# Report-3
# Preliminary results of THz characterization of materials in transmitting mode
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## 1. MODEL DESCRIPTION

The double-layer configuration of a sample employed as a measuring cell is shown in Fig.1 where the thickness of slab is $t$, and the thickness of an adjustable air gap is $L$.

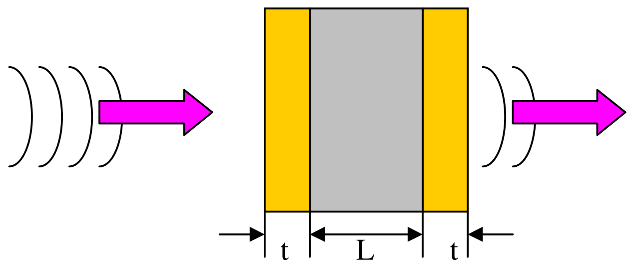


Fig.1. Configuration of the measuring cell used in THz experiments.

Assuming that the measuring cell is illuminated by plane wave we can calculate transmittance matrix of the cell $T_c$ as a product of matrix describing separate layers , namely,

$$T_c = T_t \cdot T_L \cdot T_t \qquad (1)$$

where:

$$T_t = \begin{bmatrix} \cosh(\beta_t t) & \dfrac{i}{\sqrt{\varepsilon_r}}\sinh(\beta_t t) \\ i\sqrt{\varepsilon_r}\sinh(\beta_t t) & \cosh(\beta_t t) \end{bmatrix}, \quad T_L = \begin{bmatrix} \cos(\beta_L L) & i\sin(\beta_L L) \\ i\sin(\beta_L L) & \cos(\beta_L L) \end{bmatrix} \qquad (2)$$

$$\beta_t = 2\pi\sqrt{\varepsilon_r}/\lambda, \quad \beta_L = 2\pi/\lambda, \quad \varepsilon_r = \varepsilon`_r - i\,\varepsilon``_r$$

The power transmittance $T_p$ of the measuring cell forming the double-layer sample can be presented in the following form:

$$T_p = \left| \frac{2}{2T_{c(11)} + T_{c(12)} + T_{c(21)}} \right|^2 \qquad (3)$$

where $T_{c(11)}$, $T_{c(12)}$ and $T_{c(21)}$ are elements of transmittance matrix $T_c$.

Typical behavior of power transmittance as a function of distance $L$ calculated using (3) at frequency 1 THz is depicted in Fig.2 for $\varepsilon`_r = 10$ and $\varepsilon``_r = 0.2$. The thickness of layers is varied, namely, $t$ = 0.25mm (solid line), 0.5mm (dotted line) and 0.75 mm (dashed line). We can see that transmittance is reduced with increasing the thickness of the layers due to increased power absorption. Also, spatial variations of the transmission coefficient are taken place depending of geometry and material’s properties.

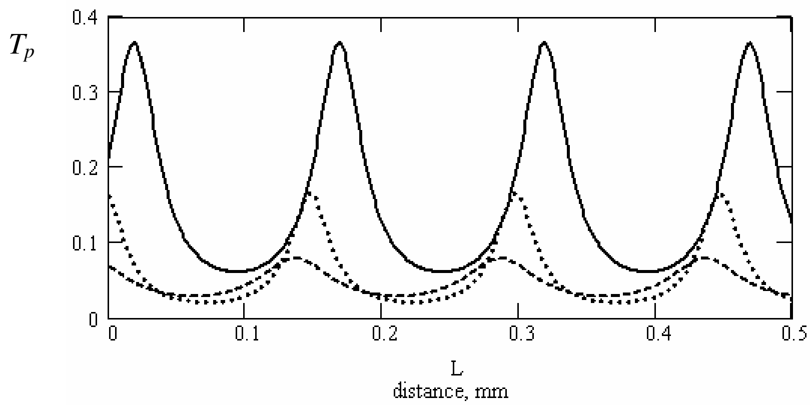


Fig.2 Calculated power transmittance as a function of distance $L$ between slabs: frequency 1 THz, $\varepsilon'_r = 10$ and $\varepsilon''_r = 0.2$;
$t$ = 0.25mm (solid line), 0.5mm (dotted line) and 0.75 mm (dashed line).

## 2. RECONSTRUCTING PROCEDURE

There are specific points in the transmittance interferogram - maximums and minimums. The distance between maximums (or minimums) is always $l/2$ while values of minimum and maximum transmittances are determined by $\varepsilon'_r$ and $\varepsilon''_r$. So we can write the following system of non linear equations in order to find complex dielectric constant:

$$
\begin{aligned}
T_p(L_1, t, \varepsilon'_r, \varepsilon''_r, f) &= A_1 \\
T_p(L_2, t, \varepsilon'_r, \varepsilon''_r, f) &= A_2 \\
T_p(L_3, t, \varepsilon'_r, \varepsilon''_r, f) &= A_3
\end{aligned}
\qquad (4)
$$

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 (4) as unknown parameter since the positions of maximums and minimums are frequency dependent. As a result, a stability of solution of the system (4) is improved.

## 3. EXPERIMENTAL SETUP AND PRELIMINARY MEASUREMENTS

The schematic view of the experimental setup is shown in Fig.3. Step motion programmable motor has been used for changing distance $L$ with the accuracy about 20 µm. The tunable BWO generator (0.8 – 1.1 THz) is employed as source of THz radiation and pyroelectric room temperature detector is used for recording a transmitted signal. The general view of experimental setup is depicted in Fig.4.

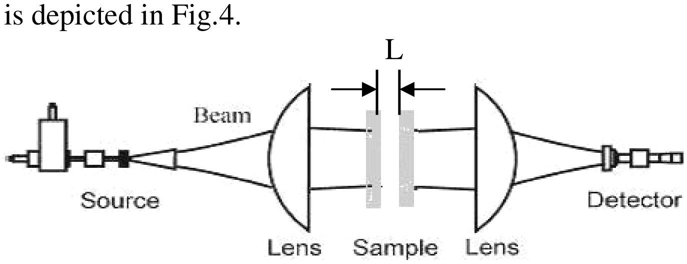


Fig. 3 Schematic of transmitting configuration.

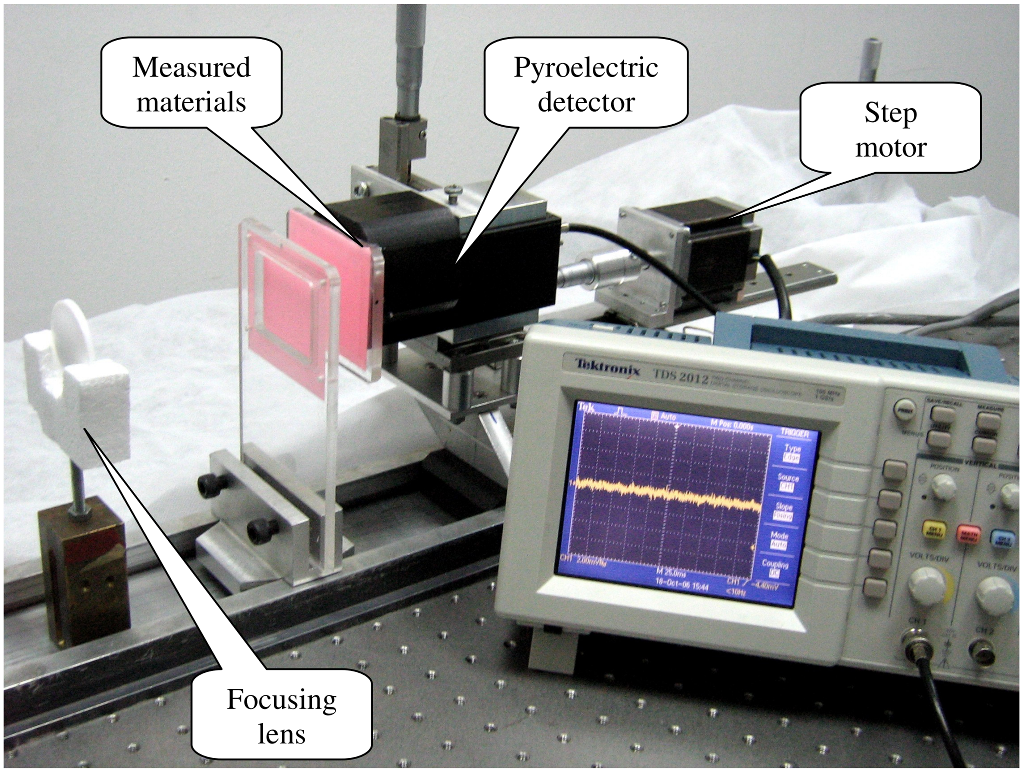


Fig. 4. Photo of experimental setup.

As an illustrating example we have recorded transmittance of the double-layer sample fabricated from $Al_2O_3$ with the slab's thickness t = 0.5mm and adjustable distance $L$ between them. The recorded transmitted signal at the output of the detector is shown in Fig. 5 demonstrating typical interferometric behavior. This pattern is employed below for determination of the real and imaginary parts of a material under test.

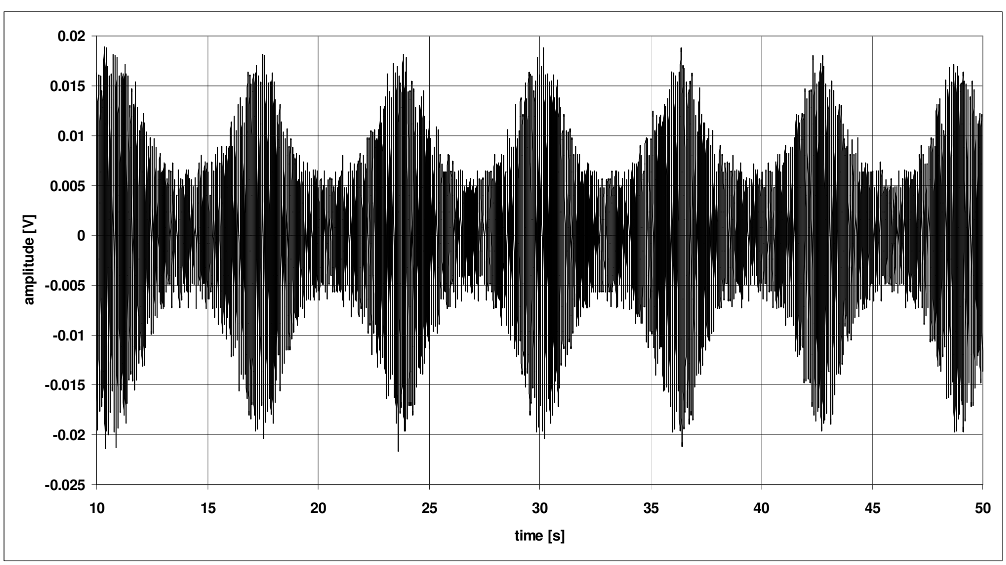


Fig.5. Recorded interferomentic pattern.

As a first step it is necessary to extract a power transmittance coefficient from the measured results. This action needs smoothing measured data and their normalization to the incident power. The result of smoothing the data depicted in Fig.5 with the reconstructed envelope is shown in Fig.6 for the specified fragment of the recorded signal converted to the distance scale. After normalizing to the incident power we have obtained the plot of transmittance power coefficient as shown in Fig.7 that can be used for calibration experimental setup.

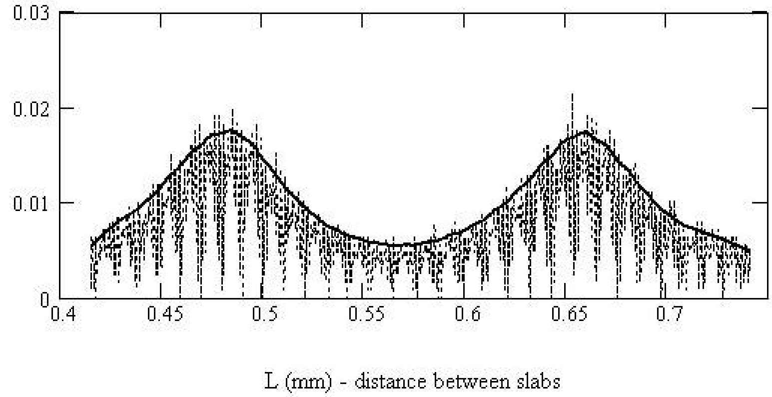


Fig.6 The fragment of smoothing (dotted lone) and the reconstructed envelope (solid line) of the measured data.

The measured parameters needed for a numerical solution of the system (4) were extracted from Fig.7 and summarized in Table 1. The numerical solution of (4) yields the following parameters: $\varepsilon^{`}_{r} = 9.602$, $\varepsilon^{``}_{r} = 0.042$ ($\tan\delta = 4.4 \times 10^{-3}$) and f = 0.855 GHz. Validation of these parameters can be done directly by calculating the power transmittance from (3). The comparison of measured (solid line) and reconstructed transmittances (dotted line) is depicted in Fig. 7 and reveals a good agreement proving validity of suggested technique and extracted parameters. The measured value of complex dielectric constant of alumina sample is close to results obtained with the time-domain terahertz spectroscopy method [1].

Table 1. The measured parameters needed for a numerical solution the system (2)

| Parameter | i = 1 | i = 2 | i = 3 |
|---|---|---|---|
| Position, $x_i$ (mm) | 0.487 | 0.575 | 0.663 |
| Transmittance, $T_{ri}$ | 0.68 | 0.21 | 0.68 |

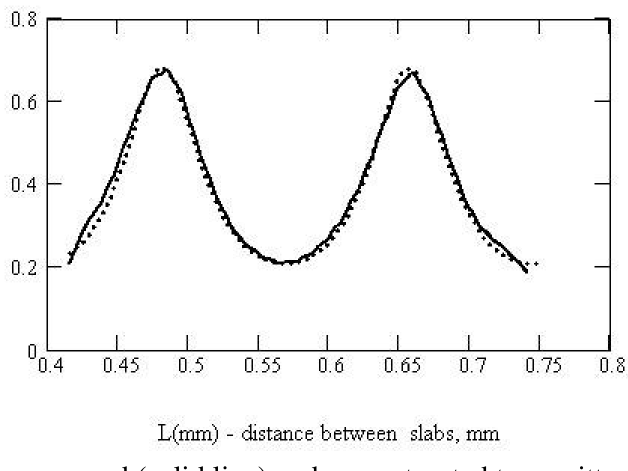


Fig.7 Comparison measured (solid line) and reconstructed transmittances (dotted line) for determined $\varepsilon^{`}_{r} = 9.6$, $\varepsilon^{``}_{r} = 0.04$ ($\tan\delta = 4.4 \times 10^{-3}$) and f = 0.855 GHz.

**4. CONCLUSIONS**

The method of THz characterization of materials using double-Layer sample has been developed and tested. It is based on reconstructing the recorded interferogram of a power transmission coefficient. The reconstructing algorithm for determination or real and imaginary parts of dielectric constant has been suggested and verified. Measured permittivity of alumina samples has demonstrated a good agreement with independent results reported in [1].

References

1. P.Bolivar, et al., Measurement of the Dielectric Constant and Loss Tangent of High Dielectric-Constant Materials at Terahertz Frequencies, IEEE Trans. MTT, 51(2003), no.4, 1062-1065.

**5. Next actions**

Preliminary measurements of palm leafs have demonstrated very high attenuation in THz range due to huge amount of water content. So that, for such a situation it is necessary to assemble experimental setup operating in reflection mode. To do it we need the following components:

1. Focusing lenses from polyethylene, 4 units (Workshop);
2. Lens frame, 2 units (Workshop);
3. Rotating stage on the basis of ThorLab for focusing lens, 1 unit (Workshop);
4. Rotating stage on the basis of ThorLab for reflecting mirror, 1 unit (Workshop);
5. Adapter between BWO and antenna, 1 unit (Workshop);
6. Holder for polarizing grid, 1 unit (Workshop);
7. Nano-stepper with programmable controller, 1 unit (ThorLab);
8. Laptop for controlling nano-stepper and processing recorded experimental data (IBM ThinkPad);
9. Active Filter 10 Hz to improve S/N ratio, 1 unit (Analog Device);
10. Post detector amp D-86, 1 unit (Analog Device).
11. Modified modulator (chopper), 1 unit (Workshop);