RECENT DEVELOPMENTS IN COMPACT X-RAY AND GAMMA-RAY SOURCES BASED ON INVERSE COMPTON SCATTERING

<u>B. HORNBERGER</u>
Lyncean Technologies, Inc., Fremont, CA, USA

J. KASAHARA
Lyncean Technologies, Inc., Fremont, CA, USA

Inverse Compton scattering (ICS) can generate high-flux, energy-tunable, narrow-band, collimated beams of X-rays or gamma-rays in a compact setting [1,2]. It works by scattering laser photons off relativistic electrons, whereby the electrons transfer part of their energy to the photons and up-shift their energy to the keV or MeV range. Fig. 1 illustrates the principle of ICS and plots the energy of the X-rays or gamma-rays vs. electron energy for the operating ranges of the CLS and CGS systems described below.

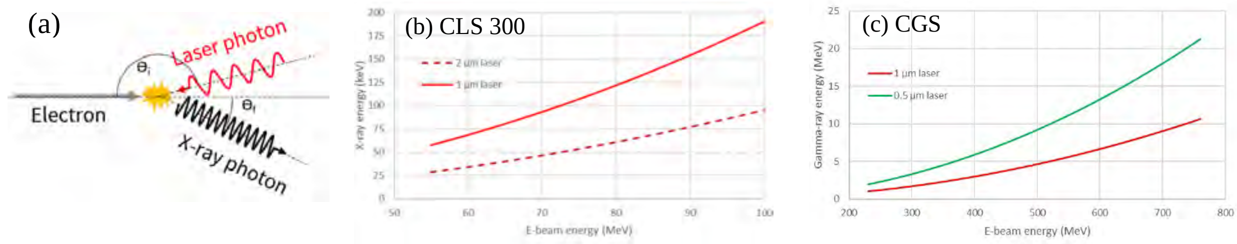

FIG. 1. (a) Principle of inverse Compton scattering. (b) X-ray and (c) gamma-ray energy as a function of electron energy.

The Lyncean Compact Light Source (CLS) [3] bridges the large performance gap between conventional and synchrotron X-ray sources, providing high flux and brightness, collimated, energy-tunable and quasi-monochromatic X-rays in a local laboratory. It enables a variety of techniques such as X-ray imaging, diffraction, spectroscopy and scattering with synchrotron-like capabilities. At the Munich Compact Light Source (MuCLS) [4,5], a Lyncean CLS has been operating in a user facility since 2015, with a research focus on biomedical imaging (see, for example, references in [3,5]). An application example is shown in Fig. 2.

A new design, the CLS 300 [6], is more than two orders of magnitude brighter than the MuCLS. Depending on configuration, it covers an X-ray energy range of about 30-90 keV, or 60-180 keV. It will provide X-ray flux of >4 x 10^{12} photons/s with a beam divergence of 4 mrad and a bandwidth around 10%. This is well-suited for high resolution, micro-CT imaging of millimeter-sized samples at micron resolution, with a flux density similar to some high-energy synchrotron beamlines. The beam properties of the new design are also compatible with focused beam applications such as high-energy diffraction, since using a lower divergence part of the beam with lower bandwidth allows the use of several types of X-ray optics commonly used at synchrotron beamlines. Furthermore, it provides a pathway to clinical implementation of radiotherapy requiring collimated, narrow-bandwidth, energy-tunable beams, such as microbeam radiation therapy (MRT).

FIG. 2. (a) Photograph of the Lyncean Compact Light Source. (b) Example of a dynamic in vivo imaging application from the Munich Compact Light Source, showing delivery of liquid instillations to the nose of a mouse (adapted from [7], Creative Commons License).

Monochromatic, tunable gamma-ray beams with high spectral density (flux/eV) are of interest for many applications [8,9]. Since no monochromators exist for gamma-rays, such beam properties must be generated at the source, and ICS is the only practical method to do so. Lyncean Technologies is currently developing the Compact Gamma-ray Source (CGS). The first CGS will be installed as the Variable Energy Gamma (VEGA) System at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP), a European Center of Excellence for scientific research in high-power lasers and nuclear physics in Romania (http://www.eli-np.ro).

Upon completion, this gamma-ray source will have about an order of magnitude higher flux and a factor of two lower bandwidth than the current state of the art. It will deliver gamma-rays with continuously variable energy from 1 to 19.5 MeV, covering the energy range relevant for low-energy nuclear physics and astrophysics studies, as well as applied research in materials science, management of nuclear materials, and life sciences. The beam will be quasi-monochromatic with a relative bandwidth of <0.5%, high intensity with a spectral density of >5 x 10^3 ph/eV/s and linear polarization of >95%.

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