THz Characterization of Lossy Materials Using Multi-Layers Measuring Cell

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***Abstract* — A method of measurement of the real and imaginary parts of thin-layer materials at THz frequencies is described. The method is based on application of multi-layers measuring cell consisting of unknown lossy slab and the slabs of low loss material with known dielectric constant. The recorded power transmittance interferogram is employed for reconstructing the complex permittivity of a material under test. Reconstructing algorithm based on solution of the system of non-linear equations is proposed. The example of characterization of the thin lossy sample such as a paper sheet of thickness 0.1 mm in 0.8 – 1.1 THz is reported**.

I. Introduction And Background

MULTI-layers plane-parallel structures demonstrate typical oscillating behavior of transmission coefficient in the frequency domain which originates from the Fabry-Perot effect. Similar behavior of the transmission coefficient is also taking place when the distance between slabs is varied yielding a spatial distribution of the interference maxima (minima). A periodicity, swing and height of interference maxima (minima) depend on both real and imaginary parts of refractive index n and k (or complex dielectric constant $\varepsilon'=n^2-k^2$, $\varepsilon''=2nk$). By recording the Fresnel curves in the frequency or spatial domain the dielectric constants ε' and ε" can be reconstructed by means of a numerical solution of proper formulated system of non linear equations. This approach has been successfully employed for characterization of metal meshes and wire grids on mm-waves [1] and extended here towards THz range using multi-layers configuration shown in Fig.1 where the thickness of slabs made from the known low loss material is t while the material under test has thickness d. In order to create a transmittance interferogram the adjustable air gap L is introduced.

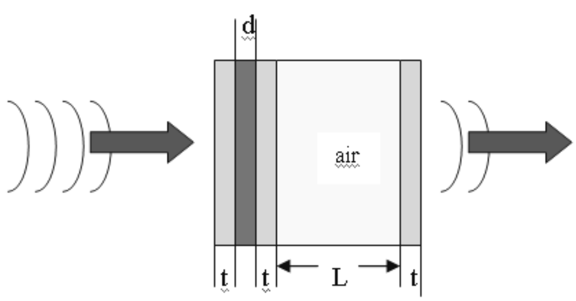

Fig. 1. Configuration of the measuring cell used in THz experiments.

The maximums and minimums of the transmittance interferogram are determined by ε'_r and ε''_r. If the transmittance of the measuring cell as a function of distance is measured, the proper system of non linear equations can be formed in order to find the complex dielectric constant:

$$
\begin{aligned}
T_p(L_1, t, \varepsilon'_r, \varepsilon''_r, f) &= A_1\\
T_p(L_2, t, \varepsilon'_r, \varepsilon''_r, f) &= A_2\\
T_p(L_3, t, \varepsilon'_r, \varepsilon''_r, f) &= A_3
\end{aligned}
\qquad (1)
$$

where L_1 and L_3 are the positions of neighboring maximums, L_2 is the position of minimum, $A_1 = A_3$ are the measured maximums of a transmission coefficient and A_2 is the measured minimum of a transmission coefficient. It should be pointed out that the frequency f is introduced into (1) as unknown parameter since the positions of maximums and minimums and their magnitudes are frequency dependent. As a result, a stability of solution of the system (1) is improved.

II. Experimental setup and calibration

The general view of experimental setup is depicted in Fig.2. The High-Performance Mid-Range Travel Linear Stage (the programmable micro-stepper), model ILS-100pp, Newport Co. is used for changing distance L with the resolution about 2 μm. The tunable BWO generator (0.8 – 1.1 THz) is employed as source of THz radiation and pyroelectric room temperature detector is connected to the digital Tektronix scope for recording a transmitted signal. The THz beam generated by tunable BWO is modulated by the chopper at frequency 10 Hz. The calibration of the experimental setup shown in Fig 2 has been done using a double-slab configuration with the thickness $t = 0.5mm$ fabricated from Al_2O_3. The measured transmittance interferogram (clearly seen on the scope's screen) was used for reconstructing the envelope and further processing to determine complex dielectric constant of the slab: $\varepsilon'_r = 9.602$, $\varepsilon''_r = 0.042$ at $f = 0.855$ GHz [2]. The measured complex dielectric constant of alumina sample is close to the result obtained with the time-domain terahertz spectroscopy method [3].

III. Characterization of lossy mateials

From the previous experiment we have determined the complex permittivity of the low loss material that is used as the "known" layers of the thickness t in the cell shown in Fig.1. Now, we can characterize "unknown" material of the thickness d using the same measuring cell. To illustrate the process we have employed the paper's sheet of the thickness $d = 0.1mm$ at the room temperature.

The recorded transmittance pattern as a function of time is shown in Fig.3. The power transmittance extracted from this measurement is depicted in Fig. 4 using smoothing and standard normalizing technique described [2]. The numerical solution of the system (1) yields the following parameters: $\varepsilon'_r = 2.5$, $\varepsilon''_r = 0.3$ ($tan\delta = 0.12$) at $f = 0.917$ THz.

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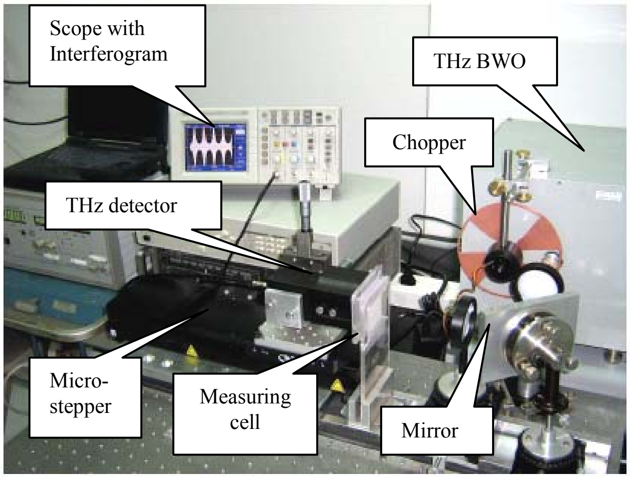

Fig. 2. The general view of the experimental setup.

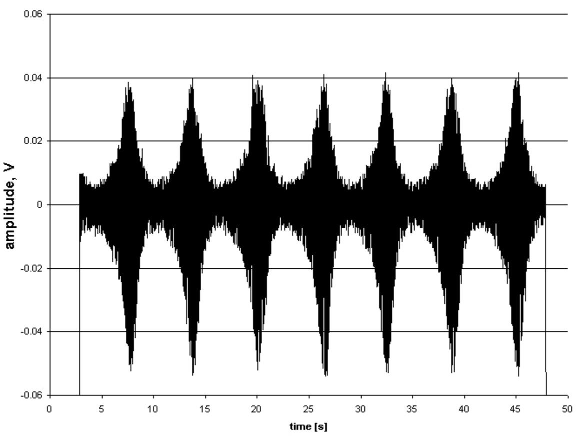

Fig. 3. The recorded voltage of the transmitted signal at the output of the detector as a function of time for the measuring cell with the paper's sheet *d = 0.1mm.*

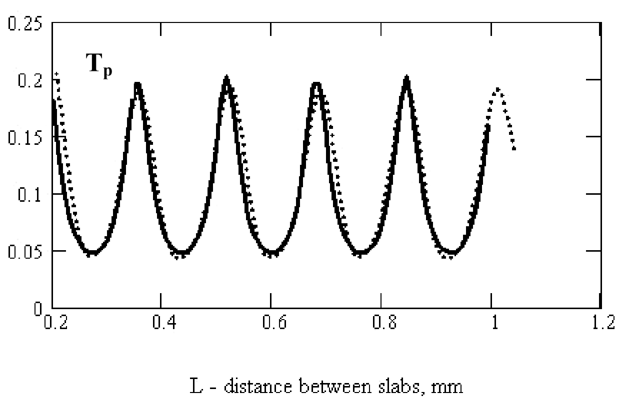

Fig..4. Comparison measured (dotted line) and reconstructed transmittances (solid line) for the determined ε'_r = 2.5, ε''_r = 0.3 ($tan\delta$= 0.12) at f = 0.917 GHz.

The comparison of the measured (dotted line) and reconstructed transmittances (solid line) for the above parameters is depicted in Fig. 4 and reveals a good agreement between the measured and reconstructed transmittances.

The suggested method can also be applied to thin-layer bio-materials provided that a uniform thickness within the tested area is realized

IV. Conclusion

The method of THz characterization of lossy dielectric materials using multilayer measuring cell has been presented. The complex dielectric constant has been estimated from the recorded interferogram converted to the power transmission coefficient. The reconstructing algorithm for determination of real and imaginary parts of dielectric constant has been suggested and verified. Examples of characterization both low loss and lossy samples have been described.

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