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Visualization of Propagating Picosecond Ultrasonic Pulses in Transparent Solids
透明固体試料内におけるピコ秒超音波伝播の可視化

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1. Introduction

The visualization of propagating ultrasonic waves inside materials is valuable for determining their elastic properties. Conventionally this can be done with photoelastic techniques in which a sample is put between two polarizers and the strain distribution detected as a polarization change using stroboscopic illumination. However the spatial resolution of the method is typically on the order of millimeters. It would therefore be interesting to extend this method to smaller length scales. It has proved possible to generate and detect nanometer-scale wavelength ultrasonic pulses with ultrashort laser pulses [1,2]. This method, known as picosecond ultrasonics, can be used to measure the physical properties of nanoscale materials such as thin films but is not suitable for visualization.

We recently developed an optical tomographic method to visualize propagating picosecond ultrasonic pulses in transparent solids by means of the photoelastic effect at different probe angles of incidence [3]. This technique is based on the interference between components of scattered probe light from ultrasonic pulses. Ultrasonic pulses with ~200 nm spatial resolution and 1 ps temporal resolution can be detected. In this study we present an improved system for this type of measurement based on automated angle scanning.

2. Theory

This method is based on the Brillouin scattering of light by acoustic waves in transparent materials. When monochromatic light is reflected from an ultrasonic pulse in a homogeneous and isotropic medium, the amplitude of the reflected light is proportional to the amplitude of the ultrasonic wave component at a particular acoustic wavelength, corresponding to the condition:

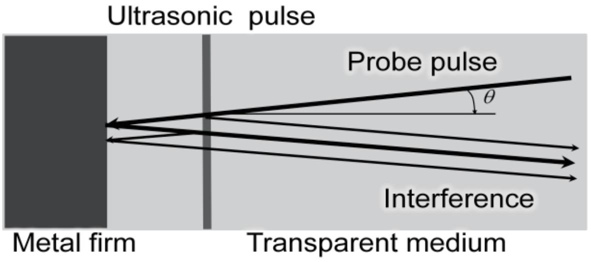

Fig. 1 Diagram of the probe light reflected from an ultrasonic pulse and from an interface, producing interference effects.

$$\Lambda = \lambda/(2n\cos\theta) \qquad (1)$$

where Λ is wavelength of the ultrasonic wave, λ is wavelength of the probe light, θ is the probe incident angle, and n is refractive index. This condition is in fact the Bragg scattering condition. If the probe light incident angle θ is varied, then the detected acoustic wavelength Λ also varies. We can exploit this variation by making measurements at different angles and then using an inversion technique to reconstruct the ultrasonic pulse shape. The details of this procedure are given in Ref. 3.

3. Sample

We use hemi-spherical sample of BK7 glass (n=1.517) of diameter 10 mm coated with an Al film of thickness 400 nm. This shape is chosen to avoid refraction of the probe beam. Picosecond ultrasonic pulses are generated at the Al-glass interface.

4. Experiment

Figure 2 shows the experimental set-up. We use a mode-locked Ti-sapphire laser of central wavelength 830 nm, pulse duration ~200 fs, and repetition rate 80 MHz. The laser beam is divided into a pump beam (of wavelength 830 nm) and a probe beam (415 nm). The pump light is chopped

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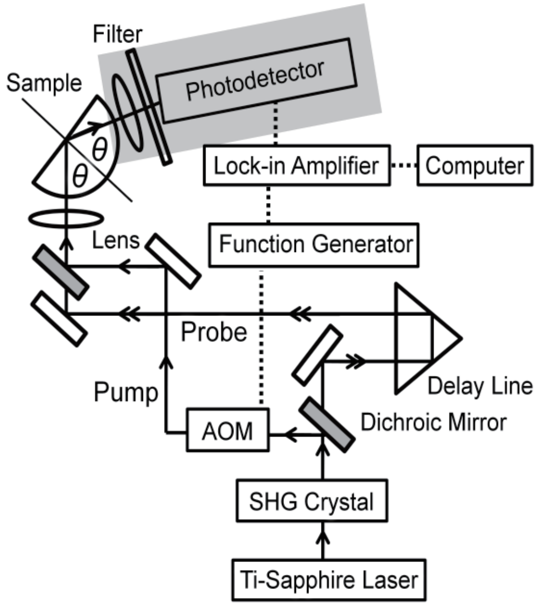

Fig. 2 Optical system. SHG: second harmonic generation, AOM: acousto-optic modulator.

by an acousto-optic modulator. After passing through an optical delay line the probe beam is combined with the pump beam, and these beams are focused on the Al-glass interface. The pump pulses generate picosecond ultrasonic pulses which propagate in the depth direction in the sample.

The intensity of the probe light reflected from the sample is detected with a photodetector and amplified with lock-in amplifier. The sample and the detector are set on automatic rotation stages. The stages are chosen so that the detector rotates by angle 2*θ* when the sample rotates *θ*.

5. Results and discussion

Figure 3 shows relative reflectivity changes between 10° and 80° for the angle of incidence of the probe pulse. The angle step is 0.2° and the time step is 20 ps; this measurement took about 12 hours. The reflectivity is normalized by cos*θ* to compensate for the change in the elliptical pump light spot area with angle. The reconstructed strain is shown in **Fig. 4**. The strain clearly propagates in the depth direction in the sample. The straight line is a result of the ultrasonic pulse propagating at constant velocity. The longitudinal sound velocity of BK7 glass, 5900 m/s, can be derived from the gradient of this line. The parallel straight line starting at 230 ps corresponds to the second pulse reflected from Al film surface. The periodic pattern as a function of depth is thought to be an artifact, the origin of which is as yet not understood.

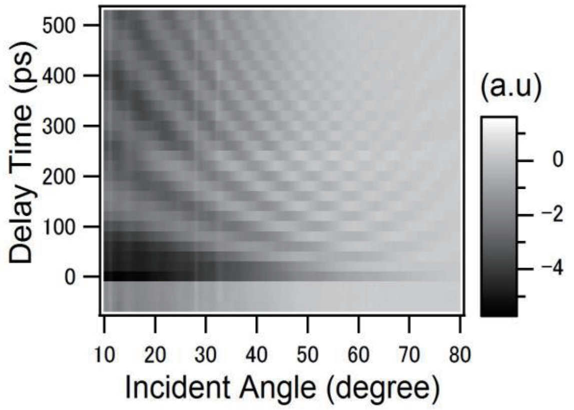

Fig. 3 Measured reflectivity changes vs. delay time and angle. The angle step is 0.2°.and the time step is 20 ps.

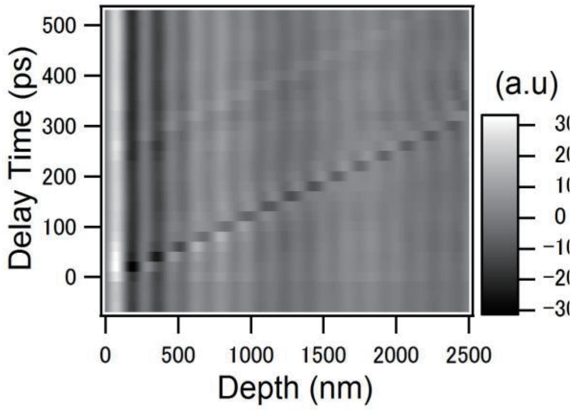

Fig. 4 Reconstructed strain image as a function of depth and time.

6. Conclusion

We have developed an automatic measuring system for visualizing high frequency ultrasonic pulse propagation. This technique is restricted to one dimensional probing in homogeneous, isotropic and transparent solids. In future, the technique could be extended to three dimensional ultrasonic wave images in more complex materials.

References

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