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Study of Ohmic loss of high power polarizers at 170 GHz for ITER

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Abstract

ECCD system in ITER needs the polarizer for obtaining suitable polarization in a magnetize plasma. The Ohmic loss evaluation code was developed for high power grooved mirror polarizers. The Ohmic loss strongly depends on the mirror rotation angle and the rotation angle of incident linear polarization. Calculation results can explain the strange loss dependences.

Keywords: ECCD; Polarizer; Ohmic loss

1. Introduction

An electron cyclotron current driving (ECCD) method is one of the most promising methods for suppressing the neoclassical tearing mode, which may degrade the performance of fusion reactors. High efficient ECCD operations need the obliquely propagating electromagnetic wave with the specified elliptical polarization. The conventional high power polarizers in a mirror box or a pair of miter bends consist of a polarization twister and an elliptical polarizer [1–3]. These universal polarizers can generate an arbitrary polarization. On the other hand, a single mirror polarizer using a deep grooved mirror installed has been developed from a point of view of cost reduction [4].

In the ITER design, the transmitted power per one waveguide is planed to be 1 MW at CW operation. So that the thermal stress of the grooved mirror in miter bend should be estimated quantitatively for designing the polarizer and its cooling system. In this paper, the Ohmic loss analysis of the polarizers has been performed using the Fourier expansion method [5]. The validity of the loss estimation code has been confirmed with the comparison between the theoretical predictions and the high power experimental results.

2. Calculation model

The principle of a polarizer is the application of the phase difference between a fast polarization and a slow

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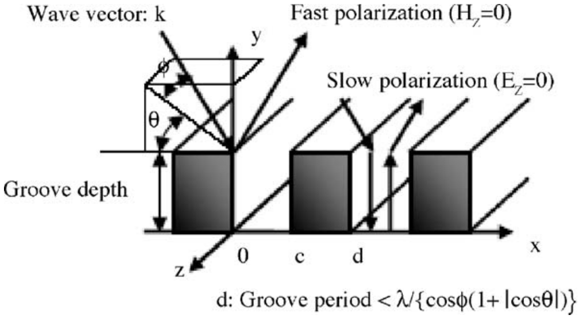

Fig. 1. Groove structure.

polarization. The fast polarization is reflected on the ridge top due to no z-component of magnetic field, and the slow polarization is reflected on the bottom of grooves due to no z-component of electric field as shown in Fig. 1. The groove period d must be less than $\lambda/\{\cos\phi(1+|\cos\theta|)\}$ for suppressing higher diffractive modes. The Ohmic loss of the grooved mirrors can be estimated from the surface resistance and the current density profile on the metal surface in the grooves. The Ohmic loss of groove surface can be evaluated with the following equation:

$$\text{Ohmic loss} = \frac{R_\mathrm{s}}{2}\int |\mathbf{H}_\mathrm{t}|^2\,\mathrm{d}S = \frac{1}{2}\sqrt{\frac{\omega\mu}{2\sigma}}\int |\mathbf{H}_\mathrm{t}|^2\,\mathrm{d}S \qquad (1)$$

where $\mathbf{H}_\mathrm{t}$, R_s, σ, μ and ω are tangential component of magnetic field, surface resistance, electric conductivity, magnetic permeability and angular frequency, respectively. The electromagnetic fields exterior and interior to the groove are obtained in order to get the tangential magnetic field $\mathbf{H}_\mathrm{t}$.

2.1. Exterior to the groove ($y \geq h$)

Oversized circular corrugated waveguides are suitable for the transmission of high power millimeter waves in ECCD system of fusion reactor. The HE_{11} mode in a corrugated waveguide is a linearly polarized fundamental mode, which can be approximated to be a plane wave except for the electric field profile in the radial direction. Therefore, the electromagnetic field components of the propagating mode can be expanded with Fourier series at the outside of grooves. The variation of the electromagnetic field along the z-axis direction is assumed only phase changes, other electromagnetic field components can be derived from Maxwell equation with z-components. The z-components normalized by the amplitude of the incident electric field 1 [V/m] are represented as follows.

Fast polarization

$$E_{\mathrm{F}z} = \left\{\{\exp[i(\alpha_0 x - \beta_0 y + \gamma z)\right. \left. + \sum_{n=-\infty}^{\infty} r_n \exp[i(\alpha_n x - \beta_n y + \gamma z)]\right\} \frac{1}{\cos\phi} \qquad (2)$$

Slow polarization

$$E_{\mathrm{S}z} = \left\{\{\exp[i(\alpha_0 x - \beta_0 y + \gamma z)\right. \left. + \sum_{n=-\infty}^{\infty} S_n \exp[i(\alpha_n x - \beta_n y + \gamma z)]\right\} \times \frac{1}{Z_0 \cos\phi} \qquad (3)$$

where $\alpha_0 = k\cos\theta\cos\phi$, $\beta_0 = k\sin\theta\cos\phi$, $\gamma = k\sin\phi$, $\alpha_n = \alpha_0 + n2\pi/d$, $\beta_n = (k^2 - \alpha_n^2 - \gamma^2)^{1/2}$, $k = \omega(\mu\varepsilon)^{1/2}$, and $Z_0 = (\mu/\varepsilon)^{1/2}$.

The power ratio of the fast polarized wave to the slow polarized one of incident wave can be calculated using the angles of T and U, where T indicates the rotation angle of polarization plane, and U is the projection angle of the mirror rotation angle: S to the

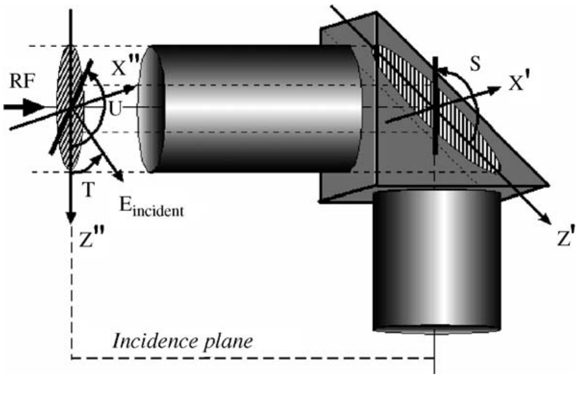

Fig. 2. Definition of each angle.