

Title	Terahertz Wave Resonance Profiles in Micro Patterns of Dielectric Tablets Fabricated by Using Stereolithography of Structural Joining Process
Author(s)	Kirihara, Soshu; Hotta, Mikinori; Niki, Toshiki et al.
Citation	Transactions of JWRI. 2009, 38(1), p. 7-11
Version Type	VoR
URL	https://doi.org/10.18910/7469
rights	
Note	

The University of Osaka Institutional Knowledge Archive : OUKA

https://ir.library.osaka-u.ac.jp/

The University of Osaka

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

KIRIHARA Soshu*, HOTTA Mikinori*, NIKI Toshiki** and OHTA Noritoshi**

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

^{*} Associate Professor

^{**} Specially Appointed Researcher

^{***} Graduate Student

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

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



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).

 $240 \times 240 \times 100 \ \mu m$ 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 $2520{\times}2520{\times}100~\mu m$ in whole dimensions. The real sample was fabricated trough the micro-stereolithographic 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



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).

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.

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



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

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.

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



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.

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



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.

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.

References

- Martin Van Exter, Ch. Fattinger, and D. Grischkowsky: Terahertz Time-domain Spectroscopy of Water Vapor", Optics Letters Vol. 14, Iss. 20, pp. 1128-1130, October, 1989.
- 2) Daniel Clery, "Brainstorming Their Way to an Imaging Revolution", Science, Vol. 297, pp. 761-

763, August, 2002.

- Kodo Kawase, Yuichi Ogawa, Yuuki Watanabe, and Hiroyuki Inoue, "Non-destructive Terahertz Imaging of Illicit Drugs Using Spectral Fingerprints", Optics Express, Vol. 11, Iss. 20, pp. 2549-2554, October, 2003.
- 4) R. M. Woodward, V. P. Wallace, D. D. Arnone, E. H. Linfield, and M. Pepper, "Terahertz Pulsed Imaging of Skin Cancer in the Time and Frequency Domain", Journal of Biological Physics, Vol. 29, No. 2-3, pp. 257-259, June, 2003.
- V. P. Wallace, A. J. Fitzgerald, S. Shankar, N. Flanagan, "Terahertz Pulsed Imaging of Basal Cell Carcinoma ex Vivo and in Vivo", The British Journal of Dermatology, Vol. 151, No. 2, pp. 424–432, August, 2004.
- Yutaka Oyama, Li Zhen, Tadao Tanabe, and Munehito Kagaya, "Sub-Terahertz Imaging of Defects in Building Blocks", NDT&E International, Vol. 42, No. 1, pp. 28-33, January, 2008.
- Weiwu Chen, Soshu Kirihara, and Yoshinari Miyamoto, "Fabrication and Measurement of Micro Three- Dimensional Photonic Crystals of SiO₂ Ceramic for Terahertz Wave Applications", Joiurnal of the American Ceramic Society, Vol. 90, No. 7, pp. 2078-2081, July, 2007.
- Weiwu Chen, Soshu Kirihara, and Yoshinari Miyamoto, "Three-dimensional Microphotonic Crystals of ZrO₂ Toughened Al₂O₃ for Terahertz wave applications", Applied Physics Letter, Vol. 91, No. 15, 153507-1-3, October, 2007.
- 9) Weiwu Chen, Soshu Kirihara, and Yoshinari Miyamoto, "Fabrication of Three-Dimensional Micro Photonic Crystals of Resin-Incorporating TiO₂ Particles and their Terahertz Wave Properties", Journal of the American Ceramic Society, Vol. 90, No. 1, pp. 92-96, January, 2007.
- Weiwu Chen, Soshu Kirihara, Yoshinari Miyamoto, "Static Tuning Band Gaps of Three-dimensional Photonic Crystals in Subterahertz Frequencies", Applied Physics Letters, Vol. 92, pp. 183504-1-3, May, 2008.
- 11) Hideaki Kanaoka, Soshu Kirihara, and Yoshinari Miyamoto "Terahertz Wave Properties of Alumina Microphotonic Crystals with a Diamond Structure", Journal of Materials Research Vol. 23, No. 4, pp. 1036-1041, April, 2008.
- 12) Yoshinari Miyamoto, Hideaki Kanaoka, Soshu Kirihara "Terahertz Wave Localization at a Three-dimensional Ceramic Fractal Cavity in Photonic Crystals", Journal of Applied Physics, Vol. 103, pp. 103106-1-5, May, 2008.
- Eli Yablonovitch: Inhabited Spontaneous Emission in Solid-state Physics and Electronics", Physical Review Letter, Vol. 58, No. 20, pp. 2059-2062, May, 1987.

- Sajeev John, "Strong Localization of Photons in Certain Disordered Dielectric Superlattices", Physical Review Letter, Vol. 58, No. 23, pp. 2486-2489, June, 1987.
- 15) K. M. Ho, C. T. Chan, and C. M. Soukoulis, "Existence of a Photonic Gap in Periodic Dielectric Structures", Physical Review Letter", Vol. 65, No. 25, pp. 3152-3165, December, 1990.
- 16) B. Temelkuran, Mehmet Bayindir, E. Ozbay, R. Biswas, M. M. Sigalas, G. Tuttle, and K. M. Ho, "Photonic Crystal-based Resonant Antenna with Very High Directivity", Journal of Applied Physics, Vol. 87, No. 1, pp. 603-605, January, 2000.
- 17) Soshu Kirihara, Yoshinari. Miyamoto, Katsuhiro Takenaga, Mitsuo Wada Takeda, and Kenji Kajiyama, "Fabrication of Electromagnetic Crystals with a Complete Diamond Structure by Stereolithography", Solid State Communications, Vol. 121, No. 8, pp. 435-439, March, 2002.
- 18) Soshu Kirihara, Mitsuo Wada Takeda, Kazuaki Sakoda, and Yoshinari Miyamoto, "Control of Microwave Emission from Electromagnetic Crystals by Lattice Modifications", Solid State Communications, Vol. 124, No. 4, pp. 135-139, October, 2002.
- 19) Shingo Kanehira, Soshu Kirihara, and Yoshinari Miyamoto, "Fabrication of TiO₂-SiO₂ Photonic Crystals with Diamond Structure", Journal of the American Ceramic Society, Vol. 88, No. 6, pp. 1461-1464, June, 2005.
- 20) Hitomichi Takano, Bong-Shik Song, Takashi Asano, and Susumu Noda, "Highly Efficient in-Plane Channel Drop Filter in a Two-Dimensional Heterophotonic Crystal", Applied Physics Letters, Vol. 86, No. 24, pp. 241101-1-3, June, 2005.
- 21) Soshu Kirihara and Yoshinari Miyamoto: "Terahertz Wave Control Using Ceramic Photonic Crystals with Diamond Structure Including Plane Defects Fabricated by Micro-stereolithography", The International Journal of Applied Ceramic Technology, Vol. 6, No. 1, pp. 41-44 January, 2009.
- 22) Soshu Kirihara, Toshiki Niki, and Masaru Kaneko, "Terahertz Wave Behaviors in Ceramic and Metal Structures Fabricated by Spatial Joining of Microstereolithography, Journal of Physics, in printing.
- 23) Soshu Kirihara, Toshiki Niki, Masaru Kaneko: "Three-dimensional Material Tectonics for Electromagnetic Wave Control by Using Micorostereolithography", Ferroelectrics, in printing.
- 24) Soshu Kirihara, Kota Tsutsumi, Yoshinari Miyamoto: "Localization Behavior of Microwaves in Three-dimensional Menger Sponge Fractals Fabricated from Metallodielectric Cu/polyester Media", Science of Advanced Materials, in printing.