# Terahertz Wave Resonance Profiles in Micro Patterns of Dielectric Tablets Fabricated by Using Stereolithography of Structural Joining Process†

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**Abstract**

*Materials tectonics is new concept to control energy flows form environmental field to human beings through spatial patterns of ceramics or metals fabricated by using structural joinings. Recently, we have developed two dimensional micro patterns composed of dielectric ceramics in order to control terahertz waves effectively by using stereolithography. In this process, photosensitive resin pastes with titania particles dispersion were spread on a glass substrate with 10 μm in layer thickness by moving a knife edge, and two-dimensional images of ultra violet rays were exposed by using a digital micro-mirror device with 2 μm in part accuracy. Through the layer by layer stacking, periodic structures composed of micro polygon tablets were formed. Dielectric constant of these tablets was measured as 40. Subsequently, the electromagnetic wave properties of these samples were measured by using a terahertz spectroscopic device. In transmission spectra, forbidden bands were observed form 0.33 to 0.57 THz through electromagnetic wave diffractions. Moreover, a localized mode of a transmission peaks was formed in the band gap frequency range. Through transmission line modeling simulations at the peak frequency, electromagnetic energies were concentrated strongly into the thin micro patterns. The terahertz waves are well known to resonate with various types of protein molecules, and expected to control the biological material syntheses through the frequency excitements. Fabricated dielectric ceramic micro patterns are considered to be applied for the new types of reactors to create the useful materials as artificial interfaces between the electromagnetic energy and the biological materials.*

**KEY WORDS:** (Dielectric Micro Pattern) (Band Gap) (Micro-Stereolithography) (Terahertz Wave)

## 1. Introduction

In near future industries, electromagnetic waves in a terahertz frequency range with micrometer order wavelength will be expected to apply for various types of novel sensors which can detect gun powders, drugs, bacteria in foods, micro cracks in electric devices, cancer cells in human skin and other physical, chemical and living events [1-6]. In our group, micro-stereolithography of a computer-aided design and manufacturing (CAD/CAM) system was newly developed to realize a spatially structural joining of ceramic or metal components in micro- meter orders to control the terahertz wave effectively [7-12]. By using this system, diamond type photonic crystals with periodic arrangements of micrometer order dielectric lattices were fabricated successfully to exhibit forbidden gaps through Bragg diffraction in the terahertz wave frequency rages [13-20]. Moreover, the spatial propagations of the electromagnetic waves were controlled effectively by using the the modified photonic crystals with twinned diamond lattices [20-24]. The incident electromagnetic wave was resonated and localized in a plane defect interface through multiple reflections between the twinned mirror-symmetric diffraction lattices, and a plane wave radiation of the terahertz wave beam emission was realized. In this investigation, two dimensional periodic patterns composed of acrylic resins with nano-sized titania particles dispersions were fabricated by using the micro-stereolithography to realize the wave diffractions and resonations in the terahertz frequencies. Filtering effects of the electromagnetic waves for a perpendicular direction to the dielectric patterns were observed through time domain spectroscopic measurements. These micro geometric patterns of extremely thin devices with a high dielectric constant were designed to concentrate the electromagnetic energies effectively through a theoretical simulation method.

## 2. Experimental Procedure

The micro dielectric pattern was designed as the periodic structure composed of micro square tablets of

† Received on July 10, 2009

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Transactions of JWRI is published by Joining and Welding Research Institute, Osaka University, Ibaraki, Osaka 567-0047, Japan

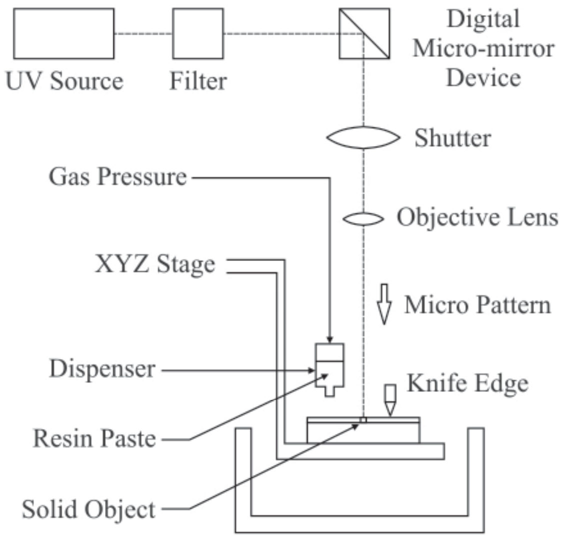


**Fig. 1** A schematically illustrated free forming system of a micro-stereolithography machine by using computer aided design and manufacturing (CAD/CAM) processes. (D-MEC Co. Ltd., Japan, SI-C 1000, http://www. d-mec.co.jp).

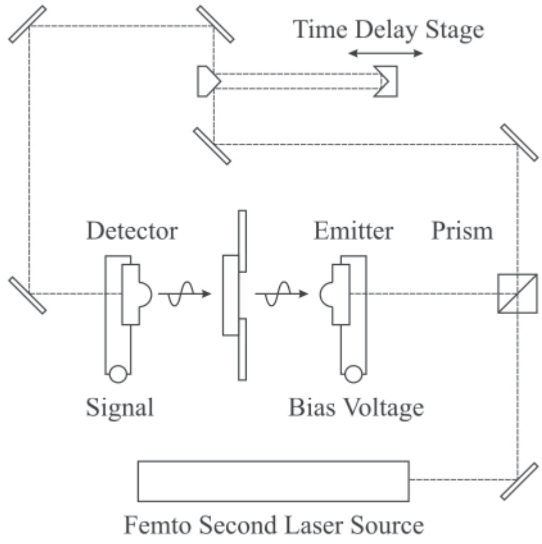


**Fig. 2** The schematically illustrated measuring system of a terahertz wave analyzer by using a time domain spectroscopic (TDS) detect method (Advanced Infrared Spectroscopy, Co. Ltd. Japan, J-Spec 2001, http://www. aispec.com).

240×240×100 μm in dimensions at intervals of 45 μm. These micro tablets of 9×9=81 in numbers were arranged to form the extremely thin dielectric device of 2520×2520×100 μm in whole dimensions. The real sample was fabricated trough the micro-stereo-lithographic system. A designed graphic model was converted for stereolithography (STL) data files and sliced into a series of two dimensional layers. These numerical data were transferred into the fabrication equipment (D-MEC: SIC-1000). **Figure 1** shows a schematic illustration of the fabrication system. As the raw material, nanometer sized titania particles of 270 nm in average diameter were dispersed into a photo sensitive acrylic resin at 40 volume percent. The mixed slurry was squeezed on a working stage from a dispenser nozzle. This material paste was spread uniformly by a moving knife edge. Layer thickness was controlled to 5 μm. Ultra violet lay of 405 nm in wavelength was exposed on the resin surface according to the computer operation. Two dimensional solid patterns were obtained by a light induced photo polymerization. High resolutions in these micro patterns had been achieved by using a digital micro-mirror device (DMD). In this optical device, square aluminum mirrors of 14 μm in edge length were assembled with 1024×768 in numbers. Each micro mirror can be tilted independently, and cross sectional patterns were dynamically exposed through objective lenses as bitmap images of 2 μm in space resolution. After stacking and joining these layers through photo solidifications, the periodical arrangements of the micro dielectric tablets were obtained. A bulk sample of the titania dispersed acrylic resin with the same material composition was also fabricated to measure the dielectric constant of the composite tablets. A terahertz wave attenuation of transmission amplitudes through the micro pattern were measured by using a terahertz time domain spectrometer (TDS) apparatus (Advanced Infrared Spectroscopy: Pulse-IRS 1000). **Figure 2** shows the schematic illustration of the measurement system. Femto-second laser beams were irradiated into a micro emission antenna formed on a semiconductor substrate to generate the terahertz wave pulses. The terahertz waves were transmitted trough the micro patterned samples perpendicularly. The dielectric constant of the bulk samples were measured through a phase shift counting. Diffraction and resonation behaviors in the dielectric pattern were calculated theoretically by using a transmission line modeling (TLM) simulator (Flomerics: Micro- stripes Ver. 7.5) of a finite difference time domain (FDTD) method.

## 3. Results and Discussion

The dielectric micro patterns with the periodic arrangement of the acrylic tablets with the titania particles dispersion was fabricated successfully by using the micro-stereolithography system as shown in **Fig. 3**. Dimensional accuracies of the fabricated micro tablets and the air gaps were approximately 0.5 percent in length. The nanometer sized titania particles were verified to disperse uniformly in the acrylic resin matrix as shown in **Fig. 4** thorough a scanning electron microscope (SEM) observation. The dielectric constant of the composite material of the titania dispersed acrylic resin was measured as 40. **Figure 5-(a) and (b)** show transmission spectra measured and simulated by using the TDS and TLM methods, respectively. The measured result has

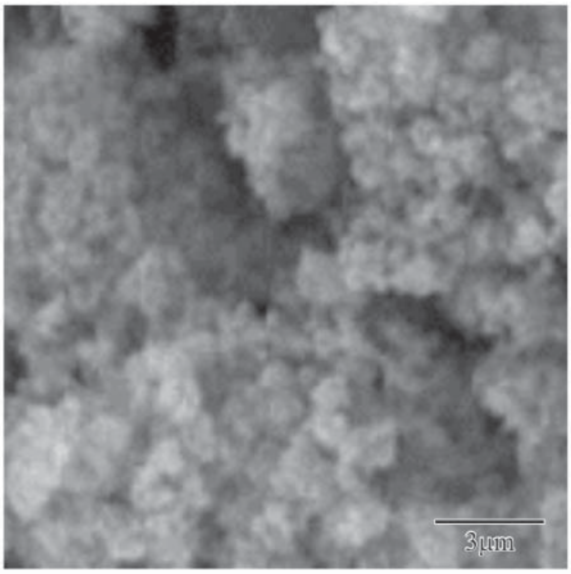


**Fig. 3** A dielectric micro pattern composed of titania particle dispersed acrylic resin fabricated by using the micro-stereolithography.

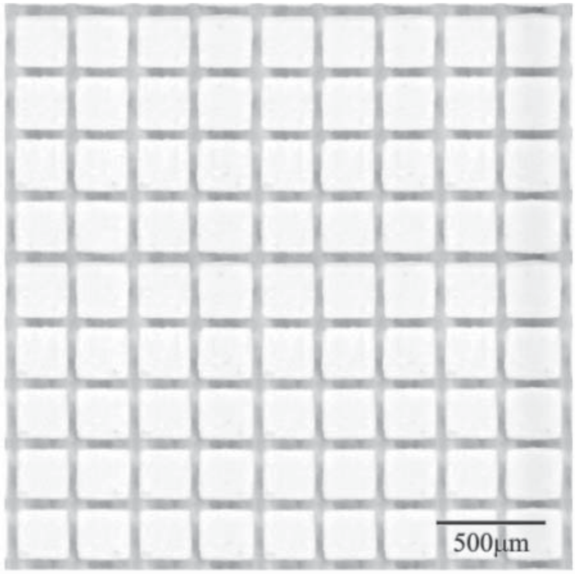


**Fig. 4** Microstructure in an acrylic resin bulk with titania particle dispersion observed by using a scanning electron microscope (SEM).

good agreement with the calculated one. Opaque regions were formed in both spectra form 0.33 to 0.57 THz approximately. Maximum attenuation was measured as about -20 dB in transmission amplitude, and the minimum transmittance showed below 1 percent. The two dimensional photonic crystals with periodic arrangement with the lower dielectric contrasts were well known to open the band gaps limitedly for the parallel directions to the plane structures. However, the micro patterns with the periodically arranged square tablets above 30 in dielectric constant could exhibit the clear forbidden bands in the transmission spectra toward the perpendicular direction to the plane patterns through the theoretical simulations. The fabricated dielectric pattern is considered to totally reflect the terahertz wave at the wavelength comparable to the optical thickness as schematically illustrated in **Fig. 6**. Two different standing waves vibrating in the air and the dielectric regions form

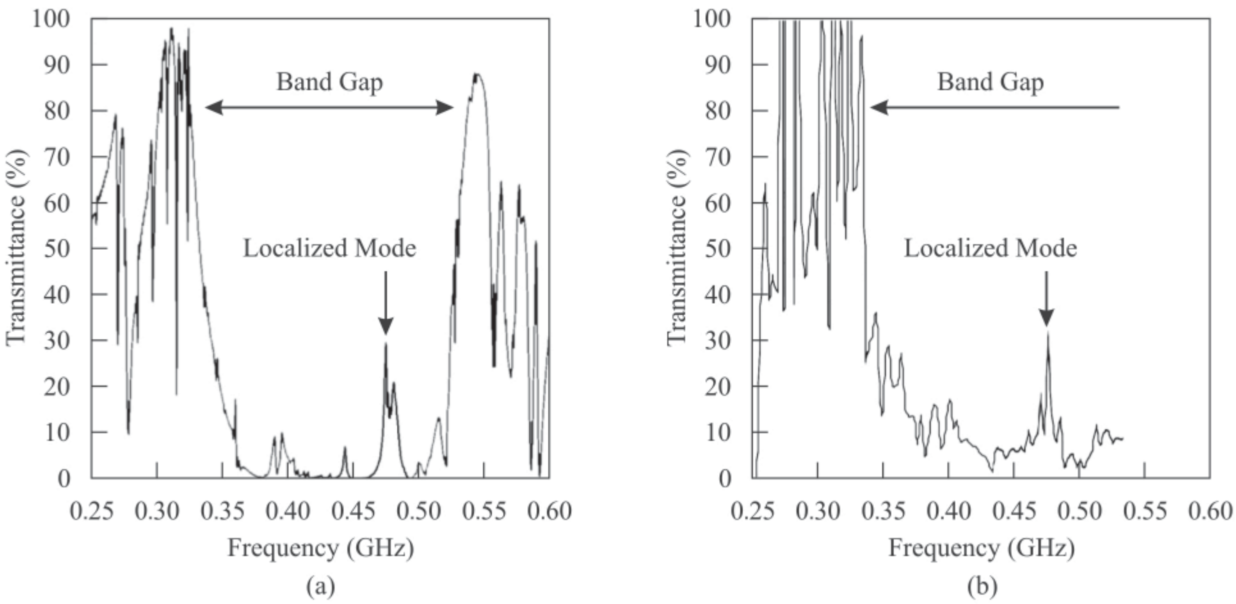


**Fig. 5** Transmission amplitudes of the terahertz wave through the dielectric micro pattern. The spectra (a) and (b) are measured and calculated properties by using the terahertz wave time domain spectroscopy (TDS) and a transmission line modeling (TLM) methods, respectively. In both transmission spectra, localized modes of transmission peaks are formed at specific frequencies in band gap regions.

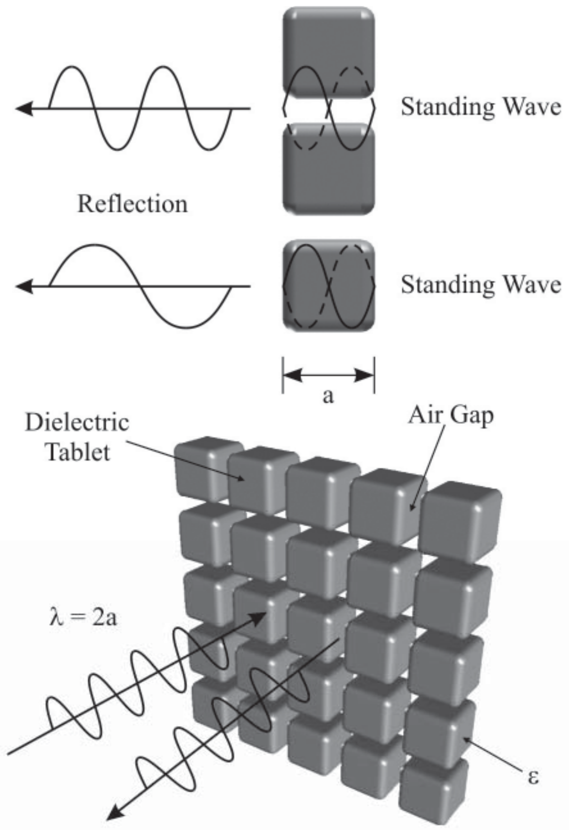


**Fig. 6** An intensity profile of electric field on a cross sectional plane in the dielectric micro pattern calculated at the peak frequency of the localized mode by using the TLM simulation of a finite difference time domain (FDTD) method.

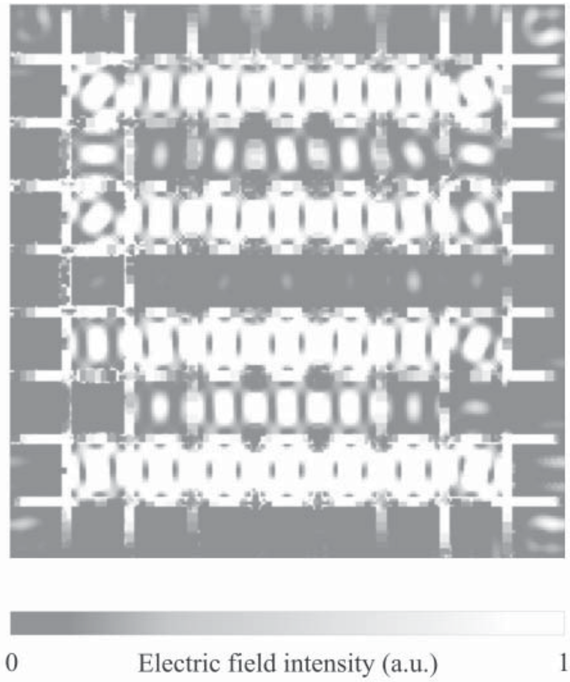


**Fig. 7** The schematic illustrations of formation mechanisms of the electromagnetic band gap through the dielectric micro pattern by Bragg diffraction. Incident direction of the electromagnetic wave is perpendicular to the dielectric arrangement with the plane structure.

the higher and the lower edges of the band gap. The gap width can be controlled by varying geometric profile, filling ratio, and the dielectric constant of the tablets. As shown in **Fig. 5**, the localized mode of a transmission peak was observed at 0.47 THz in the band gap. **Figure 7** shows a simulated distribution of electric field intensities in the micro pattern at the localized frequency. The white area indicates that the electric field intensity is high, whereas the black area indicates it is low. The incident terahertz wave is resonate and localized along the two dimensionally arranged dielectric tablets at the specific frequency. The amplified terahertz wave can transmit through the micro pattern. Therefore, the transmission peak of the localized mode should be formed clearly in the photonic band gap frequency range.

## 4. Conclusions

Micro square tablets of acrylic resin with titania particles dispersions were arranged periodically in two dimensions by using a stereolithography system of a finely joining process. Fabricated micro pattern was verified to be able to exhibit a forbidden band of opaque region. A localized mode of a transmission peak was clearly formed at a specific frequency to concentrate electromagnetic energies in the periodic arrangement of the dielectric constant. The terahertz waves are well known to resonate with various types of protein molecules, and expected to control the biological material syntheses by using frequency excitements through characteristic resonation effects. The fabricated micro pattern can include various types of solutions into their air gaps between the square tablets, therefore, it will be applied for novel micro reactors to create useful biological materials.

## Acknowledgments

This study was supported by Priority Assistance for the Formation of Worldwide Renowned Centers of Research - The Global COE Program (Project: Center of Excellence for Advanced Structural and Functional Materials Design) from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

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