Electron-Beam Based Coherent Radiators and Traditional Lasers for Security and Defense

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Abstract
A broad spectrum of electromagnetic radiation from many sources continues to serve the security and defense communities. Light sources used for laboratory-based materials investigations to field-based asset defense will be discussed.

Summary
Generation of incoherent and coherent radiation from the mm-wave band to gamma-rays using electrons as well as, over a more limited wavelength range, traditional lasers have numerous applications in security and defense. Further, other charged and neutral particle beams also have utility in these fields. Examples of the utility of photon and particle beams in these disciplines will be provided.

Synchrotron light sources, free-electron lasers, and coherent electron radiators
Synchrotron light is nothing more than the electromagnetic radiation emitted when relativistic particles, typically electrons, are accelerated. The term synchrotron describes the circular machine in which such radiation was first observed. Due to the Lorentz contraction and the Doppler shift, the synchrotron radiation is emitted in a narrow cone in the forward direction, tangent to the particle's orbit. This light is unique in its intensity and brilliance as well as bandwidth in that it can be generated from the infrared to the hard x-ray region. Synchrotron light source facilities, such as the Stanford Synchrotron Radiation Laboratory [1], are located around the world. Synchrotron light sources are used for a variety of applications. One example of the ability of synchrotron light sources is in to determining speciation in trace quantities. This is due in part to the beam brightness and tunability. This speciation has helped, among other things, in the development of environmental remediation methods for challenging mixed waste [2]. Another example application is the use of hard x-ray methods, such as x-ray line-profile analysis, to provide input for crystal-plasticity analyses of metals, such as titanium for aerospace uses [3]. A final synchrotron radiation example is the use of photoemission spectroscopy to probe the decay mechanisms of semiconductor photocathodes such as those used in night-vision while in elevated vacuum or under high power laser illumination [4].

Free-electron lasers (FELs) are a step beyond the standard incoherent synchrotron light source and arise from stimulated emission of virtual photons by a relativistic electron beam in the presence of a magnetic undulator or wiggler (array of alternating polarity dipole magnets). An analogy exists with conventional lasers exploiting the stimulated emission in an atomic/molecular system where population inversion exists. The key thing about this type of laser as opposed to traditional lasers is the continuous tunability of this coherent emitter. Depending on the electron beam energy and the strength of the undulator/wiggler, the central wavelength can be chosen. Further, the power of FELs, because of the coherent emission, is orders of magnitude higher than synchrotron radiation sources. FELs are in operation from the so-called "Terahertz" regime [5], to the infrared regime [6], to the EUV to soft x-ray [7], to the hard x-ray [8], and are proposed for the very hard x-ray [9] to gamma regimes (Compton-backscatter) [10]. Examples of applications in security and defense are many. For instance, materials that cannot be crystallized could not be examined with conventional synchrotron light, but because of the high power of FELs in the hard x-ray, one can observe the structure in one shot in the non-crystalline form. A specific example is a human protein that requires its structure to be known in order that a pharmaceutical could be developed. Another example is the FEL weapon led by the Office of Naval Research (ONR) that will provide ships with speed-of-light fire capability [11]. Such an FEL provides optimal wavelength and precision engagement of high speed, sophisticated anti-ship missiles, as well as swarming, slow speed, unsophisticated small craft.

Conventional Lasers

One example use of a high-power infrared conventional laser, much like the uses for the FEL, is a speed-of-light weapon. Several programs have been highlighted in the recent years, including the Joint High Power Solid State Laser Program (JHPSSL) and Maritime Laser Demonstrator, the first successful laser weapon lethality demonstration from a U.S. Navy ship in April 2011 [12]. Other areas for potential applications are being pursued by the AFOSR include ultrashort pulse laser-matter interactions, such as the AFOSR (Air Force Office of Scientific Research) program [13]. This program has three main concentrations: Optical frequency combs (ultra-wide bandwidths), high-field laser physics (high peak powers), and attosecond science (ultrashort pulsewidths).

Long-wavelength sources

One example of a long-wavelength source is the so-called, "Active Denial" that produces a focused RF beam of 95-GHz energy [14]. This beam produces an intolerable heating sensation, compelling the targeted individual to instinctively move out of the beam. There is minimal risk of injury due to the shallow energy penetration into the skin at this short wavelength. It can stop, deter, and turn back suspicious individuals with minimal risk of injury.

Other source examples

Neutron sources for neutron activation analysis are important for detecting trace elemental signatures in complicated matrices, including chemical warfare agent simulants, aqueous media, and multi-layered materials [15].

DARPA is focusing on x-ray sources in its "Advanced X-ray Integrated Sources (AXIS)" program [16]. The goal is advancing x-ray source technology only found today at large electron synchrotrons that will enable phase-contrast imaging for high resolution of low-Z materials such as soft biological tissues. DARPA is pursuing miniaturization of accelerator and laser technologies to drive this program. Deployment in military field hospitals or on selected military platforms to improve combat casualty care as well as imaging capabilities is expected.

[1] http://www-ssrl.slac.stanford.edu/

[2] L. Skubal et al., "Mercury transformations in chemical agent simulant as characterized by X-ray absorption fine spectroscopy, Talanta 67 (2005) 730–735.

[3] T. Ungára et al., "Burgers vector population, dislocation types and dislocation densities in single grains extracted from a polycrystalline commercial-purity Ti specimen by X-ray line-profile analysis," Scripta Materialia, Volume 63, Issue 1 (2010) 69–72.

[4] F. Machuca et al., "Role of oxygen in semiconductor negative electron affinity photocathodes," J. Vac. Sci. Technol. B 20, 2721 (2002).

[5] See, for example, Institute for Terahertz Science and Technology, University of California, Santa Barbara, http://www.itst.ucsb.edu/

[6] See, for example, G.R. Neil et al., "The JLab High Power ERL Light Source", Nucl. Instr. & Methods A557 9 (2006).

[7] See, for example, E. Allaria, et al., "Highly coherent and stable pulses from the FERMI seeded free-electron laser in the extreme ultraviolet," Nature Photonics, Nature Photonics 6 (2012) 699–704.

[8] See, for example, H. Loos, "Operational Experience at LCLS," Proceedings of FEL2011, Shanghai, China, 166-172.

[9] http://marie.lanl.gov/

[10] C. Barty, private communication on MEGa-ray (mono-energetic gamma-ray) facility planned to operate between 1 and 8 MeV at Lawrence Livermore National Laboratory.

[11] See, for example, Office of Naval Research FEL fact sheet. http://www.onr.navy.mil/en/Media-Center/Fact-Sheets/Free-Electron-Laser.aspx

[12] See for example, High Energy Laser, Joint Technology Office (HEL-JTO), "Light on the Horizon, Recent Developments and Current Projects in HEL Technology," June 2012; R. O'Rourke, "Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress," Congressional Research Service, R41526, March 2013.

[13] R. Parra, "Ultrashort Pulse Laser-Matter Interactions Program Overview," 2 April 2013.

[14] See, for example, The DOD Non-Lethal Weapons Program Active Denial fact sheet, http://jnlwp.defense.gov/pressroom/adt.html.

[15] L. Skubal, private communication.

[16] http://www.darpa.mil/Our_Work/MTO/Programs/Advanced_X-Ray_Integrated_Sources_(AXiS).aspx