# Terahertz spectroscopic analysis using a metallic hole array

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**Abstract - We focused on terahertz wave spectroscopy using a metallic hole array (MHA), which can be applied as a frequency shift of the transmission spectra for substance detecting and its alteration. The transmission spectra have been studied by the use of FDTD simulation. As an experiment we coated PMMA on MHA followed by irradiation with and without ultraviolet light (UV). The shift of the transmission spectra indicates the changes of thickness and the dielectric constant of PMMA layer. We also covered a collodion film on MHA as a stage for a substance sample for minute trace of the substance detection. It showed a potential to be applied to sensitive detection for small amounts of substances and slight variation of the characteristic features.**

## I. INTRODUCTION

Material analysis using THz spectroscopy can obtain information abundantly on physical and chemical phenomena, and has been comprehensively applied in investigation on the dynamics characteristic of substance. In the case of trace material detection, the conventional terahertz spectroscopy method is difficult to find the characteristic information from the difference of spectra, therefore high sensitive spectroscopic methods have been desired.

It is found that the transmission phenomena for a hole array (MHA) in thin plate are analogous to the enhanced transmission of terahertz waves [1]. Due to strong localization of the electromagnetic field of surface waves in the vicinity of the MHA surface, the resonant transmission characteristics depend strongly on the dielectric distribution near the surface, so it can be applied for substance detecting as frequency shift of the transmission spectra. In this study we have been investigated THz spectroscopy applied to the detection of microanalysis of substances and slight variation of the characteristic features.

## II. EXPERIMENTAL

Two different MHAs were used in the experiments and their structural parameters are shown in Table 1. The diffraction frequencies and cut off frequencies are also listed (theoretical value).

Table 1 Parameters of MHA

| sample | Hole diameter $r$ [μm] | Lattice constant $a$ [μm] | Thickness $t$ [μm] | $f_{\text{cut off}}$ [THz] | $f_{\text{diff}}$ [THz] |
|---|---|---|---|---|---|
| MHA1 | 44 | 60 | 12 | 3.58 | 5.78 |
| MHA2 | 49 | 80 | 12 | 4.04 | 4.33 |

Both MHAs were perforated in a Ni film with a triangular lattice arrangement. The transmission characteristic of MHA is mainly determined by its structural parameters as we showed in table 1. The resonant frequency ($f_{\text{sw}}$) of surface wave mode will be generally appear at frequency closed to its diffraction limit frequency which depends on Wood's anomaly, also can be expressed as

$$f_{\text{sw}} = |k_{\text{in}} \pm \boldsymbol{G}| \frac{c}{2\pi} \sqrt{\frac{\varepsilon_{\text{m}} + \varepsilon_{\text{d}}}{\varepsilon_{\text{m}} \varepsilon_{\text{d}}}}$$

where $k_{\text{in}}$ is the in-plane vector component of the incident wave, $\boldsymbol{G}$ is the reciprocal lattice vector of the periodic structure, $\varepsilon_{\text{m}}$ is the dielectric constant of MHA, and $\varepsilon_{\text{d}}$ is the dielectric constant of interface medium of MHA [1].

## III. RESULT AND DISCUSSION

The transmittance of THz wave through MHAs has been studied by simulation approach and experimental analysis. The transmission spectra of MHAs were measured by using FT/IR-6200 (Fourier Transform Infrared spectrometer 6200), and the results of Finite difference time domain (FDTD) simulations show good agreement with the measured results. As shown in Fig. 1 the spectra simulated and measured are band-pass characteristics, and the surface wave resonance peaks of MHA1 and MHA2 are appeared on the transmission spectra at 3.7 THz and 4.8 THz, respectively. Wood's anomalies also occurred in transmission spectra of MHA1 and MHA2 at 5.7 THz and 4.5 THz as the dip of diffraction limit which correspond to $f_{\text{diff}}$ in Table 1.

As an analytical application, MHA1 was coated by PMMA (poly methyl methacrylate, average molecular weight ~996,000) after the measurement. We used dip coating method to control the thickness of PMMA film coating on MHA1 by the concentration of PMMA solution. Due to the different viscosity of coating solution, there are 2 cases of PMMA layer on MHA1, one is that the aperture of MHA1 is filled, and the other one is unfilled by PMMA. As the result shown in Fig. 2, it was found that the thickness of PMMA layer coated on MHA1 was strongly influenced on the spectra as peak shift and dip shift. And two abnormal peaks were occurred at 5.7 THz (case1 green line) and 5.2 THz (case2 red line) where none are expected, and might be related to the thickness of PMMA layer [2]. After this, the MHA1 coated with PMMA was irradiated with UV light (irradiation intensity: 2020 μW/cm$^2$, UV wavelength: 254 nm, for 7 days) for 2 cases. As the result shown in Fig. 2, the thickness of PMMA layer would be decreased by the irradiation as the dip frequency is shift to a higher frequency. And the filled aperture case showed that the dielectric constant of PMMA film was increased by UV irradiation as the peak frequency is shift to a lower frequency.

As the second application, MHA2 was covered by collodion film and the transmission spectra were measured as shown in Fig. 3. The four individual results of measurement indicated consistency of transmission spectra, therefore we infered that collodion film can used as a stage to support the liquid sample in this study. We droped 50μL glucose solution with different concentration on MHA2 with collodion film and the solution was dried to microcrystalline glucose at room temperatrue. The result of Fig. 4 shows that the resonance peaks of transmission spectra were shifted to lower frequencies and the shift amount is directly proportional to the concentration of glucose solution.

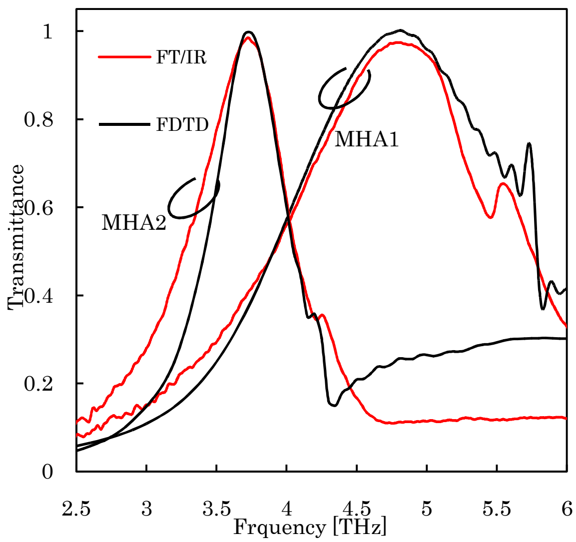


Fig. 1. Transmission spectra of MHA1 and MHA2, FT/IR (red), FDTD (black). Both experimental result and FDTD simulation result are showed.

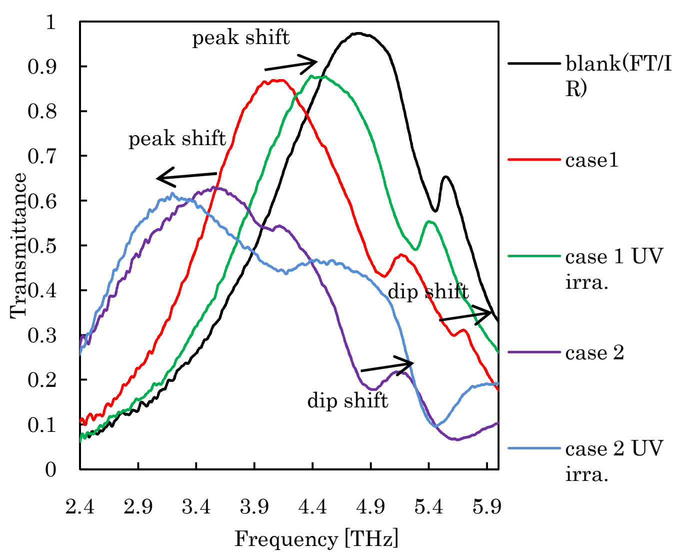


Fig. 2. Transmission spectra of MHA1 (black), transmission spectra of MHA1 coated by PMMA with and without UV irradiation, the aperture of MHA1 is unfilled (case 1, red and green) and the aperture of MHA1 is filled by PMMA (case 2, blue and purple).

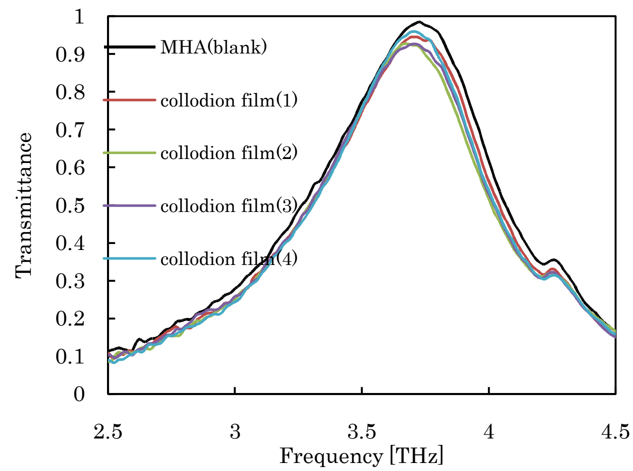


Fig. 3. Comparison of the transmission spectra of blank MHA2 and four individual samples of MHA2 with collodion film.

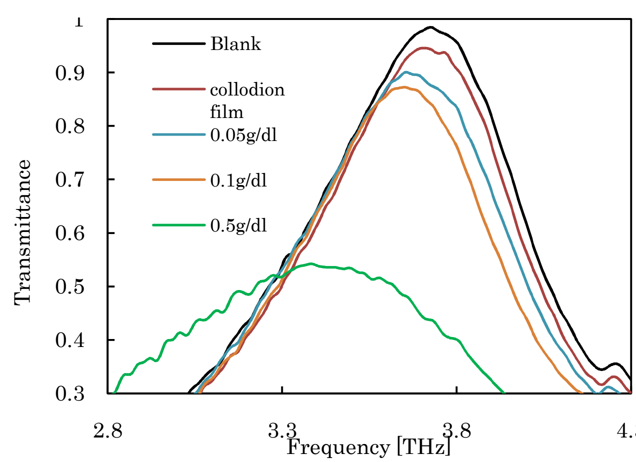


Fig. 4 Comparison of the transmission spectra of MHA2, MHA2 with collodion film, and MHA2 with collodion film dripped by 50μL glucose solution of different concentration (0.05/dl, 0.1/dl, 0.5/dl).

## IV. SUMMARY

In this study we investigated the transmission characteristic of MHA by using FDTD method and THz spectroscopy. From the frequency shift of the transmission spectra we obtained characteristic information which is related to the thickness variation and dielectric constant variation of PMMA layer coated on MHA. As another experiment we showed that resonance peak shift to lower frequencies with increasing amounts of glucose. The sensitive detection in this study could be useful in many situations such as detection for degradation of plastic or label-free sensing.

## REFERENCES

[1] F.Miyamaru et al., "Terahertz surface-wave resonant sensor with a metal hole array", Opt.Lett., 31, 8, pp.1118-1120(2006).
[2] Xiao Xiao, Wu Jinbo, et al, "Resonant terahertz transmissions through metal hole array on silicon substrate", August 2010, Vol. 18, OPTICS EXPRESS 18558.