High Speed Images of Drift Waves and Turbulence in Magnetized Microplasmas

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***Abstract*—We present high speed images from $\mathbf{E} \times \mathbf{B}$ discharges in microscale magnetically confined plasmas. The images depict strong and highly ordered drift waves and underlying smaller scale turbulence near the plasma edge, with characteristic length scales larger than the electron cyclotron radius. The phase velocity of the large-scale disturbances is in agreement with that for ∇n—driven isothermal drift waves.**

***Index Terms*—Drift waves, $\mathbf{E} \times \mathbf{B}$ discharge, magnetized discharge, microdischarge, turbulence.**

THE STUDY of fluctuations and turbulence in plasmas continues to be an active area of research. Until recently, measurements of the dynamical behavior of laboratory plasmas relied mainly on the use of intrusive probe diagnostics or nonintrusive microwave diagnostics of limited spatial resolution. The development of fast framing cameras has afforded a new tool in the study of plasma fluctuations, including turbulent phenomenon in edge regions of magnetically confined fusion plasmas [1]. However, access to these turbulent plasmas is limited, and the field of view often restricts the analyzed region to sizes much less than the reactor scale.

In this paper, we present the imaging of sequential events in magnetically confined microplasmas created by an annular $\mathbf{E} \times \mathbf{B}$ microdischarge in relatively strong magnetic fields ($\sim$1 T). We have used these discharges as microion sources [2] and micropropulsion devices [3] when operating at very low pressure (1 Pa) and on heavy gases such as xenon. In these previous studies, the electrons are strongly magnetized, the ions are nonmagnetized, and directed ion energies are as high as the applied discharge potential ($>$ 100 eV). In the images presented hereafter, we operated the discharge on a lighter gas (argon) and at higher pressure (20 Pa). Under these conditions, assuming a charge-exchange cross section of 6×10^{-19} m^2 [4], the charge-exchange mean free path is approximately 0.3 mm, and the average directed ion energy gained from the electric field between collisions is $\sim$30 eV. Subsequent collisions should thermalize these ions to less than 10-eV temperature. The lower ion energy and mass reduce the Larmor radius, so that it is of comparable scale to the strong magnetic field region ($\sim$2 mm). We then expect a plasma of moderate temperature that is partially confined by the magnetic field (confined electrons; weakly confined ions). This plasma should exhibit a number of instabilities that are characteristic of magnetized plasmas subject to strong gradients. As shown hereafter, this particular plasma exhibits large-scale azimuthal disturbances in emission that propagate along the negative $\mathbf{E} \times \mathbf{B}$ direction, likely due to fluctuations in plasma density. We attribute these to drift waves driven by gradients in plasma density ∇n. The plasma also exhibits finer scale turbulent features.

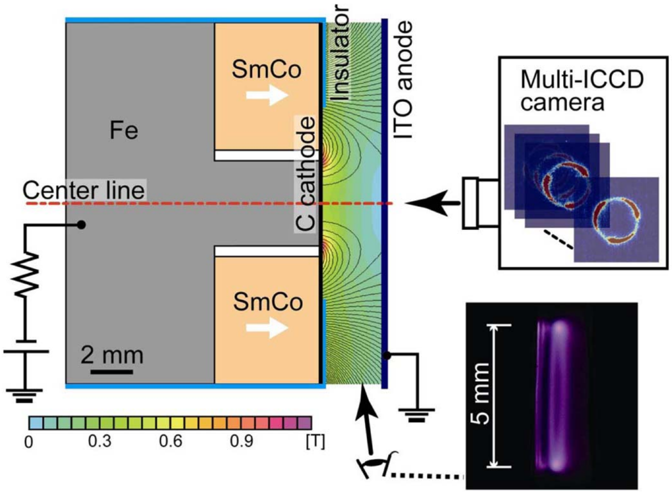

Fig. 1. Schematic diagram of the experimental setup of the plasma source and photograph (side view) of the discharge.

A schematic and photograph of this discharge, as seen from the side, are shown in Fig. 1. The plasma is generated in argon between two parallel electrodes comprising a graphite-coated thin (120 μm) cathode and an indium tin oxide anode. The discharge gap is 2.8 mm, and the pressure is 20 Pa. The cathode covers the magnetic circuit, which consists of a ring-shaped SmCo permanent magnet and an iron core for field shaping. The outer and inner diameters of the magnet are 17 and 5 mm, respectively, and the thickness is 5 mm. The outer diameter of the iron core inside the magnet is 4 mm. The simulated magnetic field is also shown in Fig. 1. The magnetic field is toroidal in shape, uniform in the azimuthal direction, but varying strongly between the cathode and anode, and is strongest ($\sim$1 T) near the region between the iron core and magnet.

High speed images are obtained through the anode with an ultrahigh framing rate camera (Cordin, model 222C-16UV), which has eight individual intensified charge coupled devices that can be triggered in sequence with as low as a 5-ns delay between frames. At a framing rate of 330 kHz or higher, a series of eight equally spaced images of the plasma can be obtained.

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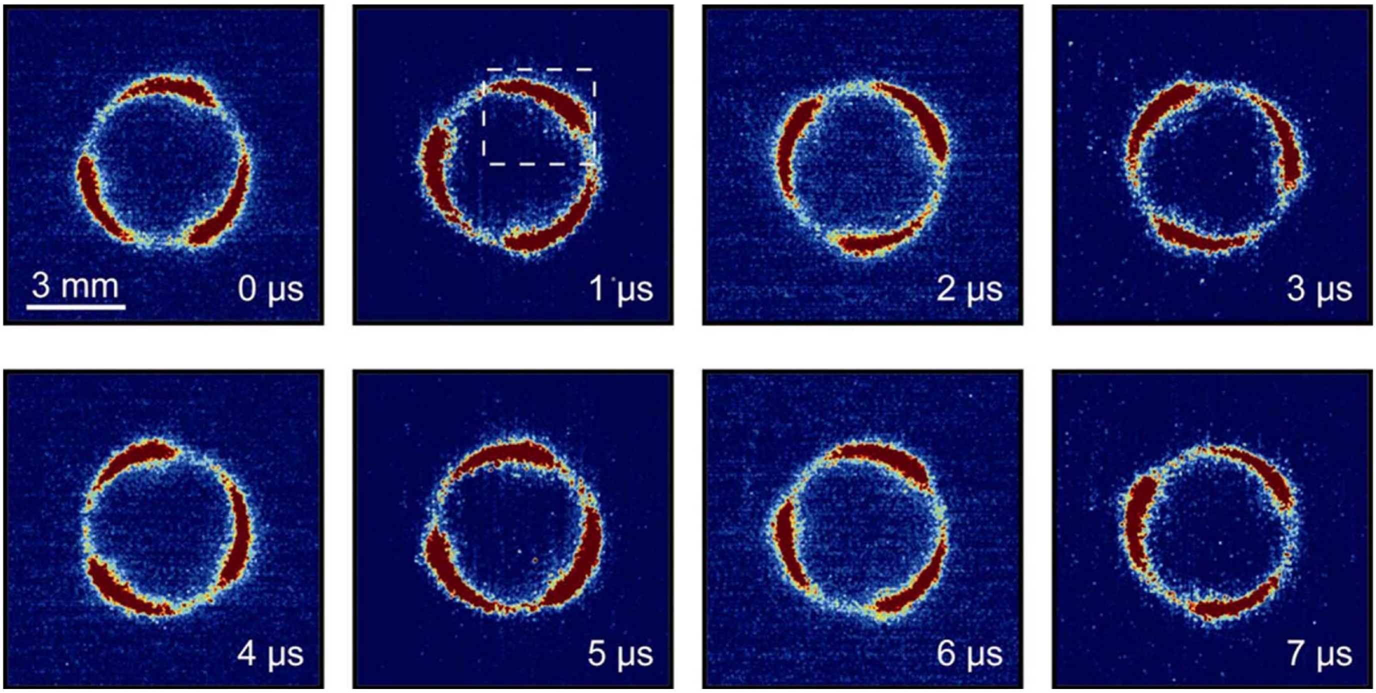

Fig. 2. Sequence of eight frames taken with an ultrahigh speed camera of the argon magnetized microplasma.

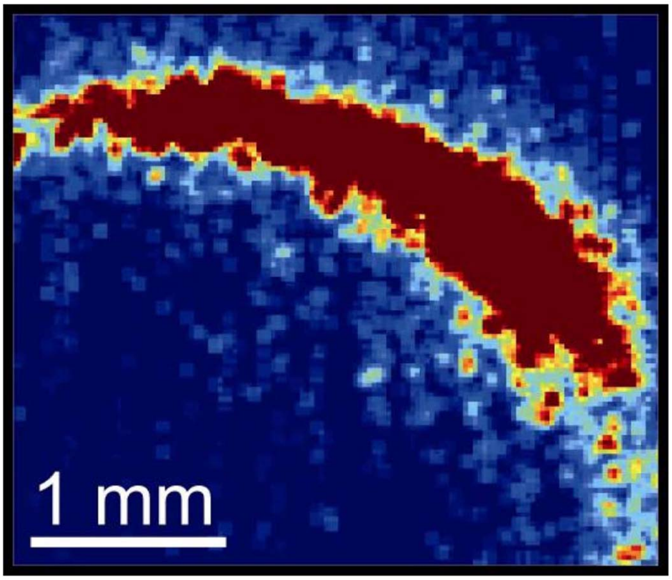

Fig. 3. Close-up view of the region shown in the second frame in Fig. 2, as defined by the dashed white boundaries.

This camera captures the dynamical behavior of this discharge, which is rich in both large- and small-scale disturbances.

Fig. 2 shows the eight sequential images (1 μs apart; 0.75-μs gate width) of the unfiltered emission from the discharge (operating at 277 V and 9.3 mA), spanning a field of 9.6 × 9.6 mm, containing a total of 1.5×10^5 pixels. The images are smoothed over the eight nearest neighboring pixels, resulting in a spatial resolution of 40 μm. Despite this, the features of scale lengths of < 200 μm are resolvable near the edge of the plasma, as seen in Fig. 3.

The images reveal the presence of a coherent ($m = 3$) azimuthal disturbance found to be propagating in the negative $\mathbf{E} \times \mathbf{B}$ direction. It is slightly nonlinear, with the intensity greater and wider in the leading edge. The wavelength is $\lambda = 5$ mm, and the disturbance makes a revolution around the azimuthal direction in 16 μs, corresponding to a phase velocity of 10^3 m/s, and a frequency $f = 0.2$ MHz. Such dispersion is consistent with the drift-wave instabilities driven by magnetized plasmas of electron temperatures of 1–10 eV and density gradient length scales $L_{\nabla n} = (\nabla n/n)^{-1} \approx 10^{-3}$ m [5]. All images reveal the presence of smaller scale features near the radial boundaries of the plasma, with dimensions that are longer along the radial direction ($\|$ to B) than in the azimuthal direction ($\perp$ to B). Ongoing experiments focus on capturing the dynamics of this finer scale turbulence. These images suggest that magnetically confined microdischarges might provide a useful test bed for the simulations of plasma confinement and turbulence in plasmas of moderate temperature.

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