Theory and simulations of X-ray/XUV amplification in the optical lattice undulator

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Abstract

The scheme of XUV/X-ray free electron laser based on the optical undulator created by two overlapped transverse laser beams is analyzed. The kinetic theoretical and numerical descriptions account for the finite energy spread, angular divergence and the spectral properties of the electron beam in the optical lattice. The theoretical findings are compared with the results of the advance three-dimensional numerical modeling with the spectral free electron laser code PLARES.

Summary

Quest for a compact X-ray/XUV free electron laser joins efforts of researchers worldwide to explore the new ways to produce and undulate the beams of relativistic electrons [1]. Such developments can be based on the modern high intensity lasers, and this attracts growing interest thanks to numerous applications of the compact X-ray sources in science and medicine.

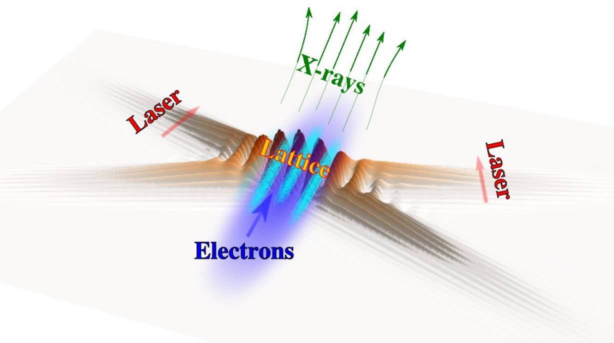

Fig *1:* Conceptual scheme of optical lattice interaction.

One possible prospect to produce a compact XFEL, is to replace the conventional RF linac with the laser plasma accelerator (LPA) [2,3]. The technology of LPA has already proved its capability to deliver pico-Coulomb femtosecond beams of MeV electrons, and has now reached the GeV level. Although the laser plasma accelerators now provide the necessary high electron flux, the level of collimation and monoenergeticity required for the X-rays amplification yet remains challenging. This motivates development of alternative schemes of a compact undulator.

In our work we explore the original scheme of an optical undulator, where relativistic electrons travel in the field of two twin laser pulses overlapped at a small angle. The laser interference forms an optical lattice that guides and wiggles relativistic electrons forcing them to emit and coherently amplify the XUV light (see Fig 1).

On the one hand, such electron guiding prevents electrons from diverging along one direction, thus, partially preserving the electron flux. On the other hand, the potential channels affect the collective behavior of the electrons predisposing them to a new mechanism of amplification similar to the stimulated Raman scattering [4]. Practically, such scheme involves the traveling-wave technique proposed in [5]. The traveling electromagnetic waves can co-propagate with electrons for a long distance, and therefore may provide a stable amplification.

We present kinetic theory and simple numerical models which give insight into the principles and properties of such amplifier. The theoretical findings are verified with the advanced three-dimensional numerical modeling. For this we use a recently developed unaveraged spectral free electron laser code PLARES [6]. The obtained results indicate that the optical lattice amplifier based on a commercially available compact laser can produce ultrashort pulses of bright XUV light on a centimeter interaction length.

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