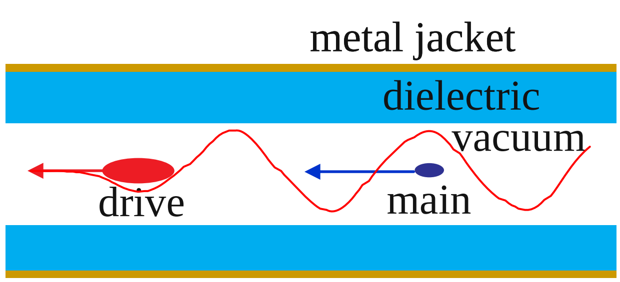
A Roadmap to Future X-Ray Lasers

Article written by J. Power and A. Zholents for the Argonne Management Blog: FOCAL POINT

Last week, twenty plus accelerator scientists gathered at Argonne to shape a roadmap to a future x-ray free electron lasers (FELs). Tremendously effective in the production of light, FELs are now actively moving into territory traditionally occupied by machines such as the Advanced Photon Source. They are poised to make a revolution in x-ray research by enabling cutting-edge experiments including time-resolved studies of matter with femtosecond (one femtosecond corresponds to millionth of a billionth second, 10^{-15} seconds) resolution and Angstrom scale spatial resolution, a dream of scientists who want to glimpse into the microscopic world of cells, molecules, and atoms.

Several facilities around the world are in a position to bring this revolution to life: the world's first, hard x-ray FEL at SLAC National Accelerator Laboratory; a new x-ray laser in Japan nicknamed "SACLA" (SPring-8 Angstrom Compact Free Electron Laser); and a new facility under construction in Hamburg Germany. Although it will take time to complete all the construction projects and fully explore the new capabilities provided by them, there is already a growing interest in the scientific community and machine builders to determine what should come next. As more and more scientists begin using these machines, the demand will soon exceed the capacity currently limited to only a few scientific instruments per FEL. Building additional machines is not an easy task since they are very large and expensive. This is where Argonne scientists think that they may be able to help by designing a more compact and possibly more economical machine.

For over two decades, Argonne scientists have been developing advanced technologies for acceleration of electrons for a future high-energy machine to study the fundamental Laws of Nature. From this research, the idea of the dielectric wakefield accelerator (DWFA) has emerged as one of the most promising approaches for rapid acceleration using high electric fields. Instead of conventional metallic radio frequency cavities, the DWFA uses hollow cylindrical dielectric structures inserted into a metal tube (as shown below), powered by a high-charge electron "drive" bunch whose main purpose is to excite strong electromagnetic waves in the structure. Trailing behind, a second low-charge "main" bunch navigates these waves and enjoys a speedy acceleration.



Schematic of the Dielectric Wake Field Accelerator.

Starting from the recent successful demonstration of the DWFA at the Argonne Wakefield Accelerator Facility, a new idea has emerged to use this state-of-the-art acceleration technology as the backbone of a future X-ray FEL. This is a double winning proposition. Not only does the DWFA reduce the footprint of the accelerator, afforded by the speedy acceleration, but it is also capable of supporting high bunch repetition rates, up to one million cycles per second with uniform bunch spacing. This is fundamentally different than what one finds in today's accelerators . The reason why this is possible is because the electromagnetic waves remain in the structure for only a very short period of time; long enough for the main bunch to "see" the accelerating fields, but short enough so that the structure doesn't overheat from the electromagnetic fields.

On the contrary, in today's accelerators the electromagnetic fields remain inside the radio frequency cavities for a long time and, therefore, one must choose between either operating at low repetition rates to avoid the overheating problem or using expensive superconducting technology where these cavities operate at a close to absolute zero temperature. The unique capabilities of DWFA make it to be a perfect candidate to work in tandem with either a large array of FELs, each servicing several scientific instruments with up to hundred thousand X-ray pulses per second or supporting a single X-ray FEL oscillator, recently proposed by Argonne scientists, providing up to a million X-ray pulses per second.

What is currently envisioned is a relatively compact, 300 to 400 mega-electron volt superconducting linear accelerator to generate drive bunches to power several DWFAs that will in turn accelerate low-charge main electron bunches up to an energy of several giga-electron volts. The main beam energy must be sufficient to produce Xrays in a short-period, small-gap undulator. The proposed superconducting linear accelerator utilizes a relatively mature cavity and linac design borrowed from a linac design for the International Linear Collider that was developed by the international community with Argonne participation. The short-period undulator requires further development, but as soon as the permissible undulator gap drops to match the small gap of the DWFA, several techniques for building such an undulator start to look realistic.

Overall, these ideas and developments may lead to a compact multi-user X-ray FEL facility. This was a subject of intense discussions at the workshop by Argonne accelerator scientists and participating accelerator scientists coming from other national laboratories (BNL, FNAL, LANL and SLAC), universities (Berkeley, NIU, UMD, UCLA, Columbia) and industry (Euclid Concepts). The workshop was extremely productive and helped to clarify key research technologies that need to be demonstrated before a compact X-ray FEL could be planned and built as a multi-user facility.

Workshop website: https://twindico.hep.anl.gov/indico/conferenceDisplay.py?confId=428

Light Source Note LS-326 by C. Jing, J. Power, and A. Zholents:
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