Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 23-24
6-8 December, 2010

Time-resolved two-dimensional imaging of surface acoustic waves generated by optical pulses focused to arbitrary spatial shapes

任意空間形状に集光したパルス光励起による弾性表面波の時間分解2次元イメージング

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1. Introduction

Time-resolved two-dimensional imaging of surface acoustic waves (SAWs) generated by optical pulses is important not only in the investigation of the elastic properties of materials but also in the evaluation of surface structures or defects. So far, several experiments that visualize SAWs have been carried out using an optical pump-probe technique [1, 2]. This all-optical technique allows one to generate and image SAWs without contacting on the sample.

In experiments using the pump-probe technique, the SAWs are often excited with a point-like source, because the resulting omnidirectional SAW propagation reveals sample anisotropy [1, 2]. However, it is sometimes convenient to propagate the SAWs in a particular direction or to make them converge to a particular point for ease of analysis or to enhance certain SAW modes. Different shaped SAW sources have been used for this purpose, such as a ring shape by means of optical focusing with an axicon lens [3]. More flexibility is achieved using computer generated holograms (CGHs) to produce arbitrary spatial shapes for the excitation light on the sample. For example, SAWs in the MHz region have been generated and concentrated using an optical source in the shape of a series of concentric arcs on a sample [4, 5].

In this study, we use a spatial light modulator (SLM) that generates CGHs in order to focus pump pulses to arbitrary spatial shapes to generate sub-GHz SAWs. The propagation of the SAWs is imaged optically in the time domain.

2. Experimental setup

Figure 1 shows a diagram of the imaging system based on the optical pump-probe technique. The sample is a crown glass plate (thickness 1 mm) coated with a thin gold film (thickness 50 nm). A mode-locked Ti-sapphire laser with a wavelength of 830 nm, repetition rate of 78 MHz and pulse duration of ~ 150 fs is used as a light source. Optical pulses (pump pulses) of wavelength 415 nm, which are generated by passing optical pulses through a second harmonic generation crystal (SHG), are used to generate the SAWs. Optical pulses (probe pulses) with wavelength of 830 nm are used to detect the SAW propagation.

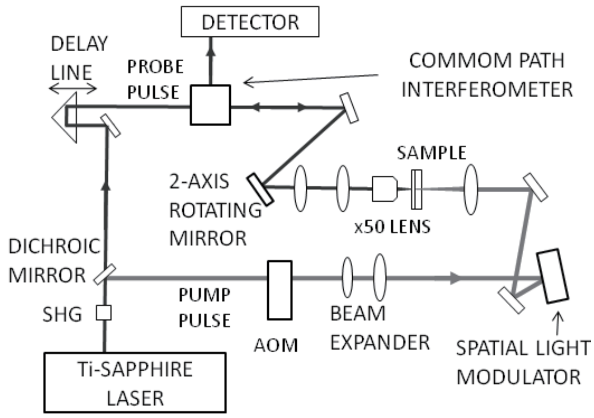

Fig. 1. Schematic diagram of the setup for the imaging of SAWs using generation with an SLM. SHG: second harmonic generation crystal, AOM: acousto-optical modulator.

To focus the pump pulses to an arbitrary shape on the sample surface, we use a reflective SLM (16×12 mm, 792×600 pixels, Hamamatsu LCOS-SLM X10468) based on phase modulation. This device allows each pixel to independently modulate the phase of the reflected light. The SLM displays computer generated holograms (CGH) which are calculated by use of an algorithm described elsewhere [5]. The pump pulses incident on the SLM are modulated according to the pattern of the CGH, and an image is formed using

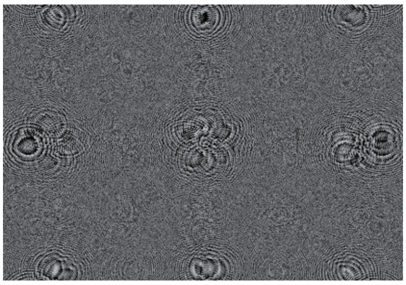

Fig. 2. An example of a CGH used for focusing light to a ring shape. This pattern has a four-step gray scale which modulates the phase of reflected light.

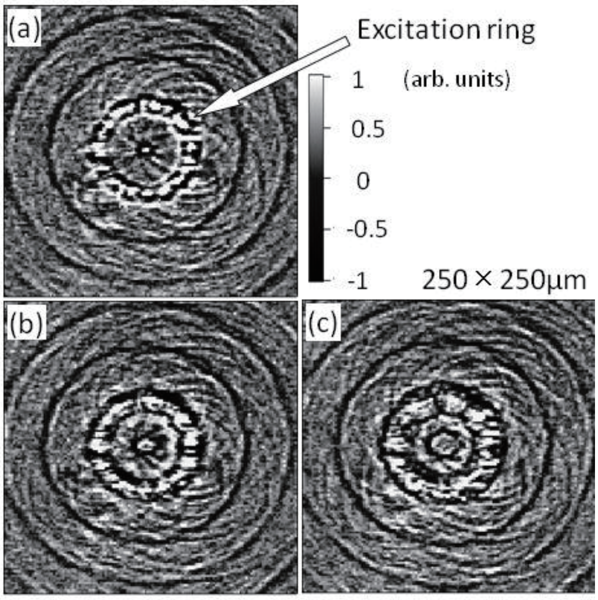

Fig. 3. SAW images produced using a ring-shaped source (of diameter about 90 μm) indicated by the arrow. Waves propagating inwardly converge to the center of the ring and then diverge outwardly. The pump-probe delay times are (a) 1.36 ns, (b) 2.72 ns, (c) 4.08 ns respectively.

focusing optics. In a further imaging step, this image is focused onto the surface of the sample to excite the SAWs.

For the detection of the surface displacement caused by the SAW propagation, we use a common-path Sagnac interferometer [6]. The probe spot position is scanned across the sample surface by use of a $4f$ lens system which consists of a dual-axis rotating mirror, a pair of lenses and an objective lens [7]. Time-resolved images are obtained by varying the time delay between the pump and probe pulses.

3. Results and discussion

We use the CGH shown in **Fig. 2** to produce a ring shaped distribution of light on the sample surface. The SAWs are generated by this ring source (diameter ~ 90 μm, width ~ 15 μm). The resulting SAW propagation images are recorded by varying the delay time in steps of 454 ps. Typically, 30 images are taken to fully cover the laser repetition period. It takes about 30 minutes to obtain a single image. **Figure 3** shows SAW propagation images recorded at some representative delay times. The SAWs are broadband pulses with a center frequency of 200 MHz, wavelength ~ 15 μm and velocity ~ 3 $\mathrm{km\,s^{-1}}$. This velocity is close to the known velocity of Rayleigh waves on crown glass, 3 km $\mathrm{s^{-1}}$ [8].

Our sample is isotropic, so the waves are expected to have circular symmetry. However, the ring appears to be made of several points. These could be caused by an imperfect algorithm, inaccuracies in the phase modulation at each pixel, or distortions in the phase or amplitude of the incident light beam.

4. Conclusions

We have produced a ring shaped distribution of laser pulsed light on a sample surface by use of a computer generated hologram and imaged the resulting propagation of SAWs in two dimensions. In future we shall try to improve the fidelity of the pattern by better algorithms that account for the phase distortion in the wave front of the incident light beam .

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