Study on microwave transmission performance of 3D EBG structure by changing ceramic slurry sedimentation time

SHIBIN CHEN*, DICHEN LI[a], YUNSHI YAO, MINJIE WANG[a]
Key Laboratory for Highway Construction Technology and Equipment of Ministry of Education, Chang'an University, Xi'an 710064, China
[a]State key laboratory of manufacturing systems engineering, Xi'an Jiaotong University, Xi'an, 710049, China

In this paper, the influence of ceramic slurry sedimentation on microwave transmission performance of diamond EBG structure was studied. Standard dielectric pillar samples and diamond EBG structure were fabricated using a combination of stereolithography (SL) and gel-casting with alumina. The alumina slurry sedimentation resulted in an obvious change in the dielectric constant of the bottom and the top of the samples when gel time was controlled between 2 to 10 minutes. Microwave transmission performance of diamond EBG structure can be affected also by controlling gel time to form gradient dielectric ceramics. The research can be used to improve the fabrication precision in gel-casting and the performance of band gap and bandpass of EBG structure by forming gradient dielectric ceramics.

(Received May 9, 2013; accepted September 18, 2013)

Keywords: EBG, Gel time, Dielectric constant, Dielectric gradient ceramic, Bandpass and bandgap

1. Introduction

Since the concept of Electromagnetic Band-gap (EBG) Structure was brought forward firstly by Yablornovitch and John in 1987 [1.2], the fabrication technology of three-dimensional (3D) EBG structure has been a hot research area. Many researchers have focused on the fabrication of 3D EBG with dielectric ceramic. However, the structural complexity of three-dimensional EBG structure such as Yablonivite, woodpile, opal, and diamond structures [3-9] has brought about great fabrication difficulty using ceramics. Moreover, the influence of fabrication process by gel-casting with ceramic material on microwave transmission performance of EBG structure was rarely studied.

In previous research, 3D EBG structures were fabricated with various ceramic materials [10]. A diamond EBG was fabricated using ceramic SL in Osaka University with titanium dioxide and Silica ceramic slurry [11]. A SiC diamond EBG was obtained using the process of SL and gel-casting with ceramics [12]. All of these EBG structures possess band gaps. However, the deposition of ceramic slurry proves to be inevitable when the formation time of ceramic samples lasts too long, thus forming gradient dielectric ceramics. Physical properties of ceramic structure will be influenced [13-14]. Especially, dielectric property and microwave transmission performance of EBG structure will be deeply affected because of the gradient ceramic formed.

In this paper, the ceramic slurry sedimentation and its influence on microwave transmission properties of EBG structure is studied. Diamond EBG structure was fabricated using a combination of SL and gel-casting with alumina [15]. The article mainly includes two phases: 1) the change of the dielectric constant of the gradient ceramics with the gel time; 2) the influence of gel time on the microwave transmission performance of diamond EBG structure.

2. Material and method

A hollow cylinder of Φ10 ㎜*100 ㎜ closed at one end was used as deposition mold to obtain a standard pillar of measured dielectric constant. A diamond EBG structure was used as an EBG model. The diamond EBG structure and hollow cylinder were designed using a CAD software. The size of the diamond-structure model was 60 mm × 60 mm × 60 mm, with a lattice constant of 12 ㎜ and an aspect ratio of 0.31. The corresponding inverse diamond-structure models were used as molds. The models were converted into STL file and fabricated using a SL machine (Product SPS-450B, Hengtong Co. Ltd, Shaanxi, China).

Fig. 1 was the fabrication flow. Alumina powder (provided by Shandong Zibo Aluminum Inc. China.), with a mean diameter of 5 μm and 25 μm and a true density of 3.9 g/m^3, was used for all experiments. The aqueous slurries were prepared with deionized water, acrylamide (AM), N,N-methylene diacrylamide (MBAM), ammonium persulfate (APS), tetramethylethylenediamine (TEMED) and sodium ployacrylate (PAAS). The solid content of slurry was 40% vol. The mixed slurry was injected into the molds after they were milled in a milling machine for two hours. After green bodies were dried using the freeze drying machine (Product DTY-1SL, Vacuum Freeze Dryer, Detianyou Technology co., China). They were heated to 350 °C with a heating rate of 6 °C/h for the removal of resin and then heated to 720 °C in 4h to ablate the organic. Subsequently, sintering was immediately carried out to 1550 °C in 2h.

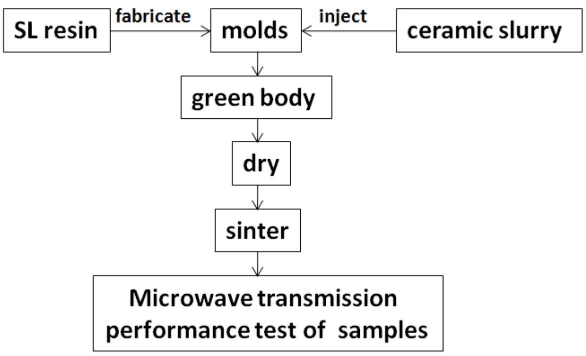

Fig. 1. The fabricating flow.

In order to study the influence of gel time on microwave transmission performance of diamond EBG structure, firstly the effect of gel time on the dielectric constant of the green body was studied. Two kinds of slurry were obtained, in one of which alumina of mean diameter of 25µm was used, the other a mixed alumina of mean diameter of 5µm and 25µm (1:1). The hollow cylinders were divided into four groups, and gel time of each group was 2 minutes, 4minutes, 5minutes and 8 minutes respectively. Next, two groups of EBG structure were fabricated by gel-casting with alumina of mean diameter of 5 µm and 25 µm (1:1). The gel time of the group one was controlled to 5 minutes and the group two 10 minutes. The standard pillar of dielectric constant and transmission performance of alumina diamond EBG structure were measured with a network analyzer (HP-85070B).

3. Results and discussions

Because of the sedimentation of internal particles before solidification, local solid content changed along the vertical direction of the cylindrical samples, resulting in the formation of gradient ceramic and the change of dielectric properties in the samples.

Fig. 2 showed the ceramic slurry deposited and formed a gradient ceramics in the process of gel-casting and the slice cut from the standard pillar (Φ10 mm × 5 mm) to measure the dielectric constant. Fig. 3 exhibited that diamond EBG structure fabricated with alumina of mean diameters of 5µm and 25µm (1:1). The EBG structure had no crack or fracture, maintaining a good structure.

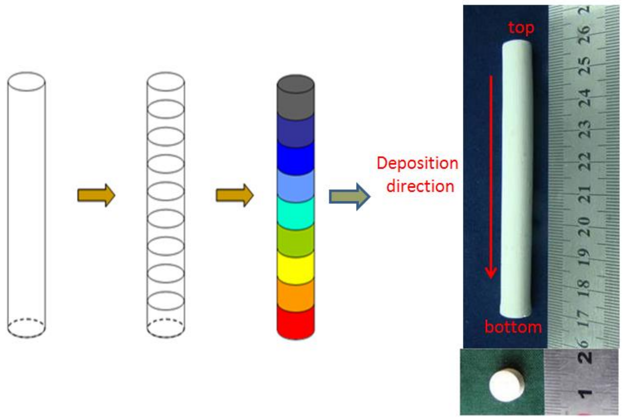

Fig. 2. The procedure of alumina sedimentation and cutting the standard pillar.

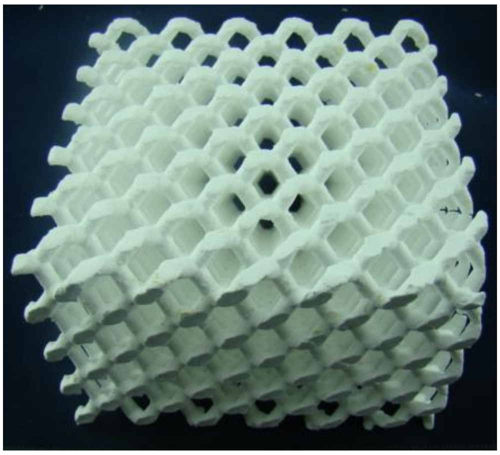

Fig. 3. Fabricated alumina diamond EBGs along <100> direction by sedimentation.

Fig. 4 was obtained by measuring the top and the bottom dielectric constant of the dried and sintered standard dielectric pillar. When the gel time was controlled to 2 minutes, the dielectric constant of the bottom and top of the cylinder samples (alumina particles with a mean diameter of 25µm) was 4.73. With the extension of the gel time, the dielectric constant in the bottom was increased and that of the top was decreased. This indicated that the internal material property of the samples had changed because of the slurry sedimentation. The longer the gel time was, the more serious the sedimentation phenomenon would be, and the bigger the gap between the dielectric constant of the top and the bottom parts became. But due to the electrostatic forces between the particles, the sedimentation could not continuously increase, thus resulting in a slowing down of the increasing rate of the dielectric constant.

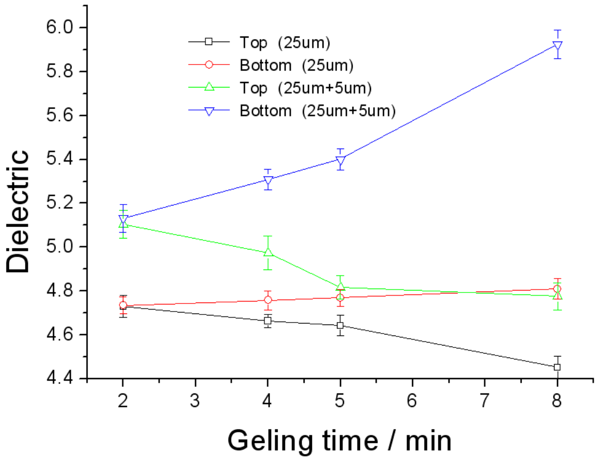

Fig. 4. Relationship between the top and bottom of dielectric constant of the sample with two kinds of alumina slurry with different gel time.

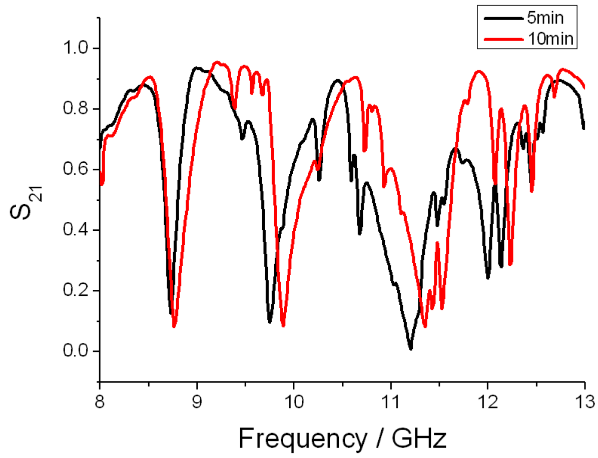

Fig. 6. A curves of microwave transmission of diamond EBGs with different gel time with alumina of mean diameter of 5μm and 25μm (1:1).

The largest advantage of gel-casting to fabricate EBG structure is that the slurry with a high solid content and good fluidity can be used. The sedimentation rate of slurry with low viscosity is higher than that of slurry with high viscosity, which results in bigger gap between the dielectric constants along the vertical direction of samples. To get a balance between the viscosity and the sedimentation of high solid content, the slurry was obtained by mixing the ceramic particle of small and large mean diameters (5μm and 25μm 1:1) to get the same the high solid content, which the viscosity was lower than that of a mean diameter of 25μm. Fig. 4 also showed that when the gel time was controlled to 2 minutes, the dielectric constant of the sample with alumina with mean diameter of 5μm and 25μm was 7.4% higher than that of 25μm, and with gelling, the gap of dielectric constant became larger. When the gel time got to 8 minutes, the dielectric constant of the top part was 4.69, while that of the bottom was 5.84, which is higher by 24.5%. Contrary to that of samples with single particles diameter, decreased amplitude of the upper dielectric constant of samples with two kinds of particles diameter was much bigger than the increase in range of the dielectric constant of bottom part.

In order to verify the influence of slurry sedimentation on microwave transmission performance of diamond EBG structure, diamond EBG structure was fabricated and the band gap alone <100> direction was measured, as shown in Fig. 3. Fig. 5 showed that the bandpass of electromagnetic transmission of these EBG structures with gel time of 5 and 10 minutes were measured, and the center frequency was obviously shifted from low frequency to high frequency. These changes occurred because the dielectric gradient was formed by longer gel time of the slurry along the microwave transmission direction.

4. Conclusion

A standard pillar of reference dielectric constant and diamond EBG structure were fabricated using the combination of SL and gel-casting with alumina. Microwave transmission performance of the diamond EBG structure and the two ends of the standard pillar under different gel time was measured. The experimental results showed that ceramic gradient dielectric material could be formed by gel-casting technology to control gel time lasted longer (exceed 2 minutes) along with slurry sedimentation. Moreover, the bandgap and bandpass of diamond EBG structure would be adjusted by control gel time. Such performance can be used to improve the fabrication precision in gel-casting and obtain gradient dielectric ceramics to control the bandgap and bandpas of diamond EBG structure.

Acknowledgement

This work is supported by National Natural Science Fundation (No. 51208044) and the Fundamental Research Funds for the Central Universities of China (No. 2013G1251029 and 2013G2251008).

Reference

[1] E. Yablonovitch, Phys. Rev. Lett. **58**(20), (1987).
[2] S. John, Phys. Rev. Lett. **58**(23) (1987).
[3] E. Yablonovitch, T. J. Gmitter, K.M. Leung, Phys. Rev. Lett. **67**(17), 2295–8 (1991).
[4] Y. Rahmat-Samii, H. Mosallaei, Eleventh International Conference on Antennas and Propagation 2001.
[5] D. Sievenpiper, L. J. Zhang, F. Romulo, B. Jimenez,

G. Nicholas, IEEE Trans. Microwave Theory Tech. **47**, 2059 (1999).
[6] J. D. Joannopoulos, G. Steven, J. N. Johnson, R. D. Meade, Photonic Crystals 2008; Princeton, NJ: Princeton Univ. Press.
[7] J. D. Joannopoulos, P. R. Villeneuve, S. Fan, Nature, **386**, 143–9 (1997).
[8] E. Ozbay, A. Abeyta, G. Tuttle, M. Tringides, R. Biswas, C. T. Chan, Phys. Rev. B **50**, 1945–8 (1994).
[9] S. Noda, Physica B **279**, 142–9 (2000).
[10] H. Q. Yin, S. Kirihara, M. Yoshinari, J. Am. Ceram. Soc, **87**(4), 598 (2004).
[11] S. Kirihara, Y. Miyamoto, K. Takenaga, M. W. Takeda, K. Kajiyama, Solid State Comm; **121**, 435–9 (2002).
[12] Z. T. Liu, S. Kirihara, M. Yoshinari, J. Am. Ceram. Soc. **89**(8), 2492 (2006).
[13] R. D. Bland, G. J. Kominiak, D. M. Mattox, Journal of Vacuum Science and Technology, **11**(42), (2009).
[14] P. F. Jacobs, Society of Manufacturing Engineers, Dearborn, 1996.
[15] L. J. Vandeperre, A. M. Wilde, J. Luyten, Journal of Materials Processing Technology, **135**(2–3), 312 (2003).

*Corresponding author: shibinchen520@sina.com