same-sized and same-spaced voids. This may have created interference effects in the signals detected from these arrays. No foreign materials were introduced in the neighborhood of the voids, therefore the present specimens are not appropriate for evaluating techniques that rely on detecting the presence of materials different from silicon. The voids in the present study had flat surfaces parallel to the faces of the bonded wafers. Reflections of probes such as ultrasound or infrared light may be influenced by these flat surfaces.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI 3D4 — Guide for Metrology for Measuring Thickness, Total Thickness Variation (TTV), Warp/Sori, and Flatness of Bonded Wafer Stacks

SEMI M1 — Specifications for Polished Single Crystal Silicon Wafers

4.2 *Other Documents*

SEMI AUX032 — Report on Round Robin Experiment on Bond Void Measurement

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

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5 Terminology

5.1 *Abbreviations and Acronyms*

5.1.1 *BWP* — bonded wafer pair

5.1.2 *IR* — infrared

5.2 *Definitions*

5.2.1 *cap wafer* — standard wafer, oxidized, to be incorporated into a bonded wafer pair.

5.2.2 *oxide bonding process* — process of applying heat and pressure to a pair of oxidized wafers placed surface-to-surface, with no other material placed between them, to produce a mechanical bond between the wafers.

5.2.3 *void wafer* — wafer with recesses etched into the surface, to produce voids in the bond when incorporated in a bonded wafer pair. The void wafers used in this study were oxidized after etching the recesses.

6 Specimens

6.1 *Design of the Experimental Study* — Participants were invited to inspect supplied bonded-wafer pair (BWP) and measure the voids using the equipment of their choice. A report form requested the key data on presence, location, in-plane size, and severity or depth was provided. Bond voids were created by etching square wells in the void wafer of each BWP. Each participant received a set of four BWP test vehicles to be inspected. Each test vehicle contained two standard thickness 300-mm silicon wafers bonded using an oxide bonding process. In each BWP, the cap wafer was unpatterned; the void wafer was patterned with voids from 0.5-µm to 300-µm wide, and void thicknesses of 4–15 (specimens varied), 400, 900, and 1200 nm. Three different void patterns were used: dense, semidense, and isolated.

6.1.1 *Artificial Bond Voids* — The design of the artificial bond voids is indicated in Figures 1 through 3. Within the actual specimens, four different void depths, on separate wafers, were used.

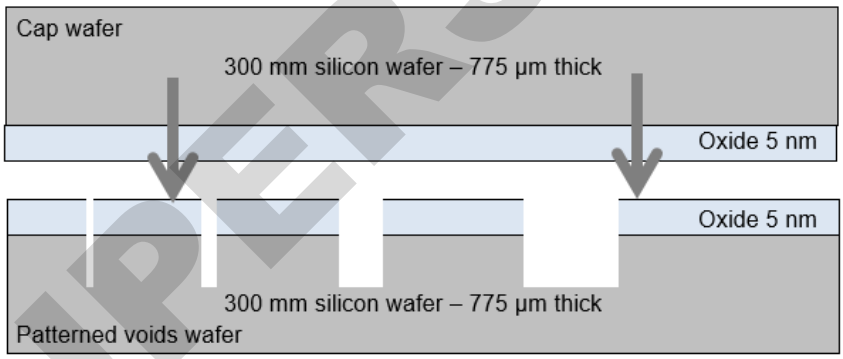

Figure 1
Schematic Diagram Showing the Etched Wells Used to Produce Voids at the Bonded Interface Between Two Wafers

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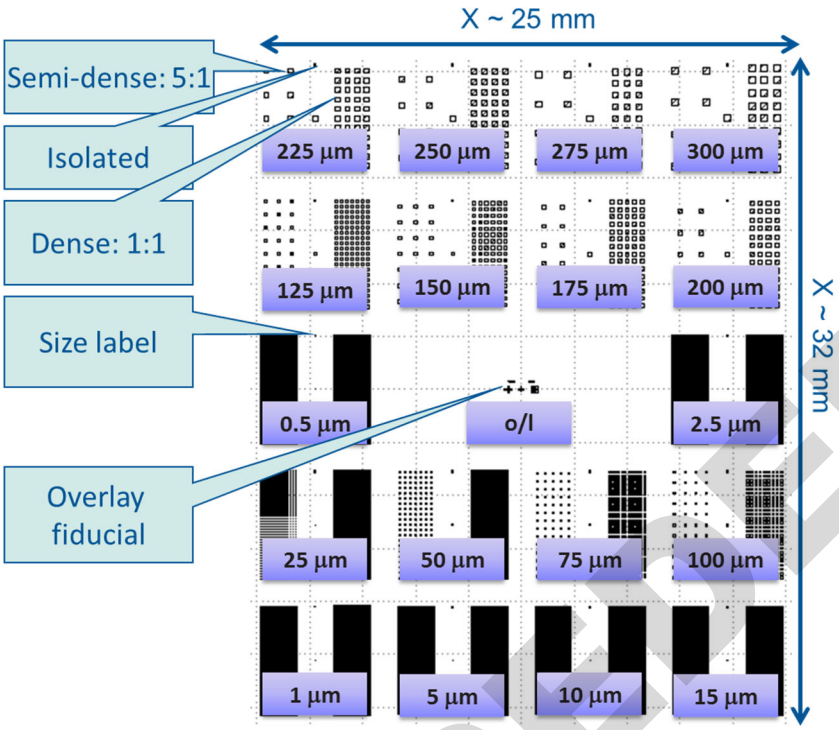

Figure 2
Layout of the Voids of Different Sizes and Densities in Die-Sized Arrays

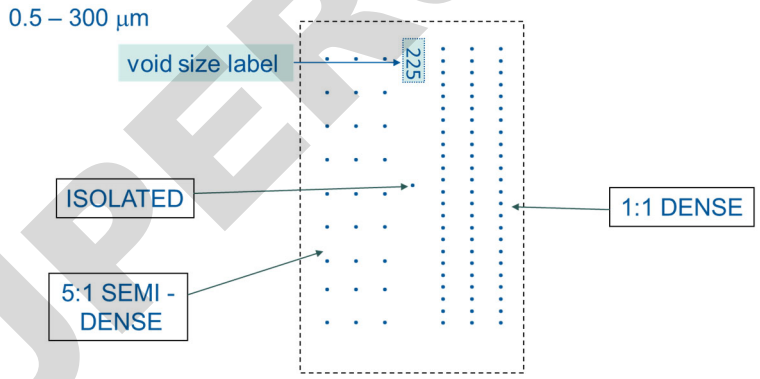

Figure 3
Details of the Arrangement of Artificial Voids at Different Densities

6.1.2 *Data Reporting* — See Note 1.

NOTE 1: The protocol supplied to each of the participants is attached to this Document as Related Information 1. It describes the specimens and their markings. The guidance to the participants placed an emphasis on quantitative results, particularly how void detectability depended on void size and on capability for measurement of void sizes.

7 Principles of operation of Inspection and Metrology Tools Relevant to Bond Voids

7.1 *Ultrasonic Techniques* — Ultrasonic inspection techniques have been adapted to survey the interface of a bonded wafer pair. In a technique called resonance ultrasonic inspection, vibrations in the 20 kHz to 100 kHz frequency range are induced in the bonded wafer pair. A second acoustic transducer monitors the frequency response. Differences in the frequency response between a void-free bonded pair and a bonded pair under inspection can indicate the presence

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of bond voids. In scanning acoustic microscopy, a single transducer both serves as the source of the signal and measures the reflected return signal. Differences in acoustic impedance at interfaces between different materials cause reflections; since air (i.e., a flat free surface) reflects 100% of the acoustic signal, the strongest reflected signals are generated by voids between wafers. The presence and size of voids can thus be determined. The propagation characteristics of ultrasonic sound depend strongly on the frequency of the sound waves, which is determined by the transducer that produces the signal. Lower frequencies propagate deeper into the wafer while higher frequencies can give better spatial resolution. The transducers used for acoustic microscopy typically have a resonant frequency somewhere between 5 MHz and 500 MHz. Since ultrasound does not propagate through air at any of the frequencies used for these inspections, a coupling fluid—typically deionized water—is used to interface the transducer and the wafer pair.

7.2 *Infrared (IR) Techniques* — A variety of techniques that utilize IR light have been developed for detection and characterization of voids, as silicon wafers are transparent to light with wavelengths longer than approximately 1 µm. Conventional IR microscopy instruments have a field of view much smaller than the full 300-mm diameter of a wafer. Full-wafer IR examination has also been applied. The IR instruments can be further split into those that identify inhomogeneities by direct measurement and those that use interferometry. IR microscopy can be used to measure the amount of light either transmitted or reflected by the bond interface; since voids tend to reflect a significant portion of the light, voids can be readily identified. As with all microscopes, a lower limit on resolution is around the order of the wavelength of the light source. Whole wafer IR uses transmitted light to capture an image of the wafer; it can be used to identify voids no smaller than approximately 50% of the size of a single pixel of the imaging system, which is typically on the order of 50 µm. Infrared interferometry can be used to create an image of the interface between the BWP. An additional IR tool, the grey-field polariscope, captures the polarization of IR light transmitted by a bonded wafer pair. This tool has been reported to be useful for identifying voids between wafers. However, because the programmed voids used in this experiment do not produce stress between the wafers, and because observable polarization effects depend on stresses, this observation was not sensitive to the voids used in this experiment.

7.3 *X-Ray Technique* — X-ray tomography has been considered as a possible technique for detecting and characterizing wafer bond voids. However, tomography depends on contrast between the different materials that make up the specimen. The silicon wafers used in this experiment are virtually transparent to X-rays and the voids were not distinguishable to a useful degree.

8 Results

8.1 *Qualitative Results* — Techniques applied by some of the contributing laboratories were capable of producing qualitative results only. These included full-wafer ultrasonic resonance and IR interferometry.

8.1.1 *Full-Wafer Ultrasonic Resonance* — The contributing laboratory concluded that this technique indicated the presence of voids in the specimen wafers with 800-nm and 1200-nm deep voids.

8.1.2 *IR Interferometry Scanning* — The contributing laboratory used an instrument with a spot size of 50 µm. Their experimental result was an image of the BWP interface showing the presence of voids.

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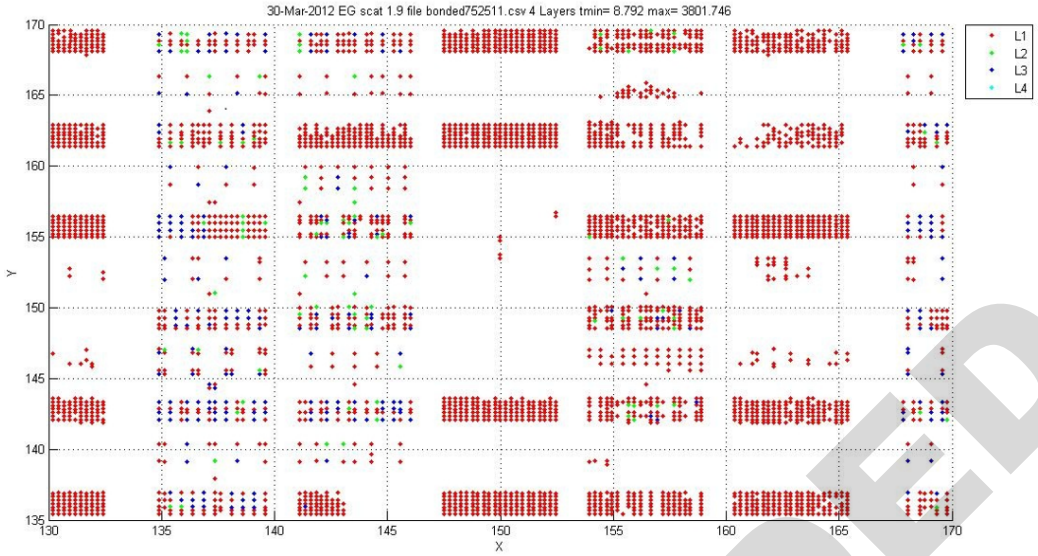

Figure 4
Result of IR Interferometry Scanning of One Die on a Bond Void Specimen Wafer

8.2 *Quantitative Results* — Quantitative results for void detection, location, and size measurement were reported by several laboratories.

8.2.1 *IR Microscopy* — Two laboratories applied IR microscopy to measure the bond voids in the supplied specimen wafers.

8.2.1.1 *IR Microscopy, Lab 3* — Laboratory 3 examined all four wafers with an instrument setting of a pixel size of 8 µm and reported quantitative results for detection, location, and void size measurement. This technique produced clear images of many of the voids, as shown in Figure 5.

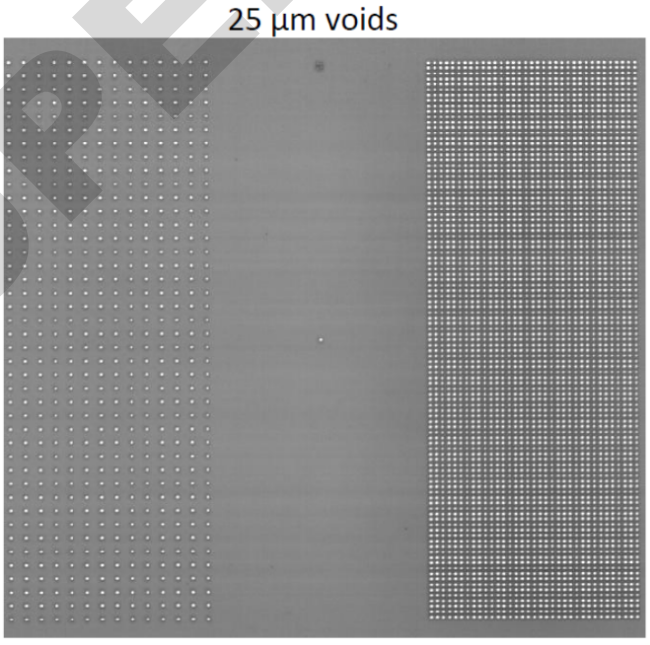

Figure 5
IR Microscopy Image of 25-µm Wide, 1200-nm Thick Voids

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8.2.1.1.1 Results for void detection by this technique are summarized in the following two tables.

Table 1 Results from Laboratory 3 on Minimum Void Sizes for Which Presence was Detected Using 8-µm per Pixel Resolution, µm

Void Thickness, nm	*Void Densities*		
	Isolated	*Semidense*	*Dense*
40	10	10	15
400	2.5	5	15
800	2.5	5	15
1200	2.5	5	5

Table 2 Results from Laboratory 3 on Minimum Void Sizes for Which Presence was Detected Using 0.8-µm per Pixel Resolution, µm

Void Thickness, nm	*Void Densities*		
	Isolated	*Semidense*	*Dense*
800	0.5	0.5	2.5

8.2.1.1.2 Void sizing results are shown in the following three plots.

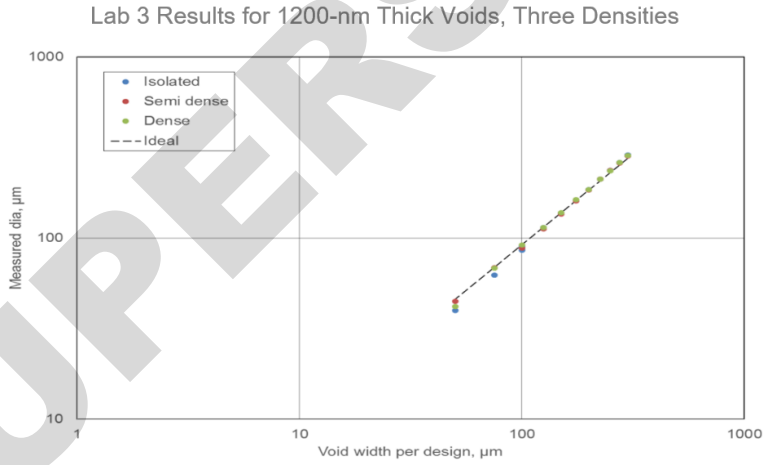

Figure 6
Plot Showing Lab 3 Void Size Measurement Results for 1200-nm Thick Voids of Three Densities

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