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Spectroscopy

Terahertz dynamics of craft glass

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ABSTRACT

We performed terahertz time-domain spectroscopy (THz-TDS) on two types of soda lime glass samples. One sample is transparent glass and the other sample is black glass. Furthermore, terahertz imaging was performed on the two-color integrated glass. It was found that the metallic element added to the black glass did not affect the terahertz light absorption. From the spectrum of the glass obtained by THz-TDS, a peak called boson peak appears in α/ν^2 spectrum, where α is absorption coefficient. This result shows that THz-TDS is suitable for observing the boson peak of colored soda lime glass.

Keywords: terahertz time-domain spectroscopy, terahertz imaging, colored glass

Introduction

Glassy materials show an excess of vibrational states over the Debye level determined by the acoustic phonons, and it is called "boson peak" [1-3]. It universally appears at the THz region in the spectrum of $g(\nu)/\nu^2$, where $g(\nu)$ is vibratinal density of states. In the THz spectra, the boson peak appears in the spectrum of $\alpha(\nu)/\nu^2$, where $\alpha(\nu)$ is absorption coefficient [4,5].

In the glass crafts, colored glass is used. It is melted in a gypsum mold with an electric furnace and modeled. By this method, artists of glass crafts can make complicated shape artworks.

Glass which is added metallic elements has color. In order to establish the way to evaluate the boson peak of the colored glass, we made the two-color integrated glass and performed terahertz imaging.

Experimental

Glass cullet was heated up to 1100 K in an electric furnace and kept for 2 hours. Then, the sample was rapidly cooled and formed a block shape. The sample was shaped to have an area of about 2 cm^2 and a thickness of about 0.3 mm by cutting and polishing. Three kinds of color glass samples were prepared, and each color was transparent, black, and two-color integrated.

The present terahertz time-domain spectroscopy (THz-TDS) measurements were performed by conventional transmission configuration (RT-10000, Tochigi Nikon Corp.) [6]. Low-temperature grown GaAs photoconductive (PC) antennas were utilized for the THz pulse emitter and detector. The PC antennas were triggered by a mode-locked Ti:sapphire pulsed laser with a wave length of 780nm, a pulse width of less than 100 fs, and a repetition rate of 80 MHz. The available frequency range is from 0.2 to 4.0 THz.

To calculate the frequency dependent complex dielectric constant $\hat{\varepsilon}=\varepsilon'+i\cdot\varepsilon''$ from the measured time-domain waveforms, we have used following equation,

$$\frac{E_{sam}(\omega)}{E_{ref}(\omega)}=\frac{4\hat{n}}{(\hat{n}+1)^2}\exp\left\{i\frac{(\hat{n}-1)}{c}\omega d\right\}$$

where $E_{sam}(\omega)$ and $E_{ref}(\omega)$ are the amplitude spectra of THz pulse transmitted the sample and the reference, respectively. $\hat{n}$, c and d are the complex

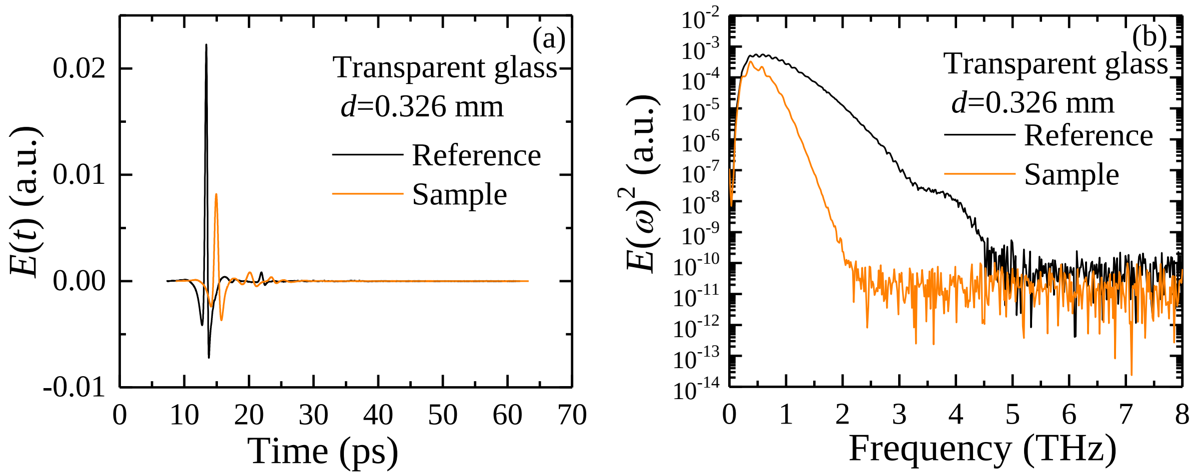

Figure 1. (a) Time-domain waveforms and (b) frequency-domain power spectra of reference and transparent glass.

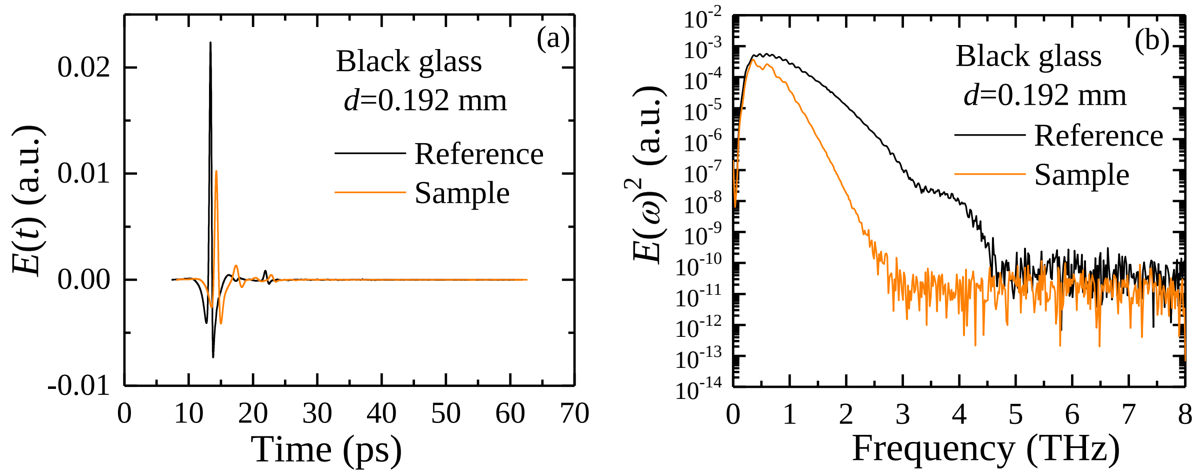

Figure 2. (a) Time-domain waveforms and (b) frequency-domain power spectra of reference and black glass.

refractive index, the light velocity and a thickness of sample, respectively. Then, the complex dielectric constant is obtained from the relation of $\hat{\varepsilon}=\hat{n}^2$.

Terahertz imaging is a method of conducting measurement by THz-TDS at each designated point and creating a distribution map of the obtained values.

This measurement was carried out at the Mie Prefecture Industrial Research Institute Ceramic Science Branch using a terahertz optical sampling system (TAS7400TS, ADVANTEST Corp.) [7].

Measurement was performed in the range of 1 cm square of the two-color integrated glass. We mapped the absorption coefficient at the frequency at which the boson peak was observed.

Results and Discussion

Figures 1(a) and 2(a) show the measured time-domain THz *E*-field waveforms transmitted through the air (reference) and soda lime glass with different colors, respectively. One is transparent glass and the other is black glass. Figures 1(b) and 2(b) show the frequency-domain power spectra of the transparent glass and the black glass, respectively.

Figures 3(a) and 3(b) show the real and imaginary parts of the complex dielectric constants $\hat{\varepsilon}=\varepsilon'+i\cdot\varepsilon''$ of the transparent glass and the black glass, respectively. Peaks are seen in real parts of the complex dielectric constants ε' of both glasses around 0.8 THz. There was no influence on the spectrum by the color of the glass.

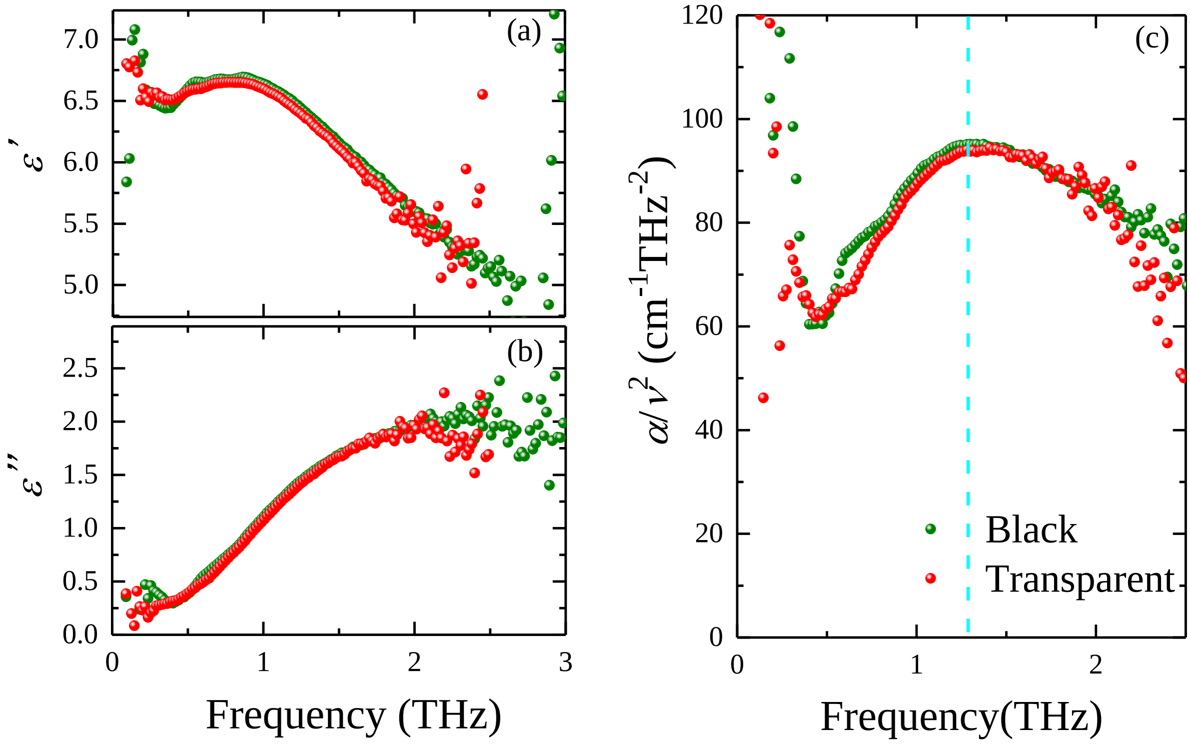

Figure 3. (a) The real part and (b) the imaginary part of the complex dielectric constants of transparent and black glass. (c) The boson peak observed in α/ν^2 spectra.

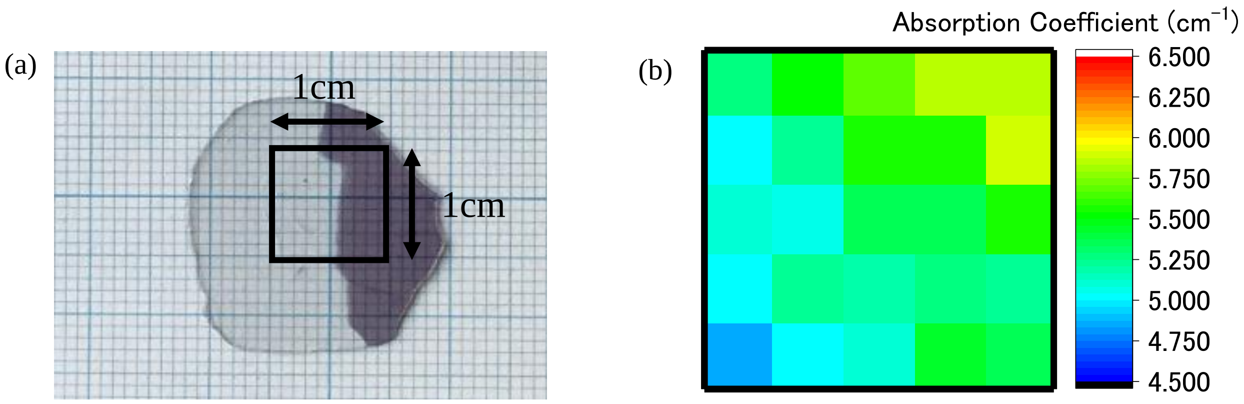

Figure 4. (a) The picture of the two-color integrated glass and (b) mapping of absorption coefficient at 1.3 THz.

Figure 3(c) shows boson peaks of the transparent glass and the black glass observed in α/ν^2 spectra, respectively. Both of them were observed at around 1.3 THz. The positions and strengths of the boson peak did not change with the color of the glass.

Metallic elements are added to the black glass to color. However, since the amount of the elements is several ppm, it does not seem to affect the terahertz spectra. This result shows that THz-TDS is a tool to accurately measure the boson peak of soda lime glass regardless of the color.

Figure 4(a) shows the picture of the two-color integrated glass. The area surrounded by the black line is the range where the imaging measurement was performed. Figure 4(b) shows two-dimensional mapping of absorption coefficients. This is a mapping at 1.3 THz at which the boson peak was observed. The measurement was made at 25 points. The color of the figure shows that the absorption coefficient is high when it is close to red, and the absorption coefficient is low when it is close to blue. No change in the absorption coefficient due to the color of the glass was observed. It shows that measurement of the boson peak is possible without being influenced by the color of glass.

Conclusions

We performed terahertz imaging for the two-color integrated glass.

Since the amount of the metallic element contained in the colored glass is very small, it is possible to measure the boson peak without being affected by the color of the glass.

Acknowledgments

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