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Plasma heating and acceleration in current sheets formed in discharges in argon

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Abstract. According to present notion, flares on the sun and other stars, substorms in magnetospheres of Earth and other planets, and disruptive instabilities in tokamak plasma are connected to development of current sheets in magnetized plasma. Therefore, current sheet dynamics and magnetic reconnection processes were studied actively during the last several decades. This paper presents the results of experimental studies of plasma heating and acceleration in current sheets formed in discharges in argon. The temperature and energy of directed motion of argon ions of different degrees of ionization were measured by spectroscopic methods. It was found that Ar II, Ar III and Ar IV ions are localized in different regions of the sheet. It was shown that Ampere forces applied to the sheet can accelerate the argon ions to observed energies.

The paper is concerned with measurements of the temperature and energy of directed motions of ions in laboratory current sheets formed in two-dimensional three-dimensional configurations with a singular X line in argon. According to theoretical notions [1], both thermal processes and plasma flows can play a decisive role in passing of a current sheet from the metastable to impulsive phase of magnetic reconnection [2].
The studies were conducted by spectroscopic methods to measure profiles of the Ar II 480.6 nm, Ar III 379.5 nm, Ar IV 280.9 nm spectral lines broadening due to Doppler Effect. The plasma radiation was collected and analyzed with the help of an optical scheme. The measurements were made in two mutually perpendicular directions, i.e. along the current (the z-axis) and along the width that is a larger size of a current sheet (the x-axis) [3-5]. The spectral line profiles were measured from the line intensity at the exit slit of a monochromator by scanning the spectrum with the help of a “Nanogate 1-UF”digital image intensifier [6]. This allowed us to measure the profile in one shot of the device.

For the current sheets formed in two-dimensional magnetic configurations (p = 28 mTorr, I_z = 45 kA, h = 0.5 kG/cm, B_z = 0), it was found that Ar II, Ar III and Ar IV ions of argon are localized in different regions of the current sheet, depending on their temperature. The Ar II ions are located in relatively cold plasma regions at the periphery with a maximum temperature T_i = (60 ± 15) eV, whereas the Ar III and Ar IV ions are located in hotter central regions of the current sheet with a maximum temperature T_i = (100 – 140) eV.

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For all spectral lines of argon ions, the FWHM (full width half maximum) values measured in the x-direction are great in comparison with the same lines measured in the z-direction. We interpreted this result to mean that the Ar II, Ar III, Ar IV ions participate not only in thermal, but also in directed motion. Such directed motion along the sheet surface (the x-axis) is interpreted as an effect of Ampere forces. It is found that all argon ions can equally gain excess velocity of directed motion $V_x \approx (2.5 \pm 0.3)\times10^6$ cm/s which exceeds the thermal velocity of the Ar II ion, but is less than (or equal to) the thermal velocity of the Ar III and Ar IV ions.

From magnetic measurements conducted under the same experimental conditions, it follows that the accelerated plasma flows with time intersect the regions of strong transverse magnetic field at edges of the current sheet and generate reverse currents in these regions [7,8]. Estimates show that the Ampere forces in a current sheet can accelerate argon ions up to the observed energies [9,10].

For the current sheets formed in the three-dimensional magnetic configurations (p = 28 mTorr, I_z = 45 kA, h = 0.64 kG/cm, B_z = 0 – 4.35 kG), we investigated how the temperature and energy of directed motion of the Ar II ions depends on the induction of guiding magnetic field B_z in the range = 0 – 4.35 kG. It was found that the temperature of the Ar II ions gradually decreases with increasing B_z from 0 to 1.45 kG: T_i = 31±3 eV is reduced to T_i = 23±2 eV. At the same time, the energy of directed motion of the Ar II ions increases but somewhat from W_x = 50±13 eV to W_x = 56±16 eV (within the limits of large experimental error). Above the point B_z = 1.45 kG, on the contrary, the temperature of Ar II ions increases and eventually reaches its maximum value T_i = 44±4 eV at B_z = 4.35 kG; the energy of directed motion of the Ar II ions is reduced to W_x = 31±14 eV.

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