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Editorial

X-ray Free-Electron Laser

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During the last decades, the advent of the short-wavelength Free Electron Lasers (FELs) in the range from extreme ultraviolet (XUV) to hard X-rays has opened a new research avenue for the investigations of ultrafast electronic and structural dynamics in any form of matter. FELs deliver coherent laser pulses, combining unprecedented power densities up to 10^{20} W/cm^2 and extremely short pulse durations down to a few femtoseconds. Thus, they offer important advantages over conventional short-wavelength light sources for many applications. Time-resolved spectroscopic and structural studies on the timescale of femtoseconds allow us to probe electrons and atoms in action. Indeed, FELs have been applied to study ultrafast charge transfer in a molecule and a molecular complex; chemical bond breaking and formation; and non-thermal phase transitions in solids. The intense, coherent and focused FEL pulses allows for the realization of single-shot diffraction imaging of non-crystalized biomolecules and nanometer-size objects. On the other hand, since the FEL pulses are entering a new regime of intensities, they are opening a new research field that involves studying the interactions between intense short wavelength laser pulses and various forms of matter. The extremely intense FEL pulse strips a certain number of electrons from an isolated atom, which leads to a violent Coulomb explosion of an isolated molecule. This instantaneously transforms a nanometer-size object into a dense nano-plasma and a single crystal into completely new disordered matter. Furthermore, rapidly developing FEL technologies allow fully coherent FEL pulses to be available routinely and permit the realization of pulse-shaping and phase-controlling of multi-color harmonic pulses. Thus, this has opened up other novel research areas of short-wavelength non-linear four-wave mixing spectroscopy and attosecond coherent control.

The aim of the present special issue is to provide an overview of the recent developments of XFELs and science at XFELs as well as to predict future opportunities. For this purpose, this issue features the reports on the current status and future plans of all eight XFEL facilities in the world. Namely, Faatz et al. describe the FLASH (the Free Electron LASer in Hamburg) in Germany, focusing on the advanced options for FLASH2 and future perspectives [1]; Schoenlein et al. describe the recent developments and future plans of LCLS (the Linac Coherent Light Source) in the United States [2]; and Yabashi et al. describe the status and future plans of SACLA (the Spring-8 Angstrom Compact free electron Laser) in Japan [3]. Giannessi and Masciovecchio discuss the present and future challenges at FERMI (the Free Electron laser Radiation for Multidisciplinary Investigations) in Italy, focusing on the phase-coherent multicolor pulse generations as a unique feature of FERMI [4]. Apart from these four facilities that have been in operation for the last decade, three new facilities started operations in the last couple years. This issue includes the first reports of these three facilities. Ko et al. describe the construction and commissioning of PAL-XFEL (the Pohang Accelerator Laboratory X-ray Free Electron Laser) in Korea [5]; Tschentscher et al. describe the photon beam transport and scientific instruments at the European XFEL (European X-ray Free Electron Laser) [6]; and Milne et al. describe SwissFEL (Swiss X-ray Free Electron Laser) [7]. In addition, Zhao et al. report the status of the Shanghai SXFEL (Soft X-ray Free Electron Laser) project in China [8].

The present issue also includes XFEL-pulse characterizations and instrumentations. Helml et al. review the progress on ultrashort pulse characterization of XEFLs [9], while Inbushi et al.

provide the measurements of the X-ray spectra of XFEL (SACLA) with a wide-range high-resolution single-shot spectrometer, which aims to measure the temporal pulse duration [10]. Szlchetko et al. describe a dispersive inelastic X-ray scattering spectrometer for XFELs [11], while Usenko et al. describe a split-and-delay unit for FEL interferometry in the XUV spectral range [12]. Kumar et al. discuss a plan for terawatt-isolated attosecond X-ray pulse generation using a tapered XFEL (PAL-XFEL) [13].

Science at XFELs is also included in this issue. Kukk et al. review the molecular dynamics of XFEL-induced photo-dissociation, placing emphasis on data analysis based on ion–ion coincidence measurements [14]; Wolf et al. discuss the observations from femtosecond fragmentation of the thymine molecule using ultrashort X-ray-induced Auger spectra [15]; and Fang et al. describe the X-ray pump-probe investigation of charge and dissociation dynamics in the methyl iodine molecule [16]. Callegari et al. describe the application of matched-filter concepts to the unbiased selection of data in pump-probe experiments with FELs [17]. Yamamoto and Matsuda review the measurements of the resonant magneto-optical Kerr effect using FEL [18]; Sun et al. review the current status of single particle imaging with XFELs [19]; and Mukharanova et al. discuss the methodology and analysis for probing dynamics in colloidal crystals with pump-probe experiments at LCLS [20]. Inada et al. review how to probe physics in a vacuum using XFEL, a high-power laser and a high-field magnet [21].

The theoretical developments related to the science of XFELs are also included in this issue. Hanks et al. report the two- and three-photon photoionization cross-sections of Li^{+}, Ne^{8+} and Ar^{16+} under XUV radiation [22], Tyrała et al. discuss the state-population narrowing effect on two-photon absorption for intense XFEL pulses [23], while Hatada and Di Cicco describe the modeling of non-equilibrium dynamics and saturable absorption induced by XFEL radiation [24]. Kirrander and Weber discuss the fundamental limits on spatial resolution in ultrafast diffraction with XFELs [25], while Kim et al. describe the algorithm for reconstruction of three-dimensional images of rice nanoparticles from the diffraction pattern of two particles in independent random orientations using XFEL [26].

Last but not least, this issue includes the meeting report by Larsson on a historic Nobel Symposium on Free Electron Laser Research, which was held in Stigtuna outside Stockholm in June 2015 [27]. During this symposium, the inventor of FEL, John Madey, delivered the keynote address. He passed away about one year later on 5 July 2016.

I believe this special issue will be helpful in providing an overview of the current status of XFELs and science at XFELs as well as future directions of this research field.

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