STUDY ON SAW ATTENUATION OF PMMA USING LASER ULTRASONIC TECHNIQUE

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INTRODUCTION

Polymethyl methacrylate (PMMA) is a kind of typical amorphous polymer, whose main mechanical property is viscoelasticity that can be of great importance in materials characterization and nondestructive evaluation (NDE). On the other hand, ultrasonic NDE technique is one of the basic methods to characterize polymeric materials. By the measurements of the velocity and attenuation of the bulk waves as a function of frequency and temperature [1-3], the moduli of PMMA can be deduced and various relaxation phenomena can be investigated. However, as we know, the studies on the SAW attenuation of PMMA have not been reported. It is difficult for the contact ultrasonic method to do so because the effect of the electric transducers working in the contact way on the SAW field can not be avoided. Some disadvantages of using electronic ultrasonic method to characterize polymers, such as the measurement must be made in the immersion apparatus and the piezoelectric transducers with different frequencies must be used to obtain the attenuation spectra etc. have been overcome by the means of the laser ultrasonic technique [4,5]. The noncontact nature of the laser ultrasonic technique can also eliminate the effect of the contact measurement on the SAW field and make it convenient for the measurement at elevated temperatures. Therefore the laser ultrasonic technique is extremely suitable for the study on the attenuation of SAW.

In this work, an experimental investigation of the SAW attenuation of PMMA is presented. In order to optimize the measurement condition, we first study the generation of SAW at the surface of PMMA sample with different power density of the pump laser. Then the attenuation of SAW as a function of frequency (1.0 - 6.0 MHz) and temperature (25.0 - 60.0 °C) is measured. The results show some relations between the SAW attenuation and the viscoelastic properties of PMMA.

PRINCIPLE OF EXPERIMENT

In general, the SAW attenuation coefficient of PMMA is a function of frequency and temperature. When a pulsed laser is focused onto the surface of the sample at certain temperature, a wide-band SAW can be generated with point-source mode [4]. By the measurement of the SAW signals at different distances, the attenuation coefficient at some
given frequency and temperature can be obtained by the formula as

$$\alpha(\omega, T) = \frac{1}{r_2 - r_1} \ln \frac{A_1(\omega)}{A_2(\omega)} - \frac{1}{2} \ln \frac{r_2}{r_1}$$  \hspace{1cm} (1)$$

where $\alpha$ is the SAW attenuation coefficient, $\omega$ is the angular frequency, $T$ is the temperature of the sample, $r_1$ and $r_2$ are the detection distances and $A_i(\omega)$ ($i = 1, 2$) is the amplitude of the normal displacement component of the SAW signal at $r_i$ respectively. $A_i(\omega)$ can be obtained by the FFT analysis of the detected SAW signal.

By changing the temperature of the sample, the relation of $A_i(\omega)$ to temperature can also be obtained.

EXPERIMENTAL SETUP

The experimental setup is shown in Figure 1. A Nd:YAG pulsed laser working in a wavelength of 532 nm with a duration of 8 ns and adjustable pulse energy from a few hundred of $\mu$J to 20 mJ is used as the excitation source of the SAW. The pump laser beam is adjusted into a parallel beam by the optical lenses $L_1$ and $L_2$, and then focused onto the sample by the lens $L_3$. A heterodyne interferometer with a frequency bandwidth of about 10 MHz, enables the normal acoustic displacement component of SAW be detected. The output signal of the probe is fed to a digital O.S.C (HP54510B) triggered by a signal from a fast photodiode excited by a weaker beam split from the pump beam. The digitized data is finally transferred to a microcomputer via an IEEE bus for further processing and analysis. The PMMA sample is enclosed in a chamber whose temperature can be controlled and maintained. On the surface of the sample, a thin aluminum film (the thickness much less than the acoustic wavelength in the measurement range) is deposited to ensure a mirror-like surface. The chamber, $L_3$ and $F_2$ are mounted on an X-Y moving platform. When the platform moving along the Y direction, the SAW signals at different distances can be detected while the source position and the exciting energy of the pump laser are fixed. By controlling the temperature of the chamber, the attenuation spectra of the sample at different temperatures can be obtained.

![Figure 1. Schematic diagram of experimental system. BS, beam splitter; $L_1$, $L_2$, $L_3$, lenses; $F_1$, $F_2$, prisms.](image)
RESULTS AND ANALYSIS

Firstly, measurement is made to determine the generation of SAW as a function of the incident laser power density. Figure 2 shows the SAW waveforms detected at a distance of 1.0 mm from the source point when the incidental power densities are 1.0 and 2.0 MW/cm$^2$ respectively. The detected SAW signal has a bandwidth of about 6 MHz and its spectrum does not seriously depend on the incident power density.

The relation of the amplitude of the SAW signal to the incident laser power density

![Amplitude vs Power Density](image)

Figure 3. Amplitude of SAW versus power density of the pump laser for PMMA at room temperature.
is shown in Figure 3. It can be seen that when the power density is rather low (< 0.6 MW/cm²), the amplitude changes slowly with the power density increasing. It may belong to the thermo-elastic regime. When the power density is in the range of 1.0 to 2.0 MW/cm², the amplitude of the SAW signal increases rapidly and linearly with the power density further increasing due to the partly vaporizing of the Al film. When the power density is larger than 2.0 MW/cm², the amplitude becomes saturated. In this region the Al film vaporizes entirely when the laser pulse impinges.

In the attenuation measurement experiment, the power density (3.0 MW/cm²) is chosen in the saturation region because in this region the detected signal has the best SNR and it is insensitive to the small drift of the laser power density. However, it has the
Figure 6. The SAW attenuation spectra of PMMA at 25.0, 40.5 and 48.5 °C respectively, in which B is the slope of the fitting line with the unit of dB·cm⁻¹·MHz⁻¹.

drawback of surface damage.

Then, the SAW attenuation spectrum for PMMA at room temperature is investigated. The experimental waveforms of SAW detected at the distance of 2.5 and 5.0 mm at room temperature (25.0 °C) are shown in Figure 4. The experimental spectra of these signals and the calculated attenuation spectrum are shown in Figure 5. To obtain the attenuation spectrum, the signals are first filtered by a digital filter with a band of 0.5 - 20.0 MHz, then are analyzed by FFT, and finally Equation (1) is used to the calculation. The frequency range of the spectrum is from 1.0 to 6.0 MHz. For PMMA at room temperature, the SAW attenuation increases as frequency increases. The attenuation changes from 0.97
Finally, the SAW attenuation spectrum as a function of temperature for PMMA is investigated. Figure 6 gives the SAW attenuation spectra at 25.0, 40.5 and 48.0 °C respectively. All of the three sets of data have the forms of \( \alpha = A + B \cdot f \) (A, B are constants). The type of attenuation observed, in which the major component is \( \alpha = B \cdot f \), is referred as hysteresis absorption. Figure 6 also shows the fitting lines (dot-lines), whose slopes (B) are 6.70, 8.14 and 7.63 dB·cm\(^{-1}\)·MHz\(^{-1}\) for 25.0, 40.5 and 48.0 °C respectively. The slope versus temperature is shown in Figure 7. The fitting range is from 1.0 to 4.0 MHz. It can be seen that at the temperature range near 30.0 °C there is a turning point of the slope B. This phenomenon might be related to the \( \beta \)-transition of PMMA [1].

Figure 8 gives a 3D-view of the SAW attenuation coefficient for PMMA as the function of temperature (25.0 - 60.0 °C) and frequency (1.0 - 6.0 MHz). It can be seen that the attenuation generally increases with either frequency or temperature increasing and has a hysteresis background over the measurement range, just like that of bulk waves [2,4]. The peaks at the range of temperature higher than 40 °C and frequency higher than 4.5 MHz may be caused by the relaxation nature of PMMA, which need to be further investigated.

CONCLUSIONS

A method to measure the attenuation of SAW at the surface of PMMA using laser ultrasonic technique is presented. In this method the effect of the transducer size and the contact measurement on the acoustic field is eliminated. The SAW attenuation as a function of frequency (1.0 - 6.0 MHz) and temperature (25.0 - 60.0 °C) is measured. The results show that at frequency range of 1.0 to 6.0 MHz and temperature range of 25.0 to 60.0 °C the SAW attenuation for PMMA has a hysteresis background. This method may be useful to investigate the viscoelastic properties of polymers.
Further work including expanding the frequency bandwidth and increasing the sensitivity of the laser probe is in progress, so that the measurement can be made in the thermoelastic exciting regime.

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