Intense Compression and Amplification of Attosecond Pulses by Laser Light Reflection from Relativistic Electron Mirrors

M.M. Škorić[1], M. Kono[2], Lj. Nikolić[3], Lj. Hadžievski[4], H. Sakagami[1] and S. Ishiguro[1]
[1]*National Institute for Fusion Science, Toki 509 5292, Japan*
[2]*Chuo University, Hachioji, Tokyo 192 0393, Japan*
[3]*Geomagnetic Laboratory, NRCan, Ottawa, ON, K1A 0Y3, Canada*
[4]*Vinča Institute, University of Belgrade, 11001 Belgrade, Serbia*

Advancing optical and electron beam technology toward the attosecond regime and high quality x-ray sources has opened new avenues in many fields of science [1]. Here, we study a compression to attosecond pulses by an incident laser reflection from a relativistic (β-velocity) electron plasma mirror (REM). Different concepts based on relativistic Doppler upshift on dense "monoenergetic" REMs aim to optimize laser backscattering on plasma wakefields [2-3] or ultra-thin solid foil electron sheets [1,4]. While most of the schemes utilize high-harmonics generation in ultra-relativistic intensity laser-plasmas, here we propose a model based on a linear laser pulse reflection from a REM [5]. A linear EM transient interaction with a collective REM's plasma is solved analytically by using Lorentz transformations, covariance of Maxwell's equations and principle of phase invariance to transform (two-fold); first, between the laboratory (rest) frame and the moving REM frame to solve a transient problem, and, then to transform results back to the laboratory frame [4,5]. Closed form time-dependent reflected fields for an obliquely incident laser pulse reveal large temporal compression and intensity amplification, for dense REMs, up to the factor of $(1+\beta)^2\gamma^2$ and $(1+\beta)^4\gamma^4$, respectively; where, $\gamma = 1/\sqrt{(1-\beta^2)}$ is the relativistic Lorentz factor. Above scalings are consistent with recent findings by [1]. Further, we compare analytical results with relativistic particle-in-cell (PIC) simulations for a variety of incident laser pulses and given REM parameters. Parametric analysis with analytical formulae is readily available for a future optimization of the scheme. As, for many applications single attosecond pulse is preferred, we study a half-period probe pulse, with a good agreement between PIC and analytical results. Finally, some ideas on proof-of principle experiments have been considered.

[1] D. Kiefer, et. al., *Nature Communications* **4**, 2775 (2013)
[2] J.T. Mendonca, et al., *J. Plasma Phys.* **58**, 647 (1997)
[3] S.V. Bulanov, et. al. *Phys. Rev. Lett.* **91**, 085001 (2003)
[4] J. Meyer-ter-Vehn, et. al., *Eur. Phys. J. D* **55**, 433 (2009); ibid., 443
[5] M.M. Škorić, et. al., *J. Plasma Phys.* **75**, 111 (2009); ibid., *Phys Scr.* T**149**, 014081 (2012)