Shape Anisotropy in Micro-sized Water Bamboo Blind Shape by High Frequency Electromagnetic Computation

Keisuke Fujisaki
Toyota Technological Institute
2-12-1 Hisakata, Tenpaku-ku, Nagoya 468-8511 Japan
fujisaki@toyota-ti.ac.jp

Abstract — Electromagnetic anisotropic characteristics in micro-sized water bamboo blind shape are observed by high frequency electromagnetic computation. In assuming that the micro-sized unit structure is repeated in 3-dimensional directions and its size is small enough in comparison with the electromagnetic wave length, the micro-sized electromagnetic field calculation is carried out. If the shapes of the dielectric material are different even if they are the same volume rate, different dielectric constant characteristics are provided. The reasons are considered to be a generation of de-electrification in the dielectric material.

I. INTRODUCTION

Microwave application to material often introduces abnormal phenomena such as raising boiling temperature [1], changing chemical reaction conditions, promoting nitriding reaction. These are considered to be caused by current generation in dielectric material by electrical field or in electrical conductive material by magnetic field with micro-structure [2]. The electromagnetic characteristics occur in micro-size, which is small enough in comparison with the electromagnetic wave length. To evaluate the electromagnetic characteristics, micro-sized electromagnetic field computation is useful and clarified a detailed phenomenon of electromagnetic field [3].

Electromagnetic field distribution within micro-structure depends on the shape, the direction and the size of the electromagnetic material. When the micro-structure of the electromagnetic material is not symmetry in 3-dimensional space, shape anisotropy is considered to be observed. In this time, shape anisotropy is researched as the electromagnetic characteristics in micro-sized water plane by high frequency electromagnetic field computation.

II. MICRO-SIZED ELECTROMAGNETIC MODEL

Usually electromagnetic wave length is large enough to compare with the size of microstructure as shown in Fig. 1. As the micro-structure of the electromagnetic material, bamboo blind shape and cube shape of water as a dielectric material are considered here. The bamboo blind shape consists of water planes with 3 μm pitch and 0.21μm thickness. The cube shape is 1.24 μm cube arranged in 3 μm pitch in 3-dimensional space. All cases are the same volume rates as 7%.

The cube shape is symmetry in 3-dimensional space, though the bamboo blind shape is not symmetry. Then 3-dimensional coordinates are arranged in the water plane as Fig. 2 in order to distinguish the directions of electromagnetic field from the micro-structure of bamboo blind shape. The electromagnetic field is applied in 3-directions.

It is assumed that the micro-sized unit structure is repeated in 3-dimensional directions and its size is small enough in comparison with the electromagnetic wave length. All the items including eddy current and displacement current in Maxwell's equations are considered and then the equations using A-φ method and jω method are as follows.

$$\nabla \times \left([\mu]^{-1} \nabla \times \vec{A}\right) + \left([\sigma] + j\omega[\varepsilon]\right)\left(j\omega\vec{A} + \nabla\phi\right) = 0 . \qquad (1)$$

Here, $\vec{A}$ is vector potential, ϕ is scholar potential, $[\mu]$ is magnetic permeability, $[\sigma]$ is electrical conductivity, $[\varepsilon]$ is dielectric constant. Finite element method is used to reduce the computation time.

Material constants are shown in Table I. Micro-sized numerical calculation model and its boundary conditions are shown in Fig. 2.

The calculation conditions are shown in Table II. Case-a is for the cube shape and case-b, c, d are for the bamboo blind shape, in which the applied electrical field direction to the water plane are different as shown in Fig. 3.

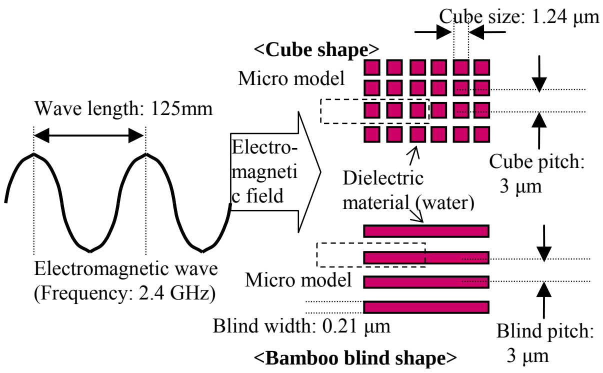


Fig. 1 Micro-sized dielectric materials and macro-sized electromagnetic wave.

TABLE I
MATERAIL CONSTANTS

	Relative magnetic permeability		Relative dielectric constant	
	Real Part	Imaginary part	Real part	Imaginary part
Unit	-	-	-	-
Matrix: Air	1	0	1	0
Dielectric material: Water	1	0	76.7	12.04

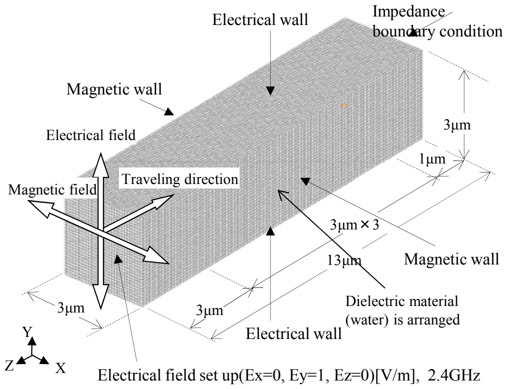
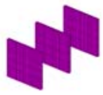


Fig. 2. Micro-sized numerical model and boundary conditions.

TABLE II.
CALCULATION CONDITIONS.

	Case-a	Case-b	Case-c	Case-d
	Cube shape	Bamboo blind, ***E*** 1 in Fig. 3	Bamboo blind ***E*** 2 in Fig. 3	Bamboo blind ***E*** 3 in Fig. 3
				
Shape of Dielectric per unit cell	1.24×1.24× 1.24 [μm^3]	3×0.21×3 [μm^3]	0.21×3×3 [μm^3]	3×3×0.21 [μm^3]
Volume rate	7.0 %	7.0 %	7.0 %	7.0 %

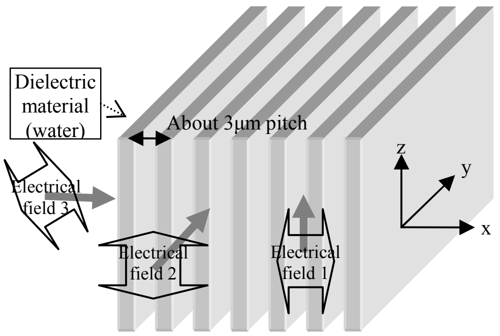


Fig. 3 High-frequency electromagnetic field application to micro-sized water bamboo blind shape. Electrical fields with 3-different directions are applied to the water and correspond to the case-b, c, d in Table II.

III. CALCULATION RESULTS AND DISCUSSION

The calculation results are shown in Table III. Input energy and output one are the same as 1.19×10^{-14} [W], which is large enough to energy consumption and reflection in the micro model. However, the energy consumptions are different, in spite of the same volume rate.

Through the electrical flux density and the electrical field vector distribution within the unit cell, the volume-averaged electromagnetic field vectors per the unit cell are defined as follows [4, 5]:

$$\dot{\vec{D}}_{ave} = \frac{\sum \dot{\vec{D}}_i \Delta V_i}{\sum \Delta V_i}, \dot{\vec{E}}_{ave} = \frac{\sum \dot{\vec{E}}_i \Delta V_i}{\sum \Delta V_i}. \quad (2)$$

Since the ferromagnetic material is not considered here, magnetic field components are ignored here. Then the equivalent relative dielectric constant $[\dot{\varepsilon}_{ave}]$ is defined as follow:

$$\dot{\vec{D}}_{ave} = \varepsilon_0 [\dot{\varepsilon}_{ave}] \dot{\vec{E}}_{ave}. \quad (3)$$

Here, ε_0 is a vacuum dielectric constant. Now these tensors are assumed to be a diagonal matrix. Then the tensors for the cube shape and the bamboo blind sape are calculated through Table III as follows:

$$[\dot{\varepsilon}_{ave}]_{cube} = \begin{bmatrix} 1.26 + j0.0023 & 0 & 0 \\ 0 & 1.26 + j0.0023 & 0 \\ 0 & 0 & 1.26 + j0.0023 \end{bmatrix} \quad (4)$$

$$[\dot{\varepsilon}_{ave}]_{bamboo} = \begin{bmatrix} 1.07 + j0.0002 & 0 & 0 \\ 0 & 6.30 + j0.843 & 0 \\ 0 & 0 & 6.30 + j0.843 \end{bmatrix}. \quad (5)$$

These dielectric tensors show that the cube shape is isotropy, though the bamboo blind shape is anisotropy. Dielectric constants vary when the shape of dielectric material is different and the dielectric anisotropy is observed in water plane in micro-structure. The reasons are considered to be a generation of de-electrification in the dielectric material.

TABLE III.
CALCULATION RESULTS.

	Case-a	Case-b	Case-c	Case-d
Energy consumption [$\times10^{-20}$W]	2.480	0.189	911.736	911.736
E_y^{real} [V/m]	1.00	1.00	1.00	1.00
E_y^{imag} [V/m]	-0.000386	-0.000386	-0.000386	-0.000386
D_y^{real} [$\times10^{-11}$C/m^2]	1.117	0.951	5.577	5.577
D_y^{imag} [$\times10^{-14}$C/m^2]	1.593	-0.224	744.077	744.120

ACKNOWLEDGMENT

This work was supported in part by Hitech Research Center Project for Private University from the Ministry of Education, Culture, Sports, Science and Technology. The author thanks for Dr. S. Satoh for his computational support.

REFERENCES

[1] David Adam, "Microwave chemistry: Out of the kitchen," *Nature,* vol. 421, pp. 571-572, 2003.

[2] K. Fujisaki, "Electromagnetic field transmission characteristics in high frequency by particle effect", *ISIJ Int.*, Vol.49, pp.1636-1643, 2009.

[3] K. Fujisaki, "Particle Effect of Electromagnetic Penetration in High Frequency in ***H*** Field and ***B*** Field application", *Intermag2008*, CV-06, 2008.

[4] K. Fujisaki, M. Fujikura, J. Mino, S. Satou, "3D Magnetic Field Numerical Calculation by *Equivalent B-H Method* for Magnetic Field Mitigation", *IEEE Trans. Magn.,* Vol.46, pp. 1147-1153, 2010.

[5] K. Fujisaki, S. Satou, "Angle Difference between ***B*** vector and ***H*** vector in Anisotropic Electrical Steel", *IEEE Trans. Magn.,* Vol. 44, pp.3161-3164, 2008.