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Optically tunable proton acceleration in femtosecond ultraintense laser-foil interaction

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The rapid development, especially in the intensity and temporal contrast of ultraintense short-pulse lasers and the achievable technology of the nanometer materials have enabled new regimes of relativistic laser-plasma-interaction research and applications, such as laser-driven ion acceleration based on novel mechanisms, warm dense matter generation. A critical aspect of these is the initial spatial density distribution of the plasma for the ultrathin foil modulated by the laser prepulse, which significantly affects or dominates the laser energy absorption, hot electron generation, transport and then ion acceleration mechanisms or whatnot. For ion beam generated from the new-parameters regime of the laser-foil interaction, its spatial quality (uniformity and collimation) is particularly important for these applications and closely related to the plasma density state.

In this paper, we propose a hybrid acceleration scheme of relativistically induced transparence and sheath acceleration for controlling the properties of proton beam by using a femtosecond prepulse in high-contrast laser-foil interaction. Two groups of collimated protons with uniform spatial distribution are observed along the target normal direction and the laser propagation direction from vacuum-gapped double-foil target, respectively. Meanwhile, it is found that the flux density of proton beam emitted along the laser axis is enhanced via increasing the intensity of the femtosecond prepulse. Hydrodynamic simulations and 2D particle-in-cell simulations indicated that the plasma shutter foil becomes relativistically transparent during the interaction due to the optically tunable preplasma density state. As a result, the distribution of hot electrons at the target rear side is mainly deflected to the laser axis. The implications for ion acceleration driven by multi-petawatt laser facilities under this hybrid acceleration scheme are also investigated.

Primary authors: Dr WEI, Wenqing (Xi'an Jiaotong University); Dr YUAN, Xiaohui (Shanghai Jiao Tong University); Dr GE, Xulei (Shanghai Jiao Tong University); Prof. ZHAO, Yongtao (XJTU & IMP)

Presenter: Dr WEI, Wenqing (Xi'an Jiaotong University)

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