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Vacuum laser acceleration of super-ponderomotive electrons using relativistic transparency injection

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Table-top petawatt-class lasers can accelerate electrons to near-light speed over a very short distance. Accelerating charged particles using intense lasers has been an active area of research over the past few decades. Such laser-based compact accelerators have several potential applications including fast ignition, high energy physics, radiography, and secondary ion/neutron sources. Existing schemes of laser-based electron acceleration falls into two broad categories: (1) Laser Wakefield Acceleration (LWFA) that uses the wake plasma field (~ 10 GV/m) driven by the laser to accelerate the electrons and (2) Direct or Vacuum Laser Acceleration (DLA or VLA) where the injected electrons are directly accelerated by the intense laser field (> 10 TV/m). The grand challenge of VLA lies in how to properly load free electrons into the fast-varying laser field such that the injected electron remains within a given half cycle of the laser wave and sees a unipolar field for continuous acceleration. This requirement necessitates the injected electron to be pre-accelerated close to the speed of light before it can be captured and accelerated by the intense laser field. Recently, a breakthrough was made in VLA using a plasma mirror injector accelerating electrons to relativistic energies around 10 MeV. The present work demonstrate VLA of electrons up to20 MeV using a qualitatively different injection method that exploits the plasma relativistic transparency (RT) effect – where dense opaque plasma becomes transparent to the driving laser due to relativistic electron mass increase by driving a thin solid foil at normal laser incidence. When the laser interacts with a thin foil, superponderomotive electrons can be generated from VLA by using the novel RT effect as the injector. The experimental results show 20 MeV super-ponderomotive electrons from thin plastic foils (5 nm thick) undergoing RT injection and subsequent VLA. Therefore, this work not only solves an outstanding problem in VLA by demonstrating a viable injection method, but also provides insight into the electron acceleration in relativistically transparent plasmas which serves as the primary driver for laser-foil based ion accelerators, x-ray source, and relativistic optics. Here we demonstrate free-electron injection and subsequent vacuum laser acceleration of electrons up to 20 MeV using the relativistic transparency effect. When a high-contrast intense laser drives a thin solid foil, electrons from the dense opaque plasma are first accelerated to near-light speed by the standing laser wave in front of the solid foil and subsequently injected into the transmitted laser field as the opaque plasma becomes relativistically transparent. It is possible to further optimize the electron injection/acceleration by manipulating the laser polarization, incident angle, and temporal pulse shaping. Our result also sheds new light on the fundamental relativistic transparency process, crucial for producing secondary particle and light sources.

References

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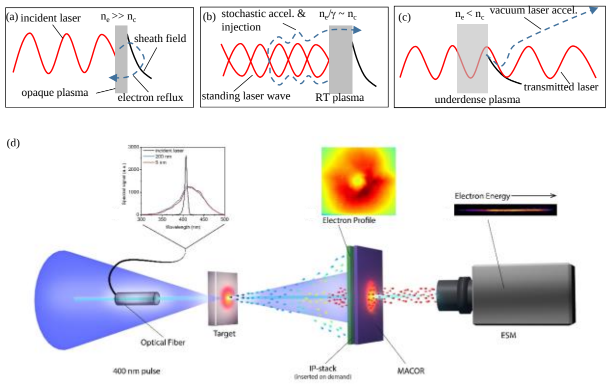

Figure 1 (a) Intense laser drives sheath field at rear of target that refluxes the electrons towards the incident laser. (b) The refluxed electrons undergo stochastic acceleration and get injected again at target rear. (c) Injected electrons undergo VLA in transmitted laser field. (d) few-nm thin targets are irradiated by 2ω, high-contrast, and high-intensity laser pulse at normal incidence. An optical fiber collects the light reflected from the target. The transmitted laser beam is captured by a calibrated MACOR sheet used as a calorimeter. The electrons, shown by tiny spheres, gain energy while co-propagating with the transmitted laser pulse, as indicated by a change of their color from blue to red. An electron spectrometer measures the kinetic energy spectrum of the on-axis electrons as they pass through a hole in the MACOR sheet.