Advanced Accelerators and Light Sources for Industrial Applications

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The advanced accelerator systems and advance light sources hitherto confined to R&D programs in Universities and National Laboratories are approaching technology readiness levels where insertion into industrial, medical, and security markets has become a possibility. These new types of accelerators and light sources, developed under the realm of the High Energy Physics (HEP) accelerator technology roadmap, include laser-plasma-accelerators (LPA), inverse-free electron lasers (IFEL), plasma-wakefield accelerators (PWFA), dielectric laser accelerators (DLA), free-electron lasers (FEL), inverse Compton scattering (ICS) radiation sources and plasma betatron radiation sources, as well as laser driven ion sources. In this paper we discuss challenges but also potential avenues of industrial implementation for some of these concepts.

If one is to distinguish the advanced technologies from more conventional accelerators in the most general terms, the “advanced” processes as a rule imply much higher power densities (such as achievable with modern ultrafast lasers and plasmas), and also occur on a much faster timescale. Advanced beam sources, as well as advanced light sources, may achieve very high brightness and energy in a compact footprint, but this comes at the expense of maintaining a tight control over the 6D phase space properties of the beams, and also overcoming many parasitic effects associated with high energy density systems (i.e. CSR, or breakdowns at media boundaries).

At the same time, there is a large industrial market for accelerators, presently served by mature technologies such as linacs and cyclotrons. The most widespread applications include radiotherapy, medical equipment sterilization, cargo inspection, food irradiation, and medical isotopes production, which together represent a large and dynamic industry. It is illustrative to the scale of this market, that just recently Varian was acquired by Siemens for $15 billion, and Varian only serves a fraction of the global market for commercial accelerator-based systems. To make an entry into this market, advanced accelerator and light source technologies have to achieve cost of ownership (CoO), reliability, throughput and ease of use that are comparable to conventional accelerators, and that is a very difficult proposition, with the notable exception of high gradient normal conducting and SCRF linac technologies mature enough to be adopted as more energy efficient or compact solutions in some niche applications (i.e. isotope production, water purification, or FLASH radiation therapy).

On the other hand, emerging accelerator technologies may offer new high added value opportunities unattainable elsewhere, and aligning these capabilities with the market needs should become the focus of the industrial insertion during the coming decade. One such example is FEL technology, which was very successful in revolutionizing the synchrotron radiation light sources landscape but has not yet produced any visible impact in industry. The unique advantages of FELs with respect to more conventional solid-state lasers include continuous tunability from THz to hard X-rays and also the ability to achieve very high average and peak powers at the same time. Industrial processes that can take advantage of these features include directed energy, THz applications, EUV lithography, and other high throughput micro-materials applications requiring source wavelengths outside the range of the solid state and excimer lasers. EUV lithography for the semiconductor industry alone represents a multi-billion dollar market opportunity. The biggest obstacle to FEL insertion into these markets is the fact that most of the existing FEL facilities are large and expensive installations, designed to satisfy research users' needs. A purpose built industrial FEL system would require over an order of magnitude reduction in cost, as well as improvements in efficiency, reliability and adaptability of the technology by non-expert users. The specific technical advances to reach these goals include: improving e-beam to light conversion efficiency through advanced seeding and undulator tapering techniques, various schemes to make FELs more compact (i.e. the use of cryo-RF, LPA or IFEL drivers, and short period undulators), electron beam energy recuperation schemes (i.e. ERL), and other means to bring the CoO and practical convenience of using the FEL system in line with industrial standards.

Another area of interest includes gamma ray and X-ray ICS sources. ICS sources produce hard X-rays and gamma rays which offer superior spectral purity and directionality compare to widely used X-ray tubes and bremsstrahlung sources. In the gamma ray range, the ICS properties are unique and unmatched by any other technology. Developing ICS gamma ray sources for such applications as nuclear resonance fluorescence (NRF), inspection and radiography, photoionization therapy, and specific action isotope production is practically within the reach of the ICS source technology today, and there are multiple ongoing initiatives to bring this technology to the market.

Other opportunities include DLA-based "accelerator on the chip" developments, laser-driven compact ion sources for radiation therapy, radiography, and radiation hardening of the space born electronics, as well as ultra-fast electron sources and beam manipulation techniques for time-resolved microscopy and ultrafast electron diffraction systems.

In all these technical areas, the market insertion of the advanced technologies developed within HEP ecosystem has the potential to disrupt many existing and emerging market segments that are currently either not using accelerators at all or relying on conventional accelerators. The HEP community has been incubating and supporting advanced accelerator and light source concepts since the 80s and transforming some of these technological advances into new viable solutions for practical applications is a worthy goal for the upcoming decade.