Ultra-strong attosecond laser focus produced by a relativistic-flying parabolic mirror

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Abstract:

As the femtosecond (fs) high-power laser technology advances [1], the acceleration of charged particles and the generation of high energy photon with fs high-power laser pulses have been well investigated [2], and nowadays much attention has been paid to the quantum electrodynamic (QED) phenomena under an ultra-strong light field (known as the strong-field QED (SF QED) [3]). A high laser intensity of >10^{26} W/cm^2, corresponding to a laser power of >100 PW in the optical wavelength, is required for this purpose. Currently-available laser systems do not yet meet this light intensity through the direct focusing of the high-power laser pulse even with tight-focusing [4] scheme. And, even with a 100 PW laser pulse, it is difficult to observe the QED phenomena since the probability for the QED event is still low when $E < E_{Sch}$, where E_{Sch} is the Schwinger field.

Thus, the idea of using an ultra-relativistic probe particle under a relatively lower power laser pulse was proposed and pursued to observe the QED. Another interesting idea is to use a relativistic-moving laser focus reflected from a relativistic-flying parabolic mirror (RFPM) [5,6]. The RFPM is formed in the plasma medium as a part of the plasma cavity when an ultra-strong laser pulse ($a \geq 2$) propagates in an under-dense ($n < n_{crit}$) plasma medium. A secondary relatively-weak and counter-propagating laser pulse can be reflected and focused by the RFPM. In this case, due to the double Doppler effect, the laser frequency is upshifted by a factor of $4\gamma^2$ and the pulse duration of the laser pulse is reduced down to a factor of $1/4\gamma^2$. Thus, the RFPM having a higher γ-factor can be a promising plasma optic component to produce an ultra-strong attosecond laser pulse in the X-ray range, which can be potentially used for the SF-QED study.

In this presentation, we derive explicit mathematical expressions describing a three-dimensional (3D) field distribution of the laser focus formed by a RFPM. Since the RFPM travels with a relativistic speed, an incoming source laser pulse in the laboratory frame of reference is re-expressed in the boost frame through the Lorentz transformation. And then, a static (non-moving) focused field is calculated in the boost frame. Finally, through the inverse Lorentz transformation, a relativistic-moving laser pulse is fully described with mathematical formulas. Since the peak field strength of this laser focus is enhanced by the Lorentz γ-factor, two counter-propagating laser focuses are considered to examine the pair production occurring in the few tens of nm within attosecond time scale.

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