THE FEATURES AND DESIGN OVERVIEW OF STATE-OF-THE-ART XFEL

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In the last decade, XFELs (X-ray Free Electron Laser) [1-3] have been constructed and operated in the world as the next generation of 3rd-generation synchrotron radiation sources. The underlying theory of a high-gain FEL has existed for three decades [4]. For VUV and XFELs, contrary to conventional optical lasers, laser cavity mirrors can no longer be applied due to their low reflectivities in normal incidence geometry and high absorption of their materials in the VUV and X-ray regions. Since a single-pass SASE (Self Amplified Spontaneous Emission) FEL operates in the high-gain regime, it does not require any optical cavity and it can be lasing in the VUV and X-ray regime.

In this lecture, the basic physics of SASE FEL will be explained in comparison to conventional optical laser and synchrotron radiation sources. The FEL radiation is explained in classical physics as interactions between radiation and electrons, and even simpler than the physics of conventional optical lasers. Conversely, the XFEL machine has more varieties (complicated) in technology. The XFEL consists of a high-brightness injector, a linear-accelerator (LINAC) and a long undulator section. Since the electrons in the FEL are not bound to ("free" from) atoms, and not limited to specific transitions between levels, the wavelength of the FEL is tunable over a wide range depending on accelerator energy and undulator parameters. These three main components are required for all of XFEL machines, but can be modified depending upon technological choice for aiming user experiments. There are three XFEL machines: Euro-XFEL (EU), LCLS (USA), SACLA (Japan), and all three are already operating or under construction [1-3]. The different choice of technologies of each facility will be compared with the performance of the machine. For instance, SACLA uses thermionic electron gun and sub-harmonic bunchers, which have a very high bunching factor (~ 3000) with velocity bunching in the low energy region and magnetic bunching in the high energy. The other XFEL facilities use laser-excited photocathode RF guns without any velocity bunching system.

Recently, the second generation of XFEL comes up as a seeded FEL scheme to improve the longitudinal (temporal) coherency. The seeding scheme has two major technologies. One is seeded directly with femtosecond-laser-driven HHG (Higher Harmonic Generation) [5]. It should be reliable for the soft X-ray region. The other is so-called "self-seeding", seeded simply with narrow-band-filtered SASE generated at the upstream part of undulator section (monochromatization of $\sim 10^5$) [6]. It is feasible for the hard X-ray region at present.

In the near future, we will have three "extreme" light sources: petawatt-class conventional optical laser, 3rd-generation synchrotron radiation source, and full-coherent seeded XFEL. These light sources are a complementary trinity to discover the dynamical nature of a variety of different materials, including the nature of life in vivo. The synergy users experiments utilizing those light sources will be openly discussed.

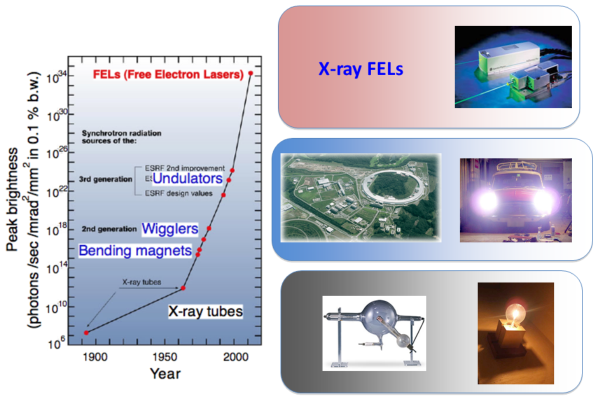

Figure 1: Historical developments of X-ray light source technologies

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