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Laser wakefield electron temporal diagnostics via single shot electro - optic sampling

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概要

One of the main goals of the **ImPACT** program is to generate high energy electron beams from staged acceleration. To achieve energy gain, the electron bunches from injector should be incident into the booster stage at proper phases. Thus, the arrival timings of the electron bunches are of great importance. We for the first time introduce the **electro-optical (EO) spatial decoding** technique into laser wakefield acceleration (LWFA) [*T. Tajima and J. Dawson, Phys. Rev. Lett. 43, 267 (1979)*]. A temporal mapping relationship with generality was derived in a geometry where the signals had spherical wavefronts. We believe this method could be used as a single-shot timing monitor for laser plasma acceleration experiments. Part of the results have been published as **[*K. Huang et al., Scientific Reports 8, 2938 (2018)*]**.

方法

By introducing a EO crystal near the path of electron beam, the probe laser passing through the crystal will undergo birefringence in the exposure of the electron beam electric field. In this case, orthogonal components of the electric field will have phase retardation. By detecting the phase retardation, we can achieve the electron beam temporal information non-destructively in a single shot. [*S. Casalbuoni et al., Phys. Rev. ST Accel. Beams **11**, 072802 (2008).*] When introducing an angle between the probe laser and the electron path, the temporal information of the electron bunches are encoded to the probe laser profile transversely.

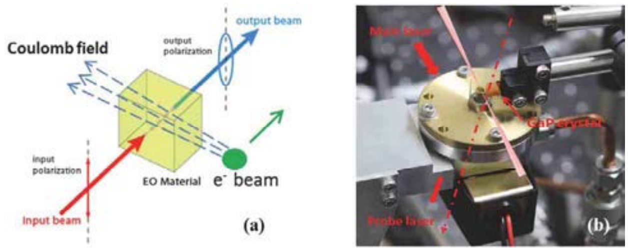

Fig. 1 ***Electro-optic method.*** (a) Linear polarized probe beam becomes elliptical polarized as a result of phase retardation. (b) By setting an angle between the probe laser and the electron path and placing the EO crystal close to the target, we perform the EO spatial decoding for LWFA.

結果

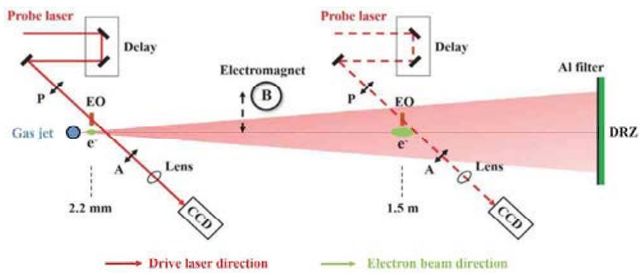

Fig. 2 ***Schematic of EO detection.*** The electron beam temporal profiles were measured at longitudinal distances of 2.2 mm and 1.5 mm from the gas jet exit to avoid damages to the crystal. The probe laser has an angle of 44 degrees to the electron path.

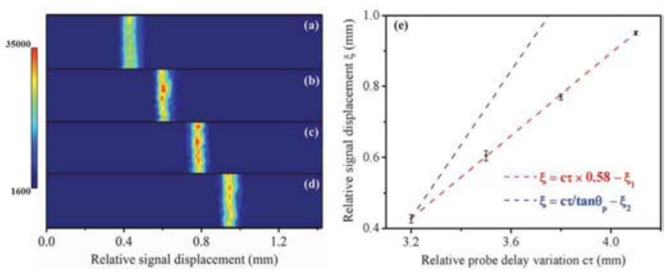

Fig. 3 ***Check on the temporal mapping relationship.*** (a-d) We measured the electron signal at 4 different probe delay settings. (b) We found that the detected timing relationship was quite different from a widely used model.

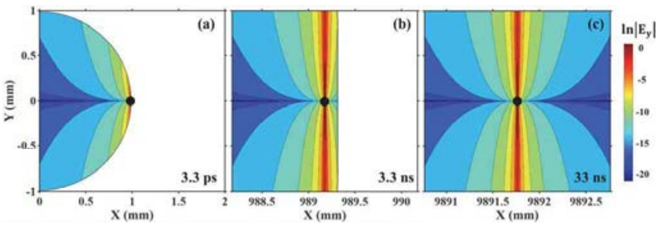

Fig. 4 ***The spherical wavefront Coulomb field of the electron bunches.*** (a) near the source position. The Coulomb field of the electron has a spherical wavefront; (b) at a propagation distance of 1 m; (c) after propagating over 10 m, similar as free space.

Due to the plasma shielding, coulomb field of the electron bunch possessed a spherical shape at the detection point, which is different from a widely used model considering the electrons propagating in free space. Based on this, we detailed discussed the temporal mapping relationship in three cases as below, in which (2) is applicable for LWFA.

$$(1)\, c\Delta\tau = \Delta\xi \tan\theta_p + \frac{L}{\cos\theta_{s0}} - \frac{L}{\cos\theta_{s0}}\sqrt{1 - \frac{2\sin\theta_{s0}\cos\theta_{s0}}{\cos\theta_p}\frac{\Delta\xi}{L} + \frac{\cos^2\theta_{s0}}{\cos^2\theta_p}\frac{\Delta\xi^2}{L^2}}$$ **[spherical wave]**

$$(2)\, c\Delta\tau = \left(1 + \frac{\sin\theta_{s0}}{\sin\theta_p}\right)\tan\theta_p\,\Delta\xi \quad (\Delta\xi \ll L)$$ **[Plane wave, with an incident angle θ_p]**

$$(3)\, c\Delta\tau = \tan\theta_p\,\Delta\xi \quad (\Delta\xi \ll L, \theta_{s0} \to 0)$$ **[Plane wave, free space]**

Notes: $\Delta\xi$ displacement on CCD, L longitudinal distance from crystal to target, θ_{s0} signal incident angle on crystal surface, θ_p probe laser angle to the electron path.

結言

For the characterization of the electron temporal information for the ImPACT program, we introduced the electro-optical spatial decoding method to laser wakefield acceleration. We succeeded observing the EO signal and measuring the electron energy spectrum simultaneously in a single shot. We discovered that the coulomb field of the electron bunch had a spherical wavefront near the target and deduced novel temporal mapping relationships for the application of this method. We demonstrated that this method could be a powerful tool for the monitoring of the electron timing in LWFA.

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