Multi-bunch Operation of a Laser-Compton X-ray Source Based on Compact X-band Accelerator Technology

D. J. Gibson, G. G. Anderson, Y. Hwang, R. A. Marsh, and C. P. J. Barty
Lawrence Livermore National Laboratory, 7000 East Ave. L-592, Livermore, CA 94550
gibson23@llnl.gov

Abstract: Multi-bunch operation of a 35 keV, laser-Compton x-ray source in which a single laser pulse interacts with a train of closely spaced electron bunches is demonstrated for the first time.
OCIS codes: (290.3200) Inverse Scattering

1. Introduction

Laser Compton-scattering based x-ray sources have advantages over traditional x-ray sources that include being easily tunable, having a narrow bandwidth, and offering a small source size (and therefore high imaging resolution). These features enable applications such as k-edge contrast imaging, and, since such sources scale efficiently in scattered energy, allow for imaging of high-density materials at high resolution.

For many of these applications, the biggest issue is ensuring sufficient flux. Because only a small amount of the drive RF and the scattering laser photons are used in the Compton-scattering process, an efficient method of scaling up the flux is to generate electron bunches within each RF pulse, spaced by the RF period. The scattered X-ray flux scales roughly as the electron beam current.

LLNL has recently commissioned a compact laser-Compton-scattering based x-ray source built around X-band accelerator technology. This source performance has been initially characterized, and is presented here. Furthermore, four-bunch bursts of electron have been generated and used for x-ray generation, showing the expected increase in output flux.

2. Laser Compton source architecture

The system is based on a specially designed X-band photoinjector [1] and a single T-53 accelerating section [2]. The system is powered by an XL-4 klystron [3] providing over 50 MW of peak RF power, which allows for an output electron energy of 30 MeV. The electron bunches are generated at the copper photocathode by a 150-fs, 261-nm laser pulse provided by an Amplitude Systems Titanium:Sapphire system. The UV pulse is passed through a hyper-Michelson pulse stacker [4] to generate 4 replicas of the pulse with an 87.5 ps spacing, corresponding to the period of the 11.424 GHz drive RF. Ultimately, this system will be replaced with a custom-build, fiber-based laser capable of generating a few hundred UV bunches, locked to the drive RF frequency [5].

For this demonstration, the interaction laser is a Continuum Powerlight 8010 DLS, providing 750 mJ of 532 nm light in a 6 ns pulse. The temporal overlap between the interaction laser and the 2-ps electron beam pulse formats is poor, resulting in roughly a factor of 1000 reduction in the expected flux compared to using a few-ps long laser pulse. However, it is sufficient to demonstrate the performance of the machine relative to simulations.

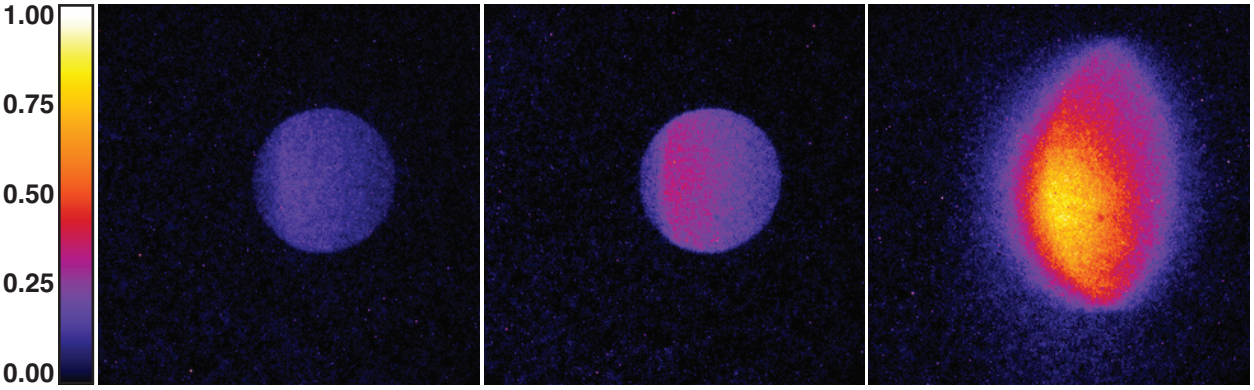

Fig. 1 X-ray images with one, two, and four electron bunches interaction with the laser. The one and two bunch images include an alignment aperture that clip the beam which was removed for the four-bunch image.

3. X-Ray results

X-rays were detected via a 145 µm thick CsI(Tl) scintillator grown on a fiber optic plate. This plate was mounted to a 3:1 image reducing fiber bundle which was in turn mounted to the input faceplate of an Andor iStar ICCD camera. Fig. 1 shows beam images with one, two, and four bunches, and demonstrates the linear scaling of the flux with total charge that is expected when interacting with a long laser pulse. Calibrating the response of the imaging system with a ^{129}I source, our early estimate of the total scattered flux produced by a single 80 pC bunch to be approximately 200,000 photons, or about 30,000 photons in the 14 mrad diameter cone observed on the screen. This result matches well with simulated results based on integrated models of the electron beam dynamics and overlap integrals with the laser.

To get a quick check of the energy and bandwidth of the source, we tuned the beam to peak around 26.5 keV, and placed a silver foil, with a k-edge of 25.5 keV, in the beam. Because of the correlation between the spectrum and the angle, on-axis x-rays are at a higher energy than off-axis x-rays, so are above the k-edge and absorbed. Fig. 2 shows the resulting beam image, which shows good agreement with the simulated image. The measured image is the result of 100 consecutive 30 s integrations of the x-ray beam on the CCD, or about 50 minutes of continuous operation, which indicates good long-term stability of the electron and laser systems.

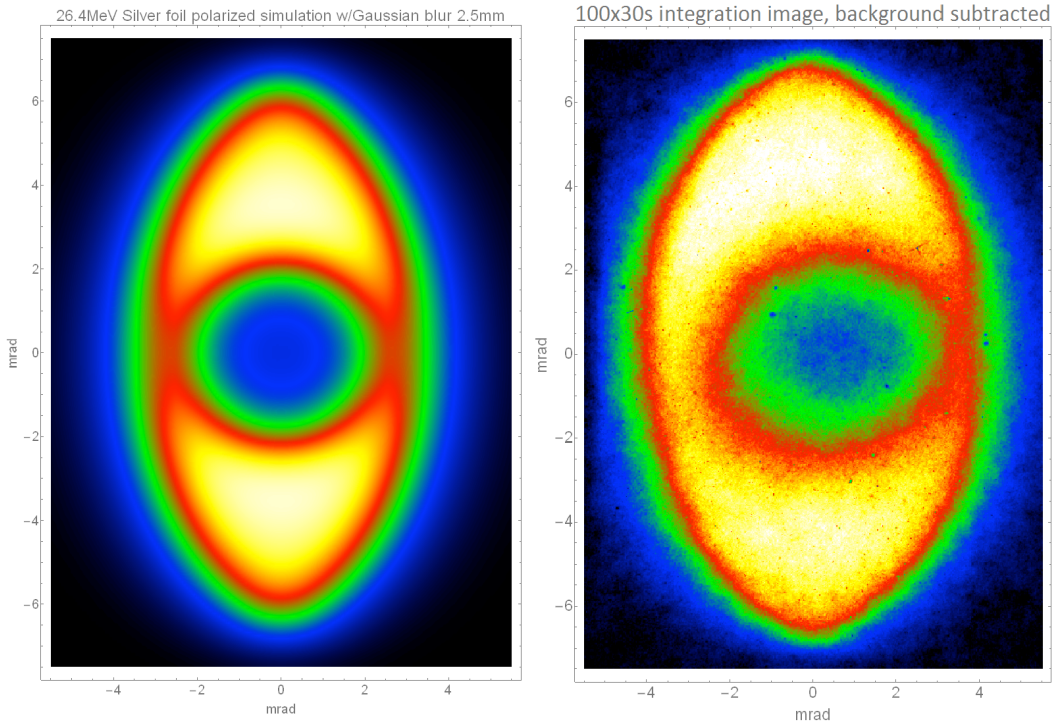

Fig. 2 Simulated and measured x-ray beam profiles after passing through a silver foil that absorbs the high-energy center x-rays.

4. Acknowledgements

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

5. References

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