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13. ABSTRACT (Maximum 200 words) Several key milestones have been reached in our investigation of photorefractive-based pulsed laser interferometry. The first issue involves the response time of photorefractive crystals under pulse illumination. The laser system is capable of producing a "top-hat" laser pulse with a maximum duration of 100 us. This means that the crystal response time must be less than 60-80us such that the grating can be formed during the first part of the laser pulse and the ultrasonic signal can be detected during the final 10-20 us. It was found that the response time of the GaAs was sufficiently shorter than 60us such that substantial two-wave mixing gain could be observed even within the first 10-20us of the pulse. Next, surface acoustic waves have been detected using the pulsed interferometer. Although only moderate signal-to-noise ratio has been achieved to date, several modifications of the system are currently underway that we hope will lead to substantial improvements.				
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LASER ULTRASONIC SENSORS
WITH NEAR PZT-TRANSDUCER SENSITIVITY

(DURIP99)

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Final Report

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EXECUTIVE SUMMARY

Laser based ultrasonics (LUT) is appealing for nondestructive testing of structures because it is a non-contact, high-spatial resolution, rapid technique that can be used on curved structures or in hostile environments. The Air Force, the Navy and the FAA have all been actively supporting various projects to bring laser-ultrasonics technology from the laboratory to the maintenance floor. Significant progress has been made in laser-based systems for the *generation* of ultrasound. However, there is currently a two-order of magnitude sensitivity disadvantage suffered by even the best extant optical *detectors* of ultrasound vis-à-vis conventional contact transducers. This sensitivity gap needs to be bridged before LUT technology can make the transition from the lab to the shop floor.

The objective of this proposed project was to acquire instrumentation which, in conjunction with an adaptive heterodyne interferometer (currently under development at Northwestern University with the support of the AFOSR), will bridge the sensitivity gap between optical detectors and conventional contact transducers for ultrasound detection. LUT will then be *technically* competitive with other ultrasonic NDE methods in all aspects — resolution, non-intrusiveness, *and sensitivity*. . Towards this end, we have configured and acquired a laser system to the following specifications: 100mJ energy in a 50-100 μ s pulse with a repetition rate of 10-20Hz. Such a laser provides sufficient optical power to be used as the laser source in our adaptive heterodyne interferometer, which can be configured to operate in several modes:

- as an omni-directional broadband *point*-receiver of ultrasound;
- as a directionally-sensitive broadband *line*-receiver of ultrasound;
- as a directionally-sensitive narrowband *line-array* receiver of ultrasound; and
- as a *chirped* line-array receiver of ultrasound with high temporal resolution.

While a certain amount of sensitivity gain can be realized by increasing the optical power in any shot-noise limited optical detector, only self-referential interferometers such as our adaptive heterodyne device can be used in single line-probe and line-array configurations to provide additional gains in sensitivity, in directionality, and in temporal resolution. These modes of operation have been demonstrated. The applications phase of this project will continue to be conducted in parallel with an ongoing AFOSR project at the Center for Quality Engineering at Northwestern University.

I INTRODUCTION

The objective of this project is to bridge the sensitivity gap between optical detectors and conventional contact transducers for ultrasound detection. There is currently a two-order of magnitude sensitivity advantage enjoyed by contact transducers over the best extant optical detectors of ultrasound. However, optical detection systems enjoy several advantages:

- ◆ they are non-contact, leading to increased speed of inspection;
- ◆ they are couplant independent, providing absolute measurements of surface ultrasonic wave displacements;
- ◆ they can be operated on curved surfaces and in hostile environments such as at high temperatures; and
- ◆ in combination with laser generation, they can form a complete non-contact NDE system.

Laser-based ultrasonics is therefore increasingly looked upon by the NDE community as a viable technology for future NDE systems for inspection of airframe and engine components. Indeed Lockheed Martin is building a Laser UT facility for inspection of composite structures that are to be used extensively in future advanced fighter aircraft.

At the Center for Quality Engineering at Northwestern University, over the past decade we have been engaged in several research projects that aim to increase the sensitivity of laser-based ultrasonics. As part of the following AFOSR funded project:

Title: *Non-Contact Ultrasonic Diagnostic Systems*
PI/Co-PI: *J. D. Achenbach & S. Krishnaswamy*
AFOSR Award #: F49620-98-1-0285

we are currently developing the following laser interferometric ultrasound detectors: (a) low-cost portable dual-probe Sagnac interferometers, and (b) speckle-insensitive adaptive heterodyne interferometers using wave-mixing in photorefractive materials.

This DURIP equipment grant is in support of the above AFOSR grant. The equipment obtained with this grant has been and will be used to improve the sensitivity of detection of the latter adaptive heterodyne interferometer by up to two orders of magnitude.

II Instrumentation Acquired

In order to achieve this gain in sensitivity, we have acquired a long pulse coherent laser source with the following specifications:

- pulse width: 50-100 μ s adjustable
- pulse energy: 100mJ
- pulse repetition rate: 10-100Hz
- pulse energy distribution: top-hat (rms noise less than 0.1% over DC-10MHz)
- optical wavelength: Nd:YAG at 1064nm, and frequency doubled at 532nm

This system features a Nd:YAG seed laser (CW at 750mW or better), the output of which is chopped into a top-hat pulse of the desired pulse width using an optical slicer. This low power pulse is then passed through several stages of optical amplification to provide a high-power top-hat pulse for use in the laser detection system.

The long pulse laser system was received from **Continuum Laser** in September, 1999. A one week training course was provided by Continuum focussing on laser operation, cavity alignment, and maintenance. The laser was subsequently put through a series of tests to insure that the pulse energy, adjustable pulse length, repetition rate, and coherence all met the required specifications. The laser was then incorporated into a photorefractive-based ultrasound detection system.

III. RESEARCH ACCOMPLISHMENTS

Adaptive holographic ultrasound detection system: The long-pulse laser has been incorporated into a photorefractive-based ultrasound detection system developed at Northwestern University. The long-pulse laser interferometric detection system is illustrated in Figure 1. The pulse exiting the laser passes through a half-wave plate/polarizing beam splitter combination and is split into an object and reference beam and rotation of the half-wave plate allows for control of the relative amount of energy in each beam. The reference beam is directed to the photorefractive crystal (PRC). The object beam passes through a second polarizing beam splitter, quarter-wave plate, and lens and is focussed to the surface of the specimen. Scattered light is collected by the lens and redirected to the crystal making a small (5 degree) angle with the reference beam. The

two beams form an interference pattern in the crystal which leads to an index of refraction modulation in the crystal. A pulsed DC field, with a pulse length on the order of the laser pulse length (100 μ s) is applied to the crystal to enhance the two-wave mixing gain. For an applied DC field, the index grating in the crystal is in phase with the intensity grating and the resulting diffracted reference beam is thus 90 degrees out of phase with the signal beam leading to optimum detection of small displacements of the object. The signal beam and diffracted reference beam are then directed to the specimen.

Selection of PRCs: Several photorefractive crystals were investigated for use in the laser system including GaAs, InP, and Cd:Te:V. Both GaAs and InP crystals were obtained. Cd:Te:V, although theoretically exhibiting high photorefractive gain, is not currently commercially available due to the difficulty in growing high quality crystals. Thus far research has been limited to the characterization of GaAs. The crystals were first studied in the diffusion regime (in the absence of an applied field) with a CW Nd:YAG laser to determine the photorefractive gain and orientation. Electrodes were then applied to the crystals and two wave mixing in the presence of an applied field characterized.

Preliminary results: Several key milestones have been reached in our investigation of photorefractive-based pulsed laser interferometry. The first issue involves the response time of photorefractive crystals under pulse illumination. The laser system is capable of producing a "top-hat" laser pulse with a maximum duration of 100 us. This means that the crystal response time must be less than 60-80us such that the grating can be formed during the first part of the laser pulse and the ultrasonic signal can be detected during the final 10-20 us. It was found that the response time of the GaAs was sufficiently shorter than 60us such that substantial two-wave mixing gain could be observed even within the first 10-20us of the pulse. Next, surface acoustic waves have been detected using the pulsed interferometer. Although only moderate signal-to-noise ratio has been achieved to date, several modifications of the system are currently underway that we hope will lead to substantial improvements.

In parallel work, we have configured adaptive holographic systems:

- as omni-directional broadband *point*-receiver of ultrasound;
- as directionally-sensitive broadband *line*-receiver of ultrasound;
- as directionally-sensitive narrowband *line-array* receiver of ultrasound; and
- as *chirped* line-array receiver of ultrasound with high temporal resolution.

We are in the process of adapting the long-pulse laser to these configurations.

Continuing Work: Work is currently underway to improve the system in two ways. First, the photodetector used for the initial measurements saturated at high incident laser intensities and thus the signal had to be attenuated before the detector. We have designed and are currently constructing a high power photodetector unit designed specifically to detect a small, high frequency intensity modulation riding on a high intensity background pulse. This detector will allow us to use more of the laser power and hopefully achieve shot noise limited performance. Finally, the GaAs crystals used have also shown electrical breakdown at high optical intensities with relatively low applied fields. This limits the amplitude of the DC field that can be applied. We are currently preparing InP samples to see if they may behave better under high illumination and are also looking into obtaining higher resistivity GaAs samples to avoid this problem.

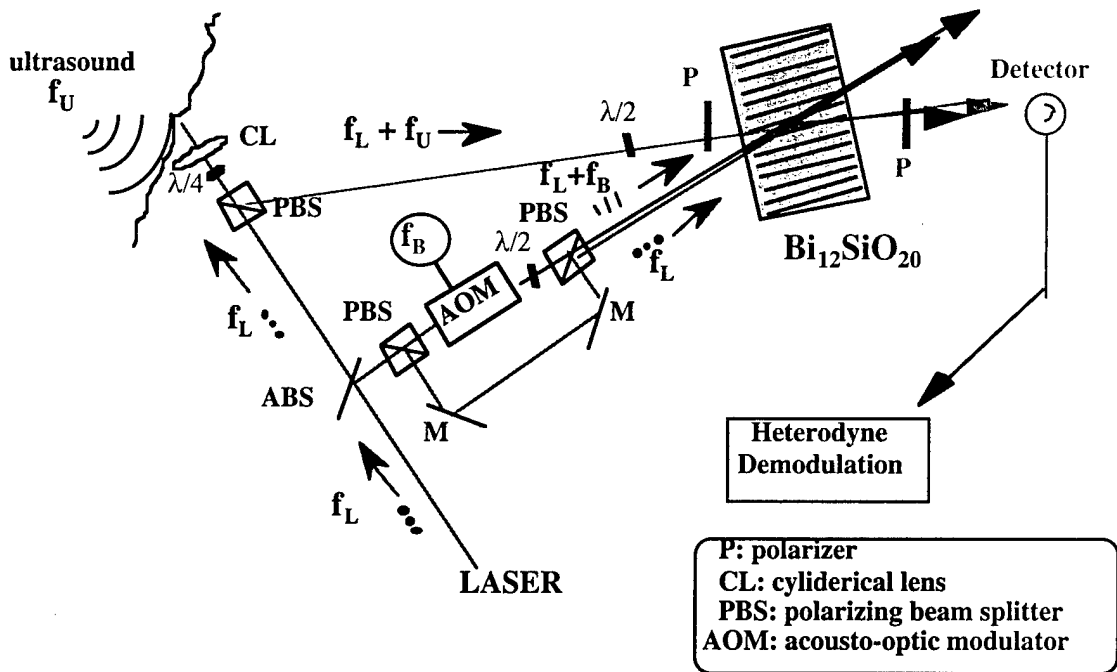


Figure 1: Adaptive holographic setup.