Proceedings of The Institute of Acoustics

PHOTOACOUSTIC MICROSCOPY FOR NDE OF METALS AND CERAMICS

R. L. THOMAS, L. J. INGLEHART, L. D. FAVRO AND P. K. KUO

DEPARTMENT OF PHYSICS, WAYNE STATE UNIVERSITY, DETROIT, MI 48202

The technique of scanning laser photoacoustic microscopy (SPAM) is developing into a useful method for the non-destructive evaluation (NDE) of surfaces and near sub-surface regions of optically opaque solids.[1-3] Sub-surface information is obtained essentially by thermal wave imaging, with the intensity-modulated laser focal spot as the heat source and the pressure variations in the boundary layer of gas at the sample surface serving to convert the information for detection by an acoustic microphone. The effective probe depth, as well as the lateral spatial resolution for thermal wave imaging is set by the thermal diffusion length, μ_s, which is a function of the laser chopping frequency (acoustic detection frequency) as well as the local value of the thermal diffusivity. For a metal such as aluminum, the thermal diffusion length is nearly 1 mm at low audio frequencies, allowing SPAM detection of defects located nearly 2 mm beneath the surface. At the other extreme, if one uses piezoelectric transducers and operates at frequencies of the order of 1 MHz, the thermal diffusion length is reduced to the order of 1 μm, allowing for high lateral spatial resolution for defects which are located within a few microns of the surface.[3]

We will illustrate the utility of photoacoustic microscopy by means of three examples: a metal slab with a well-defined back-surface defect, a semiconductor integrated circuit, and a SiC ceramic slab with a Knoop indentation and associated sub-surface crack. In each case, the data were obtained with a gas photoacoustic cell, using a mechanically chopped Ar-ion laser beam which could be focused to a spot of 10 μm diameter on the surface of the sample, and a microprocessor-controlled scanning stage, with a minimum step length of 6.35 μm. The acoustic signal is phase-sensitively detected by means of a lock-in amplifier, so that both the magnitude and the phase of the signal can be monitored as a function of position of the laser beam on the sample surface.

The aluminum sample is shown in Fig. 1, and has a tapered back-surface rectangular slot, producing a region in the center of the sample whose thickness, δ, increases uniformly from 0 to 1 mm. The resulting variations in photoacoustic magnitude and phase angle are shown for various normalized thicknesses (δ/μ_s) in Figure 2. It may be noted that the back-surface "defect" is evident in the SPAM magnitude variation to a depth of about one thermal diffusion length, and in the phase angle variation to a depth in excess of 1.8 diffusion lengths. Excellent agreement is obtained between experiment and theory for this sample, and is described in detail elsewhere.[2]

As an example of the NDE application for this technique for the characterization of subsurface flaws which are very close to the surface of the specimen, in Fig. 3 we show a high resolution SPAM picture of an integrated circuit.[4] This also illustrates a useful mode of displaying the photoacoustic data. An x-y field of 16,384 (128 x 128) readings of the photoacoustic signal

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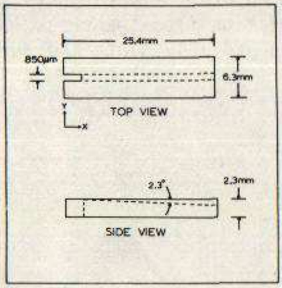


Fig. 1 Aluminum slab with back-surface slot (Ref 2)

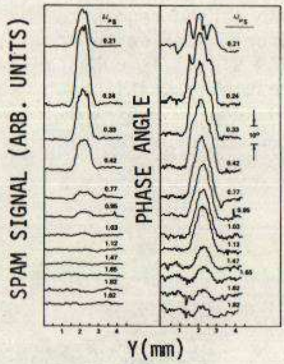


Fig. 2 SPAM magnitude and phase variation at 600 Hz for the sample of Fig. 1 (Ref 2)

was digitally recorded, corresponding to different step positions (6.35 μm/step) of the laser focal spot on the surface of the specimen. The stored data were then read rapidly and the resulting analog signal variations used to control the beam intesnity of a CRT, yielding the picture shown in Fig. 3.

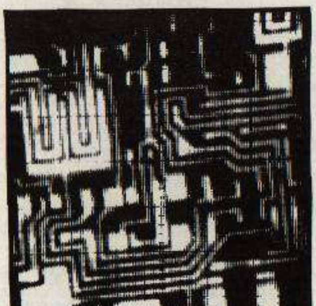
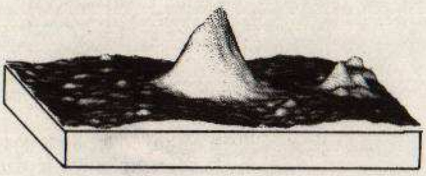


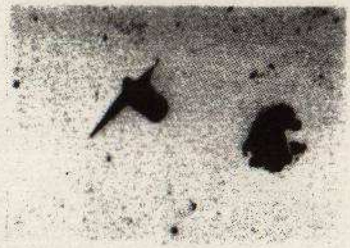
Fig. 3. Photoacoustic microscope picture of an integrated circuit (Ref 4). The field of view is 813 μm x 813 μm, with a resolution of 6 μm.

We have also applied the SPAM technique to NDE problems in the refractory ceramics of SiC and Si_3N_4.[5,6] The properties of such materials in high performance gas turbine engines, for example, is greatly affected by their susceptibility to brittle fracture initiated by very small (~50 μm) flaws. Detection and characterization of such flaws, particularly for complex-shaped parts, constitutes an outstanding NDE problem for these materials. To illustrate the possible application of SPAM to this problem, we show in Fig.4 data corresponding to a region of a polished SiC surface which contains a comparatively large natural defect as well as a fabricated (smaller) diamond shaped Knoop indentation. It should be noted that the central region of the

SPAM picture, associated with the indentation, is considerably more extensive than is the region to the right, which corresponds to the (visually) smaller natural surface defect. The reason for this apparent discrepancy is that the SPAM signal is enhanced by thermal wave reflection from the crack which was presumably initiated by the Knoop indentation and intersects the surface along the long axis of the indentation.



SPAM



OPTICAL

Fig. 4 SPAM picture of a (15 μm x 150 μm) Knoop indentation (center) and a natural surface defect (right). The field of view is 635 μm x 635 μm. Also shown is an optical micrograph of this region.

Figure 4 also illustrates the usefulness of displaying the digitially recorded picture by means of computer generated perspective plots. The particular plot routine used to generate this picture allows the picture to be viewed from arbitrary altitudes and azimuthal angles and with various degrees of magnification and smoothing.

We have also carried out SPAM scans of complex shaped ceramic turbine stator vanes and rotor blades, and have demonstrated the capability of detecting small flaws in regions which are most likely to be subject to brittle fracture.[6]

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ACKNOWLEDGMENT

This research was supported in part by the Army Research Office under Contract Number DAAG29-79-C-0151, by the U.S. Army TankAutomotive Command, by Carborundum and by Garrett Turbine Engine Company.