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FINAL TECHNICAL REPORT

"Studies of Electromagnetic Sound Generation for Non-Destructive Testing"

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Date: May 1, 1978

This research was supported by the Air Force Office of Scientific Research (AFSC) under Grant No. AFOSR-77-3347

ABSTRACT

A new technique for NDE has been studied and found to have good potential for detection of small flaws in ceramic materials. The technique utilizes photoacoustic spectroscopy. Additional studies on the use of evaporated CdS thin film transducers with contactless interdigital electrodes have been carried out.

GOALS

A major goal of this grant originally was to develop contactless techniques for possible application to non-destructive testing problems in ceramics. Originally, it had been proposed to extend the earlier work (under AFOSR Grant No. AFOSR-74-2648) on EM generation, utilizing thick rf sputtered metal films, or evaporated CdS transducers to launch and detect high frequency surface acoustic waves. During the course of this grant, however, preliminary studies have been made on a novel photoacoustic technique which shows great promise for NDE of ceramic materials. Consequently, evaluation of the feasibility of this technique became the primary goal of this program.

ACHIEVEMENTS

During the period of this grant techniques for evaporation of thick CdS transducers were studied for possible application in contactless surface acoustic wave generation. Using high vapor pressures and controlled subtrate temperatures, good quality films were achieved on metals, glasses and glass-ceramics. By varying the film thickness, it was determined that excellent broad band bulk wave transducers could be fabricated with center frequencies in the range 100-200 MHz. The thicker transducers were operable at frequencies as low as 30 MHz.

Unfortunately, the proposed method of exciting the films as surface wave transducers in a contactless fashion with interdigital electrodes on flexible printed circuit material proved unsuccessful, as the signals were dominated by the bulk wave generation. Apparently this method of surface wave generation is most efficient when the electrodes are evaporated directly on the films themselves--a method which had been used successfully by other workers, but which of course is not a contactless technique. As these experiments were conducted early in the grant period, and since the laser photoacoustic technique showed greater promise for NDE in ceramics, we then concentrated our efforts on studying its feasibility. We will now summarize our achievements on that project.

A block diagram of our photoacoustic set-up is shown in Fig. 1. In this technique, the sample is placed inside a specially designed cell containing a suitable gas and a sensitive microphone. The sample is illuminated with chopped laser radiation as shown. Absorbed light is converted in part into heat by non-radiative de-excitation processes within the sample. The resulting periodic heat flow from the sample to the surrounding gas creates pressure fluctuations

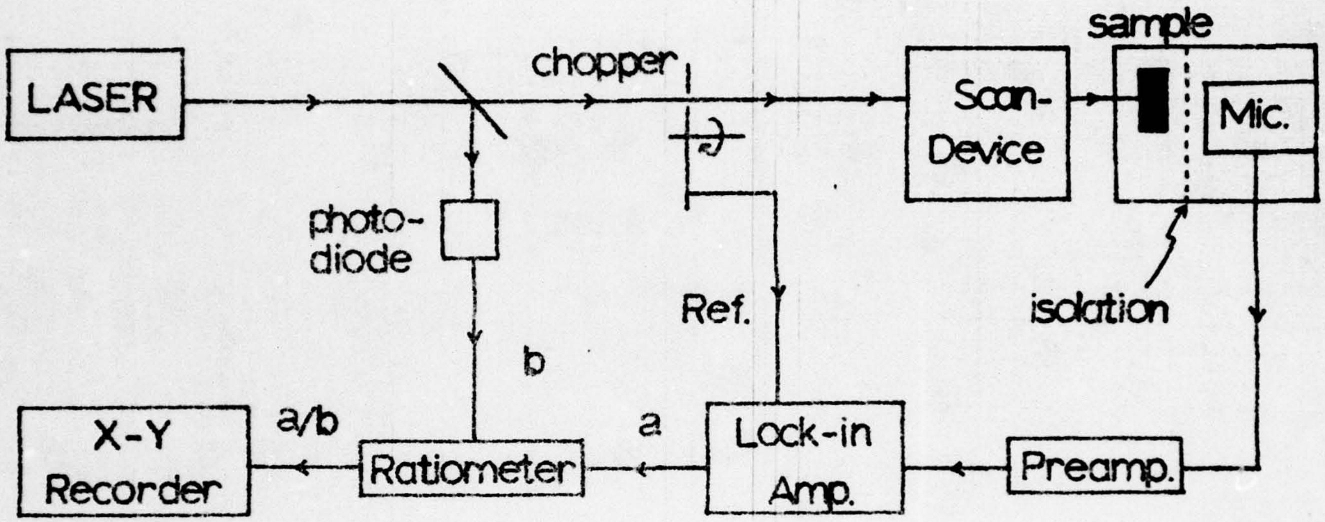

Fig. 1. Schematic diagram of the laser photoacoustic scanning system.

in the cell, which are detected by the microphone as a signal which is phase coherent at the chopping frequency. The resulting photoacoustic signal is directly related to the amount of light absorbed by the sample. In order to demonstrate the utility of this process for detecting surface flows or sub-surface inhomogeneities, we refer to Fig. 2, which illustrates the geometrical considerations. As the laser beam illuminates the sample, a well-defined effective volume, $V_{eff} = A \times d_{eff}$, is heated because of absorption of the electromagnetic energy. The area, A, depends on the focusing of the laser light, and can be as small as $\sim 10^{-12} m^2$. A characteristic optical penetration depth, d_{op}, a function of the incident wavelength and the local absorption coefficient at that wavelength, must be considered, together with an effective thermal diffusion length d_{th}, which is determined by the chopping frequency and the thermal conductivity of the sample. The overall effective absorbing depth, d_{eff}, is given by

$$d_{eff} = d_{th}, \text{ for } d_{th} < d_{op}, \text{ and}$$

$$d_{eff} = d_{op}, \text{ for } d_{th} > d_{op}.$$

For NDE considerations, it will be noted that the presence of flaws or inhomogeneities in the illuminated region will change the effective volume (optically and thermally). If the flaw is a different material (foreign inclusion) than the host, the absoprtion coefficient will also differ. If a crack or a void is present, the effective volume will differ. The combination of these effects will give rise to a change in the magnitude and phase of the acoustic signal.

We have investigated a number of silicon-nitride ceramic samples, small

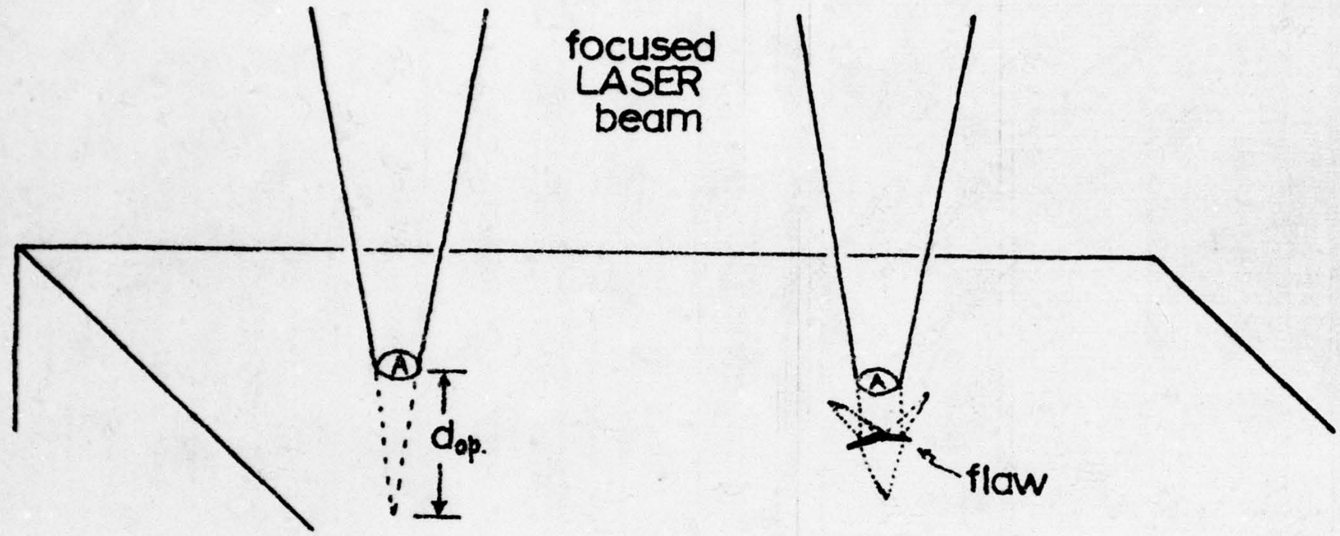

Fig. 2. Goemetric consideration of flaw detection with the photoacoustic technique.

sections of prototype turbine blades obtained from Ford Motor Company, using chopping frequencies 50 Hz < f < 200 Hz. Some of the samples have surface cracks approximately 50μ x 100μ which are visible under a microscope. Others show no obvious surface cracks. In Fig. 3, typical traces are shown of the photoacoustic signal (f = 800 Hz) as one scans across such surfaces. The surface profile is very reproducible for repeated scans along the same line, as illustrated by traces (a, b) and (d, e). Also, as one improves the focus, the resolution improves accordingly, and more detailed microstructure is revealed, as illustrated in traces d and e in Fig. 3. For these traces the diameter of the minimum focal point is $\sim 30\mu$. The difference between samples with and without cracks is also evident in Fig. 3. This is further illustrated in Fig. 4, where an x - y scan is presented. We find a reasonably good correlation between the photoacoustic signal with features which are observed under the microscope. Furthermore, the photoacoustic signal shows features not detected visually. Thes subsurface features may be related to the presence of nitrogen-deficient clusters or to precipitated impurities such as silicides, which seem to be characteristic of reaction bonded material. Subsequent studies of hot-pressed material showed a much flatter background signal.

In summary, our preliminary studies indicate that the photoacoustic technique shows excellent promise as an NDE tool.

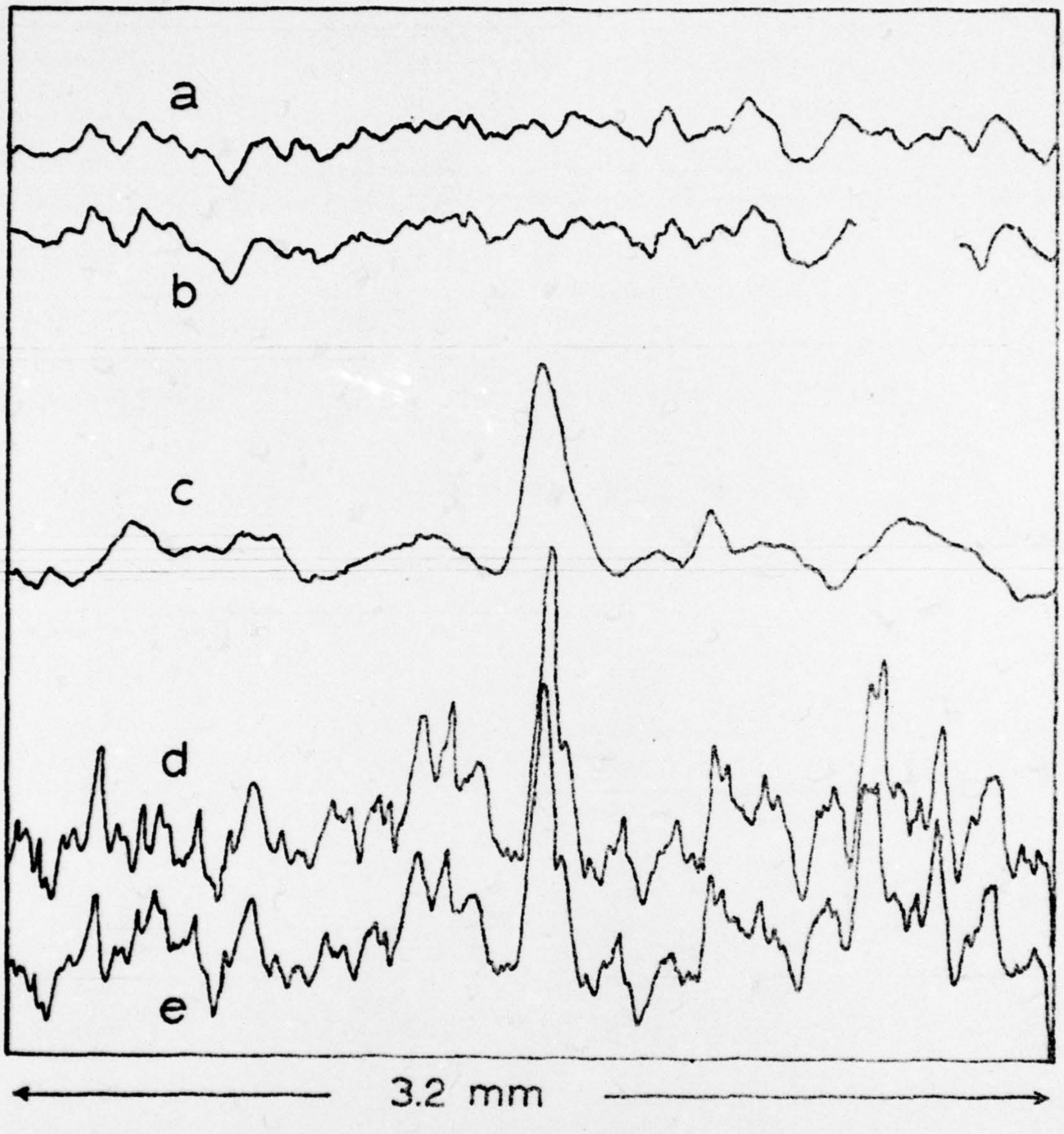

Fig. 3. Typical traces of the photoacoustic signal (f = 800 Hz).

(a-b) repeated scan on surface with no obvious crack.

(c) scan on surface with obvious cracks.

(d-e) repeated scan on surface (c) with better focused laser beam.

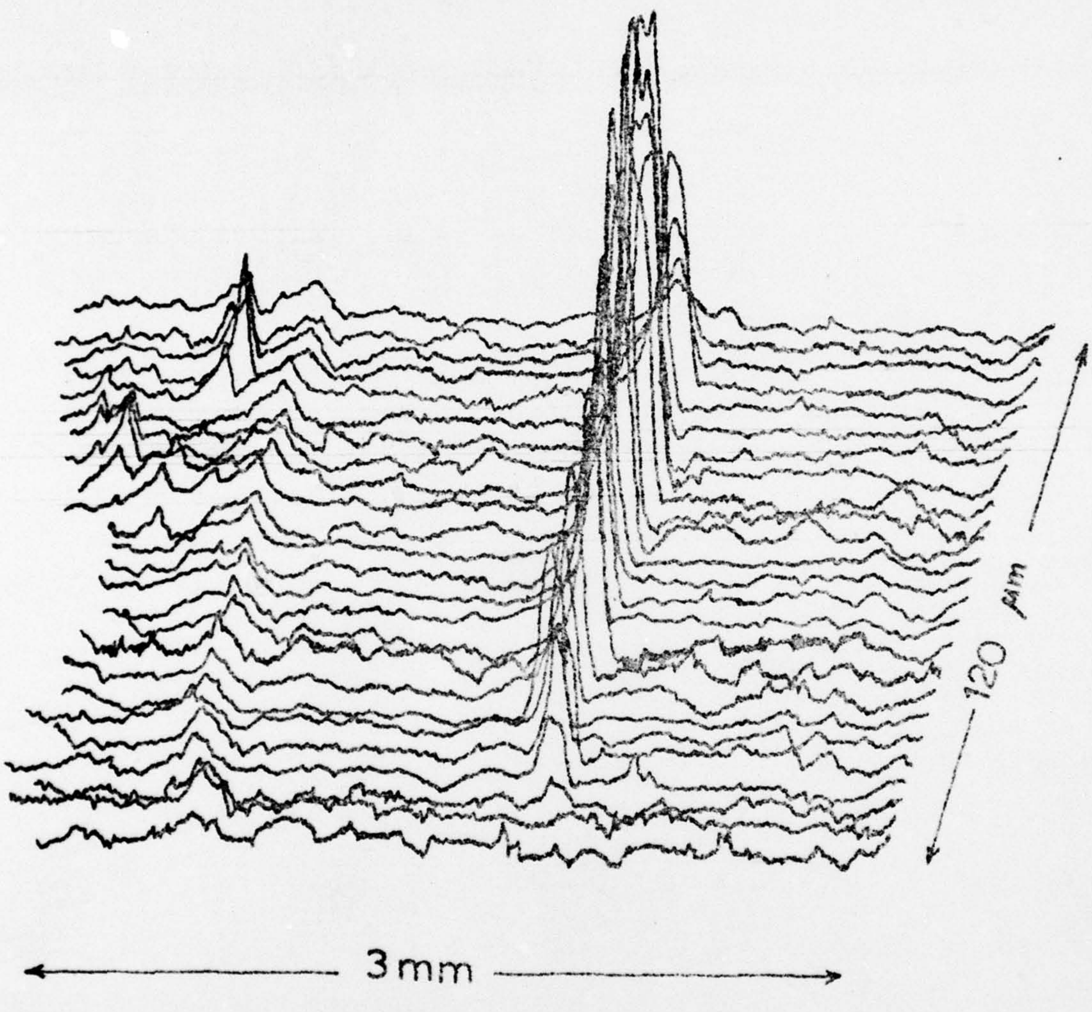

Fig. 4. An X-Y scan of surface with obvious cracks.

PERSONNEL

Professor R. L. Thomas, Principal Investigator

Professor Y. H. Wong, Faculty Collaborator on photoacoustic work

Mr. G. F. Hawkins, Research Assistant

Mr. M. J. Lin, Research Assistant

INTERACTIONS

Dr. Thomas

Participation in Review of Progress in Quantitative NDE, Cornell University, June 14-17, 1977.

Participation in IEEE Ultrasonics Symposium, Phoenix, October 26-28, 1977

Mr. Hawkins

Participation in IEEE Conference on Magnetism and Magnetic Materials, Minneapolis, November 8-11, 1977.

Dr. Wong

Participation in American Ceramic Society Conference on Composites and Advanced Materials, Cocoa Beach, January 23-25, 1978.

E. A. Fisher

Ceramic Applications Section, Ford Motor Company. Discussion with Dr. Thomas and Dr. Wong and visits to our laboratory during 1977-78, and supply of reaction bonded ceramic parts for testing.

A. G. Evans

Rockwell Science Center. Discussions with Dr. Thomas and Dr. Wong during 1977-78, and supply of a hot pressed ceramic sample for testing.

John Schuldies

Air Research Corporation. Visits to our laboratory in 1978, discussions with Dr. Thomas and Dr. Moran, and supply of hot pressed ceramic samples for testing.

PUBLICATIONS

1. "Surface and Subsurface Structure of Solids by Laser Photoacoustic Spectroscopy," Y. H. Wong, R. L. Thomas, and G. F. Hawkins, Appl. Phys. Lett. 32, 538-539 (1978).

2. "Laser Photoacoustic Techniques for Surface and Subsurface Structures," Y. H. Wong, and R. L. Thomas, Proc. American Ceramic Society Conference on Composites and Advanced Materials, Cocoa Beach, Jan. 23-25, 1978 (to be published).