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Induced phonons by laser pulses for Brillouin scattering measurement

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1. Introduction

With the term Brillouin scattering we refer to the inelastic interaction between electromagnetic and mechanical waves. Based on this phenomenon, the Brillouin spectroscopy is a well-established technique which, using a focused laser beam as probe, allows the non-contact and non-destructive investigation of local mechanical properties of transparent materials [1,2]. Usually this method is based on thermally excited phonons resulting in a low intensity of Brillouin scattered light. This badly affects the accuracy and the time of the measurements [3]. To overcome this problem, a possible solution is to artificially generate higher amplitude ultrasonic waves in the sample [4,5].

In this study, we have induced the artificial phonons (several hundred of MHz) by laser ultrasound technique and we have studied how they affect the intensity of Brillouin scattered light.

The final purpose is to develop a rapid measurement technique based on non-contact stimulation and probing of the sample.

2. Generation of the induced phonons by pulse laser technique

At first it was necessary to verify the effective generation of phonons by pulse laser. For this purpose, we used a silica glass sample (1×10×10 mm) on whose side (10×10 mm) was deposited an Al film (thickness of approximately 300 nm). We irradiated the Al film with the pulse laser (helios 1064-5-50, Spectraphysics) with a wavelength of 1064 nm, the duration of a pulse was 377 ps, the repetition rate was 20 kHz. The power near the sample was 50 mW and the diameter of the beam spot on the sample was approximately 10 µm. Ultrasonic waves were generated by the thermoelastic effect due the temperature rise of the region irradiated with the pulse laser [6]. To generate compressive waves propagating in the direction perpendicular to the surface, we constrained the sample surface with a thin glass layer [6]. Then we acquired the induced ultrasonic waves with a ZnO piezoelectric sensor (house made) positioned on the reverse side.

Here the ZnO sensor was directly deposited on the reverse side of the silica glass sample, the sensing area was 500µm×500µm, the thickness was 5µm. Figure 1 shows the obtained signal. The main frequency component of the signal was around 300 MHz. From the measurements of propagation time, we obtained the longitudinal wave velocity in the sample. It resulted to be 5770 m/s.

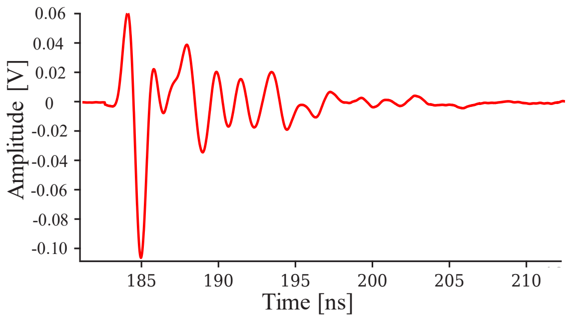

Fig. 1. Longitudinal wave acquired with the piezoelectric sensor.

3. Experimental apparatus for Brillouin scattering

A scheme of the experimental apparatus is represented in Fig. 2.

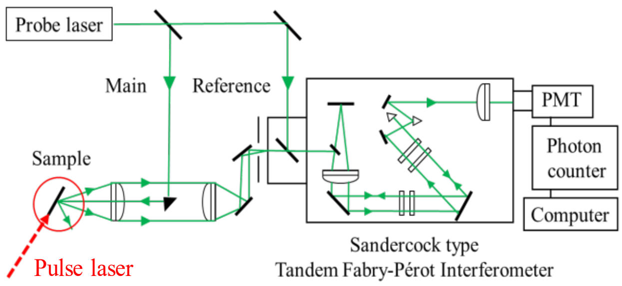

Fig. 2. Experimental apparatus for Brillouin scattering.

The probe laser used for the Brillouin measurements is the solid-state laser with the wavelength of 532 nm (mpc3000, Laser Quantum). The diameter of the beam spot on the sample was approximately 50 µm, and the power near the sample was 100 mW.

The scattered light was acquired with a six-pass tandem Fabry-Perot interferometer (JRS scientific instruments) followed by a photomultiplier system

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(Hamamatsu, R464s). Then the signal was averaged by the photon counter after the analog to digital conversion and recorded as a frequency spectrum in the computer.

The sample for the measurements was a silica glass specimen (5×20×10 mm). On the reverse side (20×10 mm) an Al film (thickness of approximately 300 nm) was deposited to reflect the probe laser. On the short side (20×5 mm), another Al film (thickness of approximately 300 nm) was deposited to generate the induced phonons.

4. Results and discussion

For the Brillouin scattering measurements we used the RIθA scattering geometry [7], and we focused our study on the effect of compressive induced waves on the intensity of scattered light. The geometry is shown in Fig. 3.

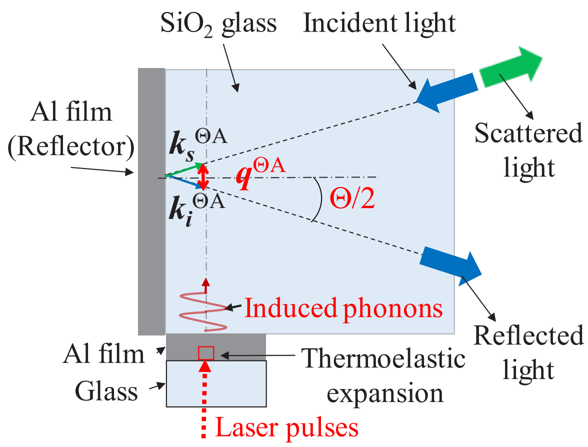

Fig. 3. *RIθA* scattering geometry: k_i is the wave vector of the incident light; k_s the wave vector of the scattered light; q the wave vector of the ultrasonic waves.

Using this configuration the relation between scattering angle (θ) and shift frequency ($f^{\Theta A}$) is given by

$$\theta = 2 \cdot \arcsin\left(f^{\Theta A} \cdot \frac{\lambda_i}{2 \cdot v^{\Theta A}}\right) \quad (1),$$

where $v^{\Theta A}$ is the velocity of longitudinal waves in the glass, λ_i is the wavelength of the probe laser. The expected shift frequency ($f^{\Theta A}$) was 300MHz (same as the frequency measured with piezoelectric sensor). From the velocity $v^{\Theta A}$ (5770 m/s) , λ_i (532 nm) and $f^{\Theta A}$ (300 MHz), we selected the scattering angle θ =1.58°. The obtained spectra are shown in Fig. 4. Here, the elastic Rayleigh peak has been deleted for clarity of presentation.

The data shows the spectrum of the Brillouin scattered light in two cases: with and without the radiation of the pulse laser. In both cases we could

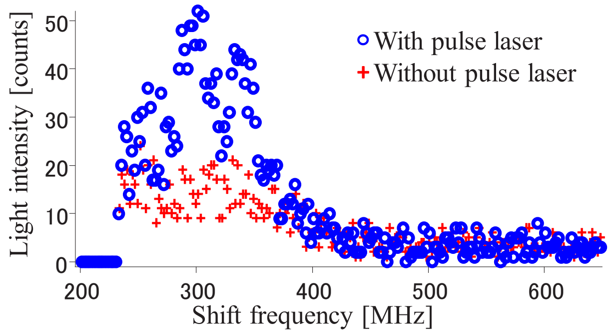

Fig. 4. Spectrum of the Brillouin scattered light with and without the use of pulse laser

observe the inelastic Brillouin scattering peak around 300 MHz, which is in good agreement with the observed longitudinal waves using the piezoelectric sensor. From a comparison of the two spectra, it turned out that the Brillouin peak has a value 2.7 time larger in presence of induced phonons.

5. Conclusions

This first study shows that it is possible to increase the intensity of Brillouin scattered light by using laser pulses to induce longitudinal phonons in the sample. However, the increase is modest and we need a better understanding of the sound field to improve the result.

6. References

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