Advances in Signal Processing, Automation and Construction of the Transient Grating Spectroscopy

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Abstract

Transient grating spectroscopy (TGS) is a non-destructive and non-contact optoacoustic method used to measure the elastic and thermal properties of solid materials. TGS can be used to measure samples over a wide range of temperatures. However, our TGS in its current design is not optimal for high and low-temperature measurements with sample rotation. The new TGS design, measurement automation and signal pre- and post-processing will be presented.

Keywords: Instruments, Transient Grating Spectroscopy, Elasticity, Thermal Diffusivity, Signal Processing

Introduction

Transient Grating Spectroscopy (TGS) [1-4] formerly known as Impulsive Stimulated Thermal Scattering (ISTS) [5-7] or also called Transient Thermal Grating (TTG) [8,9]. These methods were developed for non-destructive and contactless measurement of elastic and thermal properties of a broad range of solid materials. Choudhry *et al.* [9] discuss setup details and applications.

TGS is an optoacoustic method based on spatially periodic excitation and detection created as an interference pattern from two interfering detection or excitation beams on the sample surface. The interference creates many periodic line-like thermoelastic sources, leading to a strong constraint on spatial characteristics of the surface elastic and thermal response to a sudden excitation.

Heterodyne optical detection is used to increase the signal-to-noise ratio. Heterodyne detection is the combined diffraction of the detection beams on a transient grating formed on the sample surface after excitation with a reflection of detection beams from the surface, which is used as a reference for heterodyning. This leads to highly sensitive measurements of thermoreflectance and surface-displacement dynamics [2,10].

This work is focused on possible improvements to the experimental setup of the TGS method to enable high-precision, low-noise, user-friendly and faster measurement of the samples over a wide temperature range.

Transient Grating Spectroscopy

Our TGS currently used for measurement is shown in (Figure 1) where all important components of the TGS experiment are present. A pulsed infrared laser is used for excitation and a green continuous laser for detection. Both laser beams travel through the same optical components.

First, the profile of both beams is deformed into ellipses by a cylindrical lens and then they are diffracted on transmission phase grating. From all the created diffraction beams, we use only +1 and -1 diffraction. These diffracted beams are projected by using a 4F imaging system onto the sample surface where they interfere. Heterodyned detection beams that are created and propagated from the sample surface are then separated by a polarizing cube and detected by a detector.

The main advantage of this TGS experiment is the possibility of sample rotation on the rotational stage. This allows us to measure the angular dispersion of acoustic waves on the sample surface. The velocity of these waves and their angular dispersion are then used in the inverse procedure described in [11-13] to determine elastic tensor. In addition, the time-domain signal can be used to determine thermal diffusivity as described in [14,15] and we observed apparent anisotropy of thermal diffusivity in cubic single crystals [16]. With a sample rotation, TGS can be used to determine the true anisotropy of thermal diffusivity for hexagonal or lower symmetries if good surface orientation is measured [14].

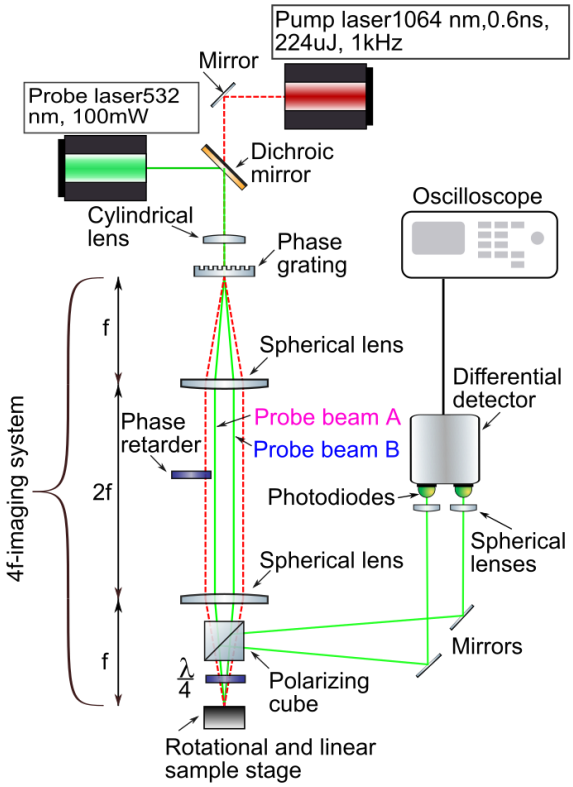

Figure 1: Top-view schematic of the TGS experiment.

The rotation of the sample is critical for the accurate determination of the elastic and thermal properties. This can easily be done in a room-temperature environment. However, for high or low temperatures when the sample is inside the temperature chamber, it is impractical or very hard to perfectly align the sample so that it is perpendicular to the optical axis during rotation with a heavy temperature chamber. Another problem is that there are no rotational stages small enough to be fitted inside the temperature chambers we own, do not have precise rotation or do not work in the temperature range we need.

Alternatively, we can try to rotate the whole TGS assembly, but this creates a similar problem with alignment and rotation as with the temperature chamber.

Our theoretical designs of the future TGS assembly led us to discover two possible and easy-to-implement methods for rotating the measurement direction using only the rotation of optical elements inside the TGS assembly. One setup was constructed and thoroughly tested.

Results

The first construction theoretically tested, was TGS with rotation of the transmission phase grating. If we rotate the phase grating by an angle θ from a horizontal position as illustrated in (Figure 1) will result in a rotation of measurement direction by an angle θ. Precise rotation of phase grating can be easily performed, and the sample needs to be only perpendicular to an optical axis.

However, heterodyne beams outgoing from the sample will rotate and de-rotation after the polarization cube will be required. If heterodyne beams are not de-rotated, we can measure both beams on one diode using a spherical lens or use a rotating detector or rotating beam blocker for one beam. De-rotation can be done with an optical component called a dove prism.

Dove prism is an optical component that rotates an image by 180° if the light is propagating along the longitudinal axis. Rotating the dove prism around the longitudinal axis by an angle θ creates 2*θ image rotation. Another advantage is that if you send the rotated image back into the dove prism it de-rotates itself back to the original image. From this, we created a new theoretical TGS design illustrated in (Figure 2) that was built and tested.

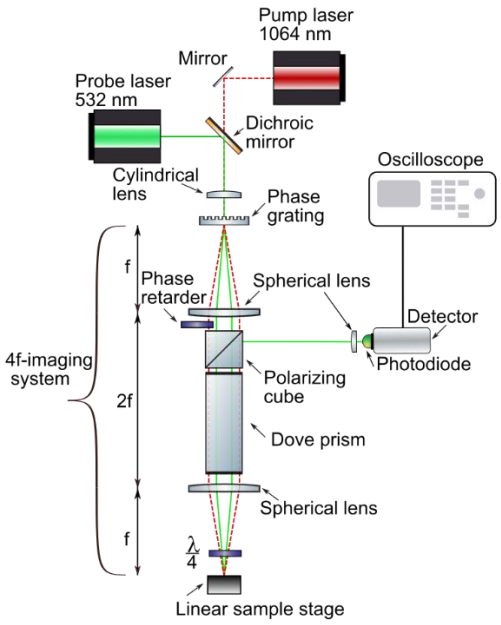

Figure 2: Top-view schematic of TGS experiment with a dove prism.

TGS with the dove prism was tested by measuring a single crystal of Ni with surface orientation (110). The results are shown in (Figure 3).

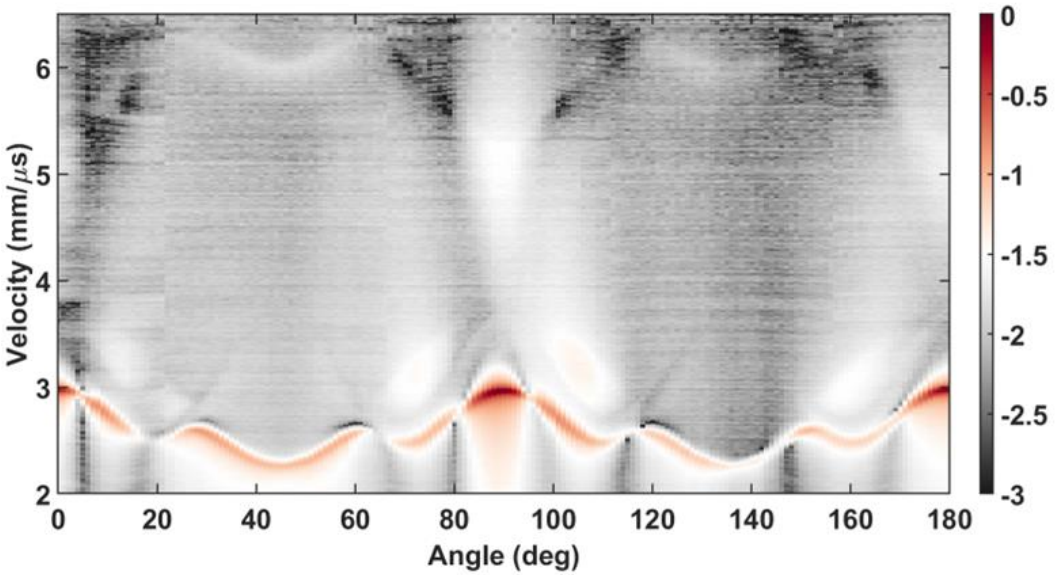

Figure 3: Velocity map of Ni (110) dependent on the dove prism angle of rotation.

Conclusion

We successfully created two new theoretical TGS assemblies with rotation of the measurement without sample rotation. TGS with the dove prism was found to be better and was constructed as illustrated in(Figure 2). The sample of single crystal Ni (110) was successfully measured.

The velocity map of the measured Ni (110) sample shown in (Figure 3) is good enough for the determination of elastic properties. All surface and limiting bulk waves are detected. However, measurement is not good for determination of the thermal diffusivity. We can observe some drops in velocity intensity. These drops in intensity result from the phase difference between beams propagating inside the dove prism. The phase difference is with high probability created because of the miss-alignment of the dove prism in a TGS assembly. For good measurement of the anisotropy of thermal diffusivity, we need stable and same phase difference for all measurement angles. We think this can be resolved by more testing and measuring by the new TGS with the dove prism.

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