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Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 447-448
6-8 December, 2010

Imaging GHz surface acoustic waves on anisotropic media through the photoelastic effect
光弾性効果による異方性媒質上での弾性表面波二次元イメージング

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1. Introduction

Surface acoustic waves (SAWs) propagate along the surface of media with an amplitude that decays exponentially with depth [1]. Since the invention of interdigital transducers, GHz SAWs have been exploited in filtering devices in telecommunication equipment such as mobile phones. Imaging of SAW propagation is crucial for the development and improvement in such devices. Such imaging in the GHz frequency region has been mainly achieved using optical interferometry, which can detect only out-of-plane ultrasonic displacements [2,3]. For a more complete understanding of SAW propagation, however, it is important to develop imaging techniques which can also detect in-plane ultrasonic displacements.

The photoelastic effect, that is the modulation of the permittivity by the strain, can be used to solve this problem. Since the discovery of this effect by Brewster in 1816, it has been applied in various fields, especially in engineering. For example, it has been reported that the photoelastic effect can visualize the propagation of MHz SAWs [4]. 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. Thanks to the relatively high degree of freedom involved in phenomena governed by a fourth-rank tensor, it is possible to detect strain components related to the in-plane ultrasonic displacement through changes in optical reflectivity provided that the appropriate polarization configuration of the probe light is chosen [5].

In this study we obtain images of the propagation of GHz SAWs on anisotropic media by detecting the transient optical reflectivity change due to the photoelastic effect. We make use of the optical pump-probe technique with ultrashort optical pulses to excite and detect the acoustic waves. This technique is a non-contact, and non-destructive method: it is possible to study SAWs without using contacting transducers such as piezoelectric devices. The acoustic waves are generated by irradiating the sample with ultrashort optical pump pulses, and the reflectivity change caused by the acoustic waves is detected with delayed ultrashort optical probe pulses. The polarization of the incident, and reflected probe pulses can be controlled appropriately to obtain scanned two-dimensional images of the SAWs. We previously obtained images of SAWs on crown glass, which is elastically isotropic, and showed that it is possible to obtain images only related to in-plane ultrasonic displacements by subtraction of two images obtained with different polarizations of optical probe pulses [6,7]. This time, we obtain images of SAWs on crystalline TeO_2, which is elastically anisotropic.

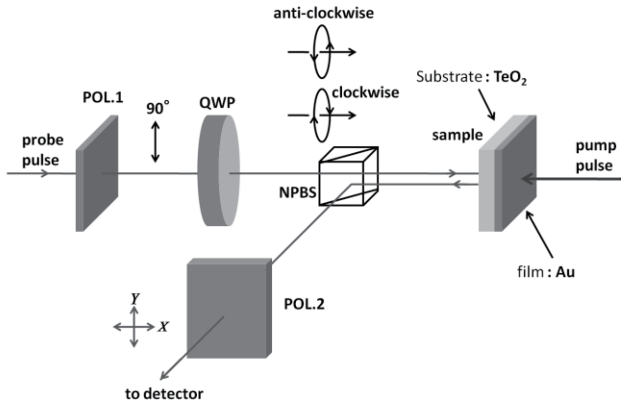

Fig. 1. Schematic diagram of the experimental setup for surface acoustic wave imaging through the photoelastic effect. POL: polarizer, QWP: quarter wave plate, NPBS: non-polarizing beam splitter.

2. Sample and experimental setup

Figure 1 shows the experimental setup. The sample is a TeO_2 (001) substrate coated with a polycrystalline Au film of thickness about 50 nm. TeO_2 is a tetragonal crystal, and has strong anisotropy. The light source is a mode locked Ti-Sapphire laser of center wavelength 830 nm, repetition rate 76 MHz, and pulse width 150 fs. A 830 nm beam is used for probing and a second

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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 of a few μm 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 on the sample from the substrate side in order to detect reflectivity changes caused by the photoelastic effect in TeO_2. The delay time between pump and probe pulse arrivals at the sample is varied from 0 to 13.3 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 and a 4f optical system [2]. The intensity change of the probe light reflected from the sample is detected as a function of the delay time and the probe spot position. The pump optical beam is modulated at 1 MHz for the purposes of synchronous detection using a lock-in amplifier at this frequency. The incident probe is chosen to have either a clockwise or an anti-clockwise circular polarization. A X- or Y-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 an image of SAWs on the tetragonal crystal TeO_2 (001) coated with a thin (~50 nm) gold film using an interferometer system [2]. The pattern shows fourfold symmetry as expected from the crystal cut. **Figure 3 (a)** shows an image for the same sample obtained with the present experimental set-up which exploits the photoelastic effect. The incident probe light is clockwise circularly polarized, and the X-linear polarization component of the reflected probe light is detected. Comparing Fig. 3 (a) with Fig. 2, there are some wave fronts which are only seen in the images based on reflectivity. In Fig. 3 (b) these wave fronts are indicated with dotted lines. From theoretical calculations one can associate the dotted lines with fast-transverse waves which don't have out-of-plane ultrasonic displacements [8]. This indicates that the present detection method involving the photoelastic effect can visualize both out-of-plane and in-plane ultrasonic displacements.

4. Conclusions

We have obtained images of SAW propagation on a TeO_2 substrate through transient optical reflectivity changes arising from the photoelastic effect. As expected, this method can detect more SAW modes than optical interferometry.

Fig. 2. A SAW image for a 180 μm square region on TeO_2 (001) obtained using an interferometer [2]. The substrate is coated with a polycrystalline Au film of thickness about 50 nm.

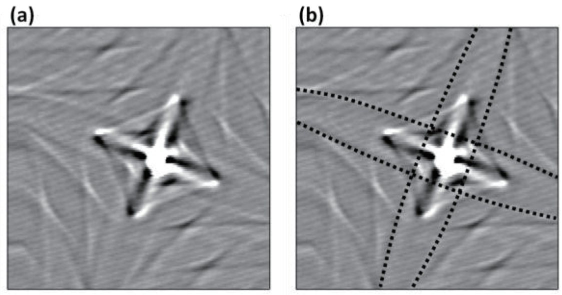

Fig. 3 (a). Images over a 140 μm square region obtained with polarization configurations of probe light with clockwise polarization incident on the samples, and X-aligned linear polarization on detection. (b) Dotted lines indicate the fast-transverse waves which don't have out-of-plane ultrasonic displacements [8]. The substrate is coated with a polycrystalline Au film of thickness about 50 nm. The sample is rotated about a vertical axis compared to the orientation in Fig. 2.

In future the results will be analyzed using light scattering theory [6,7].

References

1. 超音波便覧編集委員会：超音波便覧（丸善, 1999).
2. Y. Sugawara, O. B. Wright, O. Matsuda, M. Takigahira, Y. Tanaka, S. Tamura and V. E. Gusev: Phys. Rev. Lett. **88** (2002) 185504.
3. T. Tachizaki, T. Muroya, O. Matsuda, Y. Sugawara, D. H. Hurley, and O. B. Wright: Rev. Sci. Inst. **77** (2006) 043713.
4. K. G. Hall: Ultrasonics **20** (1982) 159.
5. H. Yamazaki, O. Matsuda, O. B. Wright, and G. Amulele: phys. stat. sol. (c) **1** (2004) 2991.
6. T. Saito, O. Matsuda, M. Tomoda, and O. Wright: USE2009 予稿集 (2009) 59.
7. T. Saito, O. Matsuda, M. Tomoda, and O. Wright: to be published.
8. Y. Tanaka, M. Takigahira, and S. Tamura: Phys. Rev. B **66** (2002) 075409.