Science Highlight

BEAMLINE
NSLS Source Development Laboratory

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Efficiency Doubling Using Electron Energy Detuning in a Laser-Seeded Free Electron Laser Amplifier

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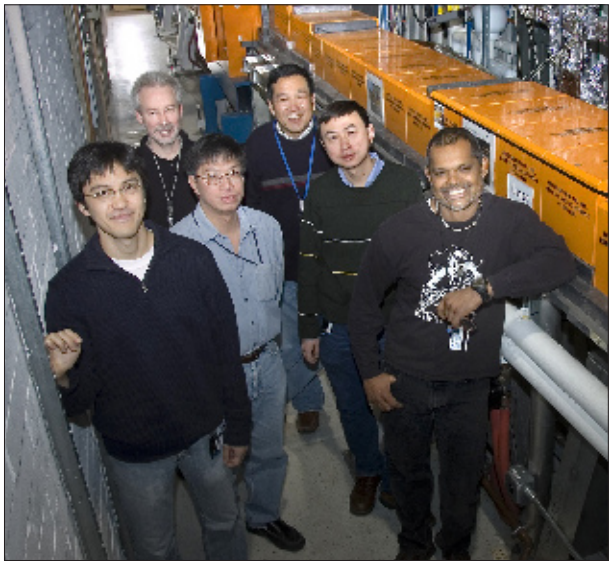
The NSLS Source Development Laboratory (SDL) detuning experiment has demonstrated the doubling of the free electron laser (FEL) efficiency without degradation of its quality. This is the first direct experimental demonstration of the FEL spectral stability in a laser-seeded FEL.

After the successful experimental demonstration of a self amplified spontaneous emission (SASE) FEL in the last decade, an FEL-based 4th-generation light source user facility now is a reality. But there is a growing desire to further improve the SASE FEL performance, such as longitudinal coherence and shorter FEL pulses. Coherent seeding – either by self-seeding through a monochromator or by using a high-harmonic generation (HHG) laser – is one of the schemes being pursued to generate fully coherent FEL light. The laser-seeded FEL amplifier experiments at the NSLS SDL were initiated to investigate basic FEL-amplification physics and demonstrate key technologies to control FEL temporal and spectral properties. Detuning is one of the fundamental properties of high-gain FEL, where the FEL operates significantly from resonance, and leads to improvement in efficiency.

Since SASE always seeks the highest gain where electron beam energy is on resonance, detuning can only be experimentally observed in a laser-seeded FEL amplifier.

In our detuning experiment, a 800 nm Ti:sapphire laser was used as the seed, and the FEL output energy **(Figure 1)** and spectrum **(Figure 2)** were measured as the electron beam energy was scanned. **Figure 1** shows more than doubling of the FEL energy when the electron beam energy is tuned to about 0.7% higher than resonance. Instead of the 1.4% spectral shift predicted by the resonance condition, we observed no FEL spectral shift within our spectrometer resolution (0.05%) as the electron beam energy was scanned **(Figure 2)**. We also observed an increase in the FEL gain length with energy detuning.



Authors (from left) Takahiro Watanabe, James Murphy, Thomas Tsang, Xijie Wang and Yuzhen Shen with NSLS physicist Boyzie Singh at the Source Development Lab.

The NSLS SDL detuning experiment not only demonstrated for the first time a simple technique to improve the FEL efficiency, but also shows that the coherent seed laser determines FEL central wavelength, hence FEL spectral is insensitive to the electron beam energy jitter.

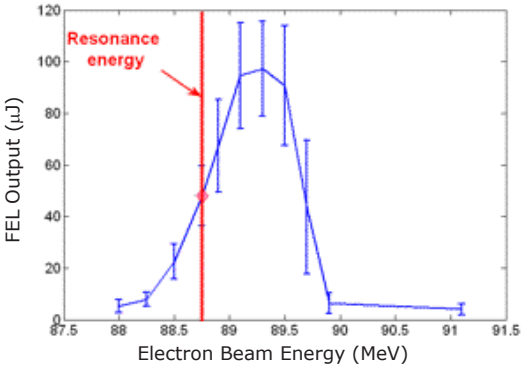


***Figure 1**. The FEL output as a function of electron beam energy. The graph shows that electron beam energy detuning can improve the FEL efficiency by more than a factor two.*

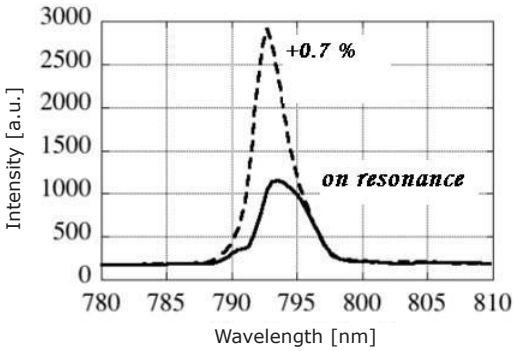


***Figure 2**. The FEL spectrum for resonance and detuned electron beam, which shows that the FEL spectrum is primary determined by the seed laser.*