Polarizer Development for Electron Cyclotron Resonance Heating Systems in a HL-2A Tokamak

Guo Qing ZHANG, Kazunobu NAGASAKI[1)], Jun ZHOU, Jin Song ZHANG, Gang Yu CHEN, Mei HUANG, He WANG and Jun RAO

Southwestern Institute of Physics, Chengdu, 610041, China

[1)]*Institute of Advance Energy, Kyoto University, Gokasho, Uji, Kyoto, 611-0011, Japan*

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The paper presents the development of sinusoidally grooved polarizers for electron cyclotron resonance heating (ECRH) systems in the HL-2A tokamak. The polarizer groove shape was designed according to a sinusoidal function with a groove period $p = 0.48\lambda$ and depth $d = 0.5\lambda$. Here, λ is the wavelength, whose value is 4.41 mm. The low-power test results of the polarizer performance are in agreement with a numerical calculation based on the integral method developed in vector theories of diffraction gratings. High-power experiments reveal that 340 kW high-power EC waves can be transmitted through the corrugated waveguide line with the polarizer assembled in a miter bend at atmospheric pressure. With the polarizer, ECRH/electron cyclotron current drive (ECCD) experiments in the extraordinary mode have been successful in a HL-2A tokamak.

Keywords: polarizer, electron cyclotron resonance heating (ECRH), electron cyclotron current drive (ECCD), HL-2A tokamak

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Electron cyclotron resonance heating (ECRH) has been widely applied in many magnetic confinement fusion devices for plasma heating, current drive, magnetohydrodynamics control, and transport study. Four 68 GHz/500 kW/1 s ECRH sub-systems were developed, and 1.6-MW EC waves in ordinary (O) mode were injected into the HL-2A tokamak from the low-field side. To explore second-harmonic extraordinary (X)-mode heating or current drive experiments, sinusoidally grooved polarizers were developed and assembled in the millimeter-wave transmission line of ECRH systems to obtain the desired polarization for effective plasma heating and current drive.

The polarizer groove shape was designed according to a sinusoidal function with the grooved period $p = 0.48\lambda$ and depth $d = 0.5\lambda$. Here, λ is the wavelength, whose value is 4.41 mm. The machining accuracy is 0.01 mm. The polarized wave is determined by the parameter α, which is the major axis rotation angle of the polarization ellipse, and the ellipticity β, which is the diagonal angle of the major and minor axes of the wave electric field [1]. Both α and β are functions of the polarizer rotation angle Φ. A low-power test was conducted to measure the polarization using a 20 mW / 70 GHz wave source, mode converter, corrugated waveguide, and the polarizer in a miter bend. Figure 1 shows the low-power test setup for measuring the polarizer's properties in the HE_{11} transmission line. The rotatable polarizer was installed on the miter bend. The detector was set on a two-dimensional rotatable scanning system, and the polarization parameters were measured by rotating a crystal diode detector. As shown in Fig. 2, the test results are in good agreement with a numerical calculation, where the alpha and beta experiments denote the test results of α and β, respectively, and the solid lines denote the calculation results of α and β.

α and β satisfy the relations,

$$\tan 2\alpha = \tan 2\gamma \cos\delta \quad (1)$$

$$\sin 2\beta = \sin 2\gamma \sin\delta, \quad (2)$$

where δ is the phase shift between two components of the reflected wave electric field, and γ is the function of phase

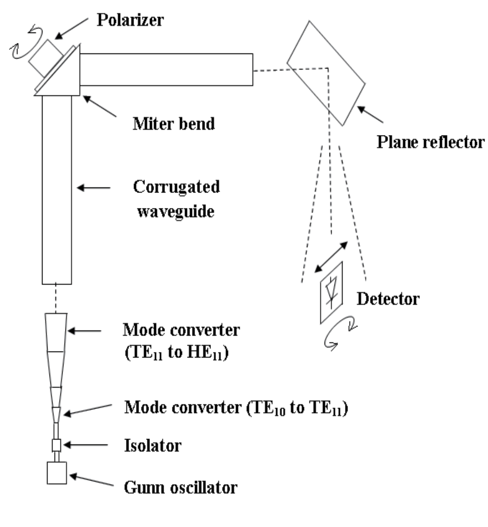

Fig. 1 Low-power test setup for measuring the properties of the polarizer in a miter bend.

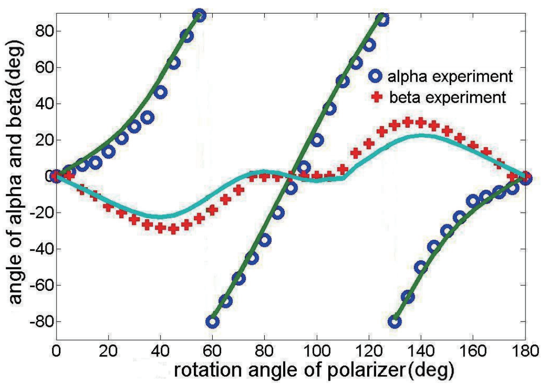

Fig. 2 Dependence of the major axis rotation angle and ellipticity on the polarizer rotation angle.

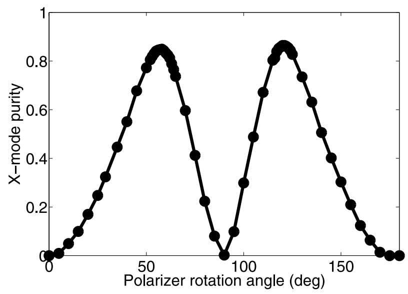

Fig. 3 Dependence of X-mode purity on the rotation angle of polarizer. The polarizer rotates from 0 to 180 deg.

difference, τ, which is determined by the two orthogonal modes (TE-and TM-like modes) of the incident wave field. Here the phase difference, τ, which is required to estimate α and β, is calculated by the integral method developed in the vector theories of diffraction gratings [2]. This indicates that the groove shape is well manufactured as a sinusoidal shape. The low power test results were applied to estimate the X-mode purity, as shown in Fig. 3. It can be seen that the X-mode purity reaches 85% at $\Phi = 57$ deg and 123 deg. When the toroidal angle of the injected wave changes from 0 to 25 deg, the X-mode purity is almost 100% for the injection angle of 15 deg at the optimum rotation angle (at $\Phi = 57$ deg), as shown in Fig. 4.

The polarizer was installed on a miter bend in the ECRH system, and applied for the ECRH experiment. The ECRH system consists of a gyrotron, a matching optics unit (MOU), one miter bend, a launching system, and 8-m corrugated waveguides [3]. The 68 GHz / 500 kW / 1 s wave output from the gyrotron is a Gaussian beam, and is injected into the corrugated waveguide after adjusting the beam shape using the MOU. The HE_{11} mode is transmitted through the corrugated waveguides and the miter bend, and then is injected into the HL-2A tokamak by the launching system. The waist of injection beam is 3.7 cm around the magnetic axis. The antenna toroidal rotation angle of the launching system can be changed from 0 to 25 deg, and was fixed as 5 deg, 10 deg, and 15 deg for the electron cyclotron current drive (ECCD) experiment.

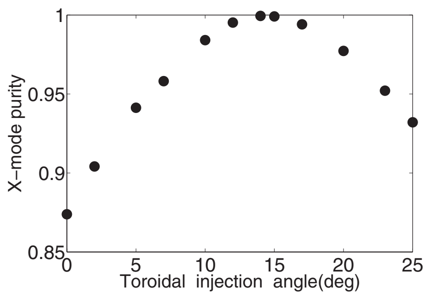

Fig. 4 Dependence of X-mode purity on the toroidal injection angle. The toroidal angle is scanned from 0 to 25 deg.

With the polarizer, the second-harmonic X-mode experiments were successfully explored in the HL-2A tokamak. The rotation angle was fixed as $\Phi = 57$ deg to obtain the high X-mode purity for a perpendicular launch. The X-mode EC waves were injected from the low-field side, and the maximum injection power was 340 kW. The transmission line with the polarizer worked well at atmospheric pressure. Although arc breakdown occurred in some plasma discharges, it was solved by adjusting the transmission system. A plasma experiment with $B{\sim}1.24$ T and $n_e{\sim}1.3 \times 10^{13}\,\mathrm{cm}^{-3}$ revealed that the electron temperature increases from 0.8 keV (Ohmic heating phase) to 1.5 keV (additional 2nd X-mode heating phase).

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[1] K. Nagasaki, Y. Itoh, H. Morioka and T. Obiki, Int. J. Infrared Millimeter Waves **20**, 823 (1999).
[2] D. Maystre, *Progress in Optics*, Vol.XXI, Chapter 1 (North-Holland, Amsterdam, 1984) p.2-67.
[3] J. Zhou *et al.*, Plasma Sci. Techno. **8**, 344 (2006).