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Optical detection of picosecond acoustic waves generated in grating structures
グレーティング構造によるピコ秒音響波の光学的励起および検出

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1. Introduction

The absorption of ultrashort light pulses of picosecond or shorter temporal width in media may generate broad-band acoustic pulses therein through various mechnisms such as the thermoelastic effect. The propagation of the acoustic pulses can be monitored by delayed light pulses through the transient optical reflectivity change[1]. The technique, which is called picosecond laser ultrasonics, can be used to study the structure and various physical properties of media with nano meter spatial resolution.

For a medium transparent to the probe light, the obtained transient optical reflectivity shows oscillations at particular frequencies. These are called Brillouin oscillations, and are caused by the interference between the light scattered by the moving acoustic wave front, and the light scattered (reflected) by fixed structures such as the sample surface or interfaces. In case of the probing light normal incident on an isotropic medium, the oscillation frequency is given as $f=2nv/\lambda$ where n is the refractive index, v the velocity of the acoustic wave, and λ the wavelength of the probe light in vacuum. In this way, the Brillouin oscillation measurement can be used to evaluate the sound velocity in the medium, provided one knows the refractive index n by other means. If both n and v are unknown, a possible way to get them simultaneously is to do the measurement at several probe light incident angles [2,3]. Performing such measurements with enough accuracy is, however, not an easy task.

In this paper, we report a method to explore the Brillouin oscillations at multiple frequencies and propagating directions in a single measurement. It utilizes metal grating structure formed on a transparent substrate. The absorption of pump light pulse at the metal grating generates the acoustic pulses propagating with multiple diffraction angles. By probing their propagation through the substrate side, the combination of the light scattering by the acoustic waves and reflection/diffraction at the

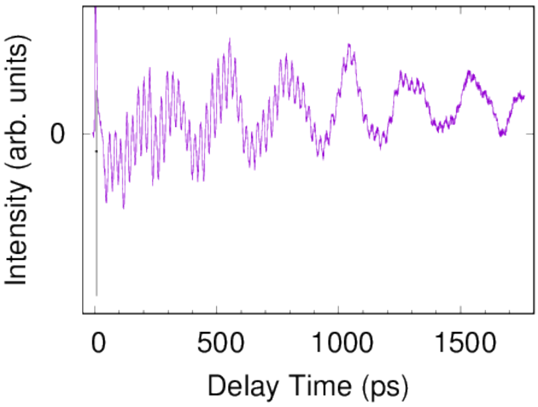

Fig. 1: Transient reflectivity change of metal-grating/silica substrate sample. The probing is done from the back side (surface without grating) with the normal incident. The intensity of the first order diffracted beam is monitored.

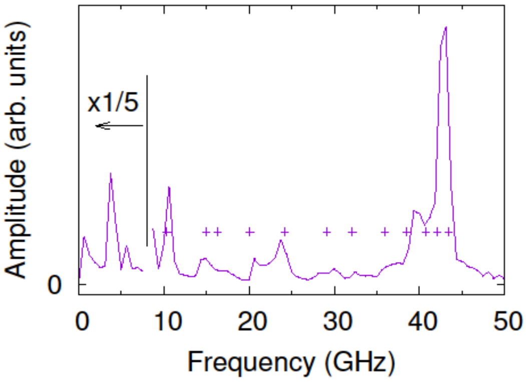

Fig. 2: Fourier spectrum of the transient reflectivity signal. The + symbols indicate the calculated peak positions.

grating structure allows one to access Brillouin oscillation at several different frequencies.

2. Experiments

The sample consists of a fused silica substrate of 1 mm thickness with a gold grating structure with the period *d*=590 nm, formed on a surface of the substrate with the electron beam lithography and lift-off technique. The light pulses of central wavelength 800 nm and the temporal width ~100 fs from a Ti-sapphire laser with a regenerative amplifier are used to generate acoustic waves through the thermoelastic process at the gold grating. The propagation of the acoustic waves with grating like wavefront in the fused silica substrate is measured by the fequency-doubled and delayed light pulses of central wavelength 400 nm. The probe light is normally incident to the sample from the surface without the grating, and the first order diffracted beam emerged from the same surface without grating is fed to a photo-detector. The polarization of the incident probe light is in parallel to the stripes of grating.

3. Results

Figure 1 shows an example of the obtained transient intensity variation of the first-order diffracted probe beam. The overall shape consists of two oscillations of different frequencies: A low frequency component around 4 GHz and a high frequency component around 40 GHz.

Figure 2 shows a Fourier spectrum of the obtained transient data shown in Fig. 1. Very strong low frequency components below 8 GHz are known to be caused by the vibration of gold thin stripes[4]. In the higher frequency region above 10 GHz, unlike the Brillouin scattering data for a simple uniform medium without grating, there are many peaks.

4. Discussions

These peaks can be explained by considering the fact that the wave vector of the probe light may vary by the diffraction at the grating structure before and after the scattering by the acoustic waves i.e. the diffraction by the moving grating-like acoustic wave front. Since the diffraction/reflection coefficient at the grating surface is reasonably high (in our case it is several 10 %), we may expect several different whole scattering processes for our geometrical setup in which the normal probe light incident and the detection at the first order diffraction direction are used. They are categolized in the following four: 1) the probe light scattered by the acoustic waves (back scattering), 2) the probe light first scattered by the acoustic waves (forward scattering), and then reflected/diffracted by the grating surface, 3) the probe light first reflected/diffracted by the grating surface, and then scattered by the acoustic waves (forward scattering), and 4) the probe light first reflected/diffracted by the grating surface, then scattered by the acoustic waves (backward scattering), and finally reflected/diffracted by the grating surface again. In the scattering by the acoustic waves, the change in the light wave vectors needs to be compensated by the absorbed/created phonon wave vector. In the reflection/diffraction of the light at the grating surface, the variation of the wave vector components parallel to the surface needs to be integer multiples of the grating wave number $2\pi/d$.

The above mentioned schemes allow one to calculate the possible Brillouin frequencies which correspond to the frequency of the phonons absorbed/created in the whole scattering process. The cross symbols in Fig. 2 indicate the expected peak positions calculated in this way with the known sound velocity and refractive index of the glass substlate[5]. The agreement between the actual peak positions and the calculation is excellent. This means that one can access several different acoustic wave vectors involved in the photon-phonon scattering process even observing for a single incident direction along a single diffracted direction.

5. Conclusion

We can get the Brillouin oscillations for the acoustic waves of multiple wavevectors using grating structure. This allows one to determine the sound velocity and refractive index simultaneously for a transparent isotropic medium from a single measurement. This also would be advantageous to study the dispersion relations for more complicated anistropic and dispersive media.

References

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