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The 4th Generation Light Source at Jefferson Lab

S. Benson, G. Biallas, J. Boyce, D. Bullard, J. Coleman, D. Douglas, F. Dylla, R. Evans, P. Evtushenko, A. Grippo, C. Gould, J. Gubeli, D. Hardy, C. Hernandez-Garcia, K. Jordan, J. M. Klopf, W. Moore, G. Neil, T. Powers, J. Preble, D. Sexton, M. Shinn, C. Tennant, R. Walker, S. Zhang and G.P. Williams

Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA, 23606, USA

Abstract

A number of “Grand Challenges” in Science have recently been identified in reports from The National Academy of Sciences, and the U.S. Dept. of Energy, Basic Energy Sciences. Many of these require a new generation of linac-based light source to study dynamical and non-linear phenomena in nanoscale samples. In this paper we present a summary of the properties of such light sources, comparing them with existing sources, and then describing in more detail a specific source at Jefferson Lab. Importantly, the JLab light source has developed some novel technology which is a critical enabler for other new light sources.

Introduction

We begin by presenting a summary of the landscape of light sources, so that the context of the present source can be seen. Fig. 1 is a generic plot of peak and average brightness for 2nd, 3rd, and 4th, generation sources using the parameters specified. As a reminder, 1st. generation light sources operated parasitically on electron synchrotrons that were built for particle physics; 2nd. generation light sources are based on dedicated electron storage rings; 3rd. generation storage rings are similar to 2nd. generation but with the addition of long straight sections for specialized magnetic structures called wigglers or undulators and with lower emittance electron beams. Finally, 4th. generation light sources are usually based on linacs, some of which incorporate energy recovery[1-3], in which electrons circulate only once, allowing them to be bunched more tightly both laterally as well as longitudinally than those in storage rings. In addition to the lower emittance, in some 4th generation sources, including the one described here, multiparticle coherence also plays a role in increasing the brightness[4,5]. Of course linac-based sources have been around for some time[6,7], and what’s new here is a new generation of machines with much average as well as peak electron beam currents, with lower emittances, pushing the sources to higher power and brightness and to shorter wavelengths[3,8,9].

The Jefferson Lab Light Source

The Jefferson Lab light source facility is based on an Energy Recovered Linac[2,3], and is shown schematically in Fig. 2. In this machine, electrons are created in bunches by photoemission from a cesiated GaAs wafer, injected into the superconducting linac at up to 10 MeV, and accelerated up to 150 MeV. The electron bunches are then compressed in a magnetic chicane from which broadband THz light is extracted. Following this, the electron bunches traverse an undulator at the center of a 32 meter long optical cavity of a Free Electron Laser (FEL) and emit tunable narrow-band light. In the FEL, about 1% of the electron energy is extracted. As example parameters, if the electron beam current is 10 mA (135 pC per bunch at 75 MHz) at 100 MeV, then the electron beam energy is 1 MW and the extraction 10,000 W. The electron beam still carrying 99% of its energy is then re-circulated back into the linac, but out of phase, so that it decelerates, giving up its energy to the cavity. The energy is used to accelerate future bunches. The spent electrons are dumped at the injection energy of up to 10 MeV. Using energies below 10 MeV ensures little activation of any parts of the accelerator.

The light source as described offers infrared beams that are at least 8 orders of magnitude brighter than storage ring sources due to multiparticle coherence[4,5,10]. In addition, since the electron beams circulate only once, the electrons can be made to occupy a much tighter volume of phase-space than in a storage ring, where electron-electron repulsion spreads them out. In ERL's the horizontal and vertical sizes are essentially the same, rather than the former being ~ 100 times the latter as in storage rings. In our case the FWHM values of the transverse and longitudinal electron beam sizes are ~ 300 microns. This implies sub-picosecond pulses, and opens up additional opportunities in ultra-fast time-domain spectroscopy, both linear and non-linear.

Major technical advances that enable such a light source are the superconducting linear accelerator structures, which can run cw rf, and in which the energy can be stored without significant loss, and photocathode driven electron guns of low emittance. The availability of multiple synchronized photon beams is an added feature that has already been used for novel electro-optic detection[11] leading to measurements of propagating electric fields, with knowledge of phase. Such techniques will bring new dimensions to spectroscopy and imaging, as well as allowing studies of out of equilibrium dynamics.

We present generic calculations of the average spectral power output of the JLab facility [3] in Fig. 3. In this figure we show other light sources for comparison. We note that the brightness of these machines is close to what would be obtained using an emittance of λ^2. Further, the peak brightness is at least 10^4 times higher than the average due to the duty cycle of 1ps every 10 ns. At Jlab we have obtained bunches shorter than 300fs FWHM to date.

Summary

We have described a new generation of light source that started operating as a user facility in 2000[2], and in the present machine configuration[3] in 2005. The machine is based on same-cell energy recovery, a low emittance photo-cathode gun, and a superconducting linac, with each electron making a single trip around. The output of this machine is based almost entirely on multiparticle coherent enhancement which boosts the output power of the circulating current of 10 mA up by about 8 orders of magnitude over a storage ring even though the latter may circulate many 100's of mA. It is to be expected that ERL's will slowly increase in brightness as higher beam currents are used. Also, it is fair to say that operating experiences with ERL's are different than storage rings. There are different sources of noise, for example, as well as different utilization of multiple photon beams for time-resolved out of equilibrium pump-probe experiments[12]. Even the multiplicity of the user operations is different, but our experiences so far are that our ability to conquer noise, and our cost metrics, are similar to those of storage rings.

Acknowledgements

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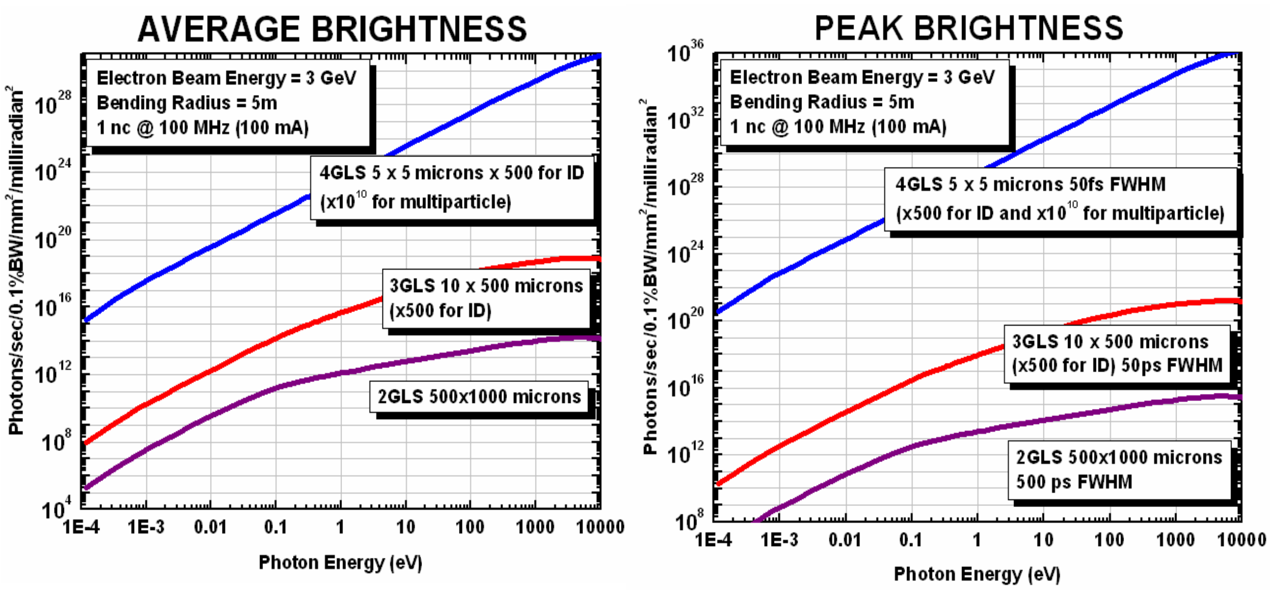
Figure Captions

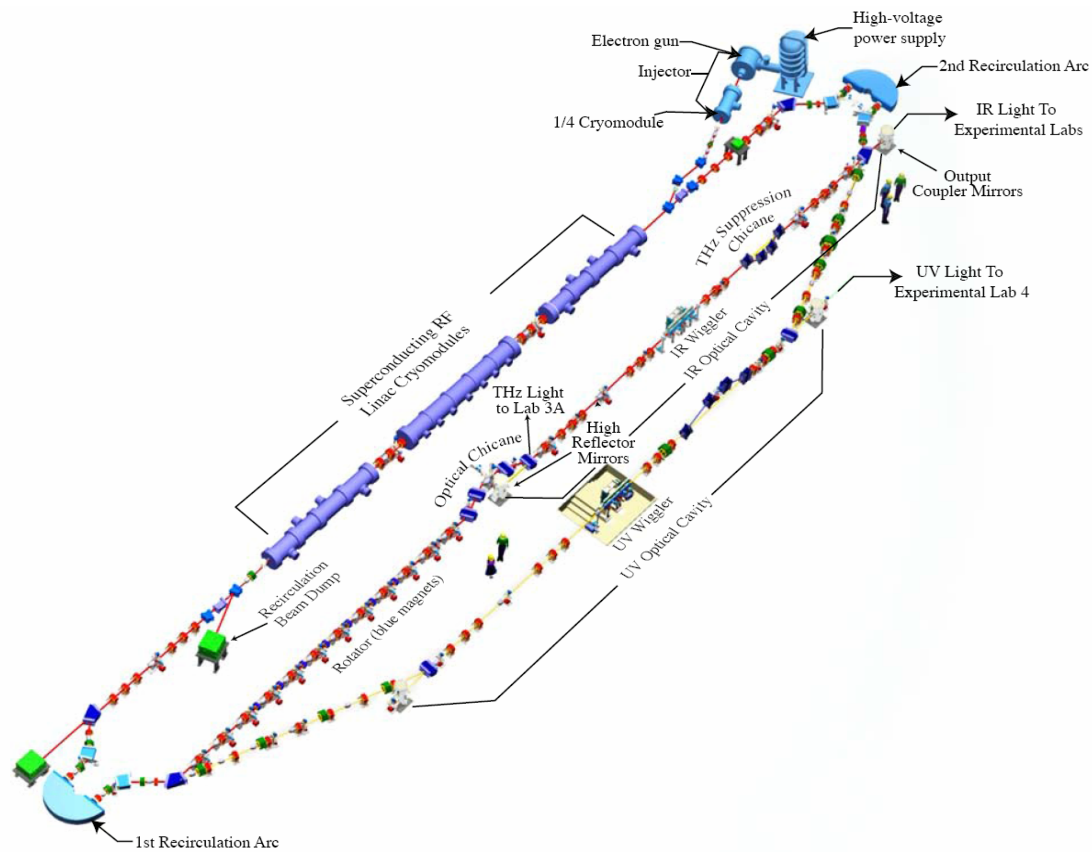
Fig. 1. Generic plots showing the landscape of average and peak brightness of accelerator-based light sources.

Fig. 2. The energy recovering linac accelerator that is operating as a light source at Jefferson Lab, offering sub-picosecond narrow band Free Electron Laser beams and broadband THz beams at repetition rates up to 75 MHz.

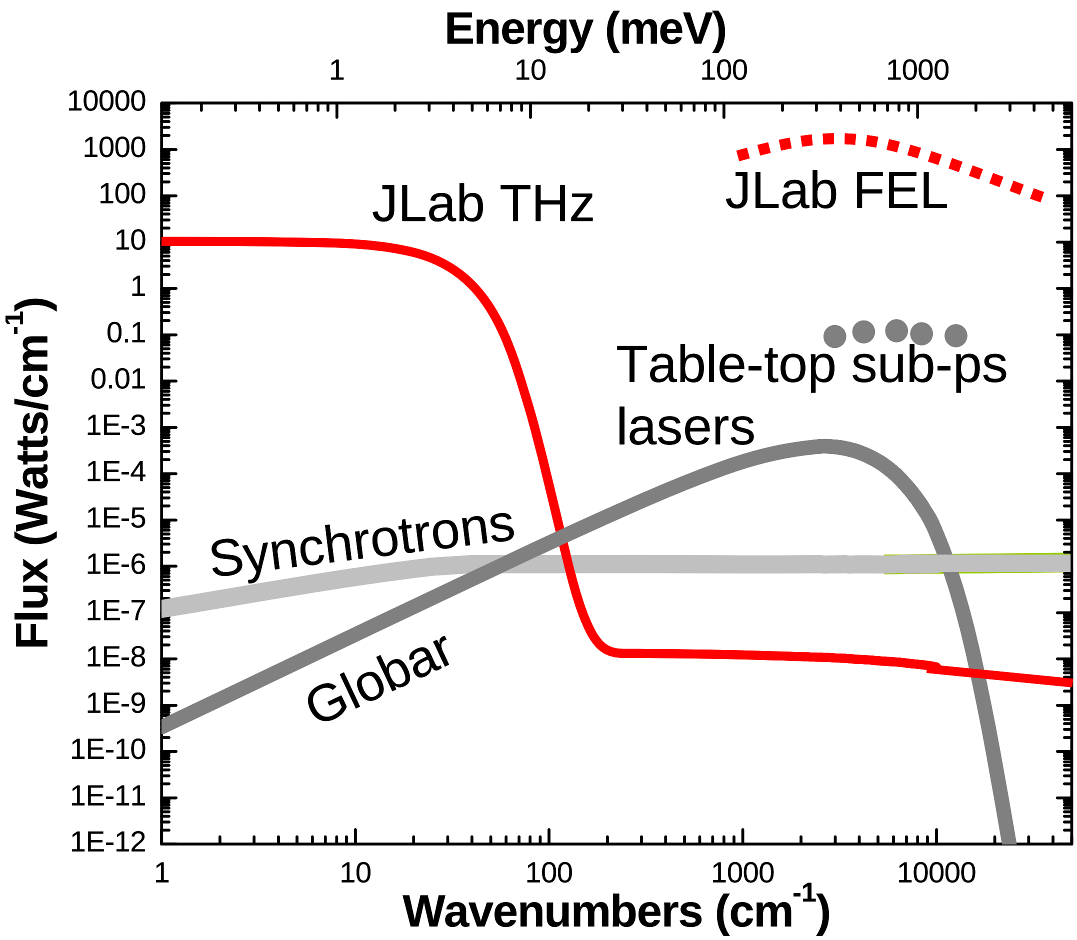
Fig. 3. Output spectra (average power) calculated for the energy recovering linac based light source at Jefferson Lab. The THz beam is broadband, but the Free Electron Laser beam is narrow-band. The dashed line on the chart shows the tuning range for this latter case. Globar, synchrotron and table-top lasers are shown for comparison.



G.P. Williams et al. Fig. 1.



G.P. Williams et al Fig. 2.



G.P. Williams et al Fig. 3.