1P1-4

Sound velocity mapping in silica glass with picosecond ultrasonics

ピコ秒超音波法による石英ガラス中の音速マッピング

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1. Introduction

Picosecond ultrasonics is a method for exciting and detecting GHz ultrasonic pulses by ultrashort light pulses.[1,2] This gives rise to nanoscale ultrasonic wavelengths in solids, suitable for inspecting nanostructures. It is also possible to measure nanoscale sound velocity distributions in transparent samples nondestructively and without contact by monitoring GHz Brillouin oscillations in optical reflectance.[2,3] This method, known as picosecond ultrasonic interferometry or TDBS (Time-Domain Brillouin Scattering), has been used for depth profiling of sound velocity and refractive index in samples of transparent inorganic materials that are homogeneous in the lateral direction [3] and for imaging the sound velocity of fixed biological cells assuming a constant refractive index.[4] Besides, various applications can be expected for TDBS.[5] It is also possible to monitor the refractive index by multi-angle measurements, but this method is complicated, time consuming, and reduces the lateral spatial resolution.

To mitigate this problem we present here a method for extracting the sound velocity from time resolved Brillouin oscillations without the requirement for a separate refractive index measurement.

2. The sound velocity mapping method

Brillouin oscillations in picosecond ultrasonics arise from the interference between the reflected probe light from the ultrasonic pulse and from any interfaces in a transparent sample. An example is shown in **Fig. 1(a)**. When the sample is homogeneous, the Brillouin oscillation frequency $f_B(t)$ is given by

$$f_B(t) = 2nv\cos\theta/\lambda, \qquad (1)$$

where n is the refractive index, v is the sound velocity, θ is the angle of incidence, and λ is the wavelength of the probe light in air. Consider the geometry in which the probe light is incident from the side of sample, as shown in **Fig. 1(b)**. This geometry for Brillouin scattering is known in high pressure physics.[5] Equation (1) is modified as follows: for a probe-light angle of incidence θ_0' and refraction angle θ', Snell's law gives

$$\sin\theta_0' = n\sin\theta' = n\cos\theta, \qquad (2)$$

where θ is the angle of incidence inside the transparent medium. The Brillouin frequency $f_B(t)$ in this new arrangement becomes

$$f_B(t) = 2v\sin\theta_0'/\lambda. \qquad (3)$$

The refractive index n does not enter this equation, allowing the sound velocity to be derived without a knowledge of n.

To obtain the depth distribution of the sound velocity, an STFT (Short Time Fourier Transform) with a Hanning window function can be applied to the time-resolved Brillouin oscillations in probe reflectance to extract the Brillouin frequency as a function of time and thereby the depth distribution of the sound velocity v from Eq. (3). The spatial resolution in the depth direction depends on the FWHM (full width at half maximum) of the Hanning window function.

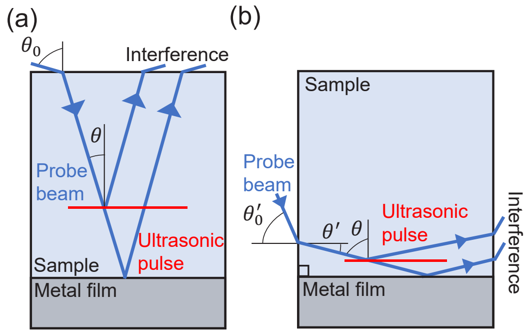

Fig. 1 Samples of (a) and (b) are homogeneous.
(a) Conventional time-resolved Brillouin scattering setup. The probe beam is incident from the top of the sample. (b) New arrangement in which the probe beam is incident from the side of the sample.

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3. Experiment

The experimental method is based on conventional picosecond ultrasonics.[1, 2] The optical setup of this experiment is shown in **Fig. 2**. A mode-locked titanium sapphire laser (center wavelength 840 nm, pulse width 200 fs, repetition frequency 80 MHz) is used. A beam of this near-infrared pulsed light is used as the pump light, and a frequency-doubled blue beam is used as the probe light. Both beams are focused to micron-sized spots onto the sample. The sample is a slab of fused quartz of dimensions 10 ×10 × 1 mm^3, and a Ti film of thickness 470 nm is deposited as a transducer. The optical setup near the sample is shown in **Fig. 3**.

The experimental results show Brillouin oscillations at $f_B = 25$ GHz. STFTs reveal a constant sound velocity distribution in the depth direction. The incident angle of the probe light is $\theta_0' = 75°$. We derive the sound velocity of the sample as $5.9\,\mathrm{km/s}$, close to the literature value of $5.97\,\mathrm{km/s}$.[6] The spatial resolution in the depth direction is ~600 nm, based on FWHM of the Hanning window function of the STFT and the derived sound velocity.

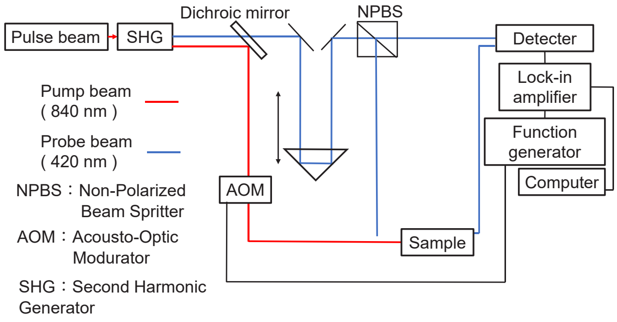

Fig. 2 The optical setup of this experiment. The red line is the optical path of the pump beam, and the blue line is the optical path of the probe beam.

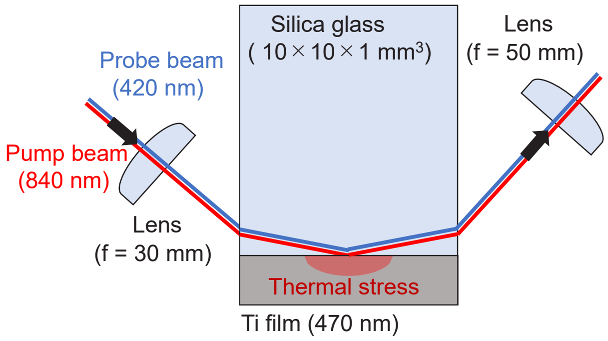

Fig. 3 The optical setup near the sample. The pump beam and the probe beam are overlapped and incident from the side. The probe light is reflected from the upwardly travelling strain pulse in the sample (not shown), generated by the thermal stress in the Ti film.

4. Conclusion

We present a TDBS method for the depth profiling of sound velocity in a transparent material without the requirement of a knowledge of the refractive index. In future we are planning to improve the spatial resolution and to map the sound velocity distribution in three dimensions in inhomogeneous samples, with applications to biological cell imaging.

5. References

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