Optical Coherence Tomography Provides Structural Analysis

▲ Monitoring laser welding is a valuable application of optical coherence tomography (OCT).

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The technique is a compelling option for inspecting details below the surface of a product or for providing real-time guidance of industrial processes.

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EXCELITAS

The term industrial imaging usually brings to mind technologies related to cameras, lenses, and machine vision — and for good reason. These systems and components serve the majority of industrial imaging applications very well. But sometimes a camera-based solution may not be ideal for a particular use case. Certain surface features cannot be easily captured, regardless of how much the illumination and lens are adjusted. The area of interest might also lie beneath the surface of a material, part, or assembly during an ongoing process, such as a laser weld or 3D-printed component. In such instances, companies are beginning to consider a modality that has proved to be essential in settings outside manufacturing — optical coherence tomography (OCT).

Some examples of OCT's utility in industry include monitoring laser welds, measuring conformal coating thickness on circuit boards, and detecting defects in flat panel displays. These settings present circumstances in which the technique can characterize the success of a process in real time or establish the structure of an object in ways that other technologies cannot.

While alternatives such as x-ray, computed tomography (CT), and ultrasound have historically been the industry standard for inspecting the features of a material or product below the surface, these technologies often come with high costs, complicated setups, and limitations in speed or resolution. There may also be a need to measure the thickness of a coating or material. A camera will generally not work in this case, and capturing this information at production speeds with sufficient resolution using x-ray or ultrasound can be challenging. For these reasons, OCT could be considered a cost-effective alternative to traditional industrial imaging methods because of its ability to provide subsurface images and thickness measurements with micron-level resolution at production speeds.

Basics of the technology

OCT is analogous in principle to ultrasound, except it uses near-infrared

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(NIR) light instead of sound waves to generate images and provide measurement data. With transparent or translucent materials, OCT can generate tomograms — cross-sectional images — of a sample part, assembly, or material, such as thin-film plastic, a ceramic component for a motor, or a stack of display glass layers for a smartphone or television screen. With opaque materials, tomograms are not possible due to surface reflection of NIR light, but detailed surface profiles, or topographic images, can be generated. In some cases, surface features that cannot be seen in a camera image become visible with an OCT-generated topographic image.

OCT is an interferometry-based imaging and measurement technology that has been used for many years in ophthalmology to diagnose eye diseases and guide treatment based on structural details in the human eye. It is also used for diagnostic imaging in cardiology, dermatology, dentistry, and otolaryngology. OCT is well suited to these and other biomedical applications because NIR wavelengths are highly compatible with biological tissue.

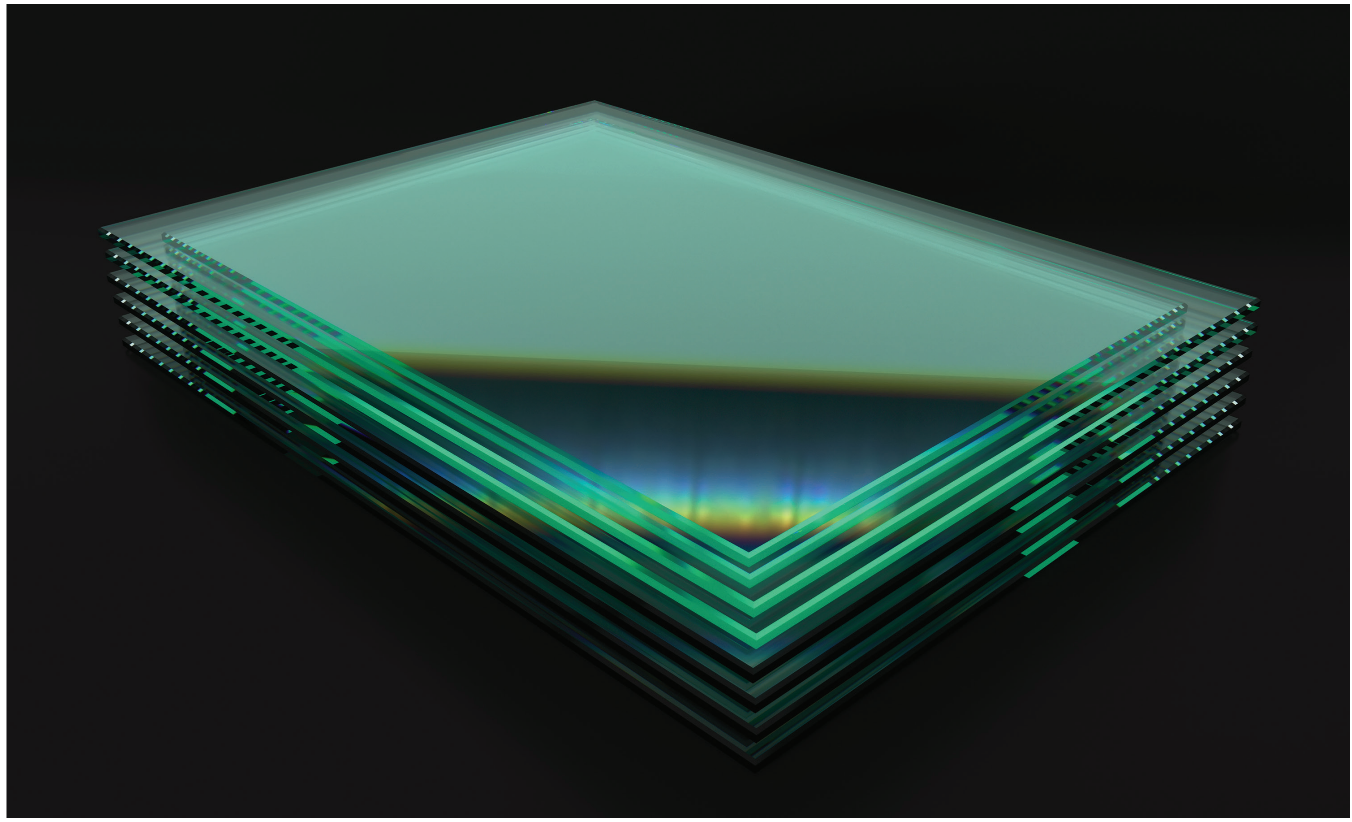
What is less well known, however, is that many materials in the industrial and manufacturing worlds also lend themselves to characterization using NIR wavelengths. Certain types of industrial imaging, measurement, and process control problems that may have previously seemed impossible to solve — such as measurement or defect detection requiring high resolution, or subsurface imaging at high speed — can be addressed using OCT technology.

An OCT system is typically used to generate a 3D data set, which can be examined manually using 3D analysis software or separated into a series of "B-scans" (tomograms) for analysis using off-the-shelf image-analysis software. Typically, the former is used for offline analysis, while the latter is more conducive to inline or automated analysis. Defect detection, presence/absence recognition, feature location, and other machine vision techniques — whether rules-based or AI-based — are all possible with OCT-generated images.

Potential applications

Some specific use cases involve the direct generation of measurement data without necessarily generating a 2D or 3D image. OCT data may be continuously fed into a process control system to provide real-time monitoring or feedback to support rapid, on-the-fly process adjustments. One such application is laser weld monitoring. The OCT light source may be colinear with the welding laser beam and use the same optics (with appropriate filtering in place), rather than requiring a separate optical path, and it continuously measures the depth of the welding keyhole in real time. Therefore, an automated system can determine if the depth of the keyhole becomes too shallow, in which case the power of the welding beam is increased. Conversely, if the welding keyhole becomes too deep, the power of the welding beam is reduced.

▼ OCT can enhance inspection of glass layers used in flat panel displays.



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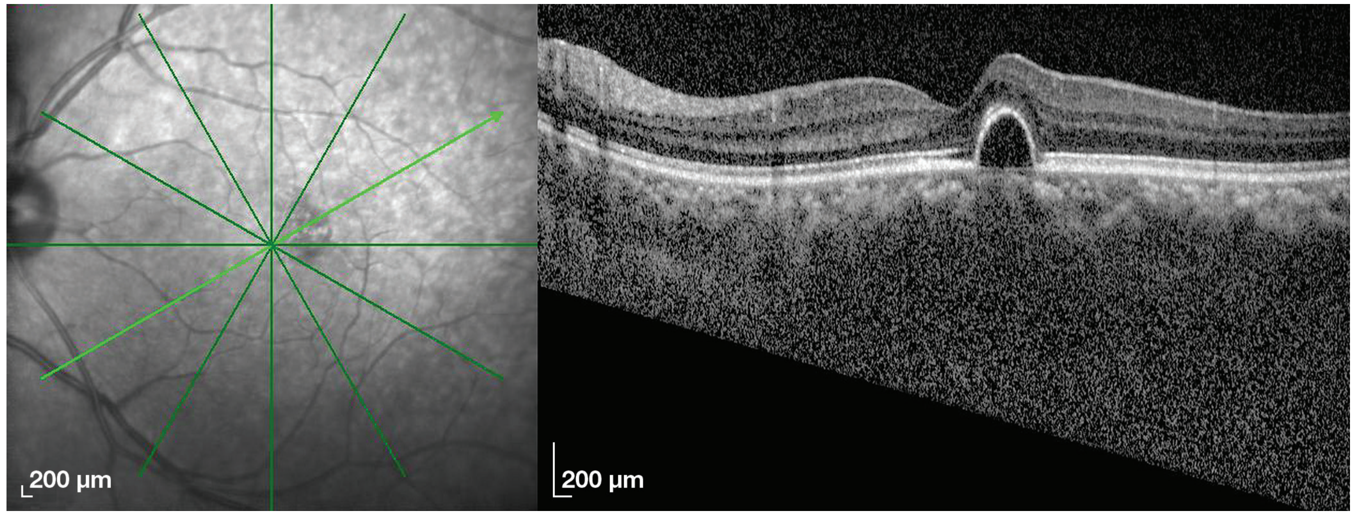

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▲ A typical result display from an eye examination using OCT.

OCT can also guide the laser weld monitoring process in other ways. It can measure not only weld depth, but also the axial (z) position of the parts using en face images (generated with the use of a scanner) of the workpieces either before or after welding. Identifying the axial position of the workpieces ensures the parts are properly aligned before beginning the welding process. The en face images may be analyzed in real time or as part of setup or post-weld examination to gather information such as the lateral position of the workpieces and width of the weld. Furthermore, en face images may be used to identify post-weld surface defects, such as porosity, undercut, or irregular bead profiles.

Another application that lends itself to OCT technology is the characterization of conformal coatings on printed circuit board assemblies (PCBAs). The application of conformal coatings to PCBAs used in harsh environments — such as automotive, aviation, outdoor, or defense-related products — is particularly important to ensure product performance and longevity. Many companies produce camera-based conformal coating inspection systems; however, the vast majority focus only on ensuring proper coating coverage — typically with a UV camera. In this example, the coating contains a UV dye, which is detectable using a UV camera. This allows for a relatively simple inspection to ensure the coating has been applied to the desired areas — or across the entire PCBA, if applicable.

What these systems lack, however, is a way to automatically measure or characterize coating thickness. This is where OCT technology can add significant value. The vast majority of conformal coating thickness inspections are performed manually by production inspectors, using micrometers, wet film gauges, or other manual processes. In high-volume production environments, this means that only a small percentage of boards can be inspected during a given time period.

By implementing OCT technology, however, a system builder gains functionality that allows in-line, automatic characterization of the coating thickness over a portion or all of the PCBA. These measurements can be performed on a single-point basis (i.e., taking individual spot measurements) or a continuous basis (scanning the entire board). The advantage of OCT in this application is that it eliminates a manual inspection process and can theoretically facilitate up to 100% inspection without slowing the rate of production.

A third application to which OCT is particularly well suited is the inspection and characterization of flat panel displays. Production rates of displays have never been higher, with ever-increasing demand from consumers for smartphones, smartwatches, PC monitors, and televisions. With increased demand comes a greater need for efficient and effective inspection technologies to ensure displays are defect-free. OCT is well equipped for examining display panels either individually or in a stack.

Each panel scatters light from the OCT source in different ways, allowing easy identification of layers and defects such as scratches, cracks, or debris. Galvanometer scanners, which use precisely controlled mirrors to steer laser light, are typically required for these inspections to ensure efficient coverage of the entire display.

Opportunities and limitations

The aforementioned applications are just a small subset of inspection challenges that OCT technology can help address. Other applications that could benefit from OCT-based quality control implementations, according to publications and industry professionals, include additive manufacturing and 3D printing, thin-film manufacturing, pharmaceutical pill coatings, wafer manufacturing, profilometry, and ceramics manufacturing.

While OCT offers speed and resolution advantages compared with x-ray and ultrasound, it is important to note that there are limitations. The penetration depth of OCT is typically less than that of x-ray and ultrasound and depends heavily on the material being inspected. OCT penetration can range from 0 mm with opaque or highly reflective surfaces, such as metal, to several centimeters in transparent or translucent materials. In contrast, x-ray and ultrasound typically penetrate to a depth of multiple centimeters, though at lower resolution and/or slower acquisition speeds.

Depending on the nature of the application, cost may also be a factor. OCT inspection systems are generally more expensive than camera-based systems but tend to be more cost-effective than x-ray or CT. As with any imaging system, the precise nature of the application — along with the required hardware and solution parameters — affects the overall cost of the system. Given these factors, it is helpful to discuss potential applications with OCT system experts.

As the fields of industrial imaging, machine vision, and process control continue to evolve, and as applications become increasingly complex, it is essential for manufacturers to have a broad set of tools at their disposal. While barriers to the widespread use of OCT remain — such as system configuration and lack of awareness — further development and ongoing conversations within the inspection industry will help to expand that tool kit in the coming years.

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Meet the author

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