1P2-22

Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 59-60
18-20 November, 2009

# Imaging GHz surface acoustic waves through the photoelastic effect
光弾性効果によるギガヘルツ弾性表面波二次元イメージング

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## 1. Introduction

Surface acoustic waves (SAWs) are acoustic waves that propagate along the surface of a material with an amplitude that decays exponentially with depth [1]. SAWs have been exploited in filtering devices, which are used in GHz telecommunication equipment such as mobile phones. Imaging of SAW propagation is therefore crucial for the development and improvement of these devices. Such imaging in the GHz frequency region has been reported using an interferometer to detect out-of-plane ultrasonic surface displacements [2,3]. It is, however, desirable to detect the in-plane ultrasonic displacements as well for a complete understanding of the SAW propagation.

In this study, we obtain images of the propagation of acoustic waves by detecting the transient optical reflectivity change due to the photoelastic effect, i.e. the modulation of the dielectric permittivity by the strain. Both the permittivity tensor and the strain tensor are second-rank tensors. The change of the permittivity tensor is related to the strain tensor through the fourth-rank photoelastic tensor. So it is possible to detect strain components related to the in-plane ultrasonic displacement through changes in optical reflectivity, provided that an appropriate polarization configuration for the probe light is chosen [4].

We make use of the optical pump and probe technique with ultrashort optical pulses to excite and detect the acoustic waves. The acoustic waves are generated by illuminating the sample with an ultrashort optical pump pulse, and the reflectivity change caused by the acoustic waves is detected with a delayed ultrashort optical probe pulse. The incident polarization and detected polarization are controlled appropriately (as described later), and under these conditions we obtain scanned two-dimensional images of the SAWs. By suitable image processing we show how it is possible to obtain an image that depends only on the in-plane displacement.

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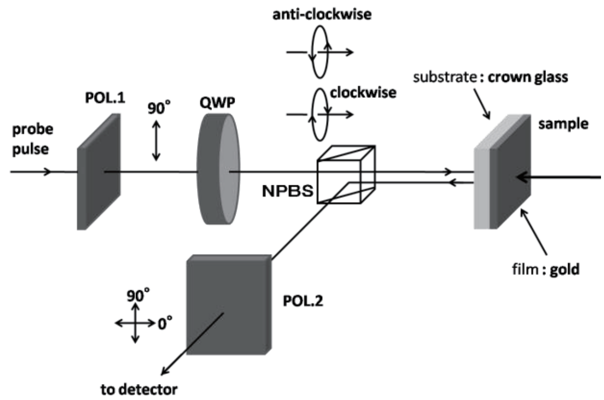


Fig. 1. Schematic diagram of the experimental setup for surface acoustic wave imaging through the photoelastic effect. POL: polarizer, QWP: quarter wave plate, NPBS: non-polarizing beam splitter.

## 2. Sample and experimental setup

**Figure 1** shows the experimental setup. The sample is a crown glass substrate coated with an Au film of thickness about 45nm. Crown glass is elastically isotropic material. The light source is a mode locked Ti-Sapphire laser of center wavelength 830 nm, repetition rate 76 MHz, and pulse width 150 fs. The 830 nm beam is used for probing and a second harmonic (415 nm) beam is used for pumping. The pump light beam is shaped by a spatial filter and then focused to a spot diameter ~ 2 $\mu$m onto the sample at normal incidence with a ×50 microscope objective from the Au film side of the sample. This excites broadband SAW pulses with frequency components up to ~ 1 GHz. The probe light beam is focused onto the sample from the substrate side. The delay time between pump and probe pulse arrivals at the sample is varied from 0 to 13 ns using a 4 m variable optical delay line. The probe light spot position is scanned in two dimensions over the sample surface using a two-axis rotating mirror (not shown in Fig. 1)[2]. The intensity of the probe light reflected from the sample is detected as a function of the delay time and the probe spot position. The excitation optical beam is modulated at 1 MHz for purposes of synchronous detection using a lock-in amplifier at this frequency. The incident probe light is chosen to have either a clockwise or an anti-clockwise circular polarization. A 0°- or 90°-aligned linear polarization component (see Fig. 1) is detected by placing a polarizer before the detector. We obtain 4 images with these combinations of polarization on detection.

## 3. Results and discussion

**Figure 2** shows images obtained with clockwise and anti-clockwise circular probe polarization incident on the sample. The polarizer is set to pass the 0° polarization component of the reflected light. Both images are taken at 11.7 ns after the pump light pulse is incident on the sample, and the imaging area is 140 × 140 μm$^2$. Concentric rings are clearly observed. The literature values of the bulk longitudinal acoustic wave velocity and the Rayleigh wave velocity on crown glass are 5660 and 3130 m/s, respectively [5]. As the velocity of the outer ring in Fig. 2 is about 5300 m/s, we identify it as a SSLW (Surface Skimming Longitudinal Wave). As the velocity of the inner ring is about 2600 m/s, we identify it as the Rayleigh wave. The pattern produced by the two waves depends on the direction of propagation of the acoustic waves and on the polarization of the probe light beam.

**Figure 3** shows an image obtained by subtraction of Fig. 2 (b) from Fig. 2 (a). The $x$ and $y$ directions are parallel to the surface of the sample. According to theory based on the photoelastic effect, it is expected that the image obtained by subtraction depends on the strain component $\eta_{xy}$, related to the in-plane ultrasonic displacement. When one tracks a path around a ring circumference, the sign of the intensity changes in the following way: 0, +, 0, −, 0, +, 0, −, 0. This result agrees with theory (not shown here) based on the photoelastic effect. This image depends only on the in-plane ultrasonic displacement.

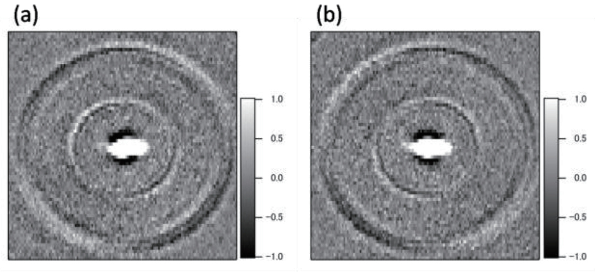


Fig. 2. Images obtained with different polarization configurations of probe light with (a) anti-clockwise circular polarization incident on the sample, and (b) clockwise circular polarization incident on the sample. Both are obtained with a 0°-aligned linear polarization on detection. The imaging area is 140 × 140 μm$^2$, and the pump-probe delay time is 11.7 ns.

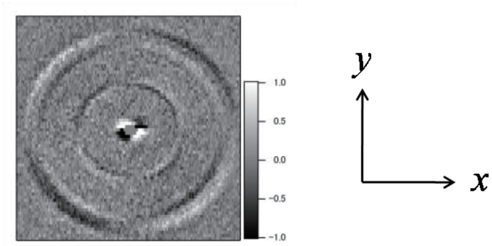


Fig. 3. Image obtained by subtraction of Fig. 2 (b) from Fig. 2 (a). The definition of the $x$ and $y$ directions is also shown.

## 4. Conclusion

We have obtained images of SAW propagation on a crown glass plate through transient optical reflectivity changes arising from the photoelastic effect. The images are analyzed to extract an image solely determined by the in-plane ultrasonic displacement. In future, we will conduct similar experiments for elastically anisotropic samples, and obtain images of each strain component for more complicated acoustic modes.

## References

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