Optical generation and detection of GHz longitudinal and transverse acoustic waves in transparent medium with metallic grating structure

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Background – Understanding propagation of GHz-THz acoustic waves in materials is important for both fundamental physics and applications. For this it is efficient to use a method called picosecond laser ultrasonics in which ultrashort light pulses (named pump light pulses) with femtosecond-picosecond temporal width are focused to the sample to generate the acoustic waves up to THz frequency region and the propagating acoustic waves are detected with delayed light pulses (named probe light pulses) by the transient optical reflectivity change caused by the photoelastic effect[1]. In this sort of measurement, when the pump light is absorbed at the surface of a uniform and isotropic semi-infinite sample, only the longitudinal acoustic waves are generated because of the symmetry of the system and the measurement configuration. It has, however, been suggested that the optical generation of transverse acoustic waves is possible by laser-induced gratings[2].

Methods – To confirm the transverse acoustic wave generation and detection, we studied a metallic grating structure with picosecond laser ultrasonics. The aluminum grating structure of the period 390 nm and the thickness 40 nm is fabricated on a surface of fused silica substrate of thickness 1 mm using the electron beam lithography and the lift-off technique. A mode-locked Ti:sapphire laser is used as a light source. The fundamental light pulses of the central wavelength 800 nm and the temporal width 100 fs are used for the pump, whereas the frequency doubled light pulses of the wavelength 400 nm are delayed and used for the probe. The pump light pulses absorbed at the metallic grating generate the acoustic waves propagating not only along the direction perpendicular to the surface but also along the directions of their diffraction by the periodic grating structure. The probe light is obliquely incident from the back surface (without grating) and the first order diffracted light is fed to the photodetector to record the transient optical reflectivity change as a function of delay time between the pump and probe light pulse arrival to the sample. The probe light scattered by the propagating acoustic waves and that reflected/diffracted by the grating interfere and thus the light intensity at the photodetector shows the so-called Brillouin oscillations having rich frequency spectra in GHz region owing to the variety of combinations of possible acoustic and optical diffraction directions by the metallic grating [3,4].

Results – Figure 1 shows the Fourier spectra of the transient reflectivity change measured at several probe light incident angles. The + and × symbols indicate the expected Brillouin oscillation frequencies calculated from the assumed (in fact, optimized, see below) longitudinal and transverse sound velocities, respectively, with the refractive index in a fused silica for the given probe light incident angles (not mentioned here). The calculated peaks for the longitudinal waves agree well with the experimental results in all curves, whereas those for the transverse waves are only partially observed in curves b) and c). All these agree well with the theoretically predicted selection rules, as it will be explained in detail in the presentation. By comparing the calculated and experimental peak positions, the sound velocities and refractive index can be refined. The calculated frequencies in Fig. 1 are obtained with the most optimized values which also agree well with the literature values.

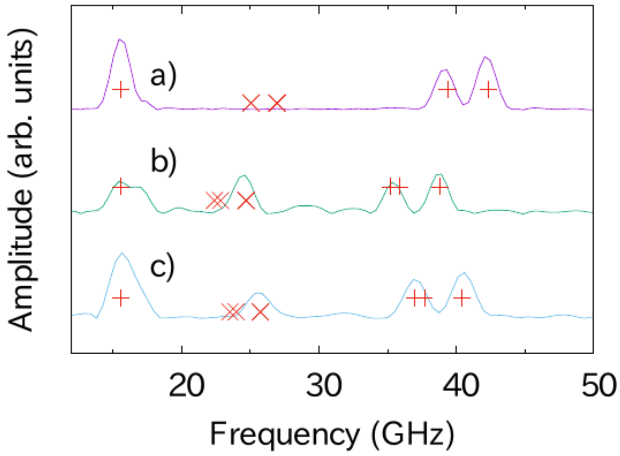

Fig. 1. Fourier spectra of Brillouin oscillation for the fused silica sample with metallic grating at several probe incident angles. The + and × symbols indicate the calculated peak positions for longitudinal and transverse acoustic waves, respectively.

Conclusions – We have demonstrated the optical monitoring of both longitudinal and transverse acoustic waves in a transparent medium using metallic grating structure. Especially we clarified the necessary condition for the generation and detection of transverse acoustic waves in this configuration. The obtained knowledge opens up a way to exploit the transverse acoustic waves as well as the longitudinal acoustic waves in various applications such as sensors.

References

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