# Polarization of the x-ray line emission of the plasma of a high-current pulsed discharge

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A polarization of the x-ray line emission of multiply charged iron ions in the plasma of a pulsed high-current discharge has been detected by means of Bragg crystal analyzers. This polarization is caused by a flux of epithermal electrons transverse with respect to the discharge axis.

The formation of local regions which are intense sources of soft x radiation in the plasma of high-current pulsed discharges of the $Z$-pinch type[1] is attributed to either a local pinch effect in the plasma column of the discharge to microscopic dimensions (a micropinch), as the result of so-called radiative contraction,[2] or the development of acceleration processes and a relaxation of an electron beam in a bounded volume of the plasma of the pinch.[3,4]

Experimental results show that, on the one hand, the observed dynamics of the plasma of a $Z$-pinch discharge which emits intensely in the x-range agrees with the model of radiative contraction,[5,6] while on the other hand there are pieces of evidence that point to the presence of epithermal electrons in the discharge plasma, which are moving along the discharge axis.[4,7]

An effective method for studying the parameters of the fluxes of epithermal electrons in a plasma medium is to measure the polarization of the x-ray emission. For example, measurements of the polarization of the bremsstrahlung x radiation from a laser plasma led to the observation of directed streams of electrons in this plasma.[8]

Calculations which have been carried out[9,10] on the excitation of lines of highly ionized ions in a plasma in the presence of a stream of high-energy electrons have shown that the line emission is polarized because of the different probabilities for the excitation of the $M$ components of the projection of the orbital angular momentum onto the direction of the electron stream. The degree and direction of this polarization differ from one transition to another. Measurements of the polarization of the x-ray line emission of multiply charged ions have been used successfully to study directed streams of electrons in the plasma of the solar corona.[9]

To determine the parameters of the dense, hot plasma in a high-pulsed discharge, one would ordinarily use spectroscopic methods. In particular, the electron temperature and density are usually determined from the relative intensities of a resonant line and its satellites in helium-like and hydrogen-like ions.[10,11]

In this letter we report a study of the line emission of the helium-like iron ion in a micropinch discharge with a steel anode.[6] The calculations of Ref. 9 demonstrate that

  

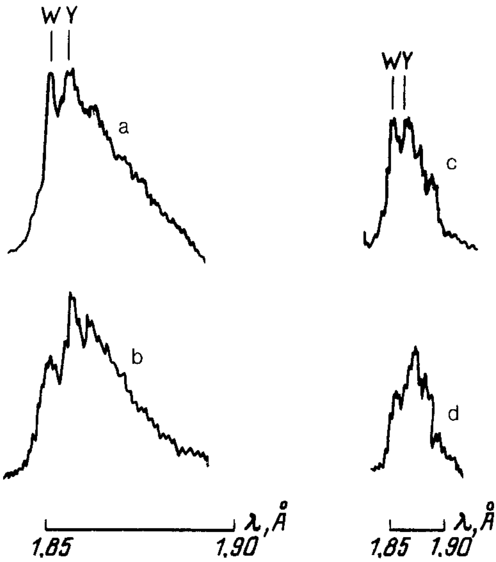


FIG. 1. Densitometer traces of the x-ray emission spectra of an iron plasma in a high-current pulsed discharge ($W$ and $Y$ are respectively resonant and intercombination lines of the helium-like ion) for various angles of the angle ($\varphi$) between the discharge axis and the plane of incidence and various values of the glancing angle $\theta$. a—$\varphi = 0°$, $\theta = 28°$; b—$\varphi = 90°$, $\theta = 28°$; c—$\varphi = 90°$, $\theta = 13°$; d—$\varphi = 90°$, $\theta = 52°$.

when epithermal electrons are present certain lines of the helium-like iron ion—the resonant line corresponding to the $1s2p^1P_1 - 1s^2\ {}^1S_0$ transition and an intercombinational line corresponding to the $1s2p^3P_1 - 1s^2\ {}^1S_0$ transition—are polarized. The polarization vector of the resonant line is in the same direction as the electron beam, while the polarization vector of the intercombinational line is directed in a way which depends on the energy of the electrons. The degrees of polarization of these lines are different and depend in different ways on the parameters of the electron beam.

The reflection coefficient of crystalline dispersive elements for polarized x radiation with a vector **E** which lies in the plane of incidence depends on the glancing angle ($\theta$) between the radiation propagation direction and the plane of the crystal.[9] The spectrum was analyzed with the help of Bragg crystals differing in lattice constant and in orientation with respect to the discharge axis.[9,12] The redistribution of the relative intensities of these lines in the measured spectra as the glancing angle $\theta$ or the angle $\varphi$, between the discharge axis and the plane of incidence, is varied is evidence that this radiation is polarized. Working from the calculations of Ref. 12, we estimate that there is a stream of epithermal electrons with energies of 7–30 keV in the discharge plasma at the stage in which helium-like iron ions exist. The density of this electron stream is on the order of 1% of the electron density of the plasma of the emitting region. Interestingly, the polarization plane of the radiation detected here corresponds to a stream of electrons which are moving for the most part in a direction orthogonal to the discharge axis. The apparent reason for this result is that at a discharge current on the order of 100 kA electrons with energies of 10–30 keV have a Larmor revolution radius which is much smaller than the dimensions of the emitting region (the micropinch), so they move predominantly along helical trajectories along the magnetic field lines, i.e., in a direction transverse with respect to the discharge axis.

The displacement of the same electrons along the discharge axis is of the nature of a drift in the nonuniform magnetic field, at a velocity two orders of magnitude below the velocity along the field lines. The cylindrical coordinate $\varphi$ will thus play a special role in the dectection of the emission from a plasma of cylindrical geometry carrying a current.

An estimate of the parameters of the epithermal electron component provides evidence that the dissipation of its energy in the pinch plasma cannot explain the observed plasma heating power in the micropinch region, but it may play an important role in the dynamics of radiative contraction, since the energy carried off by the epithermal electrons from the contracting region as a result of the drift motion is comparable to the energy of the axial outflow of plasma.

The observation of a polarization of the line emission of a highly ionized plasma is extremely important from the methodological standpoint. As was mentioned above, the parameters of the plasma of a high-current discharge are determined from the relative intensities of corresponding lines. Previous measurements of plasma densities and temperatures in discharges which were made without consideration of this effect should thus apparently be reexamined. Furthermore, the spectroscopic method should be optimized in the direction of reducing the effect of the line polarization on measurements of plasma parameters.

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