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## X-ray Free Electron Lasers (XFELs) and properties of XFEL radiation

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The Free Electron Laser (FEL) was invented by J.M.J Madey [1] in 1971 at Stanford University. The FEL radiation was produced by a relativistic electron beam moving through a magnetic wiggler that was also conceived at Stanford by H.Motz in 1951 [2]. The Original Madey's theoretical treatment was based on QED. It turned out however, that for most practical applications the classical treatment of radiation is sufficient. As a matter of fact, one of the most important XFEL parameters – the Pierce parameter – was introduced by J.P. Pierce in 1947 to describe the amplification process in Traveling Wave Tubes [3].

The first FEL operated at far infrared wavelength as an oscillator or an amplifier. Such schemes of operation limited the radiation wavelength to the UV range. This limitation was overcomed by the invention of Self Amplified Spontaneous Emission FEL (SASE FEL) theory by A.M. Kondratienko, E. Saldin, R. Bonifaccio and C. Pelegrini in the early 1980s [3,4]. This theory predicted that SASE FEL could produce a laser-like photon beam in the hard X-ray regime without the use of optical elements or a seeded beam. The SASE FEL principle was first demonstrated experimentally in the VUV regime at FLASH at Deutsches Elektronen – Synchrotron DESY in Hamburg in 2000 and in the hard X-ray regime at Linear Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory in 2009. At its birth the LCLS was the brightest X-ray source on Earth in the photon energy range 800 eV – 9000 eV. Soon after, in 2011, the SPring-8 Angstrom Compact Free Electron laser SACLA in Japan produced ultra-bright X-ray beam at 0.8 Angstroms. There are three other XFEL projects under construction in Germany (European XFEL), Korea (PAL-XFEL) and Switzerland (SwissFEL).

X-ray SASE FELs typically generate $10^{12}$ – $10^{13}$ photons in femtosecond pulses in the relative bandwidth of a fraction of a percent. Recently, seeded FEL schemes have been implemented at Electra FEL in Trieste in the XUV regime, and at the LCLS in the Soft and Hard X-ray regime. Seeded X-ray FELs have a potential of generating Terawatt X-ray pulses in a relative bandwidth that is better than $10^{-4}$.

In my talk I will present principles of operation of SASE and seeded XFELs. I will describe basic characteristics of XFEL radiation such as pulse energy, radiation spectrum, and temporal and spatial properties which also include coherence. I will compare the theoretical predictions with the experimental results. I will also refer to recent developments at the LCLS that allow generation of two pulses, multicolor SASE and seeded X-ray beams with a tunable delay time between the pulses. I will end my talk with a brief description of the LCLS II project.

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