Terahertz Resonator Diagnostics of Filamentary Dielectric Objects

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***Abstract* — Results of approbation of model of thin dielectric cylinder in open quasioptical resonator to diagnostic filamentary dielectric objects are presented. Comparison of calculated frequency shift depending on filaments diameter with the results of experimental researches in open resonator in the frequency range 80-131 GHz was carried out. Its spectral characteristics with samples of polymer filaments are investigated.**

I. Introduction

For quasioptical open resonant terahertz diagnostics, in some cases it is possible to develop methods already used at lower frequencies. In SHF range a device was created to control ultrathin conductors using an open resonator [1]. This technique is useful for quality control of filaments, such as medical threads, microwire, fishing lines and other industrially manufactured products. The control of permittivity and diameter is especially important for precision 3D-printing [2]. For filamentary objects, but already dielectric, such a quasi-optical approach can also be quite effective. In this paper we consider a model of an open resonator with extended dielectric filamentary object at millimeter and submillimeter wave ranges.

II. Results

When electric field of the basic mode of oscillation is thin in comparison with the wavelength of dielectric cylinder in center of open resonator, resonance frequency shift of this mode can be determined from equation [3]:

$$\Delta f = \frac{2r_c}{\sqrt{2\pi w_1 w_0 \varepsilon_0 L}} \mathrm{Re}\left[\sum_{n=-\infty}^{\infty}(J_n'(k_1 r_c) + A_n H_n^{(2)'}(k_1 r_c))\right] \qquad (1)$$

where r_c is the radius of the cylinder, w_0 is the radius of the "spot" of field in center of open resonator, w_1, k_1, ε_0 is the wave resistance, wave number and permittivity of the free space, L is the distance between the reflectors, J_n' and $H_n^{(2)'}$ the derivatives with respect to the complete argument, respectively, of the Bessel and Hankel functions of the second kind. A_n are well-known coefficients in theory of scattering of plane wave by circular cylinder.

The experimental setup was created on basis of the terahertz spectrometer STD-21 (Figure 1).

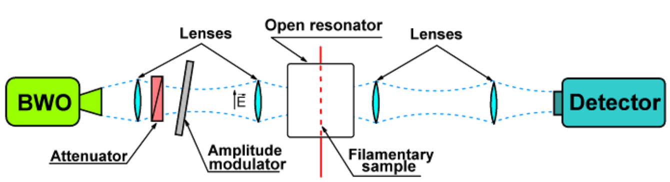

Fig. 1. The experimental setup of quasi-optical resonator system for diagnostics of filamentary dielectric objects at THz frequency range.

As a source of monochromatic radiation backward-wave oscillator (BWO) was used, detector - Golay cell. Amplitude modulation was set by chopper. The traditional scheme of excitation of an open resonator by a thin film is widely used in the microwave range (Figure 2a). In this research excitation of the resonator was carried out by waveguide with horn antenna inside of quasi-optical path (Figure 2b). The waveguide narrows on the mirror into the slit, which provides the excitation of resonator oscillations with linear polarization.

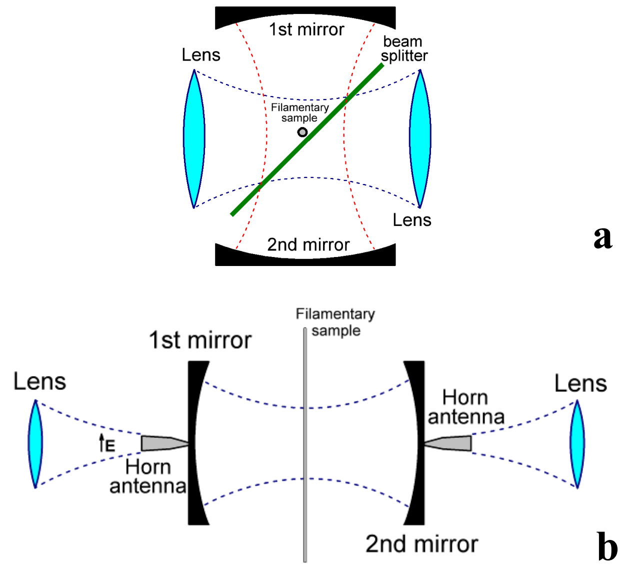

Fig. 2. The scheme of open resonator with filamentary object in quasi-optical beam of spectrometer: excitation of resonator with thin film (a); excitation of the resonator through a narrow slit on the mirror (b).

The open resonator with two spherical reflectors was used with the following parameters: distance between mirrors L = 66 mm, the concavity radius of the mirrors was 84 mm, diameter of mirror was 50 mm (Figure 3).

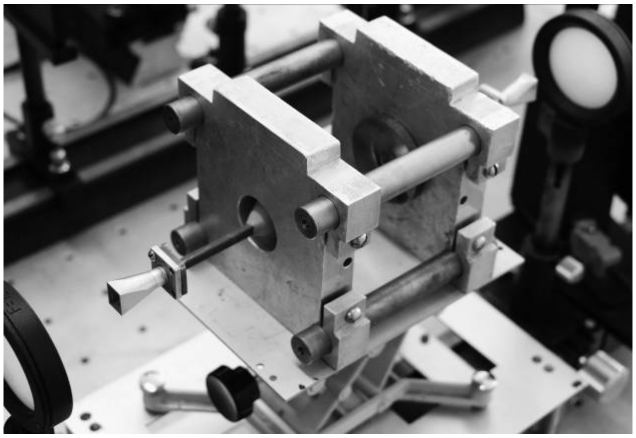

Fig. 3. Open resonator with a waveguide-horn coupling in the quasi-optical path of the spectrometer.

For the experiment 6 samples of nylon filaments of different diameters (from 150 µm to 400 µm) were selected. The results of measuring the relative transmission coefficient of an open resonator with dielectric filaments are shown in Figure 4.

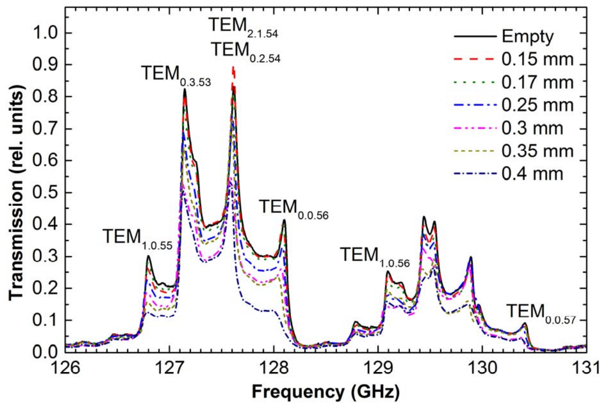

Fig. 4. Relative transmission coefficients of an open resonator with dielectric filaments of different diameters.

As a result of introducing a thin cylindrical dielectric into the resonator, a decrease in the quality factor and a shift of the resonant frequency (Figure 5). In Figure 6 calculated and measured frequency shift of main mode 128.1 GHz $TEM_{0.0.56}$ for 6 samples of dielectric filaments are presented.

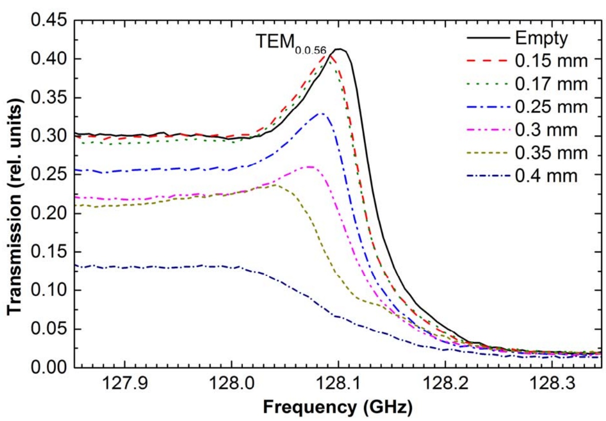

Fig. 5. Relative transmission coefficients of an open resonator with dielectric filaments of different diameters (main mode $TEM_{0.0.56}$).

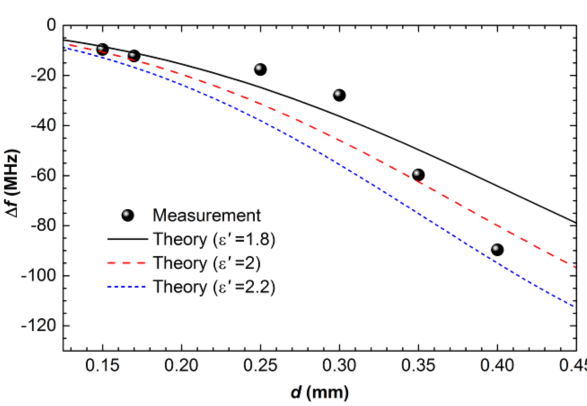

Fig. 6. Measured and calculated resonants frequency shift of open resonator depending on permittivity ε of dielectric filament at frequency 128.1 GHz (main mode $TEM_{0.0.56}$).

In Figure 7 the results of measured and calculated frequency shifts by equation (1) depending on diameter of filaments obtained earlier at 89.3 GHz and 102.8 GHz are presented [4].

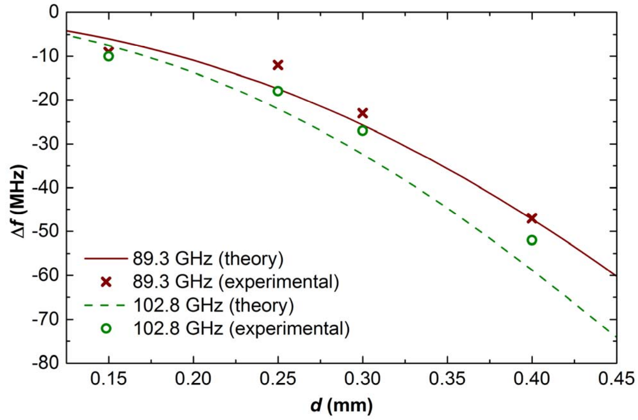

Fig. 7. Measured and calculated frequency shift of open resonator depending on diameter d of dielectric filamentary object at frequencies 89.3 GHz and 102.8 GHz.

As follows from Figure 6 and Figure 7, an increase in the diameter of the dielectric filament inside the open resonator leads to an increase in the shift of the resonance frequency. A significant contribution to the shift of the resonance frequency is made by the dielectric constant in the mathematical model. This circumstance makes it possible to determine the permittivity of thin cylindrical objects contactless.

III. SUMMARY

Thus, theoretical model of open resonator with thin cylindrical objects is consistent with the results of measurements for thin samples in submillimeter wave range. The possibility of using a resonator converter in THz devices for contactless diagnostics of filamentary objects is shown. The results of the study can be used in the industry for express diagnostics of the thickness of products, such as fishing line and medical thread.

IV. ACKNOWLEDGMENT

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