

# Spectroscopic Determination of Magnetic Fields in Pulsed-Power and High-Energy-Density Plasmas

Y. Maron<sup>ID</sup>, *Fellow, IEEE*, R. Doron<sup>ID</sup>, M. Cvejić<sup>ID</sup>, E. Stambulchik<sup>ID</sup>, D. Mikitchuk<sup>ID</sup>, C. Stollberg<sup>ID</sup>, T. Queller<sup>ID</sup>, E. Kroupp<sup>ID</sup>, G. Rosenzweig<sup>ID</sup>, B. Rubinstein, S. Biswas<sup>ID</sup>, V. Bernshtam, O. Nedostup<sup>ID</sup>, V. Litmanovich, V. Fisher, A. Starobinets, A. Fruchtman<sup>ID</sup>, *Senior Member, IEEE*, A. Fisher, V. Tangri<sup>ID</sup>, J. L. Giuliani<sup>ID</sup>, A. L. Velikovich<sup>ID</sup>, A. Dasgupta<sup>ID</sup>, *Senior Member, IEEE*, I. E. Ochs<sup>ID</sup>, E. J. Kolmes<sup>ID</sup>, M. E. Mlodik<sup>ID</sup>, S. Davidovits<sup>ID</sup>, N. J. Fisch<sup>ID</sup>, and M. D. Johnston<sup>ID</sup>

**Abstract**—We review spectroscopic methods developed for the determination of magnetic fields in high-energy-density (HED) plasmas. In such plasmas, the common Zeeman-splitting magnetic-field diagnostics are often impeded by various broadening mechanisms of the atomic transitions. The methods described, encompassing atomic transitions in the visible and ultraviolet spectral regions, are applied to the study of imploding plasmas (in a Z-pinch configuration) with and without pre-embedded magnetic fields, relativistic-electron focusing diodes, and plasma-opening switches. The measurements of the magnetic field in side-on observations of cylindrical-plasma configurations that are local in the radial direction despite the light integration along the chordal lines of sight are discussed. The evolution of the magnetic-field distributions obtained, together with the measurements of the plasma temperature and density, allows for studying the plasma dynamics, resistivity, and pressure and energy balance. In particular, for the Z-pinch, an intriguing question on the current flow in the imploding plasma was raised due to the observation that the current during stagnation

mainly flows at relatively large radii, outside the stagnation region. For the premagnetized plasma implosions, all three components of the magnetic field (azimuthal, axial, and radial) were measured, yielding the evolution of the current flow and the efficiency of the axial field compression, as well as the relation between the geometry of the field and the plasma rotation, found to develop in this configuration. The measurements in the relativistic electron diode are used to quantify the shielding of the magnetic field by the plasmas in the diode. Also described are the experimental and theoretical investigations of a nondiffusive fast penetration of magnetic field into a low-density plasma (in the plasma-opening-switch configuration).

**Index Terms**—Electron and ion Diodes, line-shape analysis, magnetic-field measurements, plasma opening switch (POS), plasma spectroscopy, polarization spectroscopy, pulsed-power systems, Z-pinch.

## I. INTRODUCTION

**T**HE determination of magnetic fields ( $B$ -fields) is