Low coherence interferometry for industrial inspection

Guiju Song, Jianming Zheng, Kevin Harding, and Kenneth Herd

Low-coherence interferometry has been extended to the inspection of translucent industrial materials, where it may prove an invaluable non-destructive characterization technique due to its high depth resolution.

New materials such as polymer composites and ceramics have found a wide variety of applications in modern industries including energy, aviation, and infrastructure. This is due to their superior properties as compared to traditional materials. For process enhancement, quality control, and health monitoring where these types of materials are used, we need sophisticated techniques to non-destructively inspect the complex geometries inside the structures produced. What are required are low-cost, non-contact, high-resolution inspection tools.

The techniques used for this non-destructive inspection, including triangulation, eddy currents, and X-ray-based micro-3D computing tomography (µ-CT), have obvious limitations. Triangulation has poor spatial resolution relative to the size of the cracks that need to be detected, and observations are usually restricted to the surface of the object. Eddy currents—although effective at finding cracks or inclusions—have poor volumetric resolution. Finally, µ-CT is tedious and expensive due to the complex algorithms and physical shielding required.

However, in the past decade, low-coherence interferometry (LCI) has been developed as a powerful tool for the cross-sectional imaging of microstructures in biological tissue\textsuperscript{1,2} for such applications the technique has become known as optical coherence tomography. Most of the new materials mentioned above are optically translucent to particular wave bands, similar to biological tissue. LCI can, therefore, potentially be used in industrial inspection as a contact-free, non-destructive technique with resolutions in the ten-micron range.\textsuperscript{3,4} We have been working on applying LCI to industrial inspection, something that has, so far, only been done a few times.

A low-coherence interferometer includes a broadband light source, a fiber coupler, a detector, a sample and a moving mirror, as shown in Figure 1. The source is used to generate a light with short coherence length and illuminate the fiber-coupled Michelson interferometer. The coupler then splits the light into sample and reference arms: this light is then reflected back from the sample and the reference mirror, where it re-combines in the coupler. If the optical path difference of the two beams is within the coherence length, they will interfere with each other in the coupler to generate a modulated signal. The very short coherence length means that only light with a very specific path length will be collected and recorded, the rest will be gated out. By scanning the reference mirror in the axial direction, a depth-resolved reflec-

Continued on next page
tivity profile for the sample is produced. With lateral scanning, a cross-sectional reflection image is created.

We wanted to investigate the potential of this type of set up for industrial rather than biological applications. Our system used a super-luminescence diode (SLD) in the near infrared: the penetration depth at this wavelength can be as much as a few millimeters in translucent polymer materials, with a depth resolution of 9/µm and lateral resolution of 20/µm. The first application we considered was defect inspection for thermal composites. Delamination due to heavy loads, as well as pores inside the composite, were clearly discriminated and sized: see Figure 2.

The second application we considered was monitoring the ‘health’ of thermal barrier coatings (TBC), which are generally composed of a ceramic material. These coatings are widely used for heat insulation in high-temperature environments such as jet and diesel engines and gas turbines. The use of TBCs would mean less cooling is necessary to keep machines at the desired temperature, and so result in huge energy savings and improved engine performance and efficiency. However, the use of TBCs in service remains limited, due mainly to a lack of understanding of the coating failure mechanisms. To help understand these better, clearly non-destructive inspection of TBCs is critical for the evaluation of coating performance.

From the cross-sectional images provided by LCI, as shown in Figure 3(a), we can see the homogeneous distribution of the deposited material, but with a ‘holes’ that reflect the internal structure of the coating. The two artificial dotted lines in this figure represent the coating and substrate surfaces. Figure 3(b) shows the backscattering intensity distribution for one single scan along the depth axis: the black line represents the backscattering from the coating surface, the blue line represents backscattering from the coated substrate, and the red line is the fitted curve of black line. The blue line (as compared with the black) has a clear peak that shows the reflectance from the substrate surface below the coating.

The third application that we have considered is the monitoring of compositions that occur due to chemical processes in the natural environment, and so may consist of both organic and inorganic elements. A sample was prepared as multiple material layers of different thicknesses. Our system was used to monitor it for 76 hours at 56°C. The result is shown in Figure 4, where Figure 4(a) is depth-resolved reflection distribution from the sample and Figure 4(b) is the cross-sectional image of the sample. The measurement results can be used to guide chemical cleaning.

To continuously and accurately inspect translucent materials used in industry, optical techniques appear to be very promising. So far, our results have shown that we can easily image the internal structure of composite materials—and both organic and non-organic composites—with a depth resolution of 9/µm. Our next steps will be to show that LCI can be adapted for material characterization by combining it with spectroscopy, and to add strain-field inspection via polarization-sensing technology.

**Figure 3.** (a) Cross-section image of TBC. (b) Blue line: the one-dimensional depth-resolved reflection from the coated substrate. Black line: the one-dimensional depth-resolved reflecting from the coating surface. Red: Exponential fitting of black line

**Figure 4.** Left: one-dimensional depth-resolved reflection distribution of chemical deposition. Right: cross-sectional image of deposition.

**Author Information**

Guiju Song and Jianming Zheng
GE Research
Shanghai, China

Dr. Guiju Song is a research scientist at GE Global Research Center, China. Prior to joining GE, she was a research fellow at Oregon Health and Science University. She acquired her Ph.D. and masters degree from the Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences. Her research interests include optical sensing, optical metrology, and biomedical imaging. In addition, she has presented papers at several SPIE conferences over the last five years.

Continued on next page
Kevin Harding  
GE Global Research  
Niskayuna, NY

References