INFRARED STRUCTURED ILLUMINATION MICROSCOPY FOR BONDED WAFER INTERFACE INSPECTION AND METROLOGY

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Abstract

Wafer bonding is a fundamental process in 3D integration and advanced packaging. This paper presents an infrared structured illumination microscopy (IR SIM) approach that combines infrared light penetration of silicon with optical sectioning for non-destructive inspection and metrology of bonded wafer interfaces. The method has been developed for the detection of defects and delamination, in addition to the 3D measurement of voids and buried structures with sub-micron precision. In contrast to conventional IR and acoustic microscopy, IR SIM has the capacity to reconstruct true three-dimensional information and to provide a non-destructive cross-sectioning view of the entire wafer stack, with particular focus on the bonding interface.

Introduction

Wafer bonding is essential for 3D integration, MEMS, and advanced packaging, where interface integrity determines mechanical stability and electrical performance. Non-destructive metrology techniques are crucial to detect voids, delamination, and other defects. Infrared (IR) microscopy offers rapid through-silicon imaging but provides mainly qualitative information, with lateral resolution limited to a few micrometers by the IR wavelength. Scanning Acoustic Microscopy (SAM) and its confocal variant (C-SAM) complement optical methods through acoustic impedance contrast, detecting delamination and voids with high sensitivity. However, SAM typically offers two-dimensional imaging and limited depth quantification, while C-SAM improves layer discrimination at the expense of penetration depth and acquisition time. Furthermore, acoustic techniques require sample preparation, unlike IR. Infrared Structured Illumination Microscopy (IR-SIM) overcomes these limitations by combining IR penetration with optical sectioning and quantitative 3D reconstruction, enabling high-resolution, non-destructive visualization of the entire bonded wafer stack.

Measurement Principle

Infrared Structured Illumination Microscopy (IR-SIM) extends the concept of optical structured illumination into the infrared spectral range to enable through-silicon, depth-resolved imaging [1]. The method projects sinusoidal illumination patterns onto the sample and records two phase-shifted images, which are computationally demodulated to isolate the in-focus signal and suppress out-of-focus light, achieving optical sectioning with nanometer-scale precision. The IR-SIM approach used in this work is based on the patented Confovis structured illumination principle. Phase shifts are generated optically without mechanical movement, allowing rapid, stable acquisition. A one-time calibration compensates for optical distortion and chromatic effects, ensuring accurate three-dimensional reconstruction. Using infrared wavelengths, IR-SIM penetrates silicon, enabling non-destructive 3D visualization of buried interfaces. The Confovis implementation combines height determination with large-area

scanning and stitching, providing quantitative topography and contrast maps of full wafers directly at the bonding interface.

Results and Discussion

Measurements on Si–Si bonded wafers demonstrated the ability of IR-SIM to image voids, delamination, and bonding non-uniformities at the interface. Optical sectioning enabled clear separation of surface and interface signals and quantitative defect analysis (see Fig. 1). Compared with conventional IR microscopy, IR-SIM provided higher spatial resolution and improved contrast by suppressing background scattering and reflections. In comparison to SAM and C-SAM, IR-SIM offered complementary information. While acoustic methods are sensitive to impedance discontinuities, they lack quantitative depth data and suffer from attenuation in complex stacks. On the other hand, IR-SIM provides volumetric optical data that reveal the three-dimensional morphology of the bonding interface without requiring coupling media or contact with the sample (see Fig. 2).

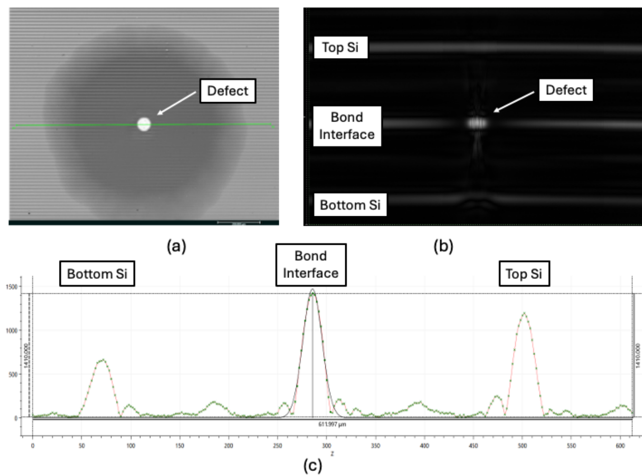

Figure 1: (a) IR SIM top view of a defect and void at the Si-Si bond interface. (b) Cross-sectioning view of bonded Si wafers with a defect at the interface. (c) Pixel view of the wafer stack. The 3 peaks correspond to the Air-Si transition of the bottom wafer, bond interface, and Si-Air transition of the top wafer from left to right.

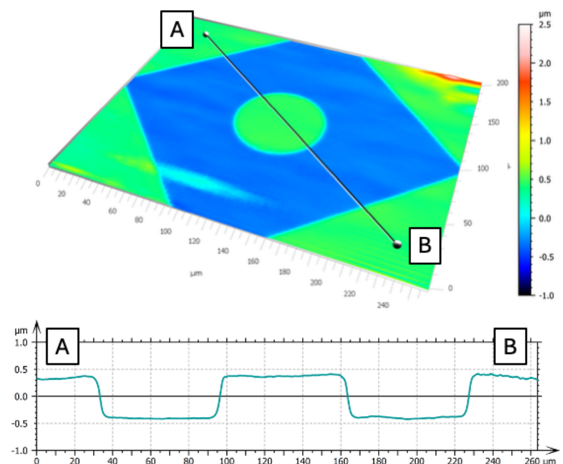

Figure 2: (Top) 3D rendering of a square cavity with a round pillar at the bonding interface of 2 silicon wafers. (Bottom) 2D measurement of the cavity and pillar along the line A-B.

Conclusions

Infrared Structured Illumination Microscopy (IR-SIM) provides a non-destructive and quantitative method for bonded wafer inspection. Combining infrared penetration with structured illumination enables detailed 3D visualization of buried bonding layers with sub-micrometer resolution providing additional information with respect to IR microscopy and SAM-based techniques.

References

[1] M. Schwertner, “Method and Device for the Optical Measurement of the Surface of an Object,” US Patent US 7,977,625 B2, Jul. 12, 2011.