# DESIGN OF FOLDED MONOPOLE ARRAY ANTENNA USED FOR LARGE AREA PLASMA PRODUCTION

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## 1. INTRODUCTION

The large area amorphous Silicon (a-Si) substrates used for liquid crystal display (LCD), Solar cells are desired [1]. In order to deposit an uniform film using the Plasma Enhanced Chemical Vapor Deposition (PECVD) [1], it is required the design of the RF discharge antenna to produce and control the plasma in a large area. Furthermore, the full-wave numerical analysis of electromagnetic field in a plasma is expected to clarify how the electric field distribution that is suggested to have a correlation with the deposition rate distribution depends on the shape and the feeding method of discharge antenna. However, it is not easy to include the properties of the plasma into the electromagnetic field analysis due to the fact that the plasma is a strongly dispersive medium and the real part of the complex permittivity could be negative in the cut-off frequency region.

In the previous paper [2], the single folded monopole antenna have been studied with respect to the frequency characteristics of input impedance obtained by the experiment and the FDTD analysis. Almost good agreement between the calculated and the measured input impedances have been obtained and it is found that the FDTD method with considering the effect of Drude type dispersion and the effect of ion sheath will provide reasonable solutions of the electromagnetic field in a RF produced plasma.

In this paper, the 25-array of the folded monopole antenna is introduced to deposit a-Si film on the large area glass substrate of 1.6m×1.2m using the frequency of 85MHz. In order to obtain the uniform deposition rate distribution, the feed-phase's of array has been controlled in both the experiment and the FDTD analysis. Also it has been investigated the correlation between the electromagnetic field distribution and the deposition rate distribution.

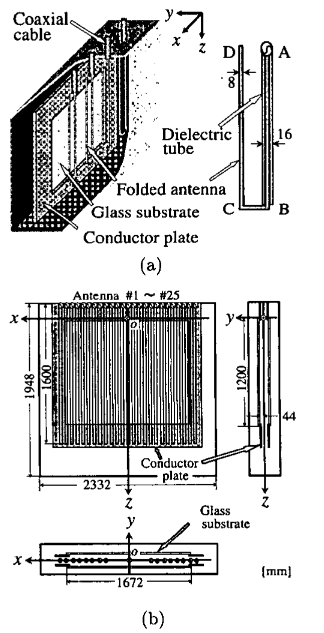
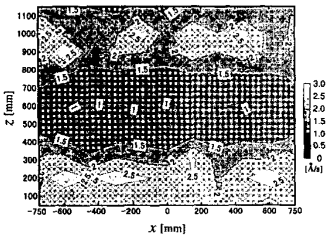


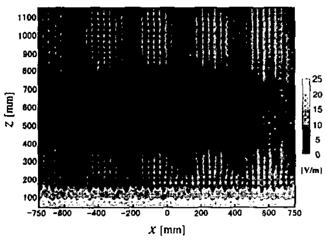

Figure 1: Analysis model (a) Bird-view, (b) Cross-view.

## 2. ANALYSIS MODEL

Figure 1 shows the model for the numerical analysis. Folded antennas of 1.6m length, 36mm folded interval, 4mm radius,

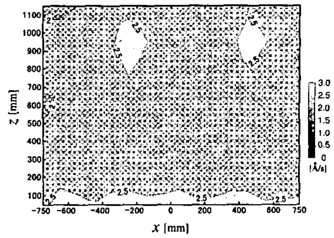



(a) Deposition rate distribution (Experiment)

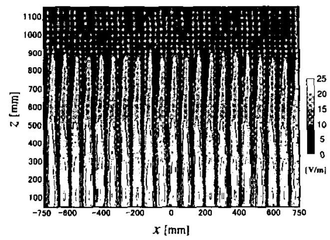



(b) Electric field distribution (FDTD)

Figure 2: Distributions of deposition rate (measured) and electric field (calculated) with co-phase feed, 85MHz.




(a) Deposition rate distribution (Experiment)




(b) Electric field distribution (FDTD)

Figure 3: Distributions of deposition rate (measured) and electric field (calculated) with alternately inverse-phase feed, 85MHz.

72mm array spacing, and with the 4mm-thick alumina cover in the range of the feeding point to the folded part are located in the vacuum chamber. The frequency used is 85MHz and the total incident power of 275W (11W for the each 25 antennas) is fed to the array antennas. The mixed gas of $H_2$ and $SiH_4$ with the each flow velocity of 500sccm and the gas pressure of 21mTorr are used. Glass substrates ($\varepsilon_r = 7.5$, 1.6m×1.2m×4mm) supported by conductor folders are placed on both planes separated 44mm from the array antennas, and thin films are formed on the both substrates.

In the analysis, the discharge antenna is assumed to be placed in the steady-state cold plasma. By using the cold plasma approximation, the plasma is regarded as a dispersive medium of the Drude type given by

$$\varepsilon_r(\omega) = 1 - \frac{\omega_p^2}{\omega(\omega - j\nu)} \qquad (1)$$

where $\omega_p$, $\nu$ are the angular electron plasma frequency and the collision frequency, respectively. The Recursive Convolution (RC) technique [3] is adopted and the plasma parameters of $f_p$=300MHz, $\nu$=200Ms$^{-1}$ are used. The ion sheath of 4mm is modeled as a vacuum cylinder around the each antenna. These parameters are the values estimated in [2]. The Gaussian pulse is used for the excitation of the antenna. The number of cells are 583 × 37 × 487, and $\Delta x(=\Delta y=\Delta z)$ are 4mm.

## 3. RESULTS

First, we have performed the experiment in the case when all the 25 folded monopole antennas were fed in co-phase (same phase) at 85MHz. The measured deposition rate

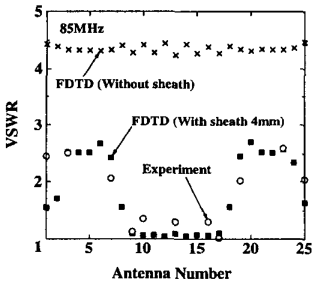



Figure 4: Calculated VSWR in the case without and with the ion sheath and measured VSWR, of 25-array with partially alternate inverse-phase feed, 85MHz.

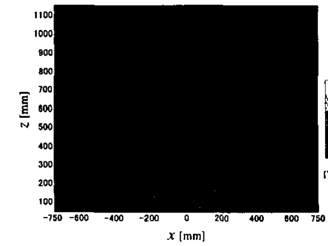
distribution with co-phase feed is shown in Figure 2 (a). The inhomogeneous distribution has been observed and the region with more than 2[Å/s] were only in the vicinity of the feed point and near the folded part of antennas.

The calculated electric field distribution on the glass substrate is shown in Figure 2 (b). The amplitude is the values corresponding to the 1W incident power. The inhomogeneous distribution with strong intensity only in the vicinity of the feed point ($z$=0) and near the folded part of antennas has been observed. Furthermore, it is noted that there has a correlation between the distributions of electric field and deposition rate, as expected, however, it is found that the co-phased array is not useful.

The measured deposition rate distribution and calculated electric field distribution on the glass substrate where the 25 folded monopole antennas are fed in alternately inverse-phase at 85MHz are shown in Figure 3 (a), (b), respectively. The uniform distributions of deposition rate and electric field with a large correlation between them have been observed. It is noted that the deposition rate of more than 2[Å/s] on the 1.6m×1.2m glass substrate is achieved.

## 4. INVESTIGATION OF MECHANISM

In order to clarify the mechanism of improvement with the alternately inverse-




(a) without ion sheath

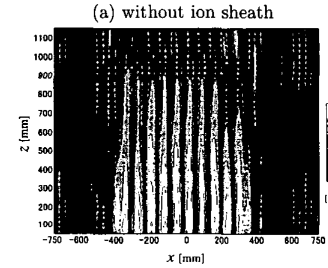



Figure 5: Calculated electric field distribution on glass substrate with partially alternate inverse-phase feed (#9, #11, #13, #15, #17 are 180°, other's are 0°), (a) without ion sheath, (b) with ion sheath.

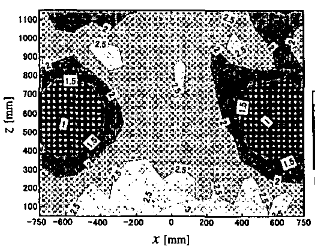



Figure 6: Measured deposition rate distribution with partially alternate inverse-phase feed.

phase feeding method, the reflection coefficient at the each feeding point and the current distribution along the folded monopole array has been investigated. To obtain the characteritics of the co-phase feed and

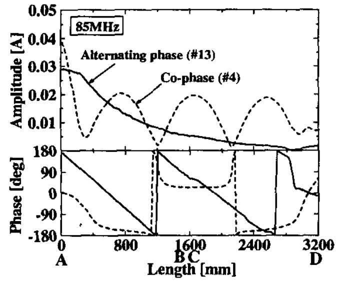



Figure 7: Calculated current distribution along the folded monopole antenna of #4 located in the region of co-phase feed and #13 located in the region of alternately inverse-phase feed.

alternately inverse-phase feed using once measurement and FDTD calculation, the feed-phase with $\theta_n$=180° ($n$=9, 11, 13, 15, 17) and $\theta_n$=0° (else) are used. Also the effect of the ion sheath in the analysis has been investigated.

Figure 4 shows the VSWR, measured (○) and calculated without (×) and with (•) the ion sheath, of 25-array with partially alternate inverse-phase feed at 85MHz. The agreement between the calculated values and the measured data has almost good when the effect of the ion sheath is considered and the impedance matching were achieved for only the elements of the alternately inverse-phase feed region.

The calculated electric field distribution on the glass substrate at 85MHz without and with considering the effect of the ion sheath are shown in Figures 5 (a) and (b), and the measured deposition rate distribution is shown in Figure 6.

It is noted that there has a strong correlation between the deposition rate distribution and the electric field distribution with considering the effect of the ion sheath. The uniform distributions has been obtained in the region fed by the alternately inverse-phase.

Calculated current distribution along the folded monopole antenna of #4 located in the region of co-phase feed and #13 located in the region of alternately inverse-phase feed. The standing wave current distribution has been observed on the antenna #4. On the other hand, it is noted that the traveling wave current distribution on the antenna #13 which continuously attenuates not only along the conductor A⇒B but also along the conductor C⇒D, and almost evanescent at the shorted position D. It can be considered that traveling waves in and near the ion sheath around the antenna conductor with no ripple of the electric field intensity produce the uniform plasma and achieve the uniform deposition rate distribution on the glass substrate.

## 5. CONCLUSION

In this paper, the 25-array of folded monopole antenna used for large area plasma production has been introduced. The FDTD analysis have been performed to clarify the correlation between the electromagnetic field distribution and the deposition rate distribution.

As a result, it is found experimentally that the array with the alternately inverse-phase feed provide the uniform deposition rate distribution of 2[Å/s] on the substrate of 1.6m×1.2m. Also the strong correlation between the measured deposition rate distribution and the calculated electric field distribution has been obtained.


## ACKNOWLEDGEMENT

This work was partially supported by the New Energy and Industrial Technology Development Organization as a part of the New Sunshine Program under the Ministry of Economy, Trade and Industry.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