2P2-7
Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 181-182
13-15 November, 2012

Precise frequency control in the time-resolved 2D imaging of GHz surface acoustic waves

GHz 帯弾性表面波の時間分解 2 次元イメージングにおける周波数の精密制御

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1. Introduction

Surface acoustic waves (SAWs) are acoustic waves localized near the surface of a material. SAWs are widly used in filtering devices in GHz radio communication, so the time-resolved imaging of SAW propagation is an important subject. We have developed a time-resolved SAW imaging system based on an optical pump and probe technique at GHz frequencies with micron lateral spatial resolution and associated analytic methods based on spatiotemporal Fourier transforms[1,2]. With this method the direct measurement of frequency band gaps and dispersion relations of phononic crystals can be measured[3]. Phononic crystals (i.e. acoustic periodic structures) have been the subject of a large body of recent research[4]. The time-resolved imaging of ~GHz SAW propagation is expected to become a powerful tool in the development and the improvement of phononic crystals.

In our time-resolved imaging method, however, there is a restriction on the possible probing frequencies. They are restricted to integer multiples of the laser repetition frequency. Therefore our method is not suitable for precise frequency measurements. Although a reduction of the laser repetition frequency in some way is the simplest solution to this problem, it results in an upsizing of the measurement system and protracted measurement times. Here we overcome this restriction in the existing method with a few modifications in our optical system and an associated analytic method.

2. Theory

In the existing method, lock-in detection is used because the measurement signals are usually quite small. For lock-in detection, the pump beam at a laser repetition frequency f (~76 MHz) is chopped at a chopping frequency F (~1 MHz) with an acousto-optic modulator (AOM). Hence the pump beam includes two frequency components $nf \pm F$ besides the original laser frequency component nf for each n, where n is an integer. The waves at frequencies $nf \pm F$ are the sidebands. By an appropriate choice of the chopping frequency F, it is possible to excite SAWs with arbitrary frequencies. This precise frequency control requires an improvement of the analytical method based on spatiotemporal Fourier transforms, which cannot be explained in the limited length of this abstract. The details of the improvement will be presented at the symposium.

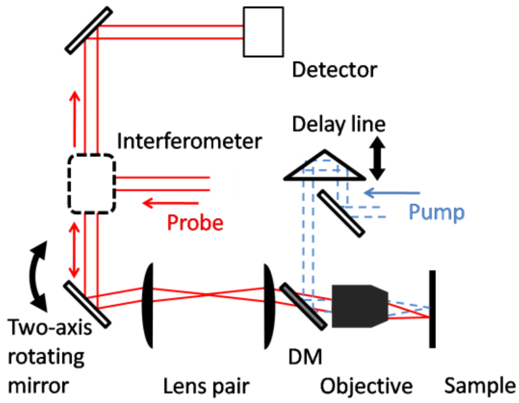

Fig. 1 Schematic diagram of the imaging system. DM: Dichroic mirror

3. Experiment

We experimentally obtain time-resolved two-dimensional SAW images in the ~GHz frequency region on a crown glass plate of thickness 1 mm covered with a gold film of thickness ~40 nm in order to apply the new analysis method to actual images. We use the optics based on the pump and probe technique, involving a two-dimensional (2D) scanner and a Sagnac interferometer to detect the SAWs, as described in **Figure 1**. The light source is a mode-locked Ti:Sapphire laser generating the light pulses with wavelength 830 nm, repetition frequency 76 MHz, and pulse width ~100 ps. Second harmonic pulses at wavelength 415 nm are used as pump light pulses to generate acoustic waves. The light pulses at central wavelength 830 nm are used as probe light pulses to detect propagating acoustic waves. The pump light is chopped at a 3 MHz chopping frequency with an AOM. The pump and probe pulses are focused on the sample surface through a microscope objective lens to a few-μm spot diameter, and the pump pulses excite up to ~1 GHz SAW pulses propagating in all directions. The probe pulses interferometrically detect the out-of-plane surface velocity[2] with the help of a system, containing a two-axis rotating mirror and lens pair, that scans the probe spot in two dimensions over the sample surface. By means of a delay line scan we obtain animations of the SAW propagation consisting of 30 images over a single repetition period of the laser pulses (~13.2 ns). The highest detectable frequency component is determined by the number of images.

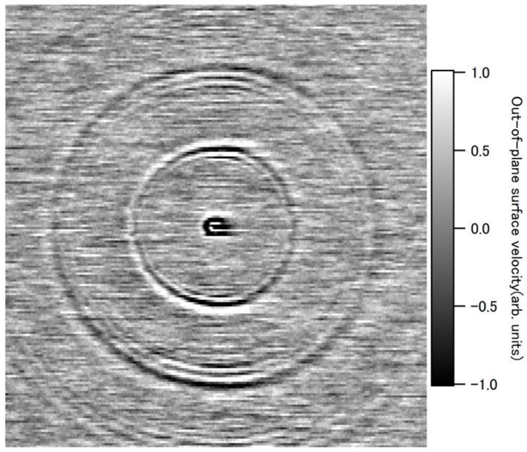

Fig. 2 Snapshot of SAW pulses propagating on the gold/crown glass sample. Imaging size is 200 × 200 μm^2.

4. Results

Figure 2 represents a snapshot of the SAW wave fronts propagating on the sample. The pump beam is focused at the center of the image, and the concentric rings spreading out from there are the wave fronts of the SAW pulses. This represents an image right after the pump pulse arrival. SAW wave fronts on these images are expected to have sidebands. We are now in the process of analyzing these images to reveal the effect of these.

5. Conclusion

We have developed a new experimental and analysis method for precise frequency control in the time-resolved two-dimensional imaging of GHz SAWs. We have obtained SAW images (animations) experimentally for the purpose of testing this method. Application of the improved analytic method to the images is in progress.

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