Improved Terahertz Sensors Based on Frequency Selective Surfaces For Thin-film Sensing

I. A. I. Al-Naib, C. Jansen, and M. Koch

Institute for High Frequency Technology, Technical University of Braunschweig

Schleinitzstr. 22, 38106 Braunschweig, Germany

***Abstract*— This paper proposes a miniaturized rectangular asymmetric double split resonator. Furthermore, a modified electrode shaping for enhanced field confinement in the gap is suggested to further increase the sensitivity for thin-film sensing.**

I. Introduction

Terahertz sensing with tiny amounts of chemical and biomolecular substances has been of particular interest to scientists and engineers alike, since it may open a broad range of potential applications. Especially the huge difference between the sensing wavelength and the nanometric scale of substance quantity proves to be challenging. However, first successful approaches have already been introduced[1-3].

Frequency selective surfaces (FSS) can be regarded as filters of electromagnetic waves. Composed of identical resonators arranged periodically in two dimensions, they can be designed either for bandstop or for bandpass behavior. The first resonance of such structure appears for a wavelength slightly greater than the array period. Unfortunately, the resonating structural elements are strongly coupled to free space and suffer from significant radiation losses so that the quality factor of such structures is rather low. Achieving resonances with a high quality factor and low coupling to free space is essential to succeed in the field of thin-film sensing.

Recent theoretical analysis has shown that a high-Q factor resonance can be obtained in asymmetric double split resonators (aDSRs)[4]. A demonstration applying this principle at microwave frequencies has been demonstrated experimentally[5]. Simulations of such a structure have shown promising performance at terahertz frequencies as well[6].

The aim of this paper is to miniaturize the aDSR design as this is crucial to further reduce the amount of required sample substance. Moreover, a modification to the electrode shape in the resonator gap is proposed, narrowly confining the electric field to further enhance the sensitivity.

II. The Proposed Structure and the Results

We propose a rectangular aDSR and modified rectangular aDSR with narrowing electrode shaping for increased field confinement as improvement of the classical circular design. In order to compare the performance of the three approaches, simulations with the finite element method based Ansoft HFSS are performed. The substrate for all simulations is fused silica with a refractive index of 2.105 and a thickness of 150 µm. The gap area is fixed for all structures. The gold metallization layer and the over-layer are both 100 nm. The thin film over-layer fills each gap completely and has the same refractive index as the substrate.

In Fig. 1, the resonance frequency and the corresponding insertion loss, with (solid symbol) and without (hollow symbol) an over-layer, are shown for each investigated geometry. The resonance of the new rectangular aDSR is 20% lower than the one of the circular design. Thus, a miniaturization by 20% is achieved. Adding shape-confining electrodes to the rectangular resonator leads to almost doubled shift in the resonance frequency compared to the circular aDSR, improving the performance of the new design even further.

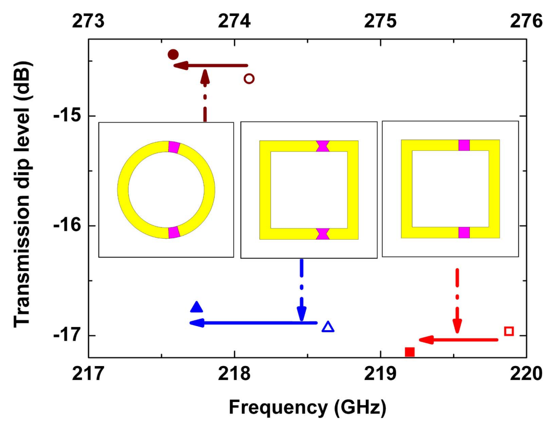

Fig. 1. Transmission dip level vs. the resonance frequency for the three structures.

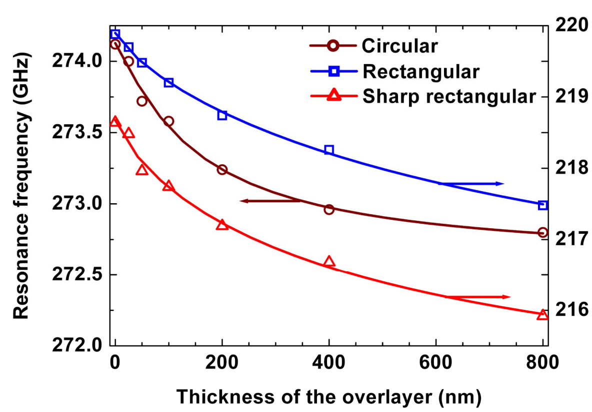

Fig. 2. Resonance frequency at the transmission dips vs. the thickness of the over-layers (The solid lines are sigmodial fits).

We further characterize the resonance frequencies of the structures as a function of the over-layer thickness. Fig. 2 depicts the resonance frequency for circular (left scale, circles), rectangular, and sharp rectangular resonators (right scale, rectangles and triangles, respectively). Note that the

978-1-4244-2120-6/08/$25.00 ©IEEE.

right scale covers twice the frequency range of the left scale. The offset in the resonance frequency is well distinguishable despite the nanometer scale of the over-layer. A sweep over a set of layer thicknesses ranging from 25 nm to 800 nm reveals that the resonance shift saturates for very thick layers. For layers above 20 µm, no further decrease in the resonance frequency is observed. The saturation is a direct consequence of the field distribution in the overlayer, which becomes weaker for positions further away from substrate.

III. Conclusion

New structures, enabling high sensitivity terahertz thin film sensors for chemical and biochemical applications, are proposed. The new rectangular geometries lead to miniaturized and more sensitive devices, compared to conventional circular structures. The over-layer detection limit is determined to be approximately 25 nm. Hence, these structures are a promising approach to future THz thin film sensors.

Acknowledgment

Ibraheem A. Ibraheem Al-Naib would like to thank the German Academic Exchange Service (DAAD) for financial support.

References

[1] P. H. Siegel, "Terahertz technology in biology and medicine," IEEE Trans. Microwave Theory Tech. 52, 2438, 2004.

[2] J. Zhang, and D. Grischkowsky, "Waveguide terahertz time-domain spectroscopy of nanometer water layers," Opt. Lett. 29, 1617, 2004.

[3] T. Baras, T. Kleine-Ostmann, and M. Koch, "On-chip THz detection of biomaterials: a numerical study," J. Biol.Phys. 29, 187, 2003.

[4] S. Prosvirnin and S. Zouhdi, in Advances in Electromagnetics of Complex Media and Metamaterials, edited by S. Zouhdi et al. (Kluwer Academic Publishers, The Netherlands), pp. 281-290, 2003.

[5] V. A. Fedotov, M. Rose, S. L. Prosvirnin, N. Papasimakis, and N. I. Zheludev, "Sharp Trapped-Mode Resonances in Planar Metamaterials with a Broken Structural Symmetry", Phys. Rev. Lett, vol. 99, 147401, Oct. 2007.

[6] C. Debus and P. Haring Bolivar, "Frequency selective surfaces for high sensitivity terahertz sensing", Appl. Phys. Lett., vol. 91, 184102, Oct. 2007.