Working Group 4: FEL based sources

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Summary

With the recent LCLS success, the Working Group 4 discussion was particularly lively, as can be seen from the wide range of topics attached to this summary. The primary goal was to look to the future, with two primary missions:

a) Evaluate light source concepts and architectures that are beyond the state-of-the art
b) Evaluate concepts that could significantly change the economics of construction and operation of advanced light sources.

In addition, a joint session was arranged with the Science Working Group to begin a two-way dialog and create a multidimensional matrix of performance goals.

Various exciting FEL schemes for improving/extending the photon performance beyond the LCLS type SASE, for higher coherence, faster time resolution, polarization control, and wider spectral coverage, were presented and critiqued. In the soft x-ray range, the main trend is various seeded harmonic generation schemes, with the seed provided by infrared or high harmonic generation (HHG) conventional lasers. Alternatively, an oscillator making use of multilayer reflectors can produce soft x-rays without external seed, albeit with bandwidth and damage limitations. A scheme combining the echo-enhanced harmonic generation and multi-layer cavities was proposed as another option for tunable, coherent soft x-rays. For hard x-rays, femtosecond to atto-second SASE can be achieved with electron bunches of low charge (< 10 pC) and ultra-low emittance (< 0.1 mm-mrad). A self-seeded, single pass system can improve the SASE bandwidth to the 10^{-5} level. A major challenge for self-seeding for hard x-ray FEL is to introduce electron beam transport with a large delay to match the delay required for the x-ray monochromator. A straightforward way to overcome the difficulty is to accelerate two bunches with appropriate bunch spacing. Another option that produces fully coherent, ultra-narrow bandwidth (~ 10^{-7}) hard x-rays is an x-ray FEL oscillator (XFELO) employing an x-ray optical cavity consisting of diamond crystals. An XFELO requires ultra-low emittance, low charge (< 50 pC) electron bunches with megahertz repetition rates.

Advanced x-ray optics are required for various functions of x-ray FELs--for x-ray beam splitting, focusing, and reflecting in an x-ray cavity. The requirements of the LCLS applications are within the reach of the state-of-the-art grazing incidence, focusing mirror technology. The diamond crystals for an XFELO must satisfy stringent requirements on reflectivity, response to heat load, radiation damage threshold, and positional and angular stability. Some encouraging progress has been made recently.

Several options are possible for accelerators for short wavelength FELs. Normal conducting linacs are appropriate for pulsed SASE FELs up to about a kilohertz repetition rate. In particular, high-frequency linacs such as X band could be the basis of a compact and economic FEL facility. High repetition rate (>~ 10 kiloherz) including CW operation will require a superconducting RF linac.

FELs in an ERL configuration were discussed in a joint session with the ERL Working Group. The ERL-based sources operate at very high repetition rates (a few gigahertz), which are not an advantage for FEL operation, where megahertz and lower rates are more appropriate. However, the characteristics in the "coherence" mode of individual ERL electron bunches are similar to that required by an XFELO. The Japanese group proposed a 5 GeV ERL facility in which electron bunches at megahertz intervals are kicked into a recirculation mode to be extracted from the ERL loop and accelerated to 7.5 GeV to drive an XFELO. Recirculation could be used for an FEL facility based on SCRF linac to save the accelerator cost. Up to three recirculation passes appear feasible with tolerable beam quality degradation. Since the cost minimum is relatively broad, recirculation more than once may not be attractive, and there are several facility proposals for soft-x-ray seeded FELs making use of SCRF linac and one recirculation pass. However, given the fixed costs of the FEL beamlines, instrumentation, and experimental halls, even a single recirculation might reduce overall facility costs by only small fraction (~10%) while significantly complicating electron beam manipulations. However, a 10 % reduction in cost of a billion-dollar class facility is nontrivial.

Electron bunch manipulation will likely become more sophisticated in the future. An idea for improving electron beam emittance via a modified scheme of transverse-longitudinal emittance exchange was presented. A scheme in which the energy modulated bunch is compressed to obtain high-frequency modulation was discussed. The compression involves two stages of energy chirping in opposite directions to avoid a significant net energy chirp.

HHG with conventional lasers has made significant advances recently, and there is much promise for extension of its photon energy reach. Phase matched HHG in water window has been demonstrated using 2 μm laser, which can be scaled to a kilovolt and possibly to somewhat harder x-rays regions by means of a longer wavelength drive laser and a high-density, longer-length medium. Due to improvement of thermo-optical properties at lower temperature, cryogenically cooled Yb:YAG lasers enable high average power with excellent beam quality. A 500W CW oscillator has been constructed with the power limited only by the diode pump power. The laser intensity can be further enhanced in a high-Q storage cavity serving as the interaction point of a compact Compton backscattering source. The laser is also suitable for pumping OPCPAs for HHG generation by improved phase matching. Seeding of FELs at higher photon energies appears possible. Average power limitations of conventional lasers and the inherent inefficiency of HHG at shorter wavelengths, however, will prevent HHG from supplanting high repetition rate FELs in the soft X-ray region.

Studies are underway for a more comprehensive understanding of noise levels in seeded FELs. The power in the phase noise scales as n^2 for general seeded nth harmonic generation. Additionally, the interaction between particles may also reduce the seeded signal level. On the other hand, an appropriately designed modulator section in an optical klystron configuration may enhance the signal level.

In the joint session with the Science Working Group, the FEL contingent asked a simple question: "What's worth fighting for as we optimize FELs for performance and cost?" or alternatively, "What combination of photon range, repetition rate, pulse length, coherence, and resolution are needed for truly transformational research?" With input from this conversation, the Science Working Group did develop a multidimensional matrix. To summarize, three distinct light sources are seen: a) x-ray FELs with low repetition rates (variations on LCLS at <~ 1kHz) for single shot measurements, b) modest repetition rate x-ray FELs matched to pump lasers for high data collection rates (>~ 10 KHz), and c) high repetition rate x-ray FELs (~1 MHz) for high average flux experiments typical of condensed matter physics. All three would have a selection of other high performance characteristics of FELs such as short pulses and high coherence. Details are presented in the Science Working Group Report.

Working Group 4 Sessions and Talks

XFELO and x-ray optics:

> KJK (Intro), Lindberg (performance), XFELO optics (Shvyd'ko), XFELO simulation (Fawley), XFELO and EuroFEL (Zemella), State-of-the Art x-ray optics (A. Barty)

Short pulse:

> Overview (Rosenzweig), 8-48 keV at LCLS (Wu), Coherent SASE (Wang, presentation not available)

Joint session with the science working group

> IEX (Bergmann), Soft x-ray spectroscopy (Guo), Imaging (Jacobsen), Moessbauer effect (Cramer), Photoemission (Parmigiani), Parameter (Bisognano)

Soft x-ray oscillators and self-seeding:

> Overview (Benson), SXR Oscillator with echo enhancement (Wurtele), self seeding (Wu), optics for self seeding (Feng)

Joint session with the ERL working group:

> XFELO with ERL (Hajima), Recirculation design for FEL driver (Smith), Issues for recirculation (Borland), Seeded FELs in ERL (Douglas)

Reducing cost and new ideas:

Laser assisted EEX (Xiang), Pulsed versus CW (Wurtele), Elettra FEL2 (Fawley), X-band XFEL (Adolphsen)

Laser seeding and manipulation:

HHG Overview (Popmintchev), HHG scaling (Kaertner), High average power lasers (Fan), Flash seeding experiment (Rossbach), Short wavelength modulation (Qiang), Hard x-ray seeding (Ding), FEL efficiency and control (Wang, presentation not available), Noise (Lindberg), Noise (Stupakov), Increasing seeded FEL/noise contrast (Penn)