IRMMW-THz 2020
November 8–13, 2020
Buffalo, NY USA
45th International Conference on Infrared, Millimeter, and Terahertz Waves

Ultra-sensitive biological THz metamaterial sensor

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ABSTRACT

An Ultra-sensitive THz metamaterial sensor with asymmetric duble-F-shaped metal resonators (ADFSMR) is proposed. Perfect narrow-band absorption at THz frequencies has been achieved, the Q factor reaches 50. It is ultrasensitive to the refractive index of the surrounding medium and is very stable to the thickness variation of the medium. Simulation results show that the sensitivity is 1800 GHz / RIU for analyte with thickness of 5um. The excellent property can be used in ultra-sensitive THz refractive index (RI) biological sensor and detectors.

INTRODUCTION

Metamaterial is artificially engineered electromagnetic material composed of periodically arranged sub-wavelength metal elements. The frequency of terahertz (THz) waves is between 0.1 THz and 10 THz, which has revealed more and more unique applications in biomedical fields such as image, label-free detection.In recent years, many biosensors based on metamaterial absorbers have made great progress [1], but the problem of insufficient sensitivity and relatively complicated manufacturing structure has blocked its effective application in biosensing.In this presentation, we propose a simple structured ultra-sensitive biological THz metamaterial sensor, which composed of asymmetric double-F-shaped unit cell array, the sensitivity is 1800 GHz / RIU for analyte with thickness of 5um, the Q factor reaches 50.

RESULT

Fig 1 shows the unit cell of the sensor, which consists of two gold layers on the top and bottom of the structure, separated by a dielectric. The top layer is composed of double F metal resonators with a thickness of h1, while the bottom layer is a continuous gold plate with a thickness of h3, and the thickness of which is more than the skin depth of the applying electromagnetic waves, and the conductivity of gold was set as σ = 4.09 × 107 S/m.The dielectric medium between them is polytetrafluoroethylene (Teflon) with a dielectric constant ε = 2.1 and a thickness of 5um [2]. In this metamaterial sensor structure, when there is no analyte on the surface layer (that is, the analyte refractive index n=1), the absorption curve with a TM wave incidence is shown in Fig. 2. There is a perfect absorption peak at 5.95Thz. The full-width half-maximum value (FWHM) was 0.12 THz, and the Q-factor was equal to 49.6, which was defined as Q = fo / FWHM, where fo is the central resonance frequency [3].

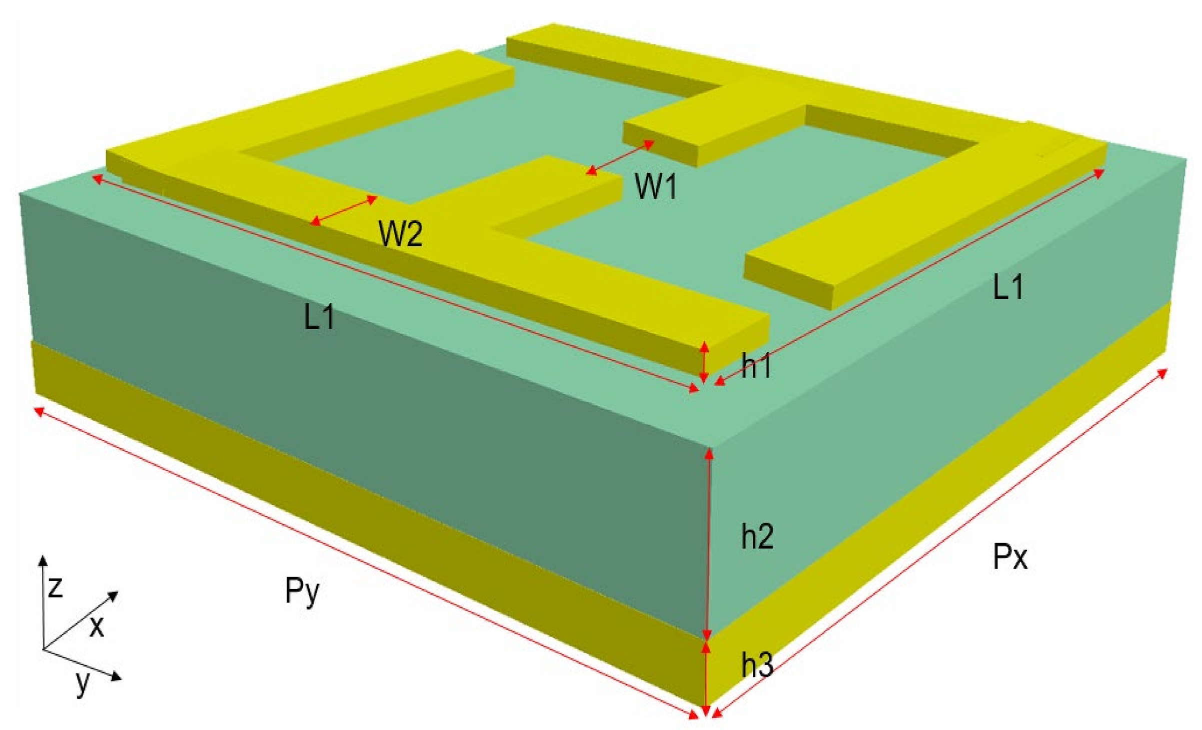

Fig. 1. Schematic of the unit cell of the sensor with Px = Py = 36μm, h1 = 1μm, h2 = 5μm, h3 = 0.2μm, L1 = 20μm, and W1 = W2 = 2.5μm..

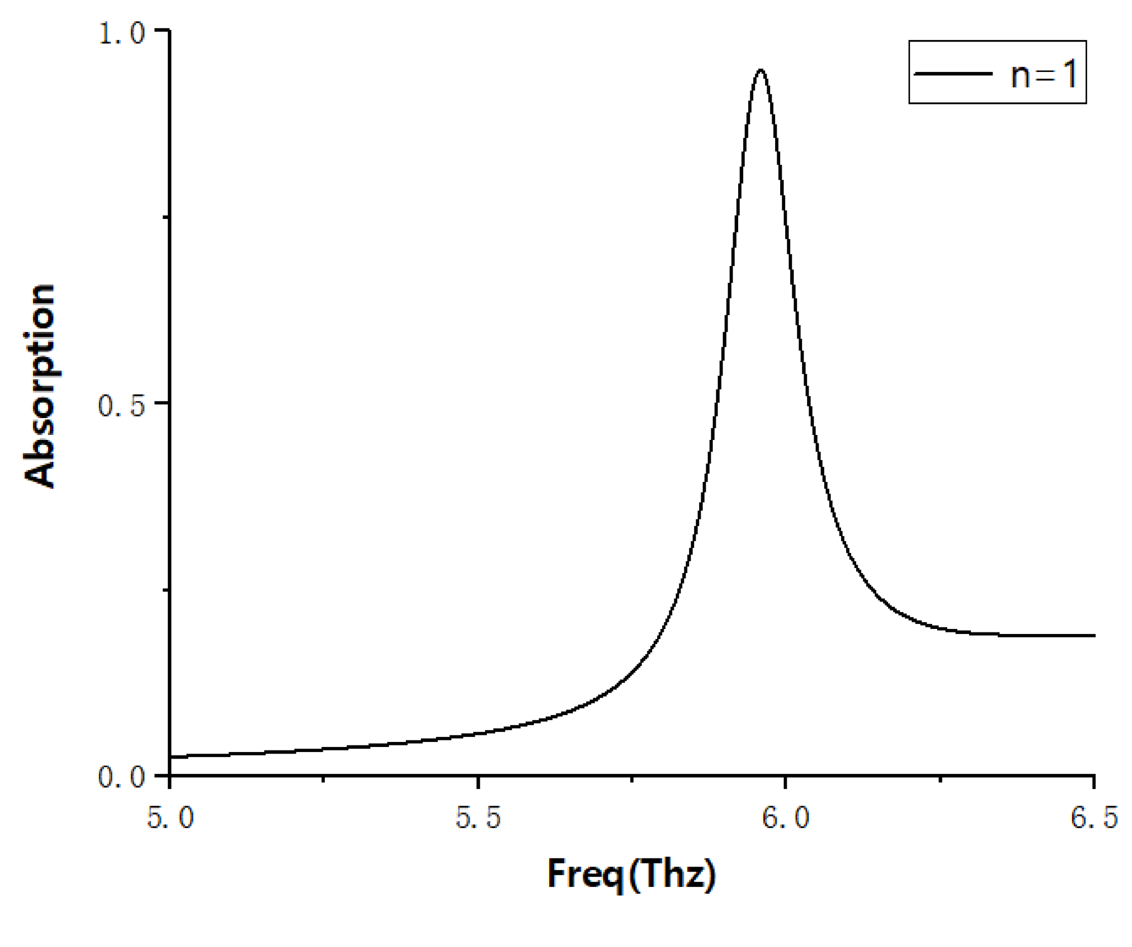

Fig. 2. The absorption spectrum of the independently tunable dual-band GMA for s-polarization.

The absorption curves are shown in Fig.3(a). An analyte layer with a fixed thickness is placed on the top layer of the sensor. By increasing the refractive index r of the analyte layer, the resonance frequencies of the sensor have remarkable red-shift. The sensitivity of a sensor is normally defined as S = △f0 / △n0, where △f0 is the offset of resonance frequency, △n0 is the variation rate of refractive index n, and the ultra-high sensitivity of 1800 GHz/RIU can be obtained for the proposed sensor. Generally, the refractive index of typical biomedical samples is between 1.3 and 1.4. For example, the refractive index of blood of healthy human beings is 1.35, and the n of blood samples infected with T-type leukemia (Jurkat) is 1.39. The deviation of resonance peaks was still distinct even though the variation step of n was only 0.02 in the range of 1.3 to 1.4. Obviously, the proposed sensor can act as a supersensitive biosensor with high Q value. An analyte layer with a fixed thickness is placed on the top layer of the sensor. The thickness of the analyte layer will impact the sensing performance. For a typical biological analyte with a refractive index of n = 1.3) the absorption curves versus thickness of analyte h0 in Fig.4 indicates that the resonance frequency will red shift non-uniformly when h0 increases from 0 μm to 6 μm with a step of 1 μm. It can be observed that the deviation of the resonance frequency tends to be gentle on per unit increase of thickness primarily, and becomes negligible when the thickness of the analyte exceeds 4 μm. Considering the thickness sensing is defined as S = △f / △h0 [3], where △f is the resonance frequency offset and △h0 is the thickness variation of the analyte slice. When the thickness of the analyte changes from 0 um – 4 um, the sensitivity of the proposed sensor can reach S = 134 GHz/μm.

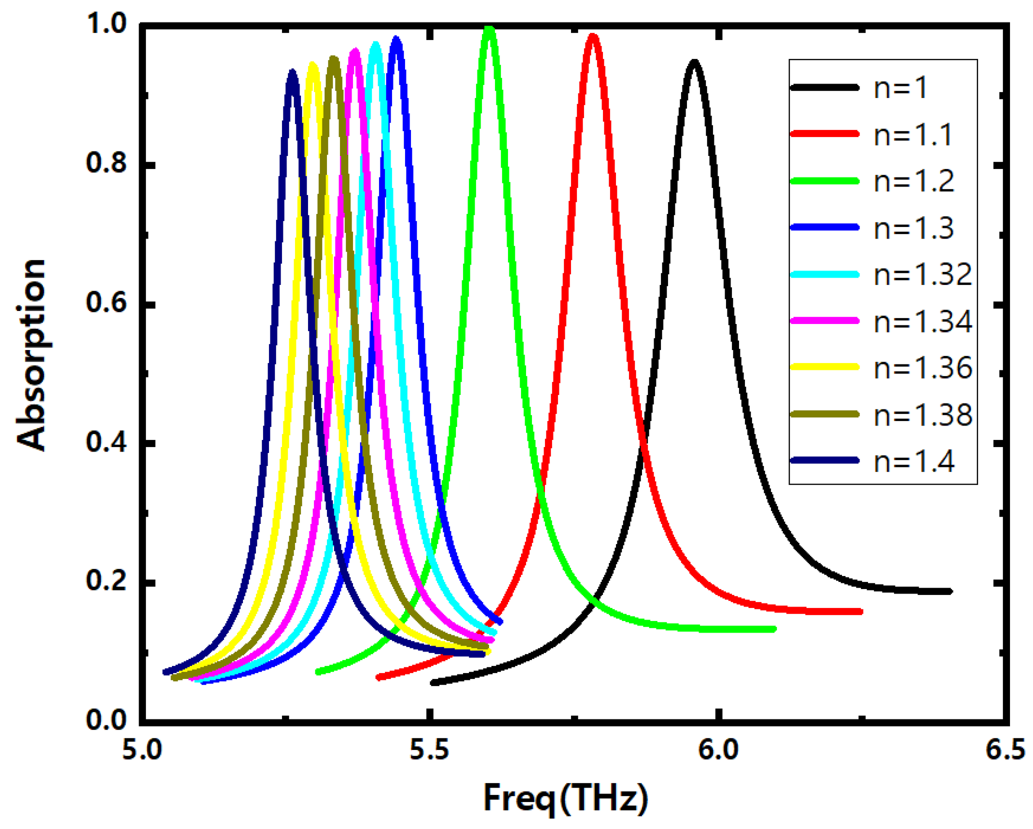

Fig. 3. absorption spectrum with different refractive index n of the surface analyte.

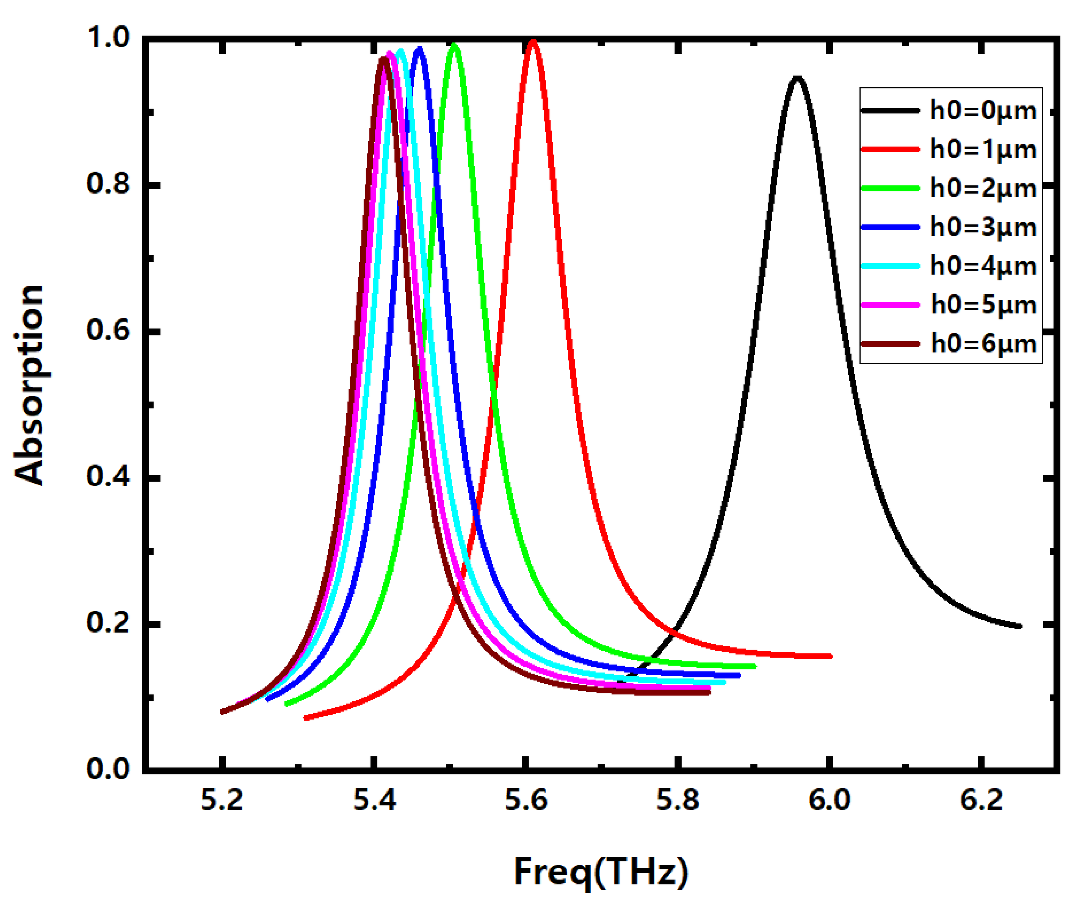

Fig. 4. absorption curves with different analyte thickness h0;

Summary

In summary, a MMs biosensor with a good performance and simple structure was proposed and designed to achieve ultra-sensitivity and a high FOM value. The simulation results showed that the sensor could achieve an average absorption rate of 0.95, a high Q-factor of 49.6, sensitivity of 1800 GHz/RIU and an FOM value of 15. In particular, when the thickness of the sensing analyte with a typical refractive index of 1.3 changes from 0 μm to 4 μm, a high sensitivity of 134 GHz/μm can be obtained.

References

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