METHOD OF PLANE STRESS MEASUREMENT BASED ON TERAHERTZ SPECTROSCOPY

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1. Introduction

Photoelastic technique is widely used as a mature method for internal stress measurement . This technique is based on the stress-optic law, which is still observed in THz regime . Therefore, it can be expected to measure plane stress state with THz radiation. Moreover, because one essential feature of THz wave is the high transmission probability through some opaque materials, such as semiconductors and wood, it can be more easily applied for studying internal stress in these opaque materials.

The polarization-sensitive detection of terahertz electromagnetic radiation as a measurement method has been applied to the THz-TDS system. With the polarization sensitive THz imaging, the determination of birefringence and orientation of the optical axis in a glass fiber reinforced polymer have been presented. For the birefringence measurement, Ebara *et al.* have constructed a polarized sensitive TDS system that detected a birefringence as small as 5×10^{-4}. This system is also applied to study the relationship between refractive index difference and principle stress difference. Similarly, other scholars have carried out many researches on stress measurement. Song *et al.* have found that the refractive index grows linearly with the applied stress, which shows a verification of the stress-optic law in the terahertz frequency regime. Furthermore, the experimental principle about the stress effect on THz wave has been derived according to TDS system. By using the principle, they have obtained the refractive index-stress coefficient *A*, which is known in the stress-optic law.

In this letter, we improve the traditional TDS system so that it can measure plane stress state in some opaque materials. With this system we can obtain the phase shift of the transmitted THz radiation by modulating loads. Then the stress components in optically opaque materials can be determined from an analysis on the phase delay.

2. System

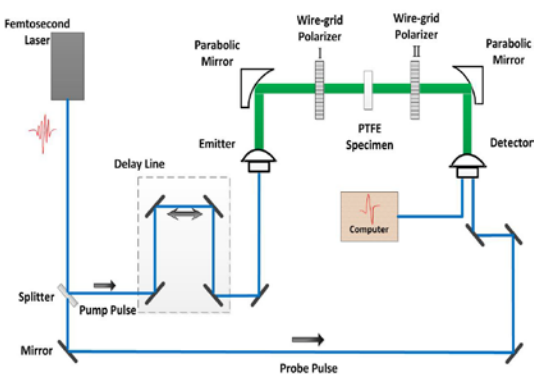

Fig. 1. Schematic diagram of the experimental setup

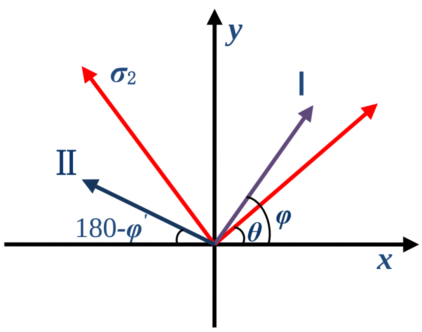

Fig. 2 Orientations of the polarizers and the principle

The schematic diagram of the improved THz-TDS system for stress measurement is illustrated in Fig. 1. A femtosecond laser is used as the pump source for both the THz emitter and detector. The THz radiation is generated and detected by dipole-type photoconductive antennas. To change the polarization orientation of THz wave, two wire-grid polarizers are introduced into the optical path. The tensile direction of the specimen is in a vertical direction. A dumbbell-shaped polytetrafluoroethylene (PTFE) specimen is fixed on a mechanical loading device that can provide the uniaxial tensile load. Meanwhile, strain gauges are pasted on the surface of the specimen to measure the tensile strain so the applied stress can be easily calculated by the measured strain and the elastic modulus of PTFE.

3. Principles and Results

By considering the stress-optical effect and Poisson effect, a theoretical model was established to simulate the relationship between the stress state applied on specimen and the phase delay of THz wave

Two verification experiments were conducted. In the first experiments, the orientation of the two polarizers were set φ=0º and φ′=0º, while φ=45º and φ′=0º in the second experiments. Respectively, Fig. 3~Fig. 4 show the phase delays between the loaded and unloaded specimen for every orientation of the polarizers. By fitting the established theoretical model to experimental data, the applied stress state were determined, as shown in Table. 1.

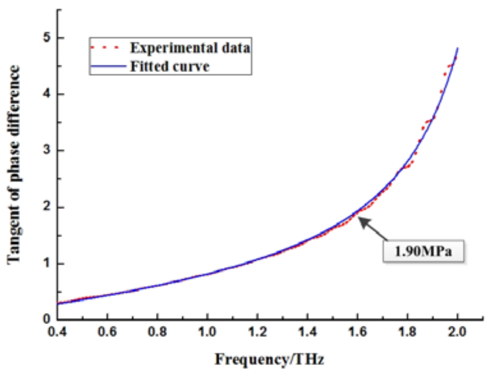

Fig. 3. The phase delay when φ=0º and φ′=0º.

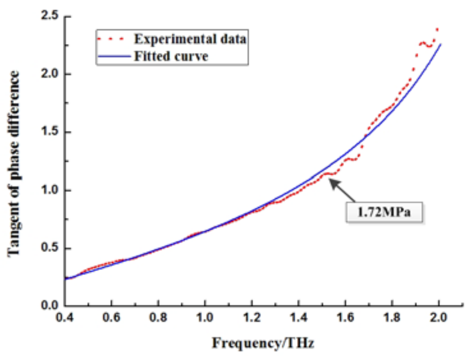

Fig. 4. The phase delay when φ=45º and φ′=0º.

Table 1. Experimental results

Polarizer Orientation	Results of strain gauge			Results of TDS system			Errors (%)		
	σ_1(MPa)	σ_2(MPa)	θ(degree)	σ_1(MPa)	σ_2(MPa)	θ(degree)	σ_1	σ_2	θ
φ=0, φ'=0	1.90	0	90	1.88	0.04	86	1.05	4.0	4.4
φ=45, φ'=0	1.72	0	90	1.68	-0.048	86.3	2.32	4.8	4.1

4. Conclusion

We combine two wire-grid polarizers into traditional THz-TDS system so that the plane stress state of any point of PTFE specimen can be determined. The principles of the proposed measuring method are established. By minimizing the defined error function, the components of the plane stress state are obtained using the Newton-Raphson scheme. The results obtained using the proposed method get a good agreement with that by strain gauge. If a two-dimensional translation device are added the system, we also can obtain a 2D stress distribution.