Infrared Laser Confocal Microscopy: Fast, Flexible, Cost-Effective Inspection and Metrology Tool for Microelectronic Manufacturing

David Rideout
Olympus Micro-Imaging Orangeburg, NY.
david.rideout@olympusindustrial.com

Microelectronics and semiconductor wafer manufacturing are among the fastest evolving technology industries today. Wafer sizes typically are 200 mm to 300 mm while critical dimensions are shrinking to 0.09 µm and smaller. As the size of discrete devices continues to be reduced while device density increases, the need for fast, accurate, flexible metrology and inspection tools in the microelectronics industry grows.

The evolution of inspection

Back in the early 1980's, semiconductor inspection was performed primarily by brightfield optical microscopes and with automated detection tools. The adaptation of automated detection tools led to the systematic control of increasingly smaller defects. The smallest detectable defect using these automated tools fell to below the 0.30-micron mark during the 1990's.

As semiconductor design rules decreased it pushed the requirements for defect inspection into the domain of the Scanning Electron Microscope (SEM). These instruments easily resolved defects of 0.25 µm and smaller. However, the increase in resolution came at a price in speed and flexibility. SEM inspection took longer due to sample preparation and pumping down the vacuum chamber. The delay in the manufacturing environment was often too long. As a result a bridge tool was developed that was based on confocal imaging.

The older confocal imaging microscope provided many of the speed advantages and ease-of-use capabilities found on the standard optical microscope. However, the new advantage was the ability to create 3D images based on the unique confocal imaging technique that enables image slices to be stacked, creating high contrast images and improved resolution down to 0.18 microns at a wavelength of 450 nm.

As the push towards the current state-of-the-art semiconductors continued, even this fast and efficient confocal technology was not enough and the most demanding users were forced to resort to the current generation of powerful SEM inspection tools and laser based confocal microscopes with 408nm lasers. And at every stage of semiconductor technology development, there was always a need to see inside the complex devices being created.

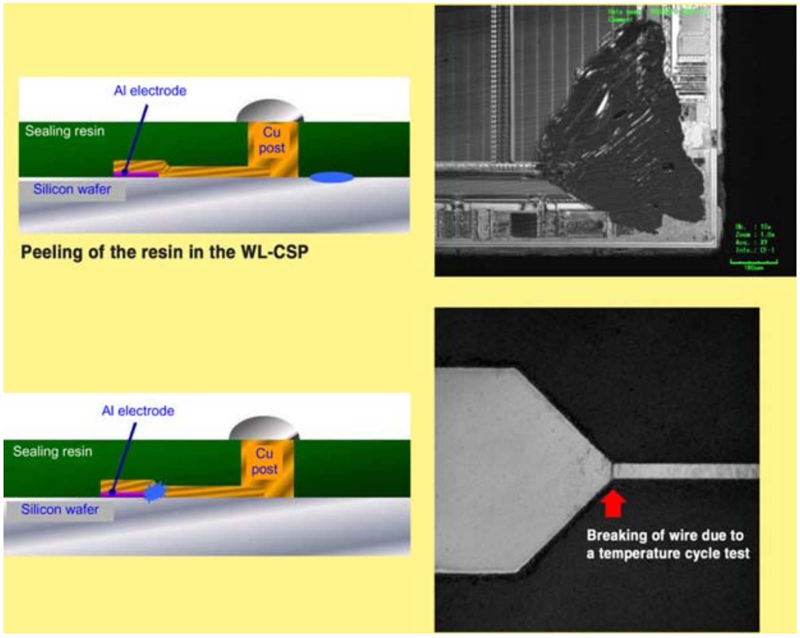
The challenge of subsurface imaging

As the need to increase circuitry complexity while increasing wafer size grew in the semiconductor industry, the need to look below the surface at the underlying layers for broken leads, faulty connections, and other defects grew correspondingly. No inspection technique was available that could penetrate the surface of the wafer without causing damage to the wafer or packaged device. The only way to perform an inspection was to destroy a wafer – to break it open, polish the edges and take a look at it. For encapsulated devices, such as MEMS components, it often meant removing layers of material with acid or other expensive and time-consuming processes. In all cases, it meant destroying expensive samples, training technicians to destroy and prepare samples correctly so that they weren't rendered useless, and then using valuable time preparing samples for insertion into a SEM vacuum chamber or even under an optical microscope.

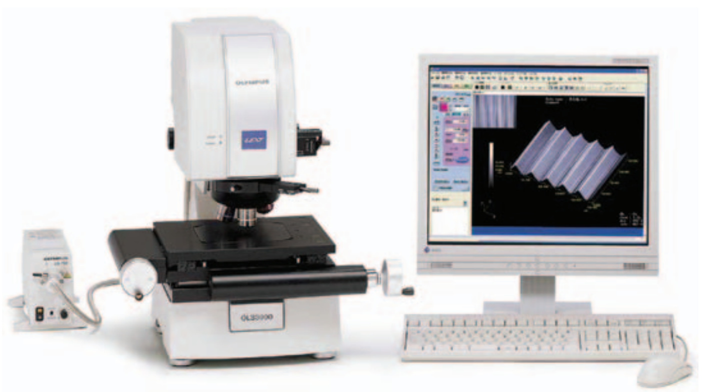
IR Laser Confocal: Nondestructive Subsurface Imaging

In response to the need for subsurface imaging, enhanced laser scanning techniques have been developed over the past five years, such as near-IR laser confocal imaging. The semiconductor industry in particular benefits from the use of infrared wavelengths because confocal IR rays easily pass through silicon wafers (as well as many other substrate materials, including GaAs, sapphire, diamond and silicon carbide), enabling manufacturers to inspect the many layers of a wafer without destroying an expensive sample. With the increased use of flip chip technology, confocal IR microscopy techniques are gaining popularity to visually inspect for pattern or leak damage to chips after electric testing and to measure gaps and alignment between the chip and its interposer. Using IR microscopy, a manufacturer can quickly identify areas that need to be further analyzed by a scanning electron microscope, saving expensive SEM operation and analysis time. For wafer-level, chip-size packages, IR microscopy is ideally suited to non-destructive inspection for delamination, deformation, and the pattern's fusion and erosion by resin expansion and contraction after heat and humidity testing.

In particular, the increasing popularity of wafer level chip size packages (WL-CSP) has created a critical need for non-destructive subsurface inspection. WL-CSPs were developed to meet the need for chip-level components to fit the shrinking form factors of today's personal electronic devices, such as cell phones, MP3 music players, and PDAs.



In the WL-CSP manufacturing process, the semiconductor IC chips are packaged right on the wafer before they are diced out into separate devices. A sealing resin is first coated on the surface of a wafer to cover and seal all IC chips, and then a dicing operation is conducted to separate the completed packages. The shock of the dicing operation can potentially cause the resin coating to peel off the IC chip, dislodging it. In addition, the heat curing process can shrink and peel off the integrated circuits inside the package. While any compromise of the exterior resin coating can be observed visually, the only way to inspect the internal condition of the IC is to take a non-destructive look inside the package. Because the IR laser



Olympus LEXT OLS-3000 Infra-Red Confocal Microscope

transmits at a wavelength of 1310 nm it can easily pass through the WL-CSP's silicon wafer, enabling the confocal microscope to create an accurate 3D image with high contrast and resolution at high magnifications previously unattainable with conventionally used infrared microscopes (see Figure 1).This wavelength laser allows current tools in the market to achieve repeatability figures of 3 sigma < 0.05 µm for *X* and *Y* and 3 sigma < 0.1µm for *Z*.

What makes confocal IR laser microscopy so attractive to the microelectronics manufacturing industry is its ability to bridge the gap between standard optical microscopy and scanning electron microscopy. Unlike SEM and standard optical system analysis, which involves time-consuming and expensive sample preparation, confocal IR laser microscopy does not require the cleaving of a costly wafer and edge polishing to get a good image. As a result, there's no possibility of contamination or deformation from the preparation work and inspection can be done immediately by relatively unskilled employees (no specimen preparation training is necessary). Put a different way, the total cost of obtaining a good image using confocal IR laser microscopy can be measured in cents rather than the cost in dollars associated with conventional SEM and optical based measuring techniques.

One of the key benefits of the IR confocal technique is its ability to perform three-dimensional measurements within the device. This allows for fast and repeatable measurements that provide quick solutions to critical alignment problems with multi-layer devices as well as bonded devices. The unique three-dimensional measurements also enable imaging and measurement of boundary layers within devices and provide roughness and volumetric data to the failure analysis and process development engineer.

The IR confocal technique is also ideal for wafer thickness measurement. When the manufacturing process requires thinning of the wafer, the IR system can look through the wafer to determine exactly how much the wafer has been thinned. This is particularly useful when the customer's process requires laminated wafers.

In short, confocal IR laser microscopy is the right technique at the right time for wafer manufacturers facing increasingly complex chip topographies, rising costs, and lowering margins. The IR confocal technique enables manufacturers to perform fast, flexible, accurate, and cost-effective inspections and measurements in real-time without the time and money costs associated with scanning electron microscopy. ■