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Improvement of transmittance using groove structured surface for microwave imaging diagnostics in tokamak plasmas

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***Abstract*-Groove plate with triangle structure has been designed and fabricated to improve the microwave transmittance in W band. The parameters of the triangle structure has been optimized via the Effective Medium Theory (EMT) and FDTD program. The antireflection surface in W band has been verified in lab, the experimental results are qualitatively consistent with the theoretical results.**

I. INTRODUCTION

COMMON methods for antireflection is accomplished by means of a single-layer coating for achieving high transmittance. Single antireflective film has been widely used in visible band [1], while high transmittance is only realized for one certain frequency. Thus the multilayer method is developed to achieve high transmittance in a board frequency range, but the multilayer method has strict requirements on the selection of coating materials and processing technology [2, 3]. At the end of the 20th century, using electron microscopy, it was found that the outer surface of the cornea of moths was distributed with conical structures with 200 nm of height and spatial distance [4], and this kind of structure overcome the reflection of the smooth cornea surface and significantly improve the transmittance of visible light in a wide frequency range. Later it is proved that this anti-reflection structure (ARS) surface can be equivalent to a graded refractive index layer, gradually increasing from the outermost air refractive index to the innermost medium refractive index. This ARS surface avoids the choice of coating material and realizes the anti-reflection in wide frequency band. So far, the ARS surface is mainly used in visible light and far infrared light band, little work has been published regarding antireflection structure in microwave range. An exception is the work of Ma and Robinson (1983) [5], in which they built the antireflection structure on fused quartz window and successfully improved the transmittance.

Nowadays microwave imaging diagnostics working in W and F bands with complicated front-end optics have been widely adopted in tokamak plasmas [6]. The reflection caused by the lens surface will reduce the S/N ratio, result in standing wave effect. In our work, one-dimensional groove structure surface is designed, optimized and finally fabricated using 3D printing method. The printing material has a refractive index close to HDPE. The experimental results are qualitatively consistent with the theoretical analysis.

II. DESIGN OF ANTI-REFLECTION STRUCTURE

The ARS is usually one or two dimensional periodic structure, as shown in fig. 1(a). To avert the occurrence of high order of diffraction and only keep zero order of diffraction, the periodic length Λ should meet the condition:

$$\frac{\Lambda}{\lambda} < \frac{1}{\max(n_s, n_i)+n_i} \qquad (1),$$

where the λ is wavelength in incident space, n_s refers to refractive index of dielectric and n_i refers to refractive index of incident medium. Since Λ is usually smaller than λ, ARS is also called subwavelength gratings.

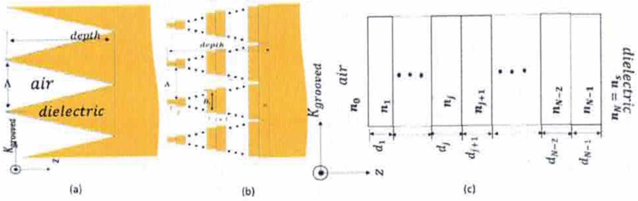

FIG.1 (a) 1D groove surface where yellow region represents dielectric substrate. (b) The triangle structure is treated as a stack of rectangle structures with different size. (c)The structure is equivalent to a multilayer film with graded refractive index profile.

Effective Medium Theory (EMT) [7] is utilized. With the incident electromagnetic field E perpendicular to K_{groove}, the dielectric constant of each layer can be expressed as

$$\epsilon^2_{E\perp K}(z) = \epsilon^{(0)}_{E\perp K}(z)\left[1+\frac{\pi^2\epsilon_0}{3\beta^2}f(z)^2(1-f(z))^2\frac{(n_s-n_i)^2}{\epsilon^{(0)}_{E\perp K}(z)}\right] \quad (2),$$

$$\epsilon^{(0)}_{E\perp K}(z) = f(z) * \epsilon_s + \left(1-f(z)\right) * \epsilon_i \quad (3),$$

where f (z) is filling factor $\frac{b(z)}{\Lambda}$.

The reflection of this multilayer can be calculated from Iterative Method (IM) , where the reflection below j_{th} layer can be written as

$$\rho_j = \frac{r_j+\rho_{j+1}\exp(2i\delta_{j+1})}{1+r_j\rho_{j+1}\exp(2i\delta_{j+1})} .$$

Here ρ_{j+1} represents the total electric field reflection coefficient of j_{th} layer and all the layers beneath it, ρ_0 represents the total electric field reflection of groove structure surface, r_j represents the reflection at interface between layer j and j+1 , δ_j refers to $\frac{2\pi n_j d_j}{\lambda} * \cos\theta_j$.

The EMT results are shown in fig. 2. The transmittances are greatly improved, except for the normal incident case of single side plate, which is caused by the interferences between layers.

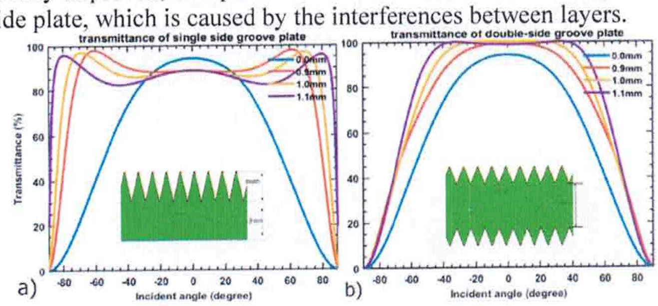

FIG.2 The transmittances of one-side and double-side groove plate with different depth and incident angle. The incident wave frequency is set to 87.5 GHz, Λ is 0.9 mm, $\epsilon_s = 2.78$. In the calculation the ARS is divided into N=1000 layers.