Non-contacting holographic surface acoustic wave microscope

M. Clark, S.D. Sharples, M.G. Somekh and A.S. Leitch

A non-contacting laser-based surface acoustic wave microscope is described, which overcomes the problem normally associated with non-contacting acoustic microscopy, namely the poor signal to noise ratio. The solution enables the scan rate to be increased dramatically. Details of the optical system and associated electronics are described.

Introduction: Laser ultrasonics is becoming increasingly important as a result of rapid developments in the laser sources for generation and detection. The need to ensure that the laser power is delivered efficiently onto the sample surface is still a major issue. Generating powers sufficient to produce large surface displacements is relatively easy; however, it is also important to avoid damage to the sample surface.

In an earlier Letter [1] we showed that a focused acoustic beam could be produced using a customised zone plate; this focused the incoming light from the laser source into an arc which formed a focus of the surface acoustic waves (SAWs). Although images were obtained with this setup it was necessary to average the signal over many cycles in a digital oscilloscope to obtain a satisfactory signal to noise ratio. This meant that the system was not suitable for practical surface wave imaging because the data acquisition was slower than one point per second (limited by the signal to noise ratio and laser fluctuations which meant that the digital oscilloscope only triggered on a fraction of the input pulses). Our aim has been to improve the data acquisition rate using simple inexpensive custom built electronics.

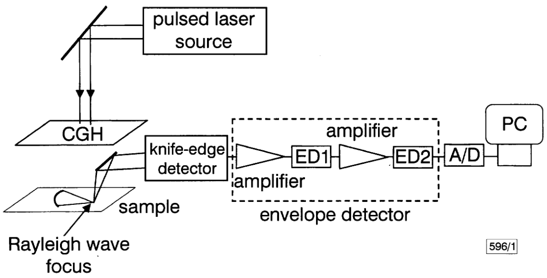

Fig. 1 *Schematic diagram of surface wave acoustic microscope*

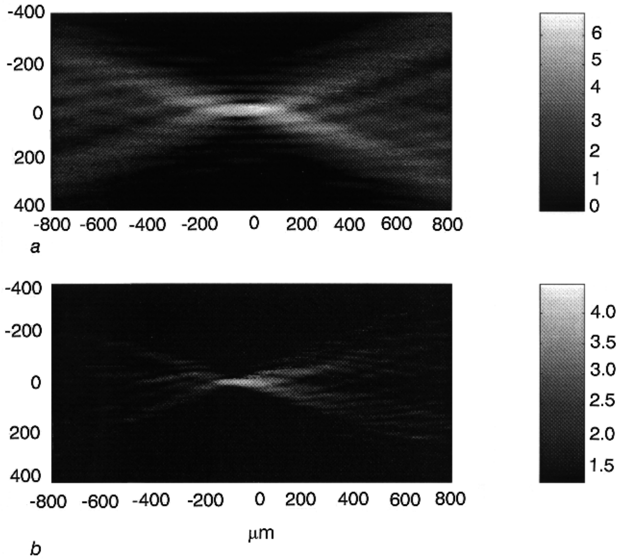

Fig. 2 *Surface wave focal distributions obtained at 82 and 164 MHz*

Full width of image 1.6 mm, direction of sound propagation left to right
a 82 MHz
b 164 MHz

Results: To achieve the aims referred to above it was necessary to improve the signal to noise ratio of the detected SAW signal at the focus so that a good dynamic range was achieved with a single laser burst. This allows a simple envelope detector (described later) to detect the signal. The system used is shown in schematic form in Fig. 1. The laser source is modelocked and Q-switched generating ~30 short pulses (each of duration ~400 ps); the separation between pulses is ~12 ns giving a fundamental frequency of 82 MHz, the short duration of each pulse ensuring that the source is rich in harmonics. The pulse repetition frequency between successive pulse envelopes was 1 kHz. The output from the pulsed laser was passed through the computer-generated hologram (CGH); this focuses and shapes the beam to produce a 60° arc of light, with radius 10 mm. Focusing increases the ultrasonic amplitude by a factor of ~15. The binary phase CGH was designed by a direct search algorithm [2] and fabricated in quartz. The use of the phase hologram gives four times the light intensity in the arc compared to the zoneplate referred to earlier; this translates to the same factor in terms of ultrasonic amplitude. This, together with careful optimisation of the knife edge detector (KED), allowed us to detect the SAW signal at the focus with a signal to noise ratio of; typically, between 10 and 30 dB depending on the sample. The output of the KED was detected with the envelope detector.

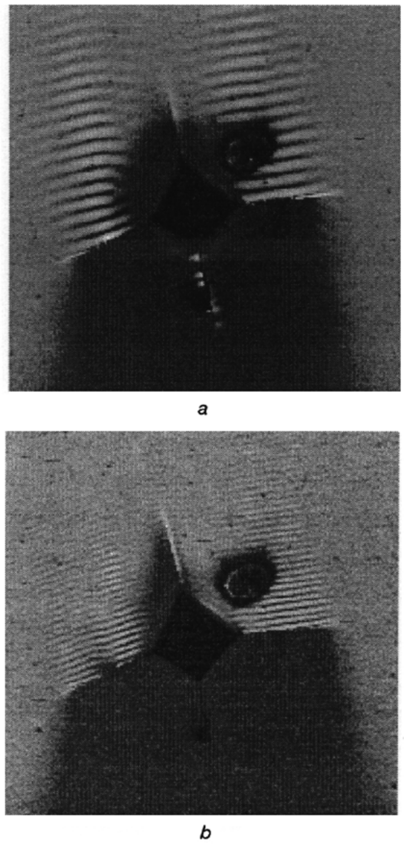

Fig. 3 *Surface acoustic wave images obtained close to Vickers indentation in silicon nitride*

a 82 MHz image
b 164 MHz image
Full width of image 1 mm, direction of sound propagation top to bottom

The requirements of the envelope detector are twofold. First, it must detect the radio frequency signal from the KED with good dynamic range and, second, it must store the signal for sufficient time to allow the amplitude of the incoming RF signal to be measured in a conventional A/D converter. It is important that the detected envelope is linear over the range of incoming amplitudes, so the diode must switch on at very low RF amplitudes. To ensure this, the incoming RF signal from the KED is amplified and the first envelope detector (ED1, of Fig. 1) is biased with a commercial bias unit (Mini-Circuits ZFBT-4R2G-FT) to reduce the switch-on amplitude. This is satisfactory as far as detection of the RF signal is concerned; unfortunately, biasing the device means that the signal level cannot be held for more than ~10 μs, which is insufficient to trigger the A/D converter. The most obvious solution is to use a sample and hold unit. A simpler approach, however, is to use an almost identical envelope detector (ED2) with no initial biasing (not necessary because the output of ED1 is amplified) and a longer time constant. The second time constant was adjusted so that the detected envelope decays by the time the next laser pulse hits the sample (1 ms), but suffered only a small and repeatable decay when the A/D conversion is made. This output is then stored in the PC, which displays the images and controls the mechanical scan stages (not shown).

To demonstrate effective focusing and detection of SAWs with the system, the KED was scanned around the focus of the surface waves. Output at both 82 MHz and 164 MHz is shown in Fig. 2. The width of each SAW focus corresponds to the expected diffraction limit.

Images were obtained by maintaining fixed separation between the illuminating arc and the KED and scanning the sample. Fig. 3*a* and *b* correspond to a 1 mm square region around a Vickers indentation in silicon nitride; these images were obtained at a scan rate of 50 points per second, an improvement of over a factor of 100 compared to the values obtained using a sampling oscilloscope. The features on the image show that the cracks around the Vickers indentations are readily observed. The characteristic Rayleigh wave reflection fringes seen in the scanning water coupled acoustic microscope are also clearly observable [3]; the period of the 164 MHz fringes is half those obtained at 82 MHz. The overall resolution is better at the higher frequency; furthermore, the reflection fringes are seen further along the crack at the higher frequency because the reflection coefficient is greater at small crack depths.

Conclusion: The scanning laser surface wave microscope produces high quality images at a speed comparable to a sample scanned acoustic microscope. The high signal to noise ratio facilitates the use of simple specialised electronics. This has the further advantage that it does not rely on precise triggering and uses all the emitted laser pulses. We are presently extending the electronic detection system to allow the phase of the SAWs to be recorded, thus providing images that can be directly correlated with the surface wave velocity.

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