7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Experimental demonstration of diamagnetism enhanced by energetic electrons in a magnetic nozzle plasma

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Diamagnetism is a fundamental and inherent characteristic of magnetized plasmas and distorts the external magnetic fields by reducing the field strength inside the plasma. This can be clearly observed for a high-beta condition, where the plasma pressure is larger than the magnetic pressure of the external magnetic fields. It plays important role in a momentum conversion process in a magnetic nozzle utilized for a development of a magnetic nozzle plasma thruster [1,2], where the plasma beta is typically much lower than unity. The identity of the magnetic field distortion is the spontaneously excited internal azimuthal plasma current.

Several laboratory experiments in low-beta plasmas have observed that the distortion of the magnetic field is smaller than the expected one calculated from the plasma beta. The effect of radial electric fields [3], magnetic field penetration and dissipation [4], and neutral pressure [5] have bee discussed to explain the observed magnetic field distortion. A recent laboratory experiment has shown that the azimuthal current can be given by the sum of the electron diamagnetic and **E**x**B** drift currents, validating the reduction of the diamagnetism by the presence of the electric field, where the electron energy distribution is assumed to be Maxwellian [6]. However, the electron energy distribution in the low-pressure plasma is indeed non-Maxwellian, e.g., having a depleted tail or energetic tail electrons [7,8]. Therefore, the measured azimuthal current seems to include the effects of both the electric fields and the non-Maxwellian electrons.

Here an electron-beam plasma source presented previously [9,10] is employed to produce a plasma having zero plasma potential, allowing us to purely investigate the diamagnetism under zero electric field. The two-dimensional mapping of the plasma-induced axial magnetic field is measured by using a B-dot probe, providing the internal plasma current by taking a rotation of the measured magnetic fields as shown in Fig.1 [11]. Furthermore, the electron energy probability functions (EEPFs) are taken over four orders of magnitude, showing the presence of the energetic tail electrons. The comparison between the azimuthal current calculated from the magnetic fields and the EEPFs are in good agreement when considering the energetic tail electrons. The results demonstrate that the tail electrons are major contributors to the diamagnetism of the plasma even if their density is a small fraction of the total density.

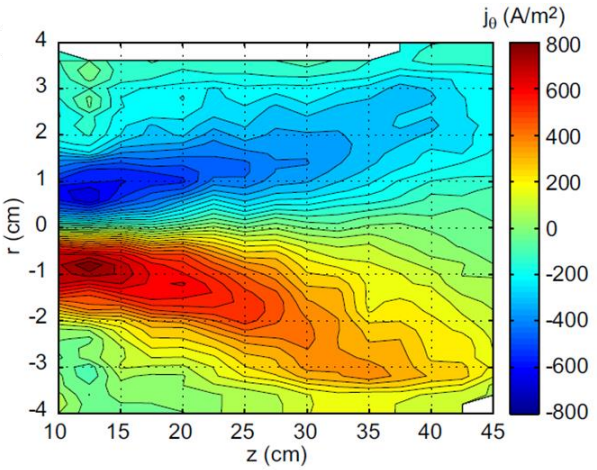

Fig.1: Two-dimensional profile of the internal azimuthal plasma current density. *Reproduced from permission from Phys. Rev. Research* ***5****, L022029 (2023). Copyright 2023, Authors, licensed under a Creative Commons Attribution 4.0 International license.*

References

[1]K. Takahashi, Rev. Mod. Plasma Phys. **3**, 3 (2019).
[2]K. Takahashi *et al.*, Phys. Rev. Lett. **110**, 195003 (2013).
[3]R.L. Stenzel and J.M. Urrutia, Phys. Plasmas 7, 4450 (2000).
[4]C.S. Corr and R.W. Boswell, Phys. Plasmas **14**, 122503 (2007).
[5]A. Fruchtman and S. Shinohara, Phys. Plasmas **24**, 103523 (2017).
[6]K. Takahashi *et al.*, Plasma Sources Sci. Technol. **25**, 055011 (2016).
[7]K. Takahashi *et al.*, Phys. Plasmas **14**, 114503 (2007).
[8]K. Takahashi *et al.*, Appl. Phys. Lett. **94**, 191503 (2009).
[9]K. Takahashi *et al.*, Phys. Rev. Lett. **120**, 045001 (2018).
[10]K. Takahashi *et al.*, Phys. Rev. Lett. **125**, 165001 (2020).
[11]K. Takahashi *et al.*, Phys. Rev. Research **5**, L022029 (2023).