Inverse Compton Source for EUVL Metrology

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Introduction

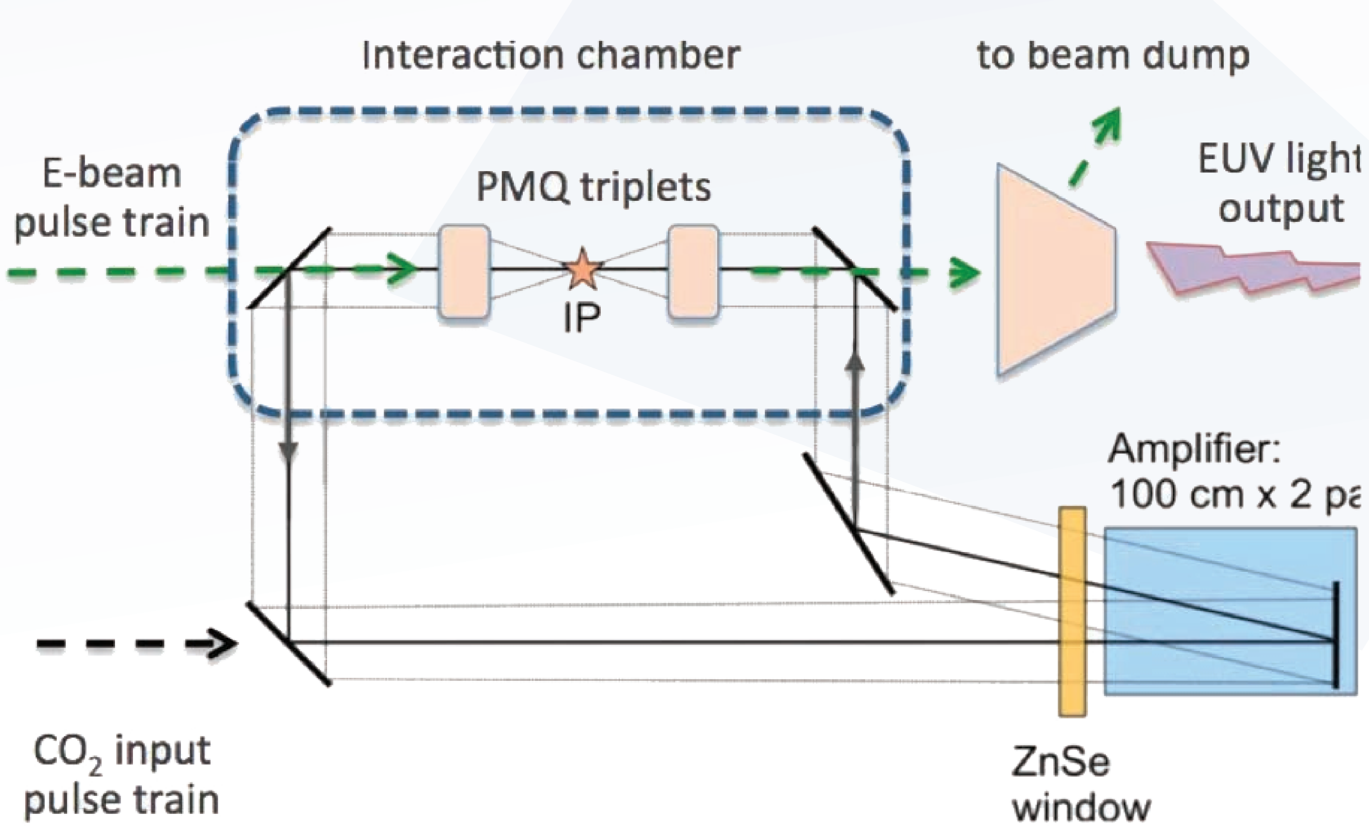
RadiaBeam Technologies has been actively involved in the development of high repetition rate Inverse Compton Scattering (ICS) X-ray sources since 2008, and is currently conducting a pilot experiment on an ICS system scalable to Extreme Ultraviolet Lithography (EUVL) wavelength range, in collaboration with the Accelerator Test Facility at Brookhaven National Laboratory.

The idea of an ICS EUVL system using a CO2 laser has been previous proposed by others (Madey et al, 2009; Sakaue, Urakawa et al., 2011) where it was proposed to achieve high average power EUV ICS flux by incorporating superconducting radio frequency (RF) beam source and the so-called "supercavity" for the CO2 laser recirculation. Herein we propose a different technical approach, based on the high repetition rate normal conducting RF photoinjector and active CO2 laser cavity, which compensates the laser re-circulation optical losses via re-amplification.

The end use EUVL ICS dedicated system would be a relatively inexpensive and compact source with brightness of ~ 100 W/mm2-sr-0.1% at 6.7 nm wavelength, suitable for EUVL metrology applications.

Design Overview

A short train of intense picosecond CO2 pulses ~ 10 ns apart enters into the active optical cavity and propagates through the interaction chamber multiple times to interact with the long electron beam pulse train, generating Compton EUV-photons output at about 100 MHz (10 ns pulse trains) repetition rate for the duration of the macropulse.



$$\lambda_r \approx \frac{\lambda_l}{4\gamma^2}\left[1+\frac{a_L^{\ 2}}{2}+(\gamma\theta)^2\right]$$

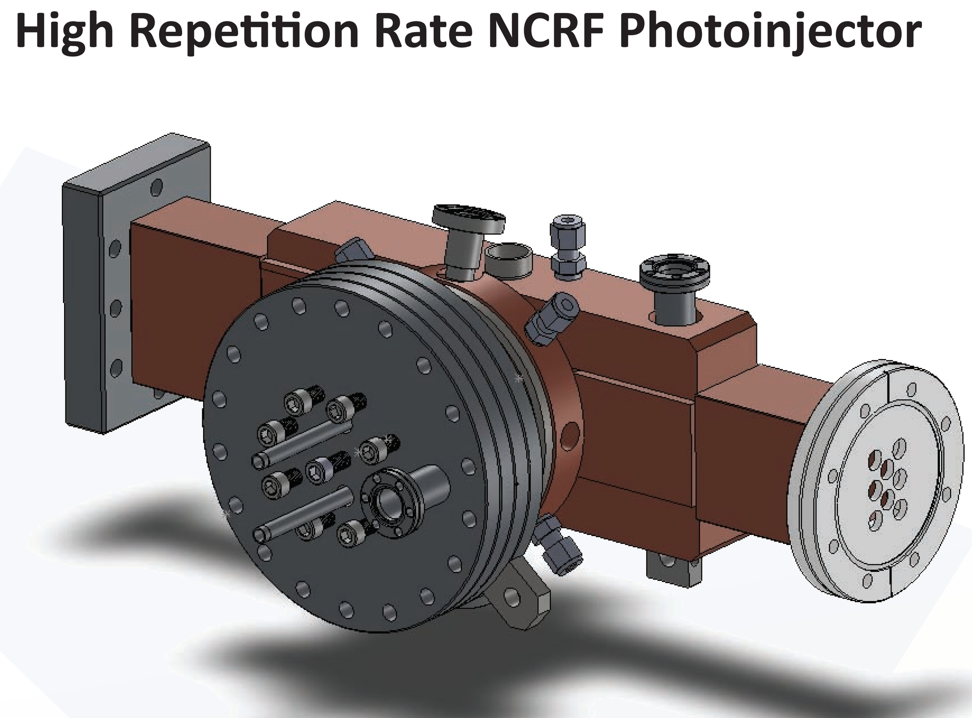
$$N_\gamma \approx \left[\frac{N_L N_e}{4\pi r_b^{\ 2}}\right]\sigma_{th}$$

The key step towards increasing the average X-ray flux is in recirculating the laser beam to match the burst mode operation regime of the electron beam.

In a dedicated system, designed specifically for this application, the output could have at least 100 bunches per train about 10-20 ns apart, with the macropulse repetition rate of at least 1 kHz, yielding the desired 100,000 beam-beam interactions per second, or in terms of the average photon flux about ~ 10^{14} cps.

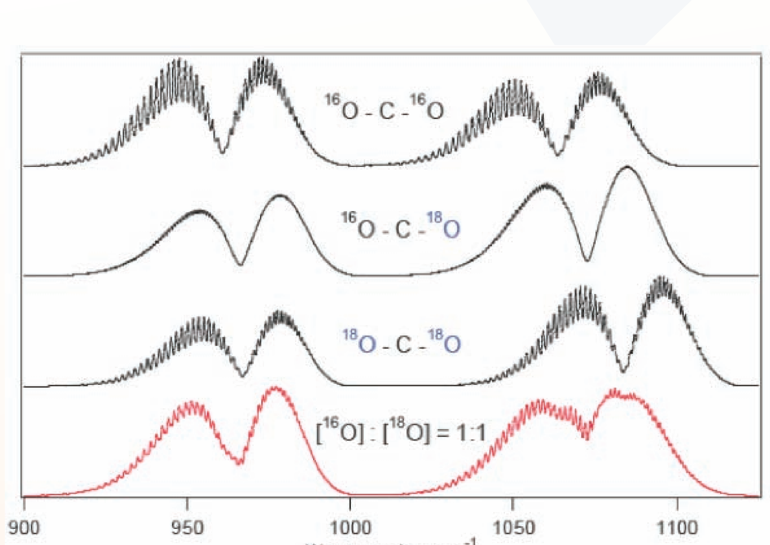
Initial Parameters	EUVL ICS
Electron beam bunch charge	0.6 nC
Electron beam energy	10 MeV
Electron and laser bunch lengths, RMS	5 psec
Electron beam spot size at IP, RMS	30 µm
Electron beam normalized emittance	2.5 mm-mrad
Electron beam peak current	50 A
Electron beam beta function at IP	2 cm
Laser wavelength	10.6 µm
Laser pulsed energy	2.3 J
Laser beam spot size at IP, RMS	50 µm
Dimensionless laser amplitude	0.30
Laser Rayleigh range	3 mm
Peak X-ray energy	170 eV (7 nm)
Maximum X-ray flux per interaction	1×10^9

High Repetition Rate NCRF Photoinjector

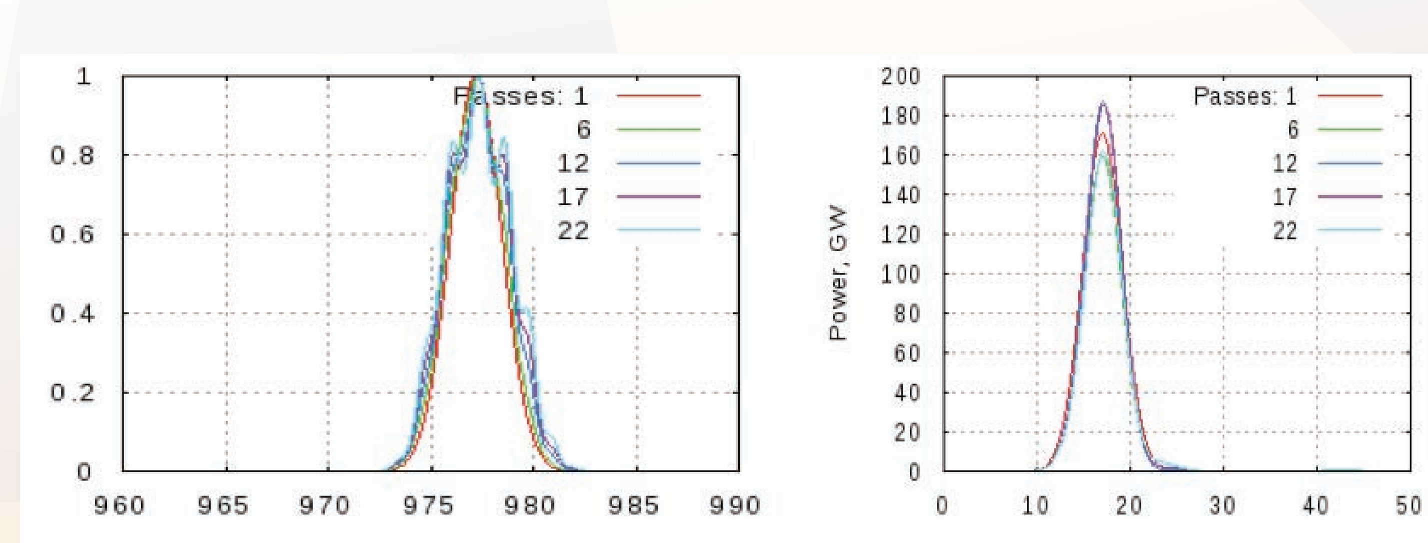


CO2 pulse recirculation and re-amplification

Since pulse shape and spectrum preservation is of particular importance to the efficient operation of the ICS EUVL in recirculation mode, a novel approach, developed at ATF, will be utilized, based on using a mixture of carbon dioxide isotopologues (molecules with different isotopic compositions, here, with different oxygen isotopes: 16O and 18O), which completely eliminates pulse splitting [Polyanskiy, Pogorelsky, and Yakimenko, AAC2010]. The idea of this approach is simple: the spectra of CO2 isotopologues are slightly shifted with respect to each other. In addition, the broken symmetry of 16O-C-18O relaxes the selection rules allowing twice as many rotational transitions as with symmetric 16O-C-16O or 18O-C-18O molecules. Mixing the three isotopic species provides an almost perfectly smooth spectrum.



Simulated spectra of three CO2 isotopologues with different combinations of oxygen-16 and oxygen-18 atoms (no enrichment in carbon isotopes, black) and the effective spectrum of their mixture in the proportion 0.25:0.5:0.25 (statistical equilibrium, red).



Simulated temporal envelope (left) and spectral evolution (right) over 22 passes through an active cavity.

About RadiaBeam

RadiaBeam Technologies is a rapidly growing R&D company founded in 2003 by a group of scientists and engineers from the UCLA Particle Beam Physics Laboratory. Our mission is to bring high impact, innovative technologies from the laboratory to market. Our current product line includes accelerator components, diagnostics, and systems; as well terahertz optics and detectors. We are also actively engaged in R&D in the areas of novel accelerator technologies, innovative optical systems, and commercial applications of accelerators.

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