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FDTD ANALYSIS OF A MULTI-MODE WAVEGUIDE WITH CW EXCITATION

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1. Introduction

1m^2 order single-layer slotted waveguide array (SWA) for plasma excitation is proposed for process plasma of large size flat panel displays (FPDs) [1]. The array design including vacuum window is very difficult task. The authors have developed the GSM-MoM [2] analysis for a unit-cell in the array [3] and succeeded in designing the array including the vacuum window (plasma was neglected) for uniform aperture field distribution [4]. But the effects of plasma with non-linearity can not neglected in experiments and must be considered in the design. The Finite-Difference Time-Domain (FDTD) method [5] [6] is a candidate to analyze the effects of plasma [7] [8]. In the unit-cell analysis using the GSM-MoM [3], the analysis code of the whole structure including plasma layer can be easily implemented by replacing Block7 in Fig.5 of [4] with a multi-mode waveguide filled with plasma layer and calculating its S-matrix. A multi-mode waveguide has been analyzed by the FDTD for pulse excitation [9] since wideband frequency characteristics are available simultaneously by a fast Fourier transform (FFT). However in some applications such as plasma simulation, continuous wave (CW) excitation is preferable to simulate non-linear phenomena of plasma in the stationary state. RF plasma analysis code is now developed with particle-in-cell (PIC)-Monte Carlo collision (MCC) simulation [10]. The authors think it is possible to develop FDTD microwave plasma analysis code with PIC-MCC simulation in the future. As the base for this code, this paper presents a multi-mode waveguide analysis by the FDTD method with CW excitation. Mode intensities along the waveguide axis are calculated from the obtained field distribution by modal decomposition and S-matrix is calculated from them. As an example, the reflection coefficients for a short-circuited multi-mode waveguide with a quartz glass block, still in the absence of plasma, are analyzed.

2. Analysis Model

Fig.1 shows a short-circuited rectangular waveguide with a quartz glass block. A rectangular waveguide with wide broad-wall, which is 1.5 times wider than a 2GHz band standard waveguide WRI-22, is used to examine multi-mode reflection characteristics. Cutoff frequencies for TE_{10} (dominant mode) and TE_{20} modes are 0.915GHz and 1.83GHz, respectively. Other higher modes are cutoff in the investigated frequency range from 2.0GHz to 2.6GHz in this paper. Quartz glass block is

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inserted in the waveguide asymmetrically in order to excite TE_{20} mode for TE_{10} incident wave.

Fig.2 shows the model for the FDTD analysis of Fig.1. Numbers in Fig.2 indicate the number of cells. Cubic cells are used and time discretization is $\Delta t = T/50$, which satisfies Courant stability condition [6], where T is the period of the incident micro wave. A TE_{10}-shaped electric current sheet is used for excitation in order to excite only TE_{10} mode selectively. CW excitation is used and stationary state (2000steps=40T) is observed. Absorbing boundary condition (ABC) is used in the left wall to simulate semi-infinite waveguide. Mur's 1st order ABC with eigenmode expansion, which is called modal absorption [11] [12], is used in this paper.

3. Results

Fig.3(a) shows the electric field distribution on the x-z plane at 2.45GHz. The distribution is distorted from TE_{10}-shape because of the scattered TE_{20} mode. The result of Ansoft HFSS Ver.8 is shown in Fig.3(b) for reference and their agreement is very well. Fig.4(a) shows y component of the electric field in Fig.3(a) along the waveguide center axis. The waveform is distorted from sinusoidal shape because two modes exist. Fig.4(b) shows mode intensities for E-fields along the waveguide axis, which are calculated from the obtained field distribution by modal decomposition. As indicated by transmission line theory, sinusoidal waveform is observed. Fig.5 shows the envelope of the mode intensity along the z-direction, which is the maximum value of Fig.4(b) in time interval 4T from 1800steps=36T to 2000steps=40T. In TE_{10} mode, the envelope is constant in Reg.I and this means that there is no reflection (traveling wave is supported) and ABC is working well. ABC is also working well for TE_{20} mode. Fig.6 and Fig.7 show frequency characteristic of $S_{11,11}$ and $S_{12,11}$, respectively. Reflection coefficient $S_{pi,qj}$ is defined to be the ratio of the coefficient for reflected TE_{i0} mode into port p and that for incident TE_{j0} mode from port q. Amplitude and phase of $S_{pi,qj}$ are calculated from Fig.5 (Reg.II) by measuring VSWR and peak position of the standing wave or traveling wave, respectively. Results calculated by the HFSS are also shown in Fig.6 and Fig.7, and they agree very well.

4. Conclusion

An analysis of the multi-mode waveguide by the FDTD method with CW excitation is presented. As an example, the reflection coefficients for a short-circuited multi-mode waveguide with a quartz glass block are analyzed. The results are compared with those calculated by the HFSS and good agreement is observed.

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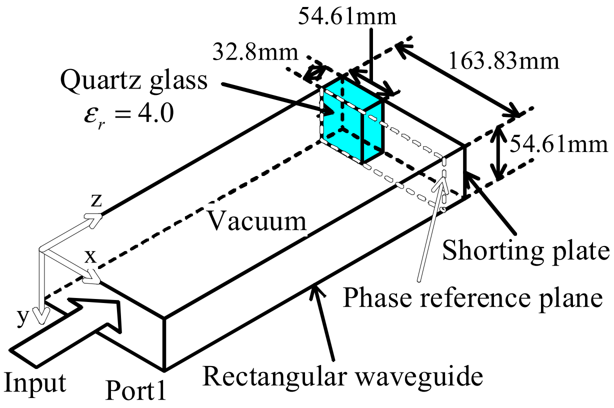


Fig.1 Analysis model

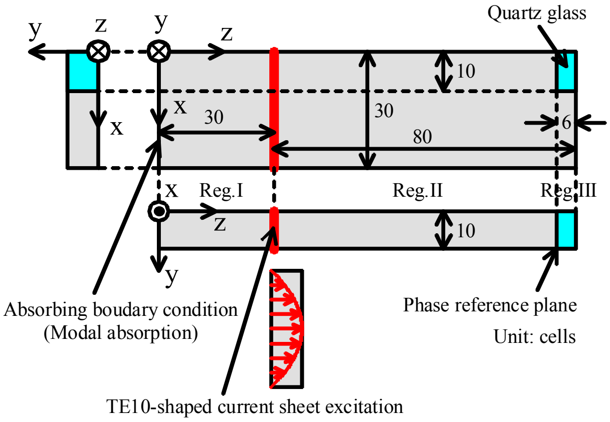
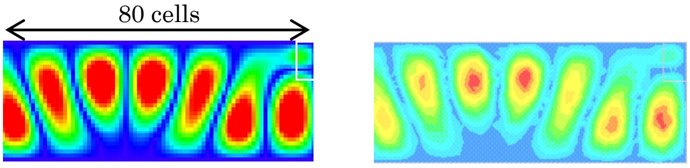


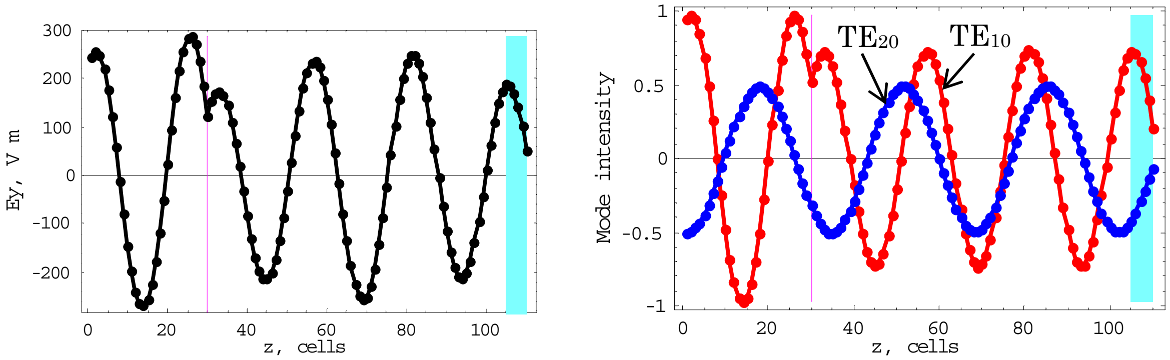
Fig.2 Model for the FDTD analysis



(a) FDTD

(b) HFSS

Fig.3 Electric field distribution on the x-z plane at 2.45GHz.



(a) Ey along the waveguide axis

(b) Mode intensity of E-field along the z-direction

Fig.4 Waveform along the z-direction.

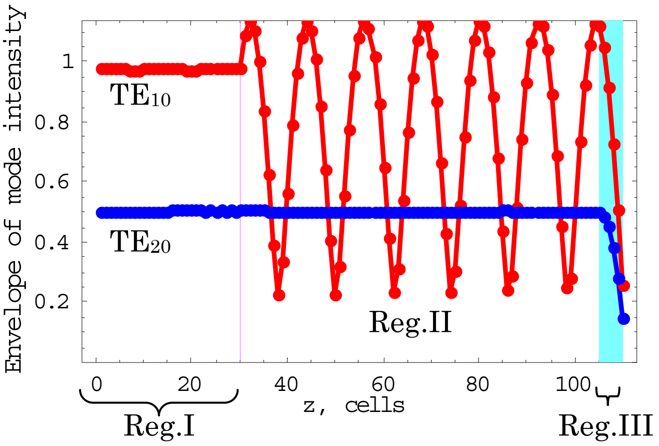


Fig.5 Envelope of the mode intensity along the z-direction.

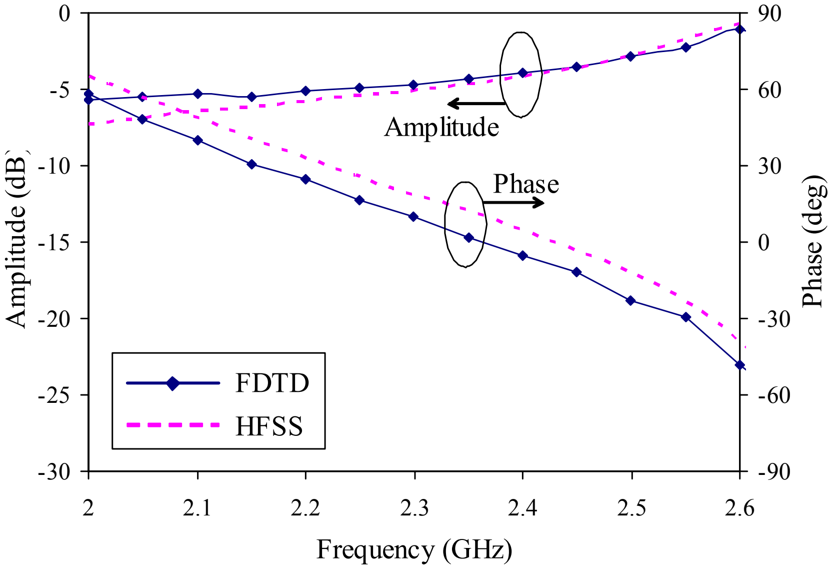


Fig.6 Frequency characteristic of $S_{11,11}$.

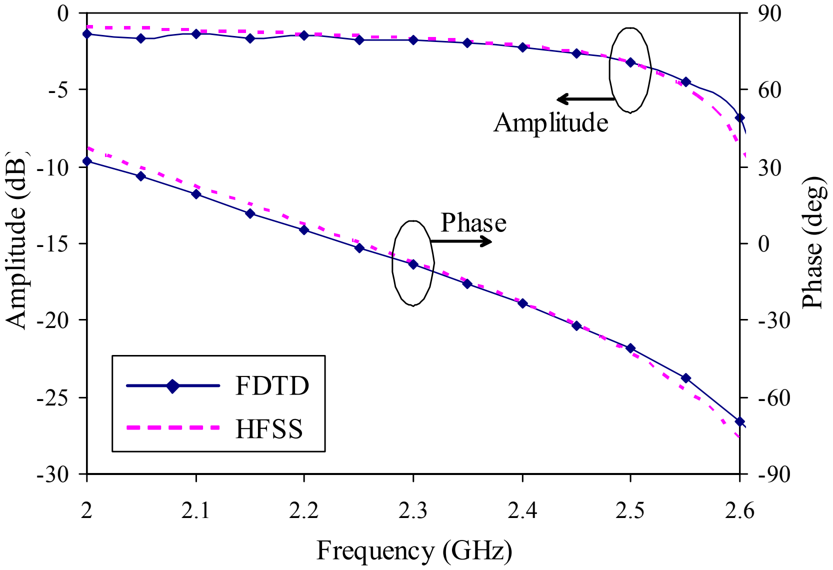


Fig.7 Frequency characteristic of $S_{12,11}$.