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Nonlinear electron and ion dynamics in the saturation of cross-beam energy transfer

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Cross-beam energy transfer (CBET) allows crossing laser beams to exchange energy. Understanding the nonlinear saturation of CBET, including effects of wave-particle interaction with ions and electrons, excitation of forward stimulated Raman scattering (FSRS), and speckle geometry, is important for controlling low-mode asymmetry in ICF implosions. The nonlinear dynamics of CBET for multi-speckled laser beams is examined using VPIC simulations under NIF-like conditions. The simulations show CBET saturates on a fast (~10s of ps) time scale through ion trapping and excitation of oblique FSRS in the seed beam. Ion trapping reduces wave damping and speckle interaction increases wave coherence length to scales much larger than the speckle width, together enhancing energy transfer, whereas ion acoustic wave (IAW) breakup increases wave damping and contributes to CBET saturation. The seed beam can also become unstable to oblique FSRS, which leads to beam deflection and a frequency downshift. FSRS saturates on fast (~ps) time scales by electron plasma wave self-focusing, leading to enhanced side-loss hot electrons with energy exceeding 300 keV. Such electrons may contribute to preheat but can be mitigated by introducing density gradients. Scaling simulations show that CBET, as well as FSRS and hot electrons, increase with beam average intensity, beam diameter, and crossing area, but that CBET is limited by excitation of FSRS, IAW breakup, and pump depletion. FSRS deflects the seed beam energy by >40% of incident beam energy and puts a few-% of incident beam energy into hot electrons. FSRS therefore limits the efficacy of CBET for symmetry tuning at late stages in the implosion and may account for some of the "missing energy" inferred in implosions with gas-filled hohlraums.
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