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Publisher’s version / Version de l'éditeur:
https://doi.org/10.1049/el:20080936
Electronics Letters, 44, 12, pp. 776-777, 2008

Integrated piezoelectric plate acoustic waves transducers

K.-T. Wu, C.-K. Jen and M. Kobayashi

A piezoelectric film has been fabricated by a sol-gel spray technique directly onto an edge of a 2 mm-thick aluminium plate as an integrated ultrasonic transducer and used to detect line defects at a distance using mode converted symmetric and shear horizontal waves at 150°C.

Introduction: The continuing requirement for increased air safety, life extension of aging aircraft fleets, increased aircraft availability and reduced operational costs, suggests the adoption of structural health monitoring [1] or real-time nondestructive testing (NDT) technologies [2] within maintenance programmes by the aerospace industry. The ultimate objective of such technologies is to employ structurally integrated sensors with associated advanced signal processing capabilities to perform short and long distance in-service component inspection, thus increasing platform availability and reducing associated maintenance costs. In this Letter the development of miniaturised lightweight thick (~90 μm) piezoelectric film integrated ultrasonic transducers (IUTs) to generate and receive plate acoustic waves (PAWs) [3, 4] for the detection of line defects in a distance of more than tens of centimetres is presented. Fabrication is based on a sol-gel sprayed technique [5, 6]. It consists of six main steps: 1. preparing high dielectric constant lead-zirconate-titanate (PZT) solution; 2. ball milling of piezoelectric PZT powders to submicron size; 3. sensor spraying using slurries from steps 1 and 2 to produce a layer of ceramic film; 4. heat treatment to produce a solid composite ceramic film; 5. corona poling to obtain piezoelectricity, and 6. electrode painting or spraying for electrical connections. Steps 3 and 4 are used multiple times to produce proper film (IUT) thickness for optimal ultrasonic operating frequencies. Silver paste was used to fabricate top electrodes. This approach permits on-site fabrication. The thick PZT film IUT can be directly deposited onto metallic planar and curved surfaces as a longitudinal (L) wave UT. This Letter focuses on the use of a mode conversion method [7]. The miniature and lightweight L wave IUT can be used to excite and receive symmetric and shear-horizontal (SH) PAWs along a 2 mm-thick aluminium (Al) plate for line defect detection. All experiments were performed in pulse/echo reflection mode.

Experimental results: PAWs can be excited and received by bulk wave transducers with a wedge and interdigital transducers [4]; however, it would be difficult to operate them at curved surfaces and elevated temperatures. Here, IUTs are deposited directly at the end edges of metallic plates without any ultrasonic couplant and with proper mode conversion angles and directions to efficiently generate and receive symmetric and SH PAWs for line crack detection demonstration.

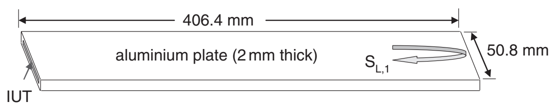

Fig. 1 *Schematic diagram of IUT coated directly onto end edge of 2 mm-thick Al plate to generate and receive symmetric PAW*

Fig. 1 shows the schematic diagram of a 88 μm-thick PZT composite film [5] IUT that was directly deposited onto the edge of a 2.0 mm-thick Al plate with length of 406.4 mm and width of 50.8 mm. The top rectangular electrode has length of 46 mm and width of 1.2 mm, defining the IUT active area. Owing to the 2 mm thickness the L waves generated by the IUT are converted into symmetric PAWs along the plate. To demonstrate the long distance NDT capability of the symmetric PAW, two artificial line defects, D1 and D2, with 1 mm depth and 1 mm width, were made onto the Al plate shown in Fig. 2. D1 and D2 had width of 25.4 and 50.8 mm, and were 146.3 and 223.5 mm away from the IUT, respectively. The measured symmetric PAW signals in the Al plate at room temperature and 150°C are shown in Figs. 3*a* and *b*, respectively. $S_{L,D1}$ and $S_{L,D2}$ are the reflected echoes from the defects D1 and D2, respectively. They clearly confirm that a symmetric PAW can be used to perform NDT of defects in a distance of more than 220 mm. However, the end of the plate at 406.4 mm away from the IUT could not be detected. It is noted that at room temperature, with a commercial hand-held pulser/receiver (EPOCH LT from Olympus Panametrics-NDT), the gain used to obtain the data shown in Fig. 3*a* was 54 dB out of an available 100 dB. Also, the centre frequency of the $S_{L,D1}$ echo was about 4 MHz and the signal strength at 150°C was 8 dB less than that at room temperature.

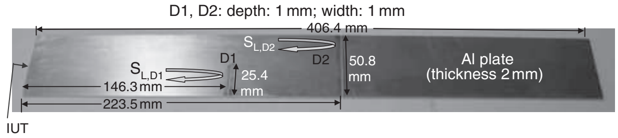

Fig. 2 *Two artificial line defects, D1 and D2, made onto 2 mm-thick Al plate for demonstration of long distance NDT capability of symmetric PAW*

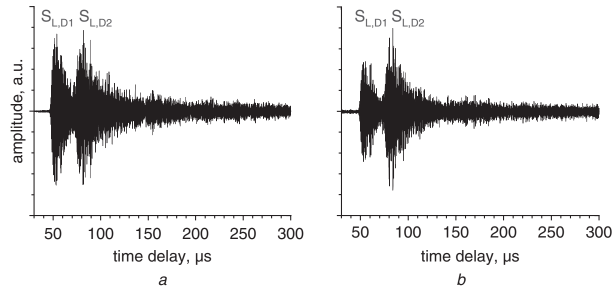

Fig. 3 *Ultrasonic symmetric PAW signal in time domain obtained using IUT shown in Fig. 2 at room temperature and 150°C*

a Room temperature
b 150°C

When a 90 μm-thick PZT composite film is deposited at the side edge near the end of a 2 mm-thick Al plate with length of 406.4 mm and width of 50.8 mm as shown in Fig. 4, the SH PAW can be excited and received by the mode conversion technique. The top rectangular electrode has length of 20 mm and width of 1.6 mm, which define the IUT active area. For this configuration, the symmetric-like PAW echo travelled nearly 25.4 mm right the way from IUT with a measured velocity of 5462 m/s and then converted to SH PAW modes at the reflection slanted edge across the width of the Al plate and vice versa. For this configuration the chosen mode conversion angle using the analogy of L to S wave was 61.7° so that the propagated SH PAW is precisely along the length direction of the Al plate [7]. The calculated energy reflection coefficient [7] at this angle from the symmetric-like PAW to the SH PAW is nearly 96%. The measured S wave velocity through the plate thickness was 2939 m/s.

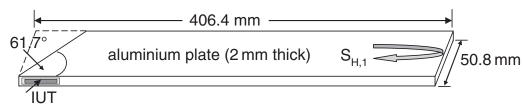

Fig. 4 *Schematic diagram of IUT coated directly onto side edge of 2 mm-thick Al plate to generate and receive SH PAW*

Two artificial line defects, D1 and D2, with 0.95 mm depth and 1 mm width, were also made onto the Al plate shown in Fig. 5 for demonstration of the ability of the SH PAW to detect such defects in a long distance. D1 and D2 had width of 25.4 and 50.8 mm, respectively. The measured SH PAW signals in the Al plate at room temperature and 150°C are shown in Figs. 6*a* and *b*, respectively. $S_{H,D1}$, $S_{H,D2}$ and $S_{H,1}$ are the reflected echoes from the defects D1, D2 and the end of the plate, respectively. They not only confirm that the SH PAW can be used to perform NDT of defects in a distance of about 223.5 mm away from the IUT but also detect the end edge which is 406.4 mm away from the IUT end. At room temperature, with a commercial hand-held pulser/receiver, the gain used to obtain the data shown in Fig. 6*a* was 56 dB out of an available 100 dB. Also, the centre frequency of the $S_{H,1}$ echo was 6.3 MHz and the signal strength at 150°C was 5 dB less than that at room temperature.

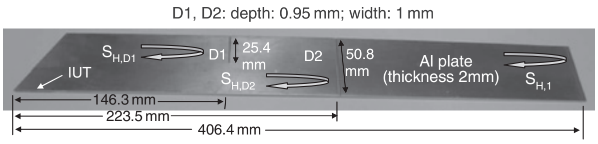

Fig. 5 *Two artificial line defects, D1 and D2, made onto 2 mm-thick Al plate for demonstration of long distance NDT capability of SH PAW*

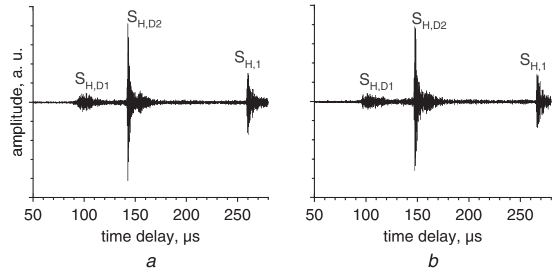

Fig. 6 *Ultrasonic SH PAW signal in time domain obtained using IUT shown in Fig. 5 at room temperature and 150°C*

a Room temperature
b 150°C

Comparing the symmetric PAW signals ($S_{L,D1}$ and $S_{L,D2}$) as shown in Figs. 3*a* and *b* with those for SH PAW as shown in Figs. 6*a* and *b* one can see that the SH PAW signals ($S_{H,D1}$, $S_{H,D2}$ and $S_{H,1}$) have narrower pulse width and higher signal-to-noise ratio. Theoretical calculation results not shown here reveal that near the operation frequency of the IUT many higher mode symmetrical PAW modes [3, 4] were excited and travelled with group velocities of a large difference, therefore $S_{L,D1}$ and $S_{L,D2}$ have long pulse durations. In contrast, $S_{H,D1}$, $S_{H,D2}$ and $S_{H,1}$ SH PAW echoes mainly come from the contribution of the zeroth-order SH PAW having the non-dispersive bulk shear wave group velocity [3, 4], and their pulse width is much narrower. It is concluded that for the samples studied SH PAWs may be the better choice for in-situ long-range NDT.

Conclusions: Near 90 μm-thick piezoelectric PZT ceramic films have been fabricated using a sol-gel spray technique as IUTs. IUTs located at the edge of a plate were used to generate and receive symmetrical and SH PAWs using the mode conversion technique [7]. IUTs were operated in pulse/echo modes at temperatures up to 150°C. The propagation lengths of the PAWs could be more than hundreds of millimetres. Line defects with dimensions of 1 mm width and ~1.0 mm depth were detected by the symmetric and SH PAWs. For the samples studied SH PAWs may be the better choice for in-situ long-range NDT.

Acknowledgment: Financial support from the Natural Sciences and Engineering Research Council of Canada is acknowledged.

2 April 2008
Electronics Letters online no: 20080936
doi: 10.1049/el:20080936

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