Advanced Fabrication Method of Planar Components for Plasma Diagnostics

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Introduction

Background

As the importance of plasma imaging diagnostics increases, the fabrication of high performance millimeter-wave planar components becomes essential.

Purpose

Development of high performance millimeter-wave planar components such as antennas and filters using low-loss fluorine substrate.

Problems

1. Low degree of adhesion between copper foil and fluorine substrate.
2. Shape of antenna pattern. (side edge, limitation of pattern dimension)

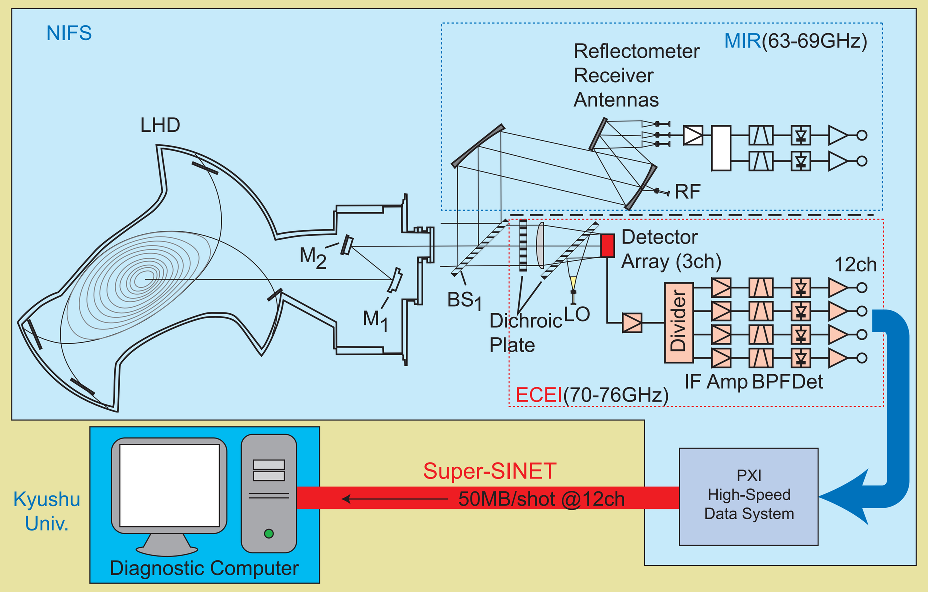
=> In order to solve the problems, surface treatment of fluorine films and a fabrication method using Electro Fine Forming (EF2) is utilized.

Applications

Millimeter-wave imaging diagnostics such as phase imaging interferometry (PII), microwave imaging reflectometry (MIR), and electron cyclotron emission imaging (ECEI) have proven to be useful in obtaining 2-D picture of electron density, electron temperature, and their fluctuations.

They are powerful tool to study localized magnetohydrodynamic (MHD) instabilities and micro instabilities, which are considered to be responsible to anomalous transport of magnetically-confined plasmas.

Microwave imaging systems are now installed in the large helical device (LHD) and the Tokamak EXperiment for Technology Oriented Research (TEXTOR).



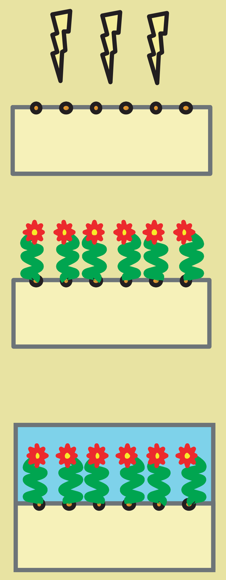
Surface Treatment

Radiation-Induced Graft Polymerization

Surface Treatment by Radiation Grafting on Fluorine Films (Improvement of Hydrohilicity)

Fluorine Films (80 mm x 30 mm) (PTFE : Polytetrafluoroethylene)

<Scheme>



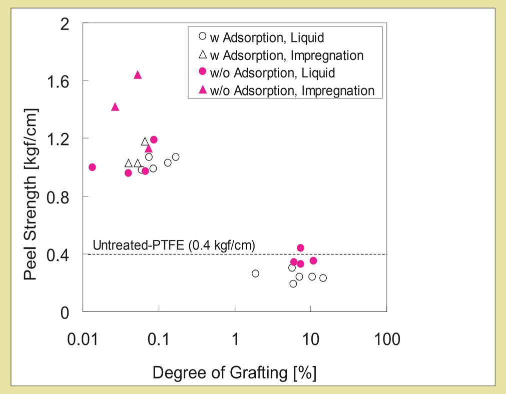
Fluorine binding is cut by using the radiation.

The generated radical unites with the functional group.

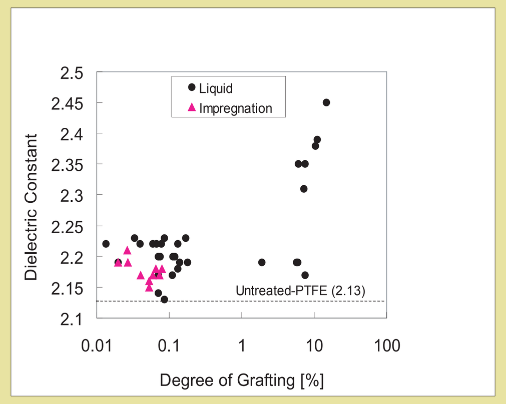
Other materials such as copper are applied to the functional group.

Pre - Irradiation

Graft Polymerization



Degree of Grafting vs. Peel Strength



Degree of Grafting vs. Dielectric Constant

Degree of Grafting [%]

$= (w_2 - w_1) / w_1 \times 100$

w_1 : Weight before Grafting
w_2 : Weight after Grafting

<Cavity Resonance Method>

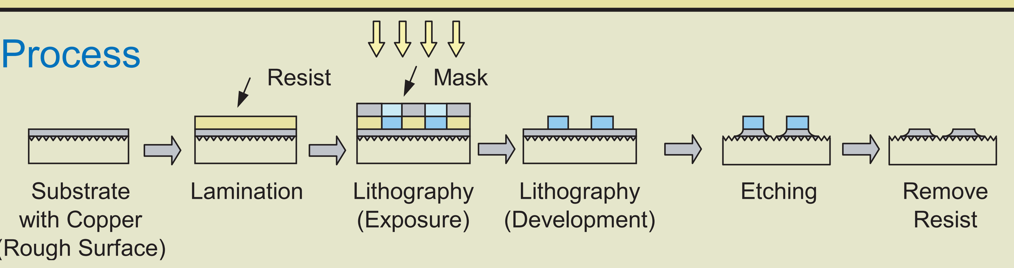
$\varepsilon_r' = 1 - (1/\alpha) \times ((f_L - f_0) / f_L) \times (V/\Delta V)$

f_0 : Resonance Frequency without Sample
f_L : Resonance Frequency with Sample
V : Volume of Cavity Resonator
ΔV : Volume of Sample
α : Constant Number
(Depend on Resonance Mode and Shape of Sample)

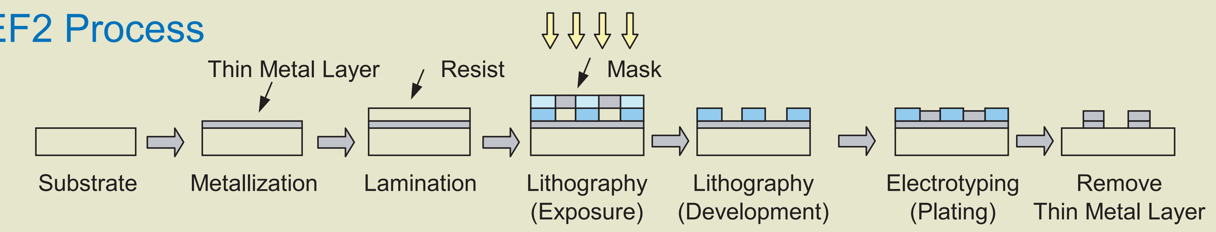
Improvement of Metal Shape

Electron Fine Forming (EF2)

Etching Process

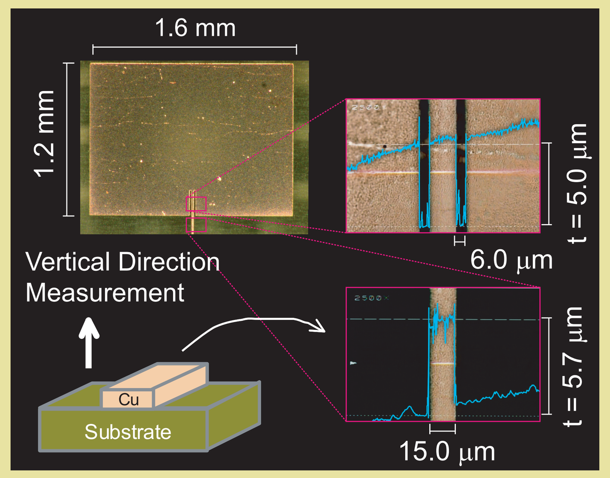


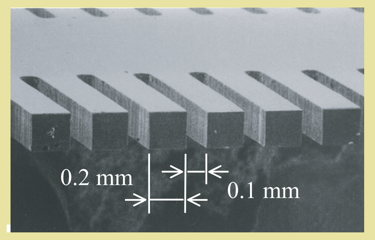
EF2 Process



EF2 abilities are made possible by the integration of two unique technologies.

1. "Parex Patterning Technology"
   A micro-lithography exposure technique used to enhance forming resolution and provide precise aperture patterns with micron level tolerances.
2. Maxell's Patented "Stay-Land Technology"
   Controls plating thickness and ensure an evenly distributed metal deposition so that parts are formed in a very controlled and uniform manner.





Achievement of Clear Cross-Section

Antenna Prototype Using Traditional Fluorine Substrate and EF2 Fabrication (Vertical Direction Measurement by Laser Microscope)

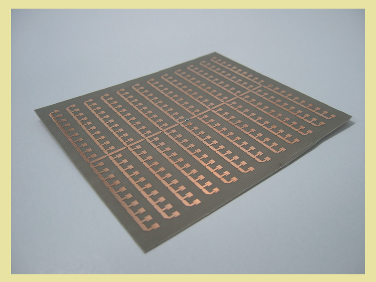
- Substrate (t = 0.254 mm, D.C. = 2.2, tan δ = 0.0006 (at 12GHz))
- Pattern (Line Width = 15 µm, Gap Width = 6 µm, t = 5 µm)

<Features>

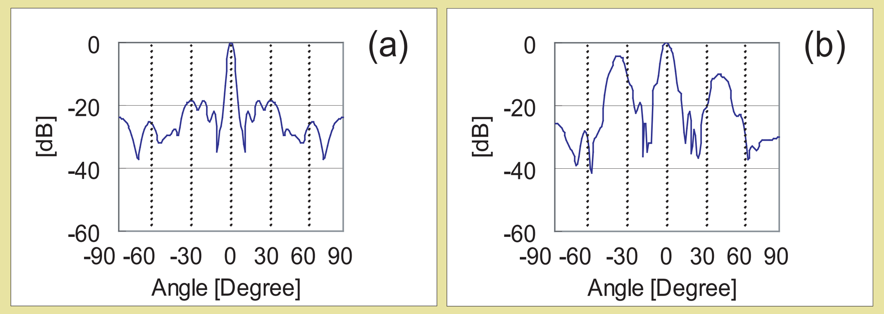
1. Excellent Vertical Cross-Section
2. Formation of Holes Smaller than the Plate Thickness
3. High-Precision Hole Measurement (less than ±5% Plate Thickness)
4. Accurately Controlled Hardness of about Hv 500)
5. Plate Thickness Control (10 µm to 300 µm, Precision better than 8%)

Planar Antenna Components

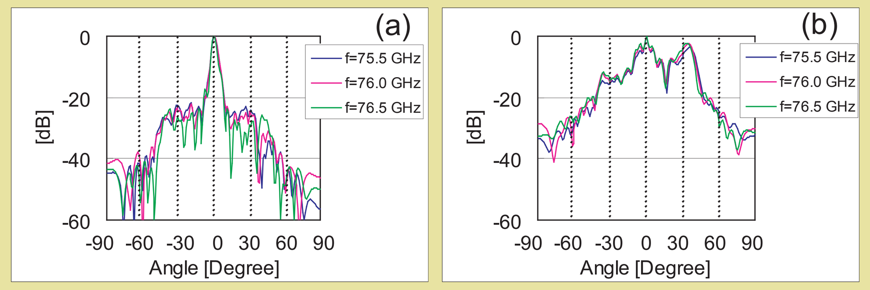
Antenna Radiation Pattern



Planar Patch Antenna Prototype
- 75 mm x 65 mm, - 240 Elements
- Substrate : NPC-F220A
  / Nippon Pillar Packing Co., Ltd.
  (t = 0.254 mm, D.C. = 2.2, tan δ = 0.0006)
  Using Traditional Substrate with EF2 Fabrication

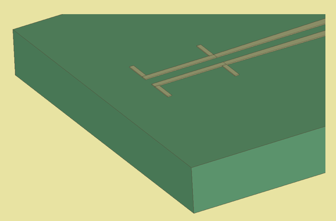


Calculated Relative Directivity (a) H - Plane, (b) E - Plane (f = 76.0 GHz)

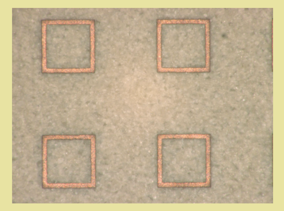


Measured Relative Directivity (a) H - Plane, (b) E - Plane via Near - Field Measurement System and Near - Field to Farfield Conversion (f = 75.5, 76.0, 76.5 GHz)

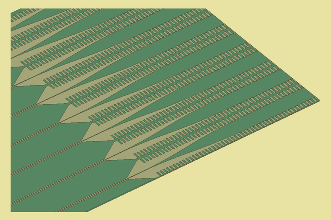
Other Prototype by EF2 Fabrication



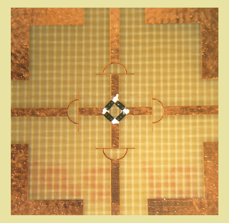
Dual Dipole Antenna
(Designed by Z. Shen)
- Line w = 30 µm
- Gap w = 30 µm
(Now Fabricating)



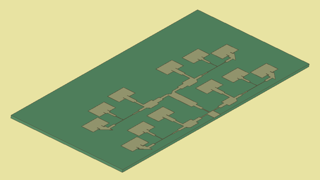
Notch Filter
(Designed by Z. Shen)
- Line w = 45 µm
(Fabricated)



Fermi Array Antenna
(Designed by L. Yang)
- Line w = 35 µm
- Gap w = 100 µm
(Now Fabricating)



Double Balanced Mixer Antenna
(Designed by Y. Kogi)
- Line w = 15 µm
- Gap w = 15 µm
(Fabricated)



Patch Antenna
(Designed by M. Matsukuma)
- Line w = 20 µm, - Gap w = 12 µm
(Fabricated)

Summary

<Results>

1. The adhesion strength of the attached metal to the PTFE films was significantly enhanced by the graft polymerization.
2. The achieved peel adhesion strength on the PTFE was 1.64 [kgf/cm]. (Untreated-films : 0.4 [kgf/cm])
3. The values of dielectric constant were confirmed to be not significantly changed.
4. The ultrafine pattern can be formed on fluorine substrate by using the EF2 fabrication.

<Future Works>

1. Surface Treatment
   - Target Peel Strength : 2.0 [kgf/cm]
   - Optimization of the Graft Condition to Achieve the Improvement of Further Adhesion (Parameter : Dose, Monomer, Concentration, Reaction Time, etc)
2. Increase in the Size of Fluorine Films beyond that of the Present one
3. Development of Various Antennas
   a. Planar Patch Antenna
   - Increase in Directivity, Radiation Efficiency, Reduction of Side Lobe)
   b. Dual Dipole Antenna and Fermi Array Antenna
   - Measurement of Antenna Radiation Pattern after the EF2 Fabrication

==> Realize to Apply to Actual Systems.