# Reduction of effect of water absorption for metamaterial sensing applications

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**Abstract**

We investigate the effect of absorption coefficient of water, which is attached on split ring resonators (SRRs) surface, for a reflection spectrum in terahertz region. When the water is dropped on the SRRs surface, the resonant dip disappears owing to the relatively high value of the extinction coefficient of water in terahertz region. This makes it difficult to use the metamaterial as a highly sensitive device for water solutions. By inserting a thin dielectric film between the SRRs and water, we can remain the apparent resonant dip, and simultaneously observe the shift of the resonant frequency.

## 1. Introduction

In the past two decades, metamaterials have been investigated to manipulate and control electromagnetic waves with subwavelength artificial structures. A split ring resonator (SRR) is one of the promising structures [1] in order to obtain a magnetic resonance at high frequency regions. Not only to obtain the magnetic resonance, but also the SRR has been used as subwavelength resonators for the sensing application [2-3]. The resonant characteristics are observed in a transmission or reflection spectrum of SRRs as a resonant peak or dip. The resonant frequency is shifted with changing the refractive index of material that is attached on the SRR surface. By using this property, we can detect the change of the refractive index in the vicinity of the SRR surface.

In our study, we aim to use the SRR structure for the sensing application of water solutions of bio-molecules in terahertz (THz) region. So far, Yoshida *et al.* reported the sensing applications of protein by using metal mesh structures in THz region [4]. In their experiment, they used a dried protein as a target sample. However, it is important to detect bio-molecules in water. In this paper, we investigate the effect of water to the reflection spectrum of metamaterials that consist of a SRR array.

For metamaterial sensing, the water is dropped on the metamaterial surface, and we measure the change of transmission or reflection spectrum as the status of bio-molecule in water changes. In THz region, however, water strongly absorbs electromagnetic waves. This strong absorption leads the resonant spectral structure of SRRs disappeared, and correspondingly the sensing of the water solution of bio-molecules in THz region is very challenging. To avoid the strong effect of water, we propose to insert a thin dielectric film between water and metamaterial surface. By choosing the appropriate thickness of the film, we can remain the apparent resonant spectral structure in the reflection spectrum, and simultaneously observe the shift of the resonant frequency of SRRs.

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## 2. Experiment

We fabricated the metamaterial that consists of an array of complementary split ring resonators (c-SRRs). The gold was sputtered on 2-mm-thick plastic plate and patterned the c-SRRs by using femtosecond laser ablation process. The picture of our metamaterial is shown in the inset of Fig. 1(a). The size of the c-SRR is 99 μm with the gap of 22 μm. The c-SRRs are arranged in rectangular lattice with a periodicity of 196 μm. We measured the reflection spectrum of our sample by using terahertz time domain spectroscopic system (THz-TDS). Fig. 1(b) shows the optical configuration of our measurement system. The THz wave is entered from the substrate of the plastic plate, and water is dropped onto the c-SRR surface.

## 3. Results and Discussions

Fig. 1(a) shows the reflection spectra of our metamaterial with (blue line) and without (red line) the water droplet on the c-SRR surface. The resonant dip is observed at 0.37 THz for the bare c-SRR (red line), while the resonant dip disappears when the water is dropped on the c-SRR surface (blue line).

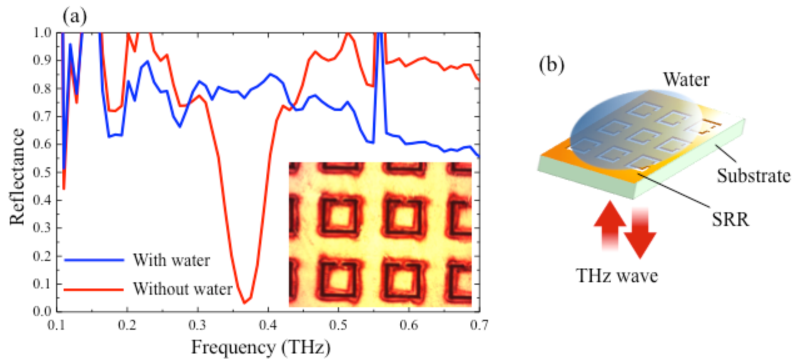


Fig. 1 (a) Measured reflection spectra of c-SRR with (blue line) and without (red line) water droplet on the c-SRR surface. Inset shows the picture of our sample used in this experiment. (b) Schematic of optical configuration of our experiment.

Next, we investigate the reason of disappearance of the resonant dip when the water is dropped on the c-SRR surface. Fig. 2 shows the calculated reflection spectra for our metamaterial when a dielectric material is attached on the c-SRR surface. We used finite-difference time-domain (FDTD) method for this calculation. We varied the extinction coefficient $k$ of the attached dielectric material while the refractive index $n$ is fixed at the value of water at 0.37 THz ($n$ = 2.32). When $k$ = 0, the resonant dip is observed at 0.21 THz. The resonant frequency is shifted to lower frequency side with respect to that of the bare c-SRR. This is due to the change of the refractive index of attached dielectric to the c-SRR surface from $n$ = 1 (air) to 2.32. As the extinction coefficient increases, the resonant dip becomes weak and broadened, and finally it almost disappears when the extinction coefficient becomes the value of water ($k$ = 0.64). From this result, we can conclude that the disappearance of the resonant dip for the water-dropped metamaterial is attributed to the relatively high extinction coefficient of water in THz region.

For the application of the water solution sensing with metamaterials, the resonant dip should be remained even when the water is dropped on the c-SRR surface. In order to avoid the effect of absorption by water, we put a thin film between the water droplet and c-SRR. Fig. 3(a) shows the calculated reflection spectra for our proposed configuration as shown in Fig. 3(b). In this simulation, the optical configuration is same to that of Fig. 2 except that we insert the thin film between c-SRRs and attached dielectric material. The refractive index and extinction coefficient of attached dielectric material are $n$ = 2.32 and $k$ = 0.64, respectively, which are the value of water. When the film thickness is 5 μm, the weak resonant dip is observed at 0.24 THz with relatively broad bandwidth. As the film thickness increases from 5 μm to 15 μm, the resonant frequency shifts from 0.24 THz to 0.26 THz, and correspondingly the resonant dip becomes deeper and sharper. When the film thickness is 20 μm, the reflection spectrum is almost same to that of 15-μm-thick film. This means that there is no effect from the attached dielectric material when the thickness of the film is more than 15 μm.

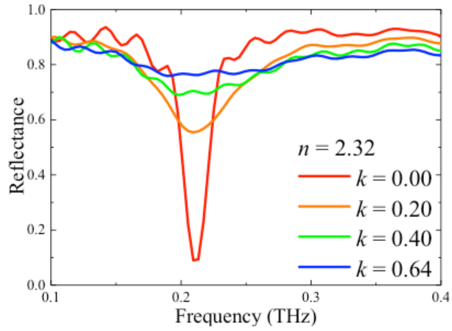


Fig. 2 Simulated reflection spectra of c-SRR with varying the extinction coefficient of the dielectric material attached on c-SRR surface. The extinction coefficient is varied from $k = 0$ to 0.64 while the refractive index is fixed at $n = 2.32$.

For the sensing application, we need the some effect of water droplet to the reflection spectrum, and simultaneously we should remain the apparent resonant dip. These two required characteristics are trade-off when the film thickness is varied. We need to choose the appropriate thickness of inserted film on demand from applications.

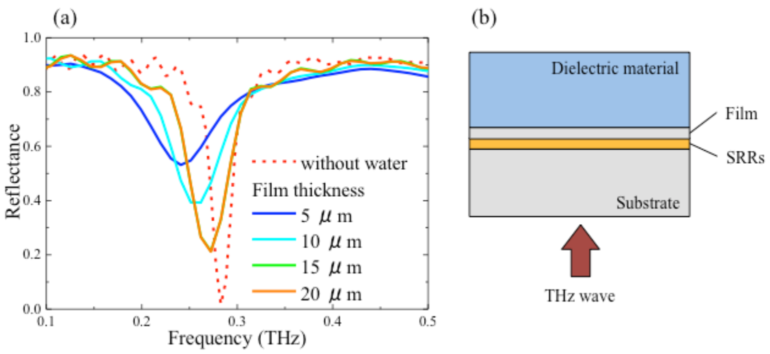


Fig. 3 (a) Simulated reflection spectra of c-SRRs with varying the thickness of plastic film that is inserted between the c-SRR and dielectric material. (b) A schematic of sample configuration used in this simulation.

## 4. Conclusion

In conclusion, we investigated the effect of water, which is dropped on the c-SRR surface, to the reflection spectrum of the c-SRR. If we dropped water directly on the c-SRR surface, the reflection dip disappeared. This is due to the high extinction coefficient of water in THz region. By inserting the thin plastic film between the c-SRR surface and water, we can remain the reflection dip and observed the shift of the resonant frequency. This result shows the possibility of sensing water solution of biomolecules even in the THz region by using metamaterials.

## References

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