Novel optical-signal acquisition method addresses grand challenges for silicon technology

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The superior image definition and nondestructive testing technology provided by optical-coherence tomography targets the characterization issues posed by nanometer-scale devices.

The UK’s Engineering and Physical Sciences Research Council’s recent consultation exercise\(^1\) reinforced the belief that future silicon technology will be advanced by new and evolving characterization techniques. Among the grand challenges identified are the development and implementation of nanometer-scale features, 3D structures, and manufacturing quality. The developing market for microelectromechanical systems (MEMS)—which integrate mechanical elements, sensors, actuators, and electronics on a common silicon substrate—provides a proof statement. Driven by the demand for smaller, cheaper, more versatile, and more reliable integrated devices, the MEMS-fabrication industry suffers from a lack of rapid nondestructive high-resolution instruments to measure the layer thickness of MEMS wafers in situ immediately after fabrication. This is especially important as the MEMS packaging process can account for around 90% of the cost,\(^2\) and early detection of irregularities would eliminate substantial expense.

To date, scanning-electron microscopy (SEM) and contact probes have been the primary tools used for MEMS quality control and quality assurance. However, although SEM provides sufficient imaging resolution of wafer surfaces, preparation is slow and destructive, while examination of subsurface layers and hidden volumes is restricted. In addition, using contact probes is limited to the surface layer.

A report from the UK’s National Physical Laboratory\(^3\) (NPL) summarized the requirements for an ideal instrument to measure wafer thickness. It suggested such devices should use a single-sided approach, have a vertical resolution of $<1\mu m$ and a lateral resolution of approximately $10\mu m$, a depth range $>200\mu m$, a scan speed suitable for industrial application, and be silicon compatible. In addition, the report identified that other measurement challenges—such as defect detection and high-aspect-ratio structures (HARS)—must be addressed.

We have identified optical-coherence tomography (OCT) as meeting many key requirements for MEMS characterization. As an interferometric optical-signal acquisition and processing method it can deliver noninvasive subsurface images of translucent or opaque materials at a resolution equivalent to that of an optical microscope. This is done by projecting a laser into the sample and collecting reflected light. Although most of the light is scattered on its way back to the surface, enough is detected by an optical interferometer. The latter uses depth and intensity information to generate an image.

OCT has thus far attracted interest from the medical community where—operating as an ‘optical ultrasound’—it provides tissue-morphology visualization at a much higher resolution (approximately $20\mu m$) than medical-resonance

Continued on next page
imaging or ultrasound. However, the key benefits of OCT are applicable to both organic tissue samples and inorganic materials such as silicon. These include real-time subsurface image acquisition to a depth of 1–2mm at near-microscopic resolution, as well as noninvasive, nondestructive operation with no need for specimen preparation, instant and direct imaging of specimen morphology, and the requirement for only one-sided specimen access. These match the NPL-identified requirements very closely. The principal difference is resolution, both vertical and lateral.

We have tackled the lateral-resolution issue by the adoption of a unique patented multibeam optical design that delivers OCT images at unprecedented resolution (see Figure 1). Compared to single-beam instruments that are limited to a focus of no better than 20µm over a depth of focus of 1mm using a 1300nm-wavelength laser beam, our microscope uses four laser beams, each focused at a different depth. The beams can be brought to a lateral focus of better than 10µm over a depth of focus of 0.25mm each, providing a total focal range of 1mm (see Figure 2).

There are several ways to improve resolution to better than 1µm. First, the refractive index of silicon is about 3. Because OCT is an interferometric technique, it measures optical-path length. Therefore, resolution is inversely proportional to refractive index, an important advantage. Second, OCT is fast. Many measurements can be taken, and a number of numerical approaches might be used to achieve subpixel resolution. For example, Richard Leach (principal scientist at NPL) believes that “using nonlinear inversion techniques shows strong promise in the quest for submicron resolution and should allow the capture of surface features such as HARS, not currently measurable due to the numerical apertures of OCT instruments.” These approaches are under investigation and show considerable promise. OCT imaging could also be highly useful to the precision-plastic-parts industry. Like silicon, OCT can penetrate poly(methyl methacrylate) (PMMA) and other plastics to provide subsurface high-precision measurements.

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Jon Holmes brought several successful imaging products to market as business director of the biomedical group at the instrumentation research and development company Sira. He was also director of the Smart Optics Faraday Partnership, the predecessor of the Photonics Knowledge Transfer Network. Having identified the opportunity for multibeam OCT, he recruited a high-caliber team and developed a vision and strategy for Michelson Diagnostics.

**References**