3P1-2

Time-domain Brillouin scattering in grating structures using two-axis-controlled obliquely-incident probe light
グレーティング構造における二軸傾斜プローブ光を用いた
時間領域ブリルアン散乱測定

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1. Introduction

By irradiating an opaque sample with ultrashort light pulses of picosecond temporal width, it is possible to excite acoustic pulses in the picosecond regime in the sample. The propagating acoustic pulses or waves can be detected using delayed ultrashort light pulses[1]. The light pulses used for the excitation and detection are called the pump and probe light pulses, respectively. The technique is called picosecond laser ultrasonics. By using this method, the physical properties as well as the structures of the sample can be obtained in a nondestructive and noncontact manner.

When the sample consists of a transparent medium with a thin opaque film, and the pump light generates acoustic waves at the opaque film, the acoustic waves propagating interior of the transparent medium may scatter the probe light. The scattered light may interfere with the light reflected at the sample surface, and lead to an oscillation of the reflected light intensity. This is called Brillouin oscillation and is regarded as the time-domain Brillouin scattering by the propagating acoustic waves. In a typical measurement of Brillouin oscillation in picosecond laser ultrasonics, we can obtain a single Brillouin frequency[1]. But by using a sample with a grating structure of opaque material, it is possible to obtain a set of several different Brillouin frequencies corresponding to the scattering by the acoustic waves propagating along different directions by the diffractions[2,3]. This allows one to measure the physical properties of the sample smarter: for example, the refractive index and the sound velocity of the transparent medium can be simultaneously and independently obtained from a single measurement. In addition, since the grating structure adds the anisotropic nature to the sample, we may excite the shear acoustic waves in addition to the longitudinal acoustic waves which are only excited commonly in traditional measurements[4,5]. With the knowledge of shear acoustic waves, we can obtain a complete information for the elasticity tensor of the medium. The purpose of this research is to generate and detect shear acoustic waves in picosecond laser ultrasonics using the grating structure.

2. Experiments

The sample is prepared by forming a grating structure of aluminum with a thickness of 50 nm on a fused silica substrate having a thickness of 1 mm by using the electron beam lithography and lift-off technique. The period of the grating is 380 nm. We use Ti-Sapphire laser as a light source which generates light pulses with a central wavelength of 830 nm and temporal width of 100 fs. The part of the light is frequency doubled (wavelength 415 nm) and used for the probe. The fundamental 830 nm light is used for the pump. Both pump and probe light is colinearly irradiated from the back side of the sample (without grating). **Figure 1** shows the sample and coordinate axes xyz which are fixed to the sample. The x and y axes are parallel and perpendicular to the grating stripes, respectively. The z axis is perpendicular to the surface, heading from the back surface to the front (with grating). The probe (and pump) light is obliquely incident to the sample. The sample position is stated as follows. First the sample is placed so that xyz are in parallel to the lab axes XYZ where the incident probe light is along the Z axis. The sample is then rotated with respect to Y by $\alpha=36.4^\circ$, and with respect to x by $\beta=40.0^\circ$, so that the first order diffracted light is (almost) in the XZ plane. The transient intensity variation in the first order diffracted light is recorded as the function of the delay time between the pump and probe light pulse arrival to the sample.

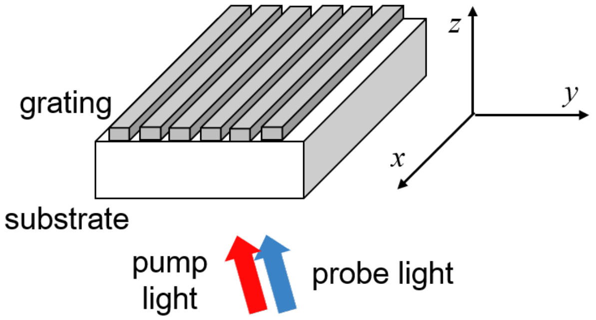

Fig. 1: Schematic diagram of the sample and coordinate axes *xyz* which are fixed to the sample. Red and blue arrows schematically indicate the directions of the pump and probe light, respectively. These are obliquely incident to the sample.

3. Results

Figure 2 shows the transient intensity change of the first order diffracted probe light. The horizontal axis represents the delay time between the pump light and probe light arrival to the sample. The vertical axis represents the intensity variation. **Figure 3** shows the Fourier spectrum of the experimental result shown in Fig. 2. The cross marks indicate the theoretically calculated frequencies by considering the light scattering by the propagating acoustic waves and the light diffracted by the grating, assuming the sound velocity (longitudinal sound velocity v_l=5968 m/s, shear sound velocity v_t=3764 m/s) and refractive index of the substrate (n=1.482) [3]. The green and blue marks correspond to the values for the longitudinal and shear acoustic waves, respectively.

The prominent peaks around 40 GHz, 36 GHz and 16 GHz agree well with the calculation for the longitudinal waves. These three peaks are also observed for the measurement with the sample position $\alpha=0^\circ$ and $\beta=33.1^\circ$ at the frequencies expected for this position (not shown). It is highly probable that these three peaks are attributed to the light scattered by the longitudinal acoustic waves.

A sharp peak around 24 GHz is observed close to one of the possible frequencies calculated for the shear acoustic waves. The observed shoulder (lower frequency side) as well as the less prominent peak around 10 GHz have corresponding calculated frequencies. We believe the observed peaks are caused by the shear acoustic waves.

There remains some unlabeled peaks, such as the one around 17 GHz. Further study with varying the sample position is necessary to clarify their origin.

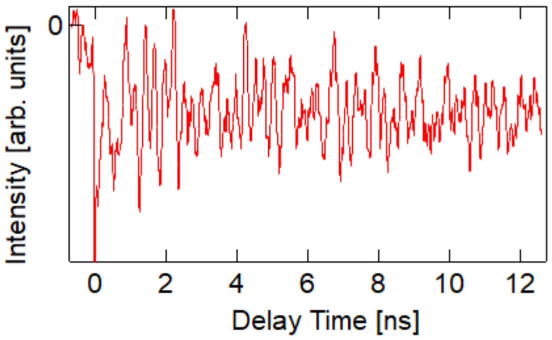

Fig. 2: Transient intensity change of the first order diffracted probe light. The probe light is obliquely incident from the back side of the sample.

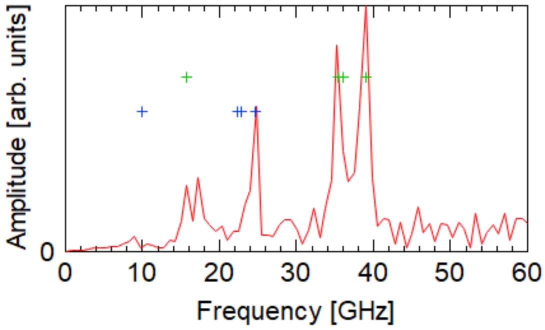

Fig. 3: Fourier spectrum of the transient intensity change shown in Fig. 2. Each cross mark indicates the theoretically calculated frequency of acoustic wave for each possible diffraction configuration. The green marks in the upper row correspond to those by the longitudinal acoustic waves, whereas the blue marks in the lower row correspond to those by the shear acoustic waves.

4. Conclusion

We have performed the time-domain Brillouin measurement for the transparent medium with grating structure. The probe light is obliquely incident on the sample with respect to the surface and to the grating stripe, and the first order diffracted light is observed. The obtained Brillouin oscillation peaks were analyzed by a theoretical model considering the light scattering by the longitudinal and shear acoustic waves. We confirmed that the shear acoustic waves are excited in the sample with grating structure for the first time.

References

1. C. Thomsen, H. T. Grahn, H. J. Maris, and J. Tauc: Phys. Rev. B **34** (1986) 4129.
2. H.-N. Lin, H. J. Maris, L. B. Freund, K. Y. Lee, H. Luhn, and D. P. Kem: J. Appl. Phys. **73** (1993) 37.
3. O. Matsuda, T. Pezeril, I. Chaban, K. Fujita, and V. E. Gusev: Phys. Rev. B **97** (2018) 064301
4. V. Gusev, Appl. Phys. Lett. **94** (2009) 164105
5. V. Gusev, Appl. Phys. Lett. **107** (2010) 114906

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