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New Application of a Deep Grooved Polarizer for ECCD

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Abstract

Frequency wideband polarizers are studied for electron cyclotron current drive (ECCD) in toroidal plasmas. A typical rectangular grooved mirror can produce the almost suitable elliptical polarizations in the wide frequency range of 100-170 GHz at any toroidal injection angle, as long as high-q plasmas. In addition, the deep grooved mirror is probably applicable as a step tunable polarizer, even if low-q plasmas. It makes a frequency-step-tunable gyrotron an attractive device as an ECCD driver in fusion reactors.

Keywords:
wideband, polarizer, grooved mirror, electron cyclotron current drive

1. Introduction

Electron cyclotron current drive (ECCD) is one of the most promising non-inductive current driving methods. Especially, it is effective for suppressing neoclassical tearing modes setting the beta limit in present tokamak plasmas [1]. Frequency wideband ECCD systems are able to improve current drive efficiencies in various operations. However, wideband ECCD system does not exist, now. Up to now, the frequency-step-tunable-gyrotron has been developed for the range of 114-170 GHz [2]. In this paper, the first study of wideband polarizers using a single grooved mirror is presented.

2. Principle of deep grooved polarizer

The various universal polarizers were proposed by using two or three grooved or smooth mirrors for producing pure ordinary wave (O-mode) and extraordinary wave (X-mode) [3-5]. The principle of those polarizers is base on the phase difference between fast and slow polarizations reflected by the grooved mirrors as shown in Fig. 1.

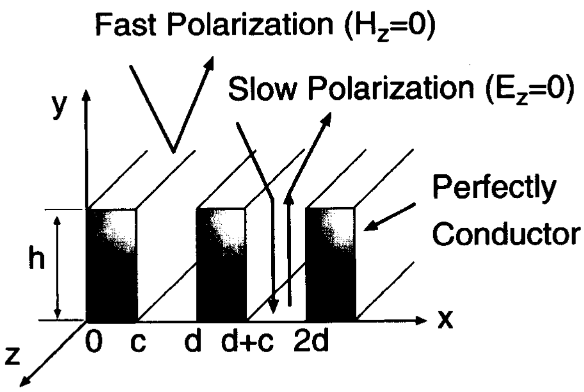

Fig. 1 Groove surface of a polarizer in rectangular coordinate system.

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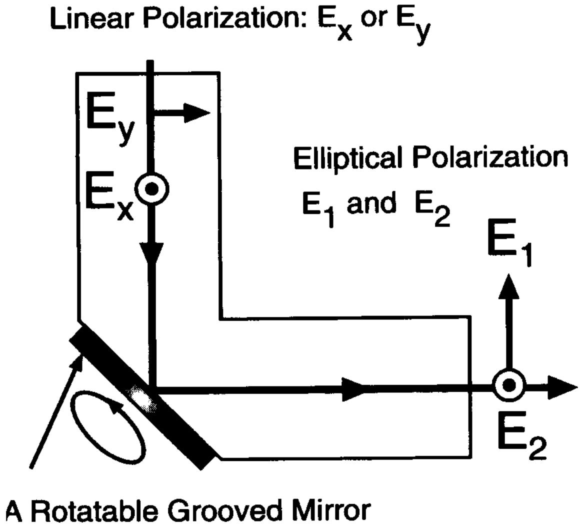

Fig. 2 Schematic view of a deep grooved mirror polarizer in miter bend

The fast polarization (H_z=0, TE-like mode) is reflected by the top of the groove, and the slow polarization (E_z=0, TM-like mode) is reflected by the bottom of groove. Therefore, the phase difference between both polarizations have been designed by the groove depth. In the case of two mirror polarizer, one mirror (groove depth ~ $\lambda/4$) rotates the axis of polarization ellipse, and the other (groove depth ~ $\lambda/8$) controls the axial ratio of polarization ellipse.

On the other hand, the single mirror polarizer installed in a miter bend as shown in Fig. 2 generates the almost pure O-mode and X-mode by adjusting mirror rotation angle [6]. The features of a single mirror polarizer are easy operation, low cost, and less possibility of the other mode resonance between two grooved mirrors (non-curvature), although that the mode purity is not 100 %. The mode purity maps of O- and X-modes produced by the deep grooved mirror are shown in Figs. 3(a) and 3(b), respectively. In those calculations, the mode separation phenomena on the plasma surface are calculated using plane wave approximation, cold dispersion relations and Snell's law [6]. The grooved mirrors are analyzed using simple Fourier expansion method [7]. The used parameters are the electron density on plasma surface of 10^{18} m^{-3}, the magnetic field of 3 T, the frequency of 110 GHz, the toroidal injection angle from 0° to 45° and the tilted angle of the magnetic field line from 0° to 30°. The toroidal injection angle of 45° means almost parallel to the plasma surface in toroidal direction, where the major radius of plasma surface is 4.23 m, the distance between

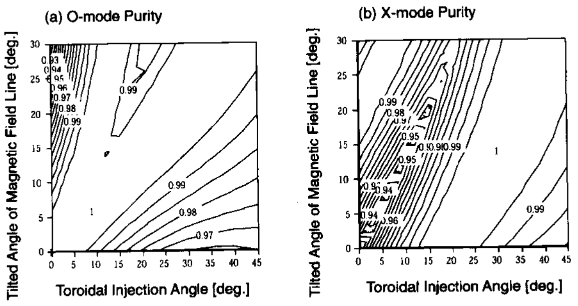

Fig. 3 Mode puritys by a deep grooved polarizer (h = 61/64λ) at 110 GHz. 3(a) O-mode purity and 3(b) X-mode purity.

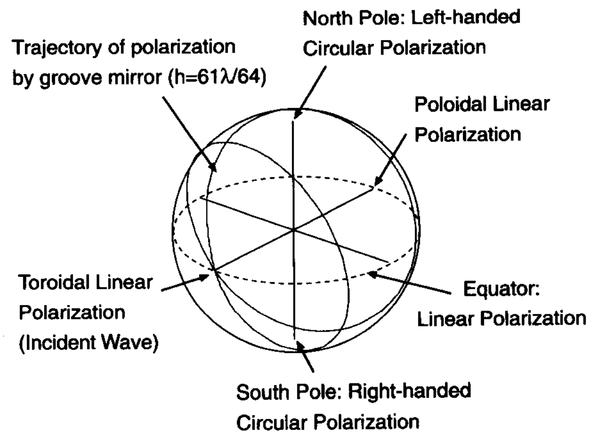

Fig. 4 Trajectory of the polarization produced by rotating a single grooved mirror (groove depth =61/64λ) for Fig. 3 on the normalized Poincaré sphere.

the plasma surface and the antenna is 0.77 m, the last stage antenna is assumend to be located on a mid-plane. A incident wave to the polarizer is assumed to be linearly polarized wave of which electric field vector is on the mid-plane. The adopted groove depths are 61/64λ for both of Fig. 3(a) and Fig. 3(b), where the groove parameters: c and d are 0.5 mm and 1 mm, respectively. These design values are following the design rule: d< 0.586λ for suppressing the higher mode propagation [5].

O-mode purity is expected to be higher than 92% in wide parameter ranges as shown in Fig. 3(a). On the other hand, the X-mode purity is expected to be higher than 93% in wide parameter ranges, as shown in Fig. 3(b). The reason why the X-mode purity is lower than O-mode one at both of the angles of 0°, is the fact that the toroidal linear polarization of incident wave is O-

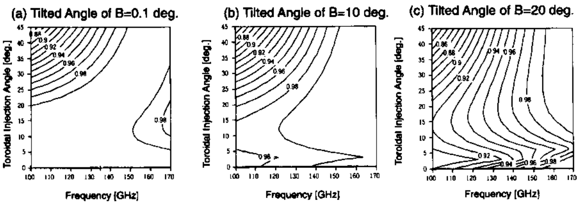

Fig. 5 Contour of the O-mode purity produced by a single mirror polarizer (h= 0.341 mm, c=d/2=0.5 mm). The tilted angles of magnetic field line are 0.1° in 5(a), 10° in 5(b) and 20° in 5(c).

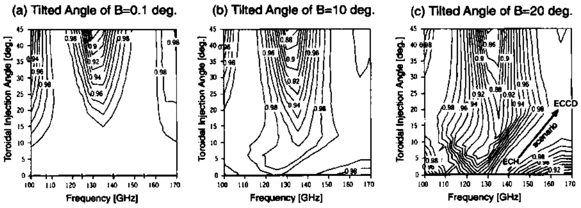

Fig. 6 Contour of the O-mode purity produced by a single mirror polarizer (h = 2.73 mm, c = d/2 = 0.5 mm). The tilted angles of magnetic field line are 0.1° in 6(a), 10° in 6(b) and 20° in 6(c).

mode polarization at a toroidal injection angle of 0°. If the incident linear polarization rotates 90°, both of the figures are exchanged to each other, approximately.

Figure 4 indicates the normalized Poincaré sphere of the rotating a single mirror polarizer (groove depth = 61/64λ) used in Fig. 3. The normalized Poincaré sphere corresponds to the all polarizations. The North Pole on the Poincaré sphere indicates left-handed circular polarization, the South Pole indicates right-handed circular polarization. The equator indicates all linear polarizations. Universal polarizers must cover all surface of the normalized Poincaré sphere, on the other hand, this single polarizer draws only two circles on the sphere surface, as shown in Fig. 4. The polarization of O-mode in vertical propagation to the magnetic field is located on the equator nearby toroidal linear polarization, while those in the parallel propagation are located on the South or North Poles, which depends on the sign of toroidal injection angle. The trajectories cross the equatorial plane at both of the sides 40° away from the point of poloidal linear polarization (X-mode polarization in perpendicular propagation). The angle of 40° on the equatorial plane in Poincaré sphere indicates 20° tilted linear polarization, which agrees with the X-mode purity of 100% at the tilted angle of magnetic field of 20° and the toroidal injection angle of 0° as shown in Fig. 3(b).

3. Wideband Properties

The wideband polarizer can not be designed by the conventional two mirror polarizer concept, because the groove depths should be designed about λ/8 and λ/4. As a first step for wideband polarizer development, the wideband properties of groove mirror have been evaluated by the numerical calculations for obtaining high mode purity in plasma.

Figure 5 shows the contour of the O-mode purity on the map of the toroidal injection angle from 0 to 45° versus the frequency from 100 to 170 GHz. The upper frequency is limited by 176 GHz for avoiding higher mode propagation at the groove parameters of d = 1 mm, c = 0.5 mm, and the lower one is limited by avoiding a cyclotron resonance at a magnetic field of 3 T (84 GHz). The groove depth adopted in Fig. 5(a) is 0.341 mm (λ/8 at 110 GHz). The tilted angles of magnetic field line are 0.1 degrees in Fig. 5(a), 10° in Fig. 5(b), and 20° in Fig. 5(c). The high mode purity can be obtained in wideband at only high-q plasmas. The numerical results suggest that the single groove mirror and roof-top converter can produce suitable polarizations for ECCD in the wide frequency band. However, the roof-top polarizer is not suitable for fusion reactors, because of large size and expensive cost.

Figure 6 shows the contour of the O-mode purity map, where the groove depth is 2.73 mm which is a wavelength at 110 GHz in free space. The tilted angles of magnetic field line are 0.1° in Fig. 6(a), 10° in Fig. 6(b), and 20 degrees in Fig. 6(c). The mode purity is improved in a wide frequency range due to deep groove structure, comparatively. The step tunable polarizer can be designed optimizing a groove depth for a typical heating and current drive scenario shifting a frequency from 140 GHz to 170 GHz with increasing a toroidal injection angle as shown in Fig. 6(c), even if low-q plasmas.

4. Summary

A wideband polarizer is studied for ECCD system in toroidal plasma. A single mirror with shallow groove or deep groove can produce the suitable elliptical polarizations over the wide frequency range at any toroidal injection angle in high-q plasmas. The deep groove polarizer may be applicable devices as a step tunable polarizer for wideband operations, even if, in low-q plasmas.

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