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Detectors

SUPPLEMENT TO
Laser Focus World

Laser ultrasonic receiver with photoelectromotive force detector can measure dynamic displacement of rough surfaces moving at process speeds.

Photo-emf detector enables laser ultrasonic receiver

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Conventional photodetectors typically are used to provide a signal proportional to the power of an incident beam of light. In recent years, a new photodetector has been developed based on the nonsteady-state photoelectromotive force (photo-emf).[1,2] Exciting advances in the field and a real-time demonstration of the detector technology, as applied to laser ultrasonic inspection, were offered as part of CLEO 2000 (San Francisco, CA) last May (see frontis).

This new detector produces an output signal proportional to the transient lateral motion of an incident optical pattern on its surface. When the pattern is stationary, no output signal is produced, regardless of the location or amount of incident power. This detector can be incorporated into an optical interferometer that can measure ultrasonic waves in materials, just as a conventional contact PZT ultrasonic transducer does, but without contacting the sample under inspection. The special properties of this detector permit in-process ultrasonic inspection in industrial environments where background vibrations, rough surfaces, high temperatures, and rapid process motions would foil both contact PZT transducers and traditional laser interferometers.


NEWPORT CORPORATION

An interferometer-based prototype laser ultrasonic receiver with a 532-nm probe laser was exhibited at CLEO 2000. The optically fast (*f*/3) system was rapidly developed from off-the-shelf components including a breadboard, mirror mounts and optics.

Detector geometry

A common photoelectromotive force (photo-emf) detector geometry consists of a chip of semi-insulating semiconductor (such as gallium arsenide:chromium; GaAs:Cr), with electrical contacts deposited at the edges of the front face (see Fig. 1). A probe laser interrogates the surface of a test sample, with the collected light relayed to the detector surface. The rough surface distorts the wavefront of the beam and produces speckle (or intensity variations) as the beam propagates and interferes with itself away from the reflecting surface.

Within the material, photocarriers are generated where the speckle intensity is highest. These carriers migrate by diffusion and then recombine in regions of low intensity. As a result, the incident beam pattern develops and stores an internal electric field oriented in the plane of the detector chip. The diffusion charge-transport mechanism leads to a field amplitude that is proportional to the first spatial derivative of the local illumination pattern; that is, it is largest in regions where the intensity pattern is changing rapidly. At equilibrium, the internal electric field produces a local drift current that exactly balances the current produced by diffusion.

When the incident intensity pattern is static, no signal current is collected by the contacts. However, there are local currents that flow in the semiconductor, with an exact balance between diffusion and drift. Now, let us assume that the surface under interrogation and thus the speckle pattern incident on the detector moves rapidly by a small amount in a direction

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toward one of the contacts. If the incident pattern moves on a time scale that is faster than the time for charges to redistribute in the material, then the internal space charge field will be "frozen."

In this case, the local drift current remains unchanged, but the diffusion current shifts with the beam pattern. This local current imbalance results in net current across the sample that is collected by the electrodes. It can be shown that this current is directly proportional to the displacement of the intensity pattern. By contrast, if the intensity pattern moves on a time scale that is slow with respect to the charge-redistribution time, then the local space charge field can track spatial changes in the diffusion current, and no net current is produced.

Thus, the photo-emf detector acts intrinsically as a high-pass filter, with high sensitivity above a certain cut-off frequency (determined by the charge-transport dynamics in the detector material) and decreasing sensitivity at lower frequencies. In semiconductors such as GaAs:Cr, the cut-off frequency is on the order of 100 kHz for a laser operating in the visible or near-infrared spectral region. Eventually, at frequencies near 100 MHz, the response rolls off, due to bulk-carrier recombination.

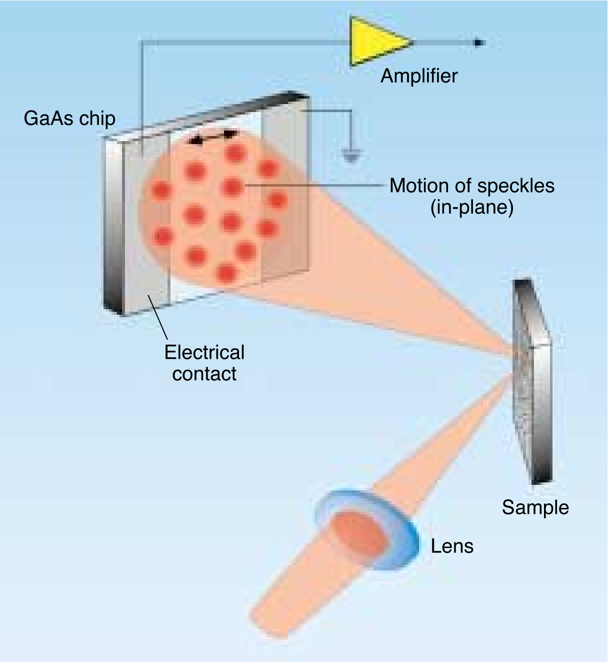

FIGURE 1. Photo-emf detector senses motion of incident illumination pattern for speckled beam. The fringes are only present when a reference-beam interferometer is used to measure out-of-plane motion.

Performing the measurement

The photo-emf detector can measure the dynamic in-plane displacement of a rough surface at frequencies from about 100 kHz to 100 MHz. However, for many testing applications, the out-of-plane motion of a surface is more easily excited and is more important to measure.

To perform this measurement, a simple reference-beam interferometer is used. Typically, the speckled signal beam interferes with a plane-wave reference beam at the surface of the detector. The interference pattern between the two beams appears in each speckle as a set of linear fringes. This periodic intensity pattern again leads to an internal space charge electric field in each speckle that lies in the direction normal to the fringe pattern. As before, in the static case (no surface motion), diffusion and drift are balanced and no external signal current is generated.

When the sample surface moves rapidly in the out-of-plane direction, the fringes in each speckle are displaced laterally by an amount proportional to the

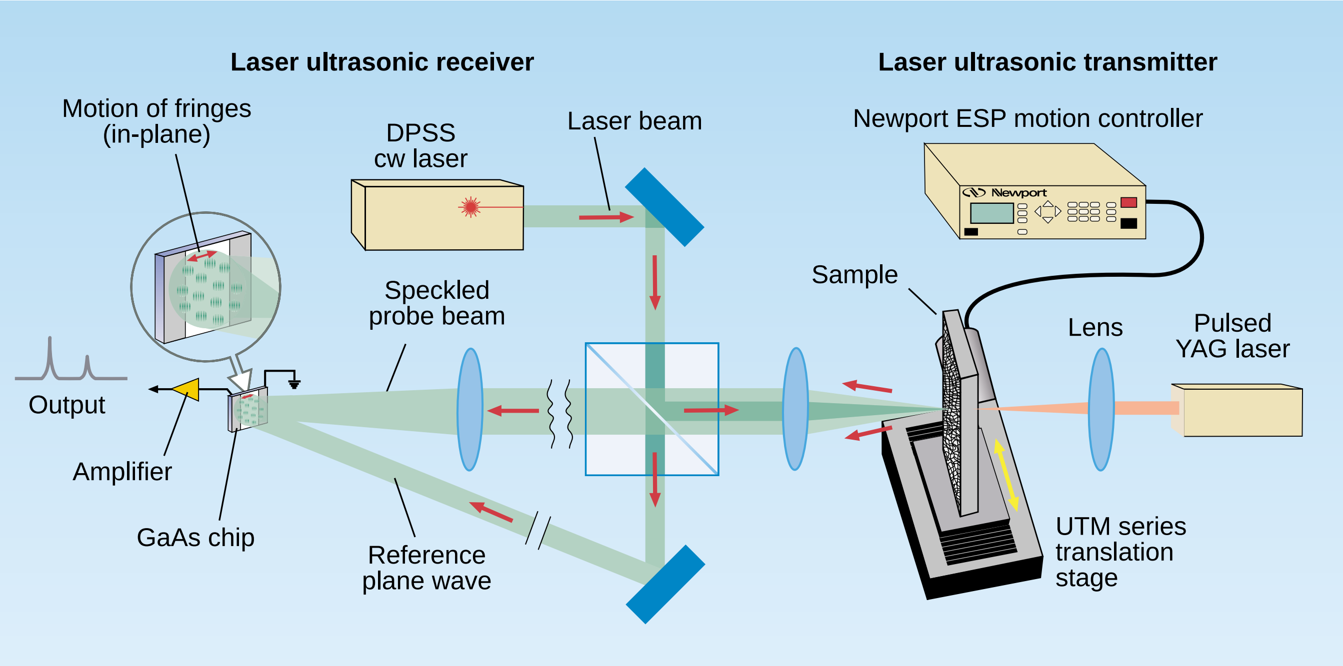

FIGURE 2. Laser ultrasonic receiver (left) measures out-of-plane displacement generated by a pulsed Nd:YAG laser (right) while the sample is scanned.

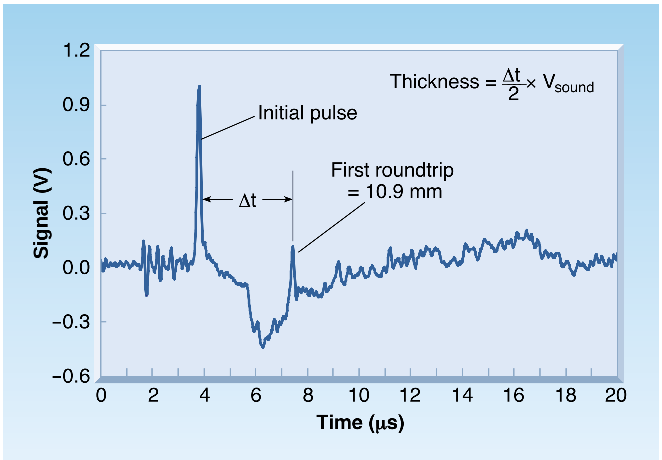

FIGURE 3. Output signal from inspection system shows pulses used to determine remote thickness measurement of scanned sample.

displacement of the rough surface. As before, the dynamic equilibrium between drift and diffusion is broken, and a signal current is generated that is proportional to the fringe displacement.

One important feature of a photo-emf-based homodyne interferometer is that it does not require a phase bias to hold quadrature; the signal current is independent of the optical phase. Thus, although the phase of the fringe pattern in each speckle is uncorrelated with the phases of the other patterns, the contributions from each fringe pattern add coherently to the signal current. So the photo-emf signal is independent of the wavefront quality of the signal beam.

The absence of a phase-bias requirement also eliminates the need for dynamic stabilization that is required in homodyne interferometers to maintain quadrature. Also, low-frequency mechanical noise and turbulence in the propagation path are compensated by the dynamics of the photo-emf process. Finally, as long as the speckle dynamics are within the compensation range of the detector, the signal from such an interferometer is not compromised by the sample moving laterally, as might exist in a production environment. These factors allow the design of an adaptive interferometer that is simple, inexpensive, and well suited to factory applications.

One promising application for such an interferometer is in the field of laser ultrasonics—a remote form of ultrasonic inspection in which lasers are used to both generate and detect an ultrasonic wave (see Fig. 2).[3] The ultrasonic wave is generated in the sample by rapid local heating or by ablation with a pulsed laser. The sound probes the sample for material properties and structural defects. A separate continuous-wave laser, integrated with a laser ultrasonic receiver, senses the dynamic displacement when the ultrasonic wave reaches the sample's surface.

Laser ultrasonics

Lasers can generate and detect the full complement of ultrasonic waves. Normal transducer-related geometries can be used, as well as familiar signal-interpretation methods. Unlike transducer-based systems, however, laser ultrasound is remote, thus allowing inspection of parts at high temperatures, of complex geometry, or in hazardous environments. In addition, the part or the laser beam can be scanned rapidly, increasing the rate of inspection over traditional water-jet/transducer-based inspection systems.

On the simplest side, cylindrical lenses can shape the beam to preferentially detect or transmit certain acoustic waves. On the more sophisticated side, multiple spots can be focused on to the sample and delays in the spots arrival times can steer the generation of the laser ultrasonic wave. Similarly, the receiver can be composed of arrays of adaptive detectors with a unique receiver spot mapped from the sample surface to the detector.[4] Compared with phased-array radar, the detector-array outputs are processed so that only signals from particular positions are in phase. These features of laser-based ultrasound add unique capabilities for next-generation inspection technologies. Finally, laser-based ultrasonic inspection has significantly larger, resonance-free, bandwidth when compared to standard PZT transducers, thus increasing the information available for signal processing.

The ability to inspect parts moving at high process speeds is one of the most important advantages of adaptive receivers and laser ultrasonics. At the CLEO demonstration, the laser ultrasonic system launched the sound on one side of a machined aluminum part and received the sound on the opposite side. A Newport ESP100 motion controller driving a UTM100 stepper stage scanned the machined part while the generation and probe laser beams remained stationary. A series of pulses were detected and from the temporal separation the thickness of the wedge was easily ascertained (see Fig. 3). In recent experiments conducted by the Institute of Paper Science and Technology (Atlanta, GA) and Lasson Technologies, laser ultrasonics was used to generate and detect plate waves in paper samples moving at speeds up to 20 m/s.[5] ❑

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