Search for the Core Materials of THz Liquid-Core Fibers

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Abstract—**Using the method of time-domain spectroscopy, we measure the absorption and dispersion of several non-polar organic solvents from 0.2 to 3 THz. Based on the results, we believe high-carbon alkane organic solvents might be a proper choice for the core material of THz liquid-core fiber.**

I. Introduction And Background

THE research of THz transmission lines has received much attention in recent years. Different kinds of THz transmission lines have been reported, such as circular and rectangular wave guides, plastic ribbons, sapphire fibers, photonic crystal fibers, parallel plates, metal wires, and so on[1-5]. Here, we report another low-loss THz transmitting structure, THz liquid-core fiber, which is more flexible, cheaper and easier to use in practice than its counterparts.

The manufacturing process of traditional optical liquid-core fiber is very mature, and we need not to emphasize the advantages of this transmitting structure. The key to bringing the structure of liquid- core fibers into THz applications is to find the right core material and cladding material, especially the former.

II. Results

Using the method of time-domain spectroscopy, in the frequency region from 0.2 to 3 THz we measure the absorption and dispersion of several non-polar organic solvents such as analytically pure dodecane, analytically pure hexadecane, analytically pure heptane, chemically pure octane, chemically pure liquid paraffin, analytically pure liquid paraffin, analytically pure carbon tetrachloride, analytically pure cyclohexane, gasoline, kerosene and diesel fuel. The thickness of our sample is 9.95 mm; while the cross section is about 40*40 mm. The experimental system is in a circumference of Nitrogen. Temperature is a little over 20 °C and humidity is below 5%. Samples are placed in a sample box that is made of Teflon. Although the material losses in Teflon are higher than that in silicon, the low index for Teflon (n = **1.427)** as compared to Si (n = **3.420),** allows for a higher transmission through a box made of Teflon. The spectra are obtained by first measuring a THz reference pulse transmitted through the empty box and then measuring a sample pulse transmitted through the same box, which is filled with the liquid under investigation. The indices and absorption ratios are next obtained by comparing the Fourier transforms of the sample and reference pulses. We have discussed the transmission process of THz wave through liquid samples in sample box and deduced below the formulas to compute the refractive index and absorption rate of liquid samples:

$$n_2(\omega)=\phi(\omega)\frac{c}{\omega d}$$

$$k_2(\omega)=-\frac{c}{\omega d}*\ln\{\frac{[n_1(\omega)+n_2(\omega)]^2*\rho(\omega)}{n_2(\omega)*[n_1(\omega)+1]^2}\}$$

$$\alpha=\frac{2\omega k_2(\omega)}{c}.$$

Here, $n_2(\omega)$ is liquid samples' refractive index, $n_1(\omega)$ is the refractive index of box (in this case, Teflon), $k_2(\omega)$ is the extinction coefficient of liquid samples, α is the absorption rate of liquid samples, d is the thickness of liquid samples, ρ(ω) is the amplitude of $E_{sample}(\omega)/E_{reference}(\omega)$, and $\Phi(\omega)$ is the phase of $E_{sample}(\omega)/E_{reference}(\omega)$, c is speed of light, ω is angular frequency. The details of deduction will be published elsewhere. Absorption and dispersion from 0.2 to 3 THz of the Teflon material that is used to make sample box has also been measured. The thickness of the Teflon sample is 10.10 mm; while the cross section is also about 40*40 mm.

The refractive indices of analytically pure hexadecane, analytically pure liquid paraffin, chemically pure liquid paraffin and Teflon are shown in Figure.1. The refractive indices of analytically pure liquid paraffin, chemically pure liquid paraffin are obviously greater than that of Teflon; while hexadecane's refractive index is very close to Teflon's index at high frequency band. But at high frequency band, due to low signal-to-noise ratio, the error is bigger than that at low frequency band. The absorptions of analytically pure hexadecane, analytically pure liquid paraffin, chemically pure liquid paraffin and Teflon are shown in figure.2 and figure.3. Although at high frequency band the results have to be further improved, it can be concluded that these three samples' absorptions are generally low; the loss of analytically pure liquid paraffin is less than that of chemically pure liquid paraffin, and analytically pure hexadecane's loss is the least among three samples.

The refractive indices of analytically pure heptane and chemically pure octane are obviously less than that of Teflon; while the refractive indices of analytically pure dodecane and analytically pure cyclohexane are very close to that of Teflon. So if Teflon is used as cladding material, these liquids can not be chosen as core material because comparing with Teflon these liquids may not be considered as optically denser materials, thus, total reflection's condition can not be satisfied.

Gasoline, kerosene and diesel fuel's losses are a little high probably due to impurity in them. The loss of analytically pure carbon tetrachloride is even higher. The loss of liquid-core fiber

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is critically dependent on the loss of the liquid material, so liquids mentioned above are not good choices for THz liquid-core fiber.

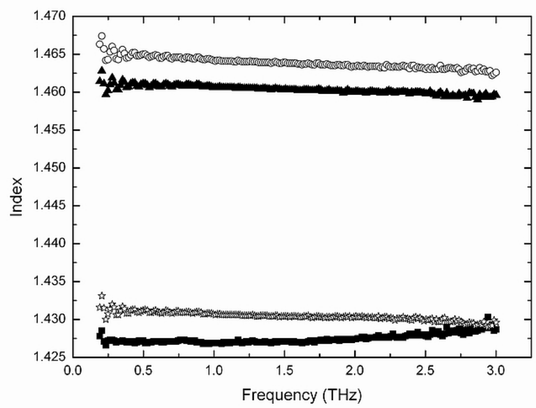

Fig.1. Refractive indices of Teflon (squares), analytically pure hexadecane (pentagrams), chemically pure liquid paraffin (triangles) and analytically pure liquid paraffin (circles).

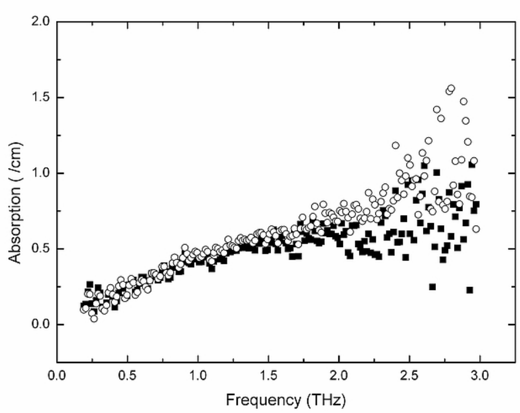

Fig.2. Absorption rates of chemically pure liquid paraffin (circles) and analytically pure liquid paraffin (squares).

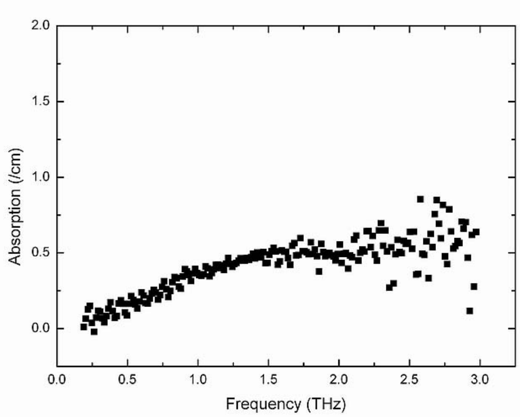

Fig.3. Absorption rate of analytically pure hexadecane.

Teflon could be a perfect choice for cladding material because of its excellent physical and chemical stability. Liquid paraffin is a mixture of n-type C_{16}-C_{20} alkanes. Liquid paraffin's volatility is bad and its price is very cheap. So if Teflon is used as cladding material, liquid paraffin might be the first choice of core material. The purity of liquid will influence the absorption of THz wave, but as mixture, liquid paraffin's purity can not be very high. So, hexadecane (at least at low frequency band) of higher purity grade might be a better choice for high quality THz liquid-core fiber. In short, high-carbon alkane organic solvents might be a proper choice for the core material of THz liquid-core fiber. The diameter of the core of the single-mode THz liquid-core fiber varies from tens to hundreds of micrometers depending on the transmitting frequency. In an attempt to couple more energy into the fibers, structures with much larger diameters are fabricated, and their properties will be tested in the future.

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