

HIGH FREQUENCY ULTRASONICS

G. S. Kino, B. T. Khuri-Yakub
Stanford University
Stanford, California 94305

and
B. R. Tittmann
Science Center, Rockwell International
Thousand Oaks, California 91360

ABSTRACT

A high frequency 250 MHz A-scan system has been used for flaw detection. We have been able to detect 25-500 μm defects of different types (C, Si, SiC, BN, Fe, WC) in a Si_3N_4 plate. Since it is difficult to determine the defect type and size from the amplitude of the backscattered signal, we have carried out Fourier transforms of the backscattered signal to obtain reflectivity as a function of frequency, and used that information to characterize the size and type of defect. Our early experiments have been with voids in glass and Si_3N_4 and we are able to predict the size of the defects we detect.

The objective of ultrasonic nondestructive evaluation of ceramics is the detection of defects in the 10-100 μm range. The aim is to detect the defects and determine their location, size, and possibly the type of inclusions within these flaws. Prior to this program of very high frequency testing, no technique existed where such an evaluation could be made.

The longitudinal wave velocity in ceramics is typically of the order of 10,000 m/sec. So, in order to obtain a maximum reflection from defects, we have decided to work in the frequency range of 150 MHz to 500 MHz, or with acoustic wavelengths in the range from 70-20 μm . For this purpose, we have constructed the A-scan system shown in Fig. 1. This system operates at frequencies 5-10 times higher than those that have been used before in the NDT field.

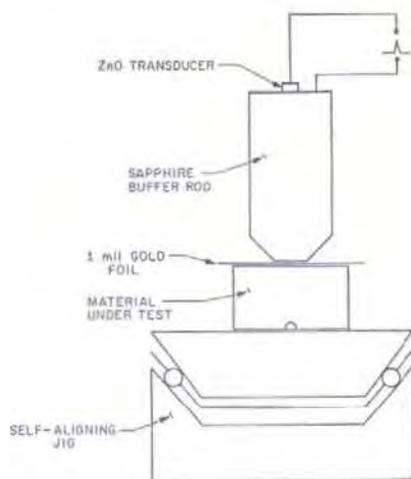


Figure 1. Schematic of A-scan system.

The system consists basically of a piezoelectric transducer on a sapphire buffer rod. This is placed in contact with the ceramic under study. The piezoelectric transducer consists of an 8 μm rf sputtered zinc oxide film on a 2000 \AA gold film that is used as a back contact of the transducer. The top contact is formed by normal photolithographic techniques; typically, we use a top contact that is .75 mm in diameter. Such a transducer resonates at a center frequency of 250 MHz, and has a useful bandwidth of 300 MHz. We use a 1 cm long sapphire buffer rod which is tapered to a diameter of 2 mm at its lower end in order to ease the problem of contacting to the ceramic. A 25 μm gold foil is used as the contacting material between the sapphire and the ceramic. Gold is soft and has an acoustic impedance comparable to those of the sapphire and the ceramic; so it makes a good contacting material. A self-aligning jig is used to help make good reproducible contact. The system is used in a pulsed echo mode. A 20 volt, 2 nsec pulse excites the transducer, and we look for reflected pulses from defects in the time range between the echoes corresponding to the front and back surfaces of the ceramic under study. The acoustic pulses obtained are of the order of 2 ns wide between 3 dB points, as shown in Fig. 2.

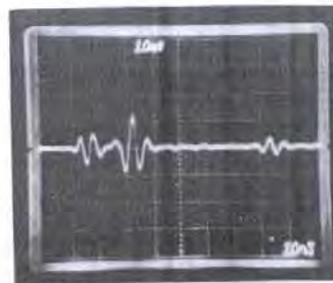


Figure 2. A demonstration of the depth of resolution obtained by measuring the thickness of a 134 μm glass slide.

The theoretical two-way insertion loss of the transducer is 26 dB, which includes 6 dB of diffraction loss in the sapphire buffer rod. Typically, we measure a round trip insertion and propagation loss of the order of 28-30 dBs. We calculate that 90% of the power incident on the gold foil passes through it to the ceramic; experimentally, we measure a reflection coefficient at the foil of 0.1. Typically, we measure the propagation loss in the ceramic to be of the order of 4 dB/cm at 200 MHz for the fully dense hot pressed silicon nitride. A theory has been developed to predict the propagation loss;¹ this is in excellent agreement with the experimental measurements on which it has been checked.

The depth resolution of the system is demonstrated, as shown in Fig. 2. We measure the thickness of a nominally 134 μm glass slide. Our experimental measurement yields a thickness of 132 μm . Notice that we can easily resolve the thickness of the gold foil, which is 25 μm thick. We can then determine the location of a defect to an accuracy of a couple of microns.

In order to test for the sensitivity of the system, we have looked for defects in the seeded sample shown in Fig. 3. This Si_3N_4 plate had six different types of supposedly spherical inclusions (Si, SiC, Fe, WC, BN, and C) of four different sizes (500 μm , 250 μm , 125 μm , 25 μm). We have been able to detect all the defects in the sample with ease, even SiC that has material constants very close to those of SiN. Typical reflections from two different inclusions are shown in Fig. 4. Notice that a 180 degree phase shift of the reflected pulse indicates whether the inclusion has a higher or lower acoustic impedance than the host material. We have also measured the amplitude of the echoes coming back from these defects and compared them to the echo from the back side of the ceramic. These measurements agree well with a simple theory which predicts that the reflected power is proportional to the square of the diameter of the defect, at least for the 125 μm , 250 μm , and 500 μm defects, but gives larger scattering than we would expect from the smallest defects (25 μm) as seen in Table I. This is due to the fact that the defect materials were actually sprinkled into the sample. So, we could have been irradiating more than one 25 μm defect.

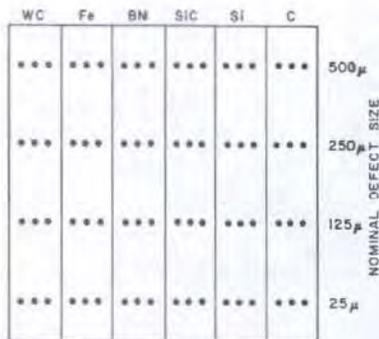


Figure 3. Schematic of Si_3N_4 seeded plate.

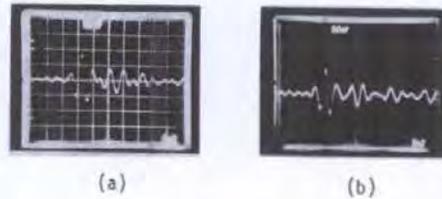


Figure 4. (a) The signal obtained from a 125 μm C defect; (b) the signal obtained from a 25 μm WC defect.

Table I. Experimental and Theoretical Scattering from Boron Nitride Defects in Silicon Nitride

Diameter	Experimental Return Signal Amplitude	Theoretical Return Signal Amplitude
500 μm	-18.4 dB	$-19.8 + 10 \log_{10} \gamma^2$
250 μm	-26.7 dB	$-25.8 + 10 \log_{10} \gamma^2$
125 μm	-30.8 dB	$-31.8 + 10 \log_{10} \gamma^2$
25 μm	-36.0 dB	$-45.8 + 10 \log_{10} \gamma^2$

In addition, the value of the reflected power from the defects, compared to that from the back side of the ceramic, was higher than expected. The discrepancy between theory and experiment made it clear that it is very difficult to use the echo from the back side of the ceramic as a reference signal. This is because misalignment that results in a 6 μm tilt across the transducer at 200 MHz results in large changes of the signal level coming from the back of the ceramic. We demonstrated this point by looking at the echoes coming back from hemispherical voids polished in the back side of a ceramic piece. Two hemispherical voids 200 μm and 400 μm in diameter gave echoes differing by 6 dBs, an excellent agreement with theory. The alignment problem becomes non-critical as the reflecting surface is spherical.

In order to tackle the problem of recognizing the type of inclusion within the defect, we turn to the frequency domain and look at the response of the defect as a function of frequency. The idea here is that different defects have different signatures, as seen in the theoretical calculations of Fig. 5. Notice the difference responses of the void and the WC inclusion in Si_3N_4 . Our first problem was to be able to read the nanosecond pulses involved into a digital computer to carry out the Fast Fourier Transformation (FFT) required. This was done using a sampling oscilloscope to give a slowed down version of the pulse in the set up shown in Fig. 6. A typical FFT of the zinc oxide transducer response is shown in Fig. 7. The useful bandwidth of the transducer is 300 MHz. The wide bandwidth and the extremely symmetric trans-

ducer response is a result of the good acoustic match of the piezoelectric ZnO transducer into sapphire. In order to obtain the frequency response of a scatterer, we divide the FFT of the pulse echo obtained from the flaws by that of a transducer, and thus eliminate the effect of the response of the transducer. To check our experimental procedures, we first carried out such an analysis on the reflection from a gold foil; the result is shown in Fig. 8. This result agrees very well with theory. By this technique, we measure the frequency minima, which yield a gold foil thickness of $22 \mu\text{m}$ for a nominally $25 \mu\text{m}$ foil; the decrease in the thickness of the foil is due to the pressure applied to it. We have also carried out Fourier analysis on some unknown defects in a SiC sample. Typical results are shown in Fig. 9. We cannot, as yet, infer the type of inclusion that we are looking at, because of incomplete theoretical information at the present time. However, we know that different defects have different signatures.

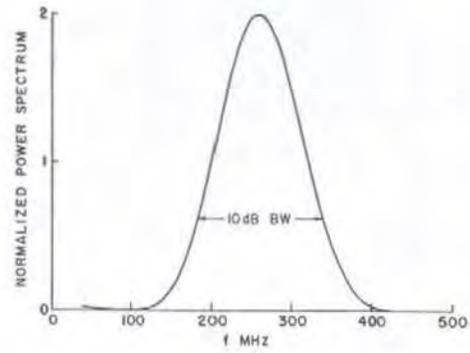


Figure 7. Power spectrum of ZnO/Al₂O₃ high frequency transducer.

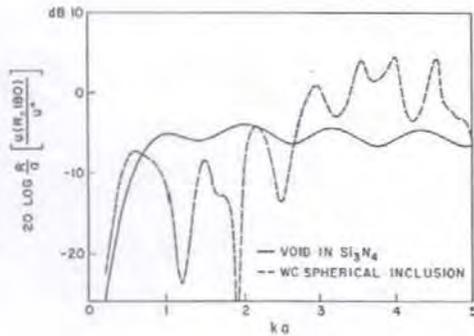


Figure 5. Theoretical backscattered spectra of a spherical void and a WC inclusion in Si₃N₄.

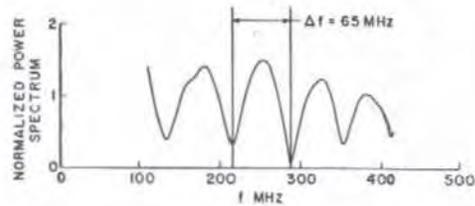


Figure 8. Measured reflection power spectrum of a $25 \mu\text{m}$ Au foil.

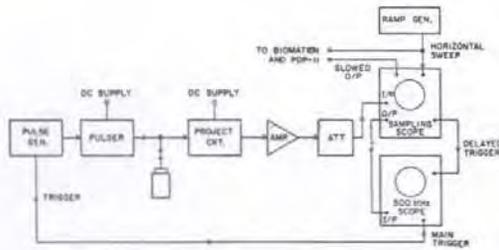


Figure 6. Schematic of setup used to digitize high frequency pulses.

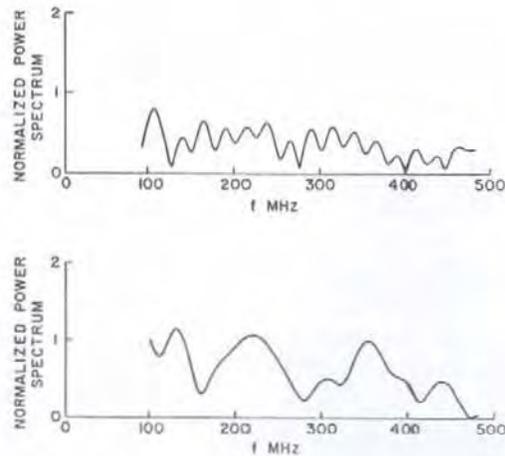


Figure 9. Experimental backscattered power spectra for unknown inclusions in SiC.

We have shown that, using high frequency ultrasonics, it is possible to detect defects in the 10-100 μm range in ceramics. The location of the defect is determined with high accuracy. We are presently working on several techniques to speed up and characterize the observation defects. We are making a 16 element B-scan system that is designed to speed the process of defect detection. We are establishing a catalog of defect responses. We measure the defect response, then, by sectioning, we characterize the defect; thus associating it with its response. We are also carrying out simplified scattering to see whether or not more information can be obtained from the response of the defect in the time domain or the frequency domain.

Acknowledgement

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References

1. A. G. Evans, G. S. Kino, B. T. Khuri-Yakub, and B. R. Tittman, "Failure Prediction in Structural Ceramics," Materials Evaluation, 35, No. 4, pp. 85-95, April 1977.