Ultrasonic Techniques for Laser Optics Inspection

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This project applied two ultrasonic methods that could be subsequently deployed to inspect NIF optics either on- or off-line. One method used ultrasonic shear-wave, the other longitudinal-wave tomography. This project has constructed ultrasonic hardware that generated images of damage to the surface of optics using a set of multiple sensors that are applied to the outside edge of the optic. The system was built and demonstrated on glass with programmed defects and actual laser damage to assess detection capabilities and sizing abilities. The system is also portable, enabling field-testing of optics or other structures.

Project Goals

The goal is to detect and size laser damage on an optic with defects ranging in size from 0.1 to 10 mm or larger by generating acoustic images of a laser-damaged optic that are easily interpreted by those less familiar with acoustics.

Relevance to LLNL Mission

NIF will benefit from nondestructive methods that can assess damage to allow for timely replacement of critically damaged optics or surface refinishing of reuseable optics. The electronic switching technology and data acquisition interface is also being used on an Advanced Development and Production Technology (ADAPT) project for monitoring a weapon production process.

FY2006 Accomplishments and Results

We investigated the application of two ultrasonic techniques, 1-MHz longitudinal waves with tomographic reconstruction and 10-MHz horizontally-polarized shear waves, to image surface damage in NIF optics. To evaluate the techniques we used fused silica samples with programmed hemispherical machined pits with diameters ranging from 0.5 to 5 mm.

In FY2005, shear-wave experiments were performed on an optic with hemispherical defects machined into the surface. The shear wave technique is able to accurately image and size all the defects. In FY2006, the tomographic experiments were performed with a 32-element, 1-MHz linear array with point-like elements, generating a broad beam. The data was reconstructed with a time-reversed MUSIC (Multiple Signal Classification) detection algorithm.

A sample detection map shows 3- and 5-mm hemispherical flaws (Fig. 1). The tomographic approach was able to detect only defects greater than or equal to 3 mm diameter. The 1-MHz linear array was not able to produce waveforms with sufficient signal-to-noise to detect the smaller flaws. Based on these results,

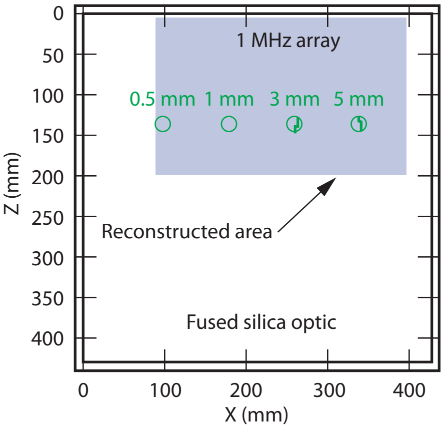


Figure 1. Tomographic detection map obtained from the 1-MHz array data overlaid on a schematic image of the defects, revealing the 3- and 5-mm hemispherical pits. The 0.5- and 1-mm pits were not detected.

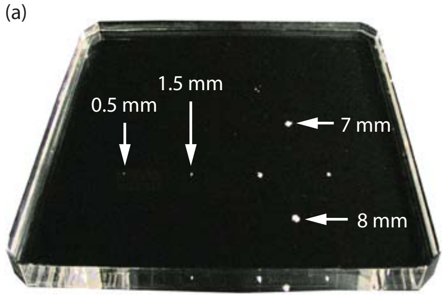
the shear-wave technique was chosen for demonstration, test, and evaluation on a NIF fused-silica optic with laser damage created without vacuum loading conditions (Fig. 2a).

The shear-wave technique uses narrow, highly-directed beams. The outer edge of an optic can be covered with shear-wave transducers on all four sides. Each transducer transmits a pulse into the optic and any damage reflects the pulse back to the transmitter. The transducers are multiplexed, and the collected time waveforms are enveloped and replicated across the width of the element. Multiplying the data sets from all four sides produces a map of reflected amplitude to the fourth power, which results in an acoustic image of the surface of the optic.

Shear-wave data were collected on the fused-silica optic shown in Fig. 2a. The shear-wave technique was able to accurately detect, locate, and size laser damage from 0.5 to 8 mm in diameter. Figure 2b shows the 25.4-mm images of the surface of 0.5-, 1.5-, 7- and 8-mm damage sites. These are size ranges in which NIF has interest. Surface damage size can be directly measured on the image. Maximum depth correlates to maximum amplitude of the detecting waveform. The shear-wave data results in a monotonically increasing amplitude as a function of maximum depth, as shown in Fig. 3. Previous efforts with 5-MHz longitudinal data showed a non-monotonic relationship. A higher signal-to-noise ratio with virtually no effects of mode conversion or multiple echoes from the bottom surface was observed, compared to previous 5-MHz longitudinal acoustic data.

Related Reference

Martin, P., D. Chambers, and G. Thomas, "Experimental and Simulated Ultrasonic Characterization of Complex Damage in Fused Silica," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, **49**, 2, pp. 255-265, 2002.



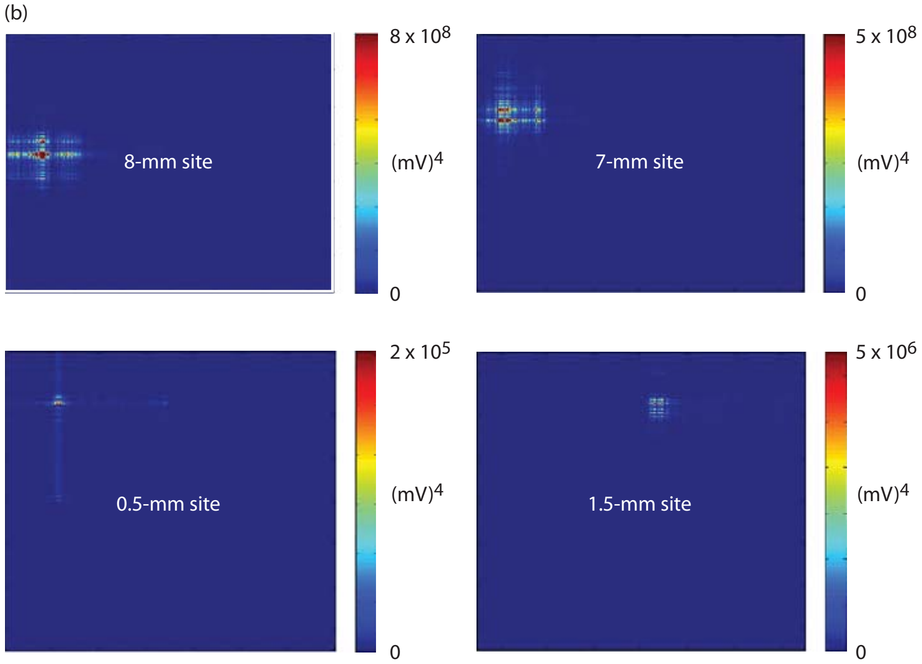


Figure 2. (a) A 430-mm-x-430-mm-x-43-mm NIF optic with laser damage of various sizes. (b) Shear wave images (25.4 mm x 25.4 mm) of the surface around 8-, 7-, 0.5-, and 1.5-mm damage sites.

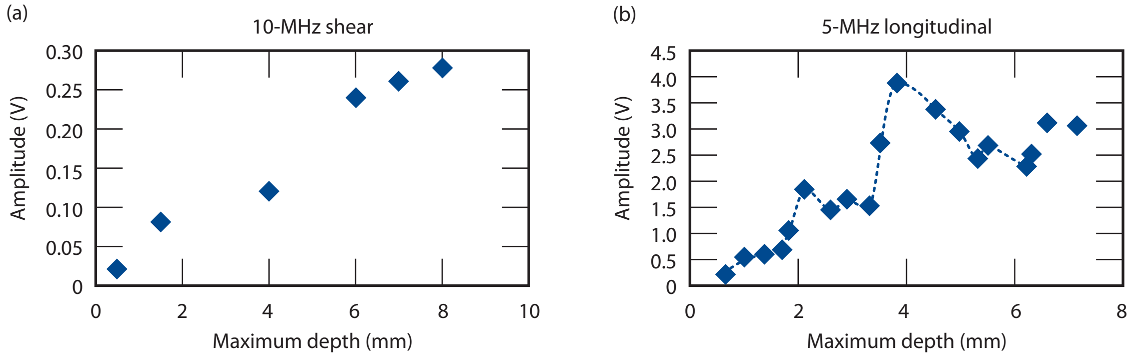


Figure 3. (a) Depiction of 10-MHz shear wave yielding a monotonic relationship with maximum laser damage depth, while (b) the 5-MHz longitudinal-wave data has a non-monotonic relationship. Data is from sample shown in Fig. 2(a).