

DIFFRACTIVE ACOUSTIC ELEMENTS FOR LASER ULTRASONICS

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INTRODUCTION

Laser ultrasonics [1] is an effective means of generating surface acoustic waves (SAWs). We have shown in previous publications how computer generated holograms can be used to project optical distributions onto the sample surface. These can be used to control both the frequency content and the spatial distribution of the resulting ultrasound field. In this paper we demonstrate diffractive elements for surface acoustic waves. We show how frequency suppression, multiple focuses and frequency selective focusing of Rayleigh waves may be achieved with these elements.

EXPERIMENTAL SET-UP

The experimental set-up used in this paper, has been described elsewhere [2,3,4,5], so a brief description will suffice. The system is shown schematically in figure 1. A mode-locked Q-switched laser was used to excite the ultrasonic beam. The laser produced a burst of approximately 30 short pulses each separated by 12ns. Each burst was repeated every millisecond. The light from the source was then passed through different CGHs, which focused the beam onto the sample surface to form the profiles described throughout the paper. The resulting surface acoustic wave distributions were detected with a specialised knife edge detector [3] which was mechanically scanned relative to the sample while the illumination optics remained fixed. The peak envelope of the ultrasonic tone bursts were normally acquired using the envelope detection electronics described in [6]. The CGHs were designed using a direct search algorithm described elsewhere [7].

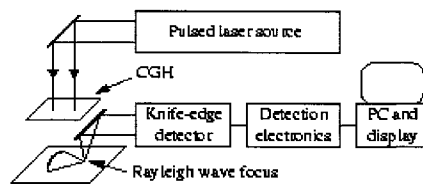


Figure 1. A schematic diagram of the experiment

In all the experiments the system operated in the thermoelastic regime and no surface treatment was performed on the samples. Inspection of the samples after the experiments revealed no detectable damage.

In order to predict the surface wave distributions expected from the samples, the predicted light distribution at the sample was calculated from the CGH design. The SAW amplitude distribution is then calculated by propagating the initial generated wavefront along the sample using angular spectrum propagation as described by Goodman [9].

CONTINUOUS DISTRIBUTIONS FOR FOCUSING AND FREQUENCY CONTROL

SAW Focusing

Focusing the Rayleigh wave distribution increases the displacement on the sample, thus improving the detectability of the surface wave distribution. In previous publications we have shown that this allows one to detect the ultrasonic distribution without averaging [3,6]. We have also shown how the increase in surface wave amplitude allows fast analog electronics to be used rather than a digital storage oscilloscope; this greatly improves the rate of image acquisition obtained in a non-contacting surface wave acoustic microscope [6]. The light distributions on the sample were obtained using a CGH, which produced a single arc. This provided focusing of the laser generated surface waves, but offered little

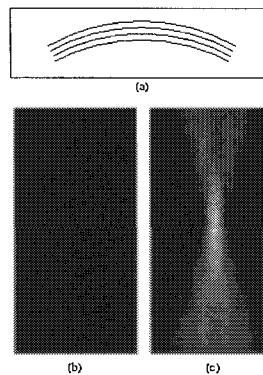


Figure 2. Focus of a four arc distribution, where each arc is separated by half a wavelength at 82MHz. (a) Schematic of four arc optical distribution. (b) No observable signal at 82MHz. (c) Strong diffraction limited focus at 164MHz. The image is size

control of the frequency content of the resulting surface wave distribution. In this section the use of several concentric arcs is described; this increases the maximum power that the sample can withstand without ablation. The spacing of the arcs determined the frequency selection.

Frequency Control: High Pass Filtering

Enhancing the harmonic signal and suppressing the fundamental can be important when trying to image at high frequencies where the signal at the fundamental is can be larger and may swamp the desired harmonic. Figure 2 shows the SAW focus obtained at the focus of a four arc distribution, this is shown schematically in figure 2a. The separation between adjacent arcs is half a wavelength at 82MHz and thus a whole wavelength at 164MHz. This means that the excitation from each 82MHz line cancels out, whereas the 164 MHz signals add in phase. The distributions shown in figure 2 clearly demonstrates this, since no 82MHz signal can be detected above the noise in figure 2b, whereas an excellent diffraction limited focus for the 164MHz signal was observed in figure 2c.

Frequency Control: Low Pass Filtering

Harmonic imaging involves excitation at a fundamental frequency and detection of the harmonic generated by non-linearities in the material. In conventional fluid coupled acoustic microscopy information about the couplant liquids and biological samples [10] may be obtained, but little information about the non-linear acoustic properties of hard solid materials is accessible. Since laser ultrasonics does not use a couplant it is a promising technique for SAW harmonic generation in solid materials, particularly at cracks and discontinuities.

To successfully perform harmonic imaging it is essential that any harmonic content in the input signal be suppressed so that it is not confused with the generated harmonic. To ensure efficient suppression of the harmonic a two arc distribution was used. In this case the arcs were separated by 3 half wavelengths at 164MHz. Figure 3 shows the SAW amplitudes at 82 and 164MHz generated by such an element, the signal at 82MHz is strong while no 164MHz signal can be seen above the noise.

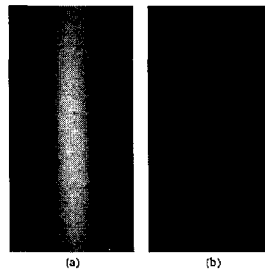


Figure 3 Focus of two arc hologram, where each arc is separated by three quarters of wavelength at 82MHz. (a) strong diffraction limited focus at 82MHz. (b) no observable signal at 164MHz. Image size 600microns by 300 microns.

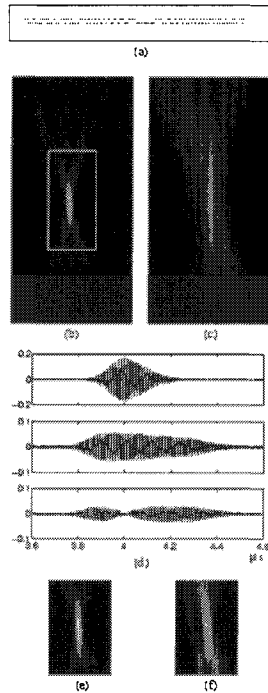


Figure 4 Results obtained with acoustic zone plate. (a) Optical distribution projected on the sample surface; acting as SAW wave zone plate. (b) Predicted point spread function at focus. Image dimensions 2mm by 1mm. (c) Measured point spread function, image dimensions as (b). (d) Waveforms showing amplitude versus propagation time from generation source (microseconds). Top trace waveform at focus from an arc with same focal length, middle trace waveform at focus, bottom trace waveform at position of first zero (notice phase dislocation in waveform). (e) zoom of predicted point spread function (b), (f) Measured point spread function after filtering.

DISCRETE DIFFRACTIVE ACOUSTIC ELEMENTS.

Discrete Acoustic Element for Focusing

Figure 4 shows a diffractive acoustic zone-plate (a) and its the simulated (b) and measured (c) amplitudes. The amplitude distributions shown in 4(b) and 4(c) do not agree well. This is a consequence of the large path difference between extreme ray paths and means that all the surface waves do not interfere at the focus (because of the short duration of the Q-switched envelope ~ 360 ns). This results in the spreading of the point spread function seen in 4(c). The point spread function shape can be recovered by digitally filtering the temporal signal for 82MHz, this is shown in 4(f), however this is slow

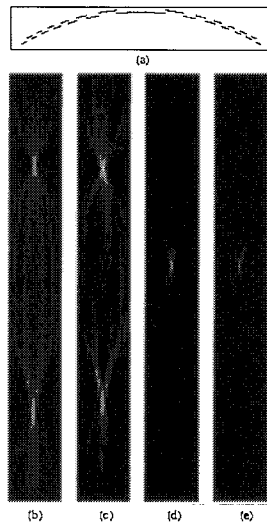


Figure 5 Hybrid diffractive element with superimposed continuous wavefront, with two focal lengths. (a) Optical distribution of hybrid DAE projected onto sample. (b) predicted focal distribution at 82MHz. (c) measured distribution at 82MHz. (d) predicted focal distribution at 164MHz. (e) measured distribution at 164MHz.

compared with the usual envelope detection. The next section demonstrates how hybrid diffractive elements may be used to overcome this problem.

Hybrid Elements for Frequency Dependent Focusing

The simple phase plate is clearly unsatisfactory if we wish to use an envelope detector. The solution to this problem is to use a hybrid continuous/discrete DAE. In this case a weak phase plate was imposed on an arc as shown in figure 5a. The arc forms the more powerful focusing element and the phase plate imposes a relatively weak

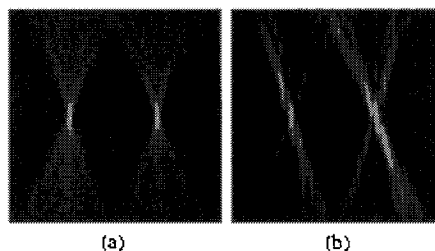


Figure 6 Hybrid diffractive element with superimposed continuous wavefront, with laterally offset focuses. (a) Predicted distribution from DAE showing laterally displaced focuses. (b) Measured distribution from DAE showing laterally displaced focuses.

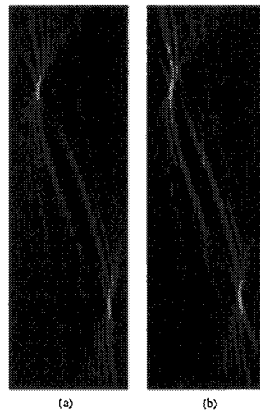


Figure 7 Hybrid diffractive element with superimposed continuous wavefront, with focuses offset both laterally and axially. (a) Predicted distribution from DAE showing laterally and axially displaced focuses. (b) Measured distribution from DAE showing laterally and axially displaced focuses.

perturbation; since the diffractive element imposed on the arc has only 6 zones between the center and the edge effective interference can take place from our 30 cycle source. The zone plate gives a +1 and a -1 diffracted order so that two focuses are formed - one inside the focus expected from the arc and one outside. The simulations of figure 5b and 5c show excellent agreement between the expected and measured focal distributions.

The 164MHz signal does not “see” the zoneplate and focuses to the geometric centre of the arc. This spatially separates the different frequency components.

Hybrid Elements for Displaced Focusing

In addition to controlling the focal position along the axial direction, a combined continuous discrete element can also act as Rayleigh wave analog of a Nomarski objective in optics, which forms two adjacent focuses. This is achieved using an arc on with a grating imposed on it. The two resulting diffractive orders at 82MHz split the focus sideways, once again 164MHz signal is unaffected and focuses to the geometric centre of the arc. The simulations and the measured distribution are shown in figure 6a and 6b respectively agreement between experiment and theory is very good.

In order to demonstrate the flexibility of our approach we once again used a continuous arc with a superimposed discrete phase plate, but rather than maintain the symmetry of this phase plate about the axis the plate was displaced. The +1 and -1 order focuses now differ not only in their axial position; but also in their height relative to the axis. Figure 7a and 7b show the excellent agreement between the predicted and measured distributions, even showing extremely close agreement in the fine detail of the wave distribution between the two focuses.

DISCUSSION

We have shown how from a specific optical design it is possible to generate an arbitrary optical distribution in the sample surface, which, in turn, acts as a Rayleigh wave diffractive element. The surface wave distribution is predicted entirely from the design of the optical element and gives excellent agreement. Combining curved sources with discrete phase plates gives control of the focal distributions and achieves multiple focuses as well as frequency selective focusing.

In this paper we have concentrated our discussion on SAWs, however concepts described here can equally be applied to bulk waves. Projection of a distribution, which acts as a diffractive element for bulk waves may be readily produced by projecting successive light and dark patches onto the sample. This element will act as an amplitude zone plate rather than a phase plate, but will produce a well defined focus in the bulk of the sample. The methodology we have described has been applied to flat surfaces only, but the method should find application to curved surfaces, as the CGHs may be readily designed to produce a desired optical distribution over any arbitrary surface.

In future work we intend to use hybrid continuous/discrete elements to enhance the operation of a non-contacting surface acoustic wave microscope and, in particular, examine the use of these elements to facilitate harmonic imaging of defects.

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