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Time-resolved imaging of GHz surface acoustic waves in TeO_2 through the photoelastic effect

TeO_2 における光弾性効果を利用したギガヘルツ弾性表面波時間分解イメージング

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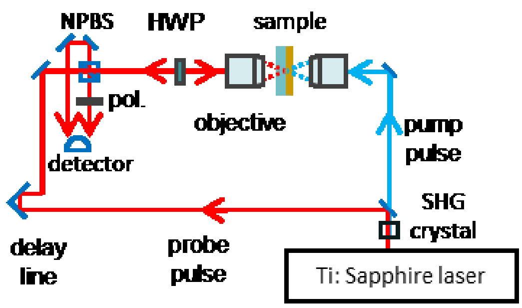
1. Introduction

Surface acoustic waves (SAWs) propagate along the surface of media with amplitudes that decay exponentially along the depth direction. Since the invention of interdigital transducers, GHz SAWs have been exploited in filtering devices for telecommunication equipment such as mobile phones. Imaging of SAW propagation is crucial for the development and improvement of such devices. So far, imaging in the GHz frequency region has been mainly achieved using optical interferometry, which can detect only the out-of-plane surface displacements [1,2]. But for a complete understanding of the SAW propagation, it is desirable to detect strain components which are not related to the out-of-plane surface displacement. One possibilty for such detection is the use of the photoelastic effect, which can detect strain directly.

The photoelastic effect, i.e. the modulation of the permittivity by the strain, has been applied in various fields, such as the imaging of the propagation of MHz SAWs [3]. Both the permittivity and the strain 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 fourth-rank tensors, 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 for the probe light is used [4].

In this study we measure images of the propagation of GHz SAWs on anisotropic media by detecting transient optical reflectivity changes caused by the photoelastic effect. We obtain SAW images depending only on the specific strain components and compare them with images provided by the simulation.



2. Experiment

Fig. 1 Experimental setup. pol: polarizer, HWP: half wave plate, NPBS: non-polarizing beam splitter, SHG crystal: Second Harmonic Generation crystal.

Figure 1 shows the experimental setup for time-resolved two-dimensional imaging of the SAW propagation using the photoelastic effect. The sample is a TeO_2 (001) substrate of thickness 1 mm with a gold thin film (thickness ~40 nm) deposited by sputtering. The TeO_2 crystal is chosen because of its 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. The 830 nm beam is used for probing, and the second harmonic (415 nm) beam is used for pumping. The pump and probe light beams are focused to a spot diameter of a few μm onto the sample at normal incidence with two independent ×50 microscope objectives. Two-dimensional images of the reflected probe light intensity can be obtained by moving the objective lens for the pump light with an automated stage to scan the position of the pump light spot across the sample surface. The incident probe light is linearly polarized with the polarization plane at 45° or 135° to the horizontal plane. A polarizer is placed before the detector to pass the 0° (horizontal) or 90° (vertical) polarization component. The images, depending only on the specific strain components, can be retrieved by processing the raw images.

3. Results and discussion

Figure 2 shows images of SAWs on TeO_2 (001) coated with a thin gold film. Fig. 2 (a) shows an image using 45°-linearly-polarized incident probe light. **Figure** 2 (b) shows an image using 135°-linearly-polarized incident probe light. Both of these images are obtained with a 90°-aligned linear polarizer in the detection. The pump light beam is focused at the center of both images. The pump-probe delay time is 11.7 ns. These SAW images show complex shapes due to the anisotropy of TeO_2.

Figure 3 shows an image obtained by subtraction of **Fig. 2 (b)** from **Fig. 2 (a)**. It is expected that the image obtained by this subtraction depends on the strain component η_{xy}, related to the in-plane ultrasonic displacement [5].

4. Conclusions

We have obtained images of SAW propagation on TeO_2 (001) through the photoelastic effect. With appropriate processing of the images measured with different polarization configurations, we have obtained a image of SAWs on TeO_2 depending only on the strain component η_{xy}. Simulations are now in progress to reproduce the experimental data.

(a) (b)

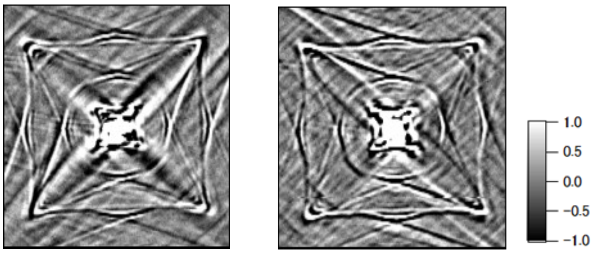


Fig. 2: SAW images for a 140 × 150 μm^2 region on TeO_2 with (a) 45°- and (b) 135°-polarized incident probe light. Both of them are obtained by detecting the horizontally-polarized component of the reflected probe light. The pump-probe delay time is 11.7 ns. The gray scale shows reflectance change of the intensity. Units are arbitrary.

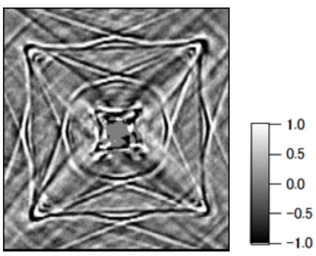


Fig. 3 Image obtained by subtraction of Fig. 2 (b) from Fig. 2 (a).

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