DPP19-2019-000117

Abstract for an Invited Paper
for the DPP19 Meeting of
the American Physical Society

Three-dimensional metal deformation and plasma formation driven by resistive inclusions[1]

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Understanding how electrical current flows through conductors is essential to a wide variety of applications, from magneto-inertial fusion to protoplanetary disk heating. The problem is complicated by the dependence of electrical conductivity σ on temperature, resulting in the Ohmic heating-driven electrothermal instability (ETI). Assuming current J flows vertically, ETI forms horizontal, hot striations in metals, and vertical filaments in plasmas. Striations seed the magneto Rayleigh-Taylor instability, which shreds apart metal in applications involving acceleration; filaments drive plasma formation, important in the design of next-generation pulsed power drivers. However, ETI theory does not address what seeds the striations/filaments, nor how horizontal striations transition into vertical filaments. In this work, we model current flow through a metal rod, using 3D MHD simulation, and show how J redistribution around a resistive inclusion can seed both striations and filaments. Initially, J amplifies around the inclusion's equator, driving enhanced Ohmic heating, which alters $\sigma(r)$, thus further modifying J. This feedback loop grows the inclusion transverse to J, forming a striation. The overheated striation later explodes, but due to J redistribution, the expanding plume develops asymmetrically, expanding vertically but focusing horizontally, thus forming the filament predicted by ETI. Hence, ETI-assisted plasma formation is a fully 3D process, occurring earlier and at 10X higher density than predicted by 1D simulation.

[1]Sandia National Laboratories is a multimission laboratory managed and operated by National Technology Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energys National Nuclear Security Administration under contract DE-NA0003525.