Terahertz waveguide sensor for small volume liquid samples

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***Abstract*—We demonstrate a refractive index sensor for liquid samples for the THz range. The sensor presents a refractive index dependent resonance which shifts in frequency at a rate that exceeds 500 GHz/RIU. The simple structure of the sensor and the low liquid volume requirement make it viable for scientific and industrial applications.**

I. INTRODUCTION

Terahertz refractive index sensors are in increasing demand owing to the enormous potential of this type of radiation for non-destructive characterization of samples with small composition, and therefore, refractive index variations. Up to date, several approaches [1] have been reported. Yet, an economical, low volume sensor with high sensitivity whose production is industrially viable is needed.

II. DESIGN

Figure 1 shows the sensor structure. The sensor consists of a periodic grove structure on 10 microns thick aluminum foil. The groove width is 330 microns with the period of 550 microns. This periodic structure is placed free-standing on a depleted aluminum plate with 10 microns depth which is the sample reservoir. In order to optimize performance of the structure, we used a numerical method developed for scattering analysis of multilayer periodic structures. Details of the numerical method are described elsewhere [2].

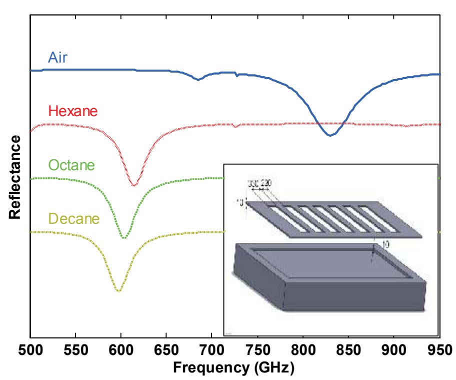

Figure 1. Calculations of resonances for air (n=1), hexane (n=1.37), octane (1.41) and decane (n=1.43). The inset shows a schematic of the sensor.

Also this figure shows the reflection spectra calculated for a p-polarized plane-wave incident on the sensor structure at an angle of 30°. It is observed that the resonance frequency changes with variations in the refractive index of the material. The incident THz broad-band pulse reflects off the sensor, with the exception of a narrow frequency band around (f_0).

This frequency fulfills the resonance condition between groove layer and the aluminum plate. Figure 2 demonstrates the electric field profile at the resonance frequency. At this frequency, the electric field is highly localized between the grooves and bottom aluminum plate. Hence, the resonance is very sensitive to the refractive index of the material filling the space between the aluminum plates.

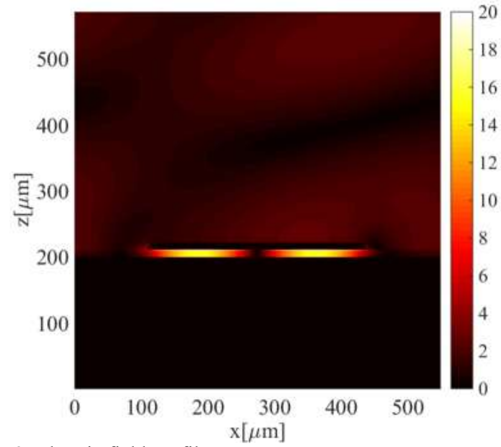

Figure 2. Electric field profile at resonance

III. RESULTS

In the measurement setup, we have used a converging Gaussian beam incident on the sensor structure. Our numerical method can also be used to analyze the scattering of Gaussian beams. Using this capability, we studied the effect of converging beams on the designed sensor. As it is seen in figure 3, the converging beam does not have a considerable effect on the performance of sensor.

We studied the effect of the distance between adjacent grooves to predict the sensitivity of the structure response to the fabrication imperfections using the numerical method by varying the periodicity of the structure on the response of the sensor (figure 4). As illustrated in this figure the resonance frequency of the sensor structure remains unchanged.

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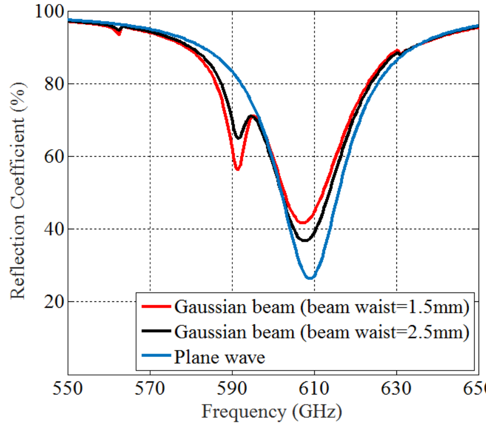

Figure 3. Reflection from the sensor structure when illuminated by Gaussian beam with a beam waist of 1.5 mm (red), Gaussian beam with a beam waist of 2.5 mm (black) and plane wave (blue).

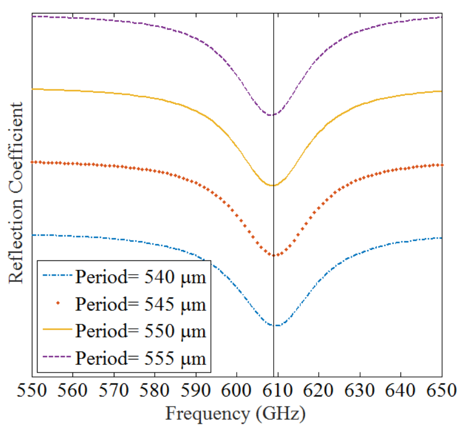

Figure 4. Reflection spectra calculated for different periodicities.

In order to verify the numerical calculation, we used a conventional THz-TDS setup in a reflection geometry with an angle of incidence of 30 degrees [3]. To measure the frequency shifts, first we recorded a reference pulse for the empty sensor. Subsequently we tested Hexane (C_6H_{14}), Octane (C_8H_{18}) and Decane ($C_{10}H_{22}$), given that they are dispersion-less liquids with similar refractive indices: 1.37, 1.41 and 1.43, respectively.

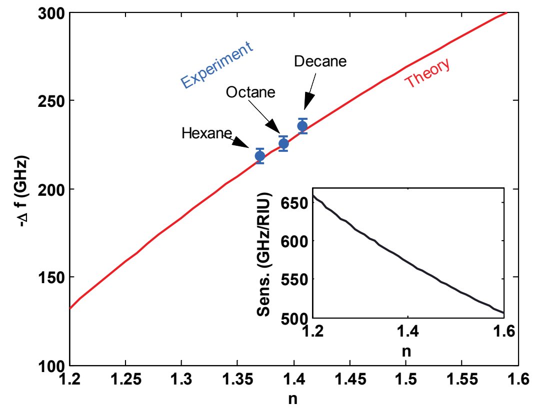

Figure 5. Numerical and measurement results for the waveguide sensor. The inset shows the calculated sensitivity of the device.

Figure 5 shows the measurement and numerical results. The curve on the main panel presents the theoretical frequency shift as a function of the refractive index, while the points represent the experimental measurements showing excellent consistency. The inset presents the sensitivity of the sensor. From the numerical calculation, it exceeds 500 GHz/RIU.

References

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