Efficient and flexible laser ultrasound generation using spatial light modulators

S.D. Sharples, M. Clark and M. Somekh

Efficient production of surface acoustic waves using optical distributions controlled by spatial light modulators is demonstrated. The measurements presented used only 40 mW average optical power on the sample surface. It is shown that a spatial light modulator produces light distributions which control the surface acoustic wave generation on the sample surface; this can be used to produce similar light distributions to those formed by computer generated holography.

Introduction: Laser ultrasonics offers a powerful non-contacting approach to non-destructive evaluation. One of the limitations of a completely non-contact approach is that non-contacting detection is relatively insensitive, which, in turn, means that it is necessary to generate large acoustic amplitudes. The generation of large amplitudes can cause damage to the sample. In this Letter we are concerned with the generation of surface acoustic waves (SAWs) at low optical power levels.

To generate measurable amplitudes without sample damage there have been essentially two approaches (i) to spread the power in the generating beam over the sample and (ii) to focus the ultrasonic distribution on the sample so that the peak acoustic displacement is increased. The use of moving gratings [1] is an example of (i), whereas the use of an axicom to focus the generating light into a ring on the sample is an early example of generating focused SAWs [2]. The present authors have been active in the use of computer generated holograms (CGHs) to produce arbitrary light distributions, which can both spread the generating power and focus the resulting SAW distribution [3]. This is a very efficient way to generate large SAW amplitudes without sample damage. When imaging anisotropic samples the problem of acoustic aberrations means that a flexible and adaptive approach is needed to generate the required optical distribution to compensate for the phase distortion introduced in the propagation path. In an earlier publication [4] we suggested that a spatial light modulator (SLM) could be used to solve this problem. This Letter describes the use of an SLM to generate arbitrary surface wave distributions and thus demonstrates that the method offers an ideal approach to the adaptive generation of laser ultrasound. Furthermore, we demonstrate the real-time detection of 82 MHz SAWs with only 40 mW of optical power incident on the sample.

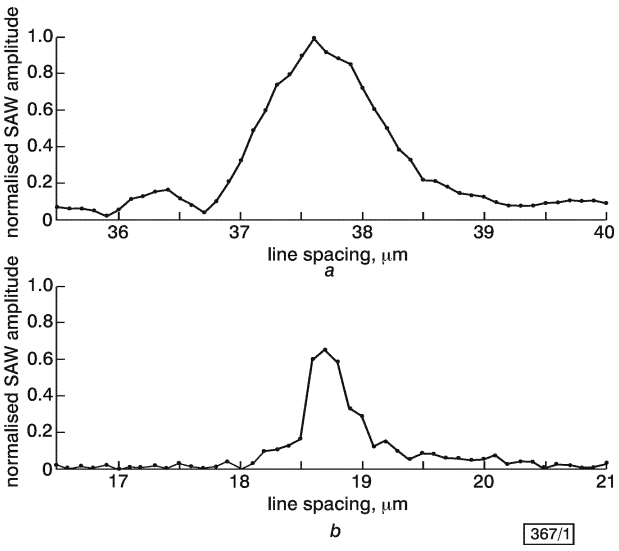

Fig. 1 *Rayleigh signal amplitude at focus against arc separation*

a 82 MHz
b 164 MHz

Experiment: The experimental setup to generate and detect shaped SAW distributions has been described elsewhere [3, 4], thus we concentrate on the salient features and the differences. A modelocked Q-switched Nd-YAG laser emitting 1064 nm radiation is incident on the spatial light modulator (Displaytech model 256A), the light distribution reflected from the SLM is imaged onto the sample surface. The resulting light distribution is detected with a modified knife-edge detector, described previously [3, 4]. It is worth noting that the most significant difference compared to our previous work using CGHs, is that the imposed phase distributions from CGHs both shape and focus the optical beam on the sample surface so that no additional optics are required. The number of pixels available on the SLM used (a 256 square array) means that this is not practical, therefore the light distribution emerging from the CGH was imaged onto the sample with an additional lens. The magnification between the CGH and the sample was 0.5. For the purposes of this Letter it is sufficient to appreciate that the electronic detection system can measure the amplitude and phase of the optical distribution directly from the detected waveform in real time, as described in [5].

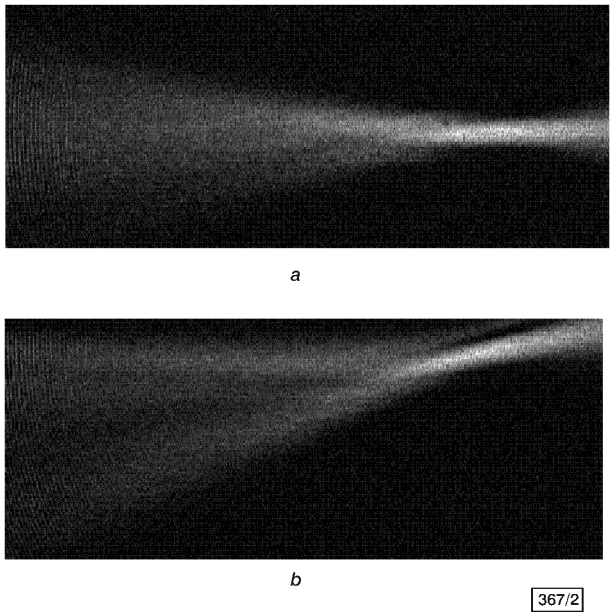

Fig. 2 *Optically measured Rayleigh wave distributions*

a Symmetrically focused beam
b With focal position tilted

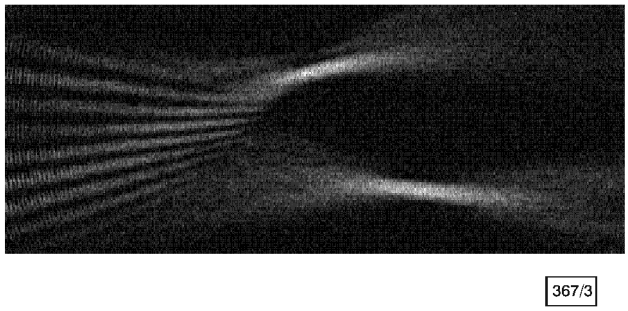

Fig. 3 *Simultaneous generation of two laterally and axially displaced focii*

Results: To demonstrate the flexibility of the system the SLM was programmed to form a series of concentric arcs, so that they each focused to the same point. In this way an optical distribution analogous to that produced by a CGH [3] was generated. Figs. 1*a* and *b* show the signal strength at 82 and 164 MHz, respectively, as the spacing between adjacent arcs is varied. We see that when the spacing corresponds to the surface acoustic wavelength there is a peak in the signal; at other spacings there is phase cancellation and therefore considerably smaller SAW output. The width of the peaks is related to the number of arcs, at 164 MHz there were 85 concentric arcs, although the square geometry of the SLM means that all the arcs do not subtend equal angles. Fig. 2*a* shows the focal distribution corresponding to the arc spacing of 37.6 μm corresponding to the frequency of maximum signal in Fig. 1*a*. We can see a strong diffraction limited focus similar to that observed when using CGHs. By tilting the arcs the focus can be moved, as shown in Fig. 2*b*, providing an ideal method to achieved the tip tilt correction described in [4]. We have previously shown that CGHs can produce near arbitrary distributions of SAW waves, and by programming the SLM to produce a pattern consisting of a thresholded output from two sets of concentric arcs, the distribution shown in Fig. 3 was produced. This consists of two separate focii displaced both axially and laterally.

Conclusions: We have shown that SLMs can be used to produced flexible distributions of light which, in turn, generate controlled SAW wave signals. We have demonstrated that the distributions emerging from the SLM can effect frequency control as well as focusing. They operate in a manner analogous to CGHs except that the distributions are programmable in real time, providing the vital component necessary to produce an adaptive ultrasonic imaging system. We have also shown the generation of more complex SAW wave distributions to demonstrate flexibility similar to that of CGHs. We believe that detection of ultrasound with single shot signal to noise considerably better than unity, at this frequency, with such a lower power, opens up exciting possibilities for the use of ultrasound in situations where laser ultrasonics has not, hitherto, been considered. The use of such low power levels however, was forced on us by the properties of the particular SLM used. The reflectivity of the device used was only approximately 10% and, furthermore, when the incident power level was increased light leakage to the backing silicon layer caused reversal failure of the device owing to carrier generation. We intend to improve the performance of the system in the near future by replacing the existing SLM with a model with both higher reflectivity and better power handling capability.

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