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Measurement of Azimuthal Bremsstrahlung Photon Emission from a 28-GHz ECR Ion Source Using NaI(Tl) Detectors

The emission of high-energy bremsstrahlung photons beyond the expected critical energy during electron cyclotron resonance (ECR) heating has attracted significant attention, and its underlying mechanism remains not fully understood. In this study, we measured the azimuthal angular distribution of bremsstrahlung photons produced in a 28 GHz ECR ion source at the Busan Center of the Korea Basic Science Institute (KBSI). Three round-type NaI(Tl) scintillation detectors were used to simultaneously measure bremsstrahlung photons emitted radially from the plasma chamber. An additional NaI(Tl) detector was positioned downstream of the ECR ion source to monitor the overall photon intensity. The ion source was operated at an RF power of 1 kW to extract an 16O ion beam, with dominant charge states of O^{3+} and O^{4+}. Bremsstrahlung photon energy spectra were recorded at nine azimuthal angles on the extraction side of the ion source. To evaluate possible systematic uncertainties arising from differences among the three detectors, measurements were repeated by alternating the detector positions. Geant4 Monte Carlo simulations were performed to account for geometrical acceptance and energy-dependent detection efficiency caused by non-uniformities in the material budget. The true bremsstrahlung spectra were then reconstructed using an inverse-matrix unfolding method. The extracted end-point energies of the bremsstrahlung spectra were (2.040 ± 0.045) MeV at 150°, (1.650 ± 0.040) MeV at 330°, and (1.610 ± 0.040) MeV at 330° for detectors D1, D2, and D3, respectively. These values exceed the maximum electron kinetic energy of approximately 1.330 MeV expected from standard ECRIS operating parameters. The higher end-point energy observed near 150° appears to correlate with the structural configuration of the ion source and the the shape of the ECR plasma. However, the secondary maximum near 330°, located roughly 180° opposite to 150◦ which is among the maximum angles, cannot be explained solely by the shape of the ECR plasma. We interpret these observations as evidence of unconfined high-energy electrons reaching the chamber wall and producing bremsstrahlung radiation. These escaping electrons likely arise from imperfect magnetic confinement within the ECR plasma. The results provide new insight into the mechanisms of high-energy bremsstrahlung production in ECR ion sources and suggest that improved magnetic confinement design could reduce electron losses and associated high-energy photon emission.

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