A Polarizer with Sinusoidal Grooves in the Electron Cyclotron Resonance Heating System of the HL-2A Tokamak

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Abstract  Theoretical calculation and experimental results for a polarizer with sinusoidal grooves used in the electron cyclotron resonance heating (ECRH) system of the HL-2A tokamak are presented. The calculation is based on an integral method developed in the vector theory of diffraction gratings, and the polarization characteristics obtained with a low-power test are in good agreement with the numerical calculated results. With the polarizer assembled in a miter bend in the ECRH transmission line, pure ordinary mode (O-mode) and extraordinary mode (X-mode) polarized waves are also expected in the high-power experiment, depending on the polarizer rotation angle and the toroidal injection angle of the electron cyclotron (EC) wave beam. Second-harmonic X-mode experiments were successfully explored in HL-2A. Experimental result revealed that the electron temperature increased from 0.8 keV (Ohmic heating phase) to 1.5 keV (second X-mode heating phase).

Keywords: polarizer, electron cyclotron resonance heating, vector integral method, ordinary mode, extraordinary mode

PACS: 52.35.Hr

1 Introduction

Electron cyclotron resonance heating (ECRH) is widely applied in fusion research. In order to conduct O-mode and X-mode plasma heating experiments, a polarizer is used to generate the desired wave polarization by rotating the grating mirror. Based on the vector theory of diffraction gratings, the polarizer mirror is designed by manufacturing periodic grooves on the surface of the metallic plane mirror. Because of the enhancement of the electric field at the edge of the groove surface, a rectangular grooved polarizer mirror tends to cause a high possibility of electrical arc breakdown for high-power EC wave transmission, while a non-rectangular mirror, such as one with a sinusoidal or rounded shape, is preferable to avoid arc breakdown. In HL-2A, a polarizer with a single sinusoidal grooved mirror is applied to the 68 GHz ECRH system. However, in most cases, a two-mirror polarizer is the best choice to obtain pure O- and X-mode at any toroidally incident angle, so the single mirror polarizer mentioned in this paper is just a compromise when considering the real structure of the ECRH transmission line of HL-2A. ECRH/ECCD experiments in the second-harmonic X-mode reveal that EC wave of 340 kW can be transmitted through the corrugated waveguide line with the polarizer assembled in a miter bend at atmospheric pressure\textsuperscript{[1]}.

2 The principle of the integral method

According to the vector theory of diffraction gratings, incident waves can be decomposed into two orthogonal modes, fast polarization and slow polarization ones. The magnetic field $\mathbf{H}$ for the fast polarization mode does not have a component in the groove direction, and the electric field $\mathbf{E}$ for the slow polarization mode does not have a component in the groove direction. The fast polarization mode is reflected at the surface of the grooves, while the slow polarization mode penetrates into the grooves and is reflected at the bottom, leading to a phase shift $\tau$ between them \textsuperscript{[2,3]}. When we consider the case where the plane of incidence (consisting of the incident wave vector $\mathbf{k}_i$ and reflected wave vector $\mathbf{k}_r$) is normal to the grooves, which are assumed to be along the $z$ direction, the electric and magnetic field of the reflected waves can be expressed as a series in the form \textsuperscript{[4]}:

\begin{equation}
F(x, y) = \sum_{n=-\infty}^{+\infty} B_n \phi_n(x, y),
\end{equation}

$F = -F^s = -\exp(ik_{xn}x - ik_{yn}y)$ for the fast polarization mode, $dF/ds = -dF^s/ds = i(k_{yn}s_y - k_{xn}s_x)\exp(ik_{xn}x - ik_{yn}y)$ for the slow polarization mode. For both cases, $F$ satisfies a radiation cond-

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