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HIGH-POWER ATTOSECOND PULSES VIA CASCADED AMPLIFICATION*

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Abstract

The timescale for electron motion in molecular systems is on the order of hundreds of attoseconds, and thus the time-resolved study of electronic dynamics requires a source of sub-femtosecond x-ray pulses. Here we report the experimental generation of sub-femtosecond duration soft x-ray free electron laser (XFEL) pulses with hundreds of microjoules of energy using fresh-slice amplification in two cascaded stages at the Linac Coherent Light Source. In the first stage, an enhanced self-amplified spontaneous emission (ESASE) pulse is generated using laser-shaping of the electron beam at the photocathode. The electron bunch is then delayed relative to the pulse by a magnetic chicane, allowing the radiation to slip onto a fresh slice of the bunch, which amplifies the ESASE pulse in the second cascade stage. Angular streaking will be used to characterize the experimental pulse durations.

INTRODUCTION

Valence electronic motion in molecular systems is on the order of hundreds of attoseconds. Consequently, the time-resolved study of electron dynamics requires a source of sub-femtosecond pulses.

The X-Ray Laser-Enhanced Attosecond Pulse Generation (XLEAP) collaboration is an ongoing project for the development of attosecond capabilities at the Linac Coherent Light Source (LCLS). The XLEAP project has previously demonstrated the generation of isolated soft x-ray attosecond pulses with pulse energy millions of times larger than any other source of isolated attosecond soft x-ray pulses, with a median pulse energy of 10 µJ and median pulse duration of 280 as [1]. Here we report recent development of a high power attosecond mode via cascaded amplification of the x-ray pulse. We experimentally demonstrate generation of sub-femtosecond duration soft x-ray free electron laser pulses with hundreds of microjoules of energy.

CASCADED AMPLIFICATION

A density perturbation is introduced in the electron beam by laser pulse stacking at the photocathode [2]. The perturbation is amplified to a high current spike by acceleration and beam compression in downstream wigglers and a magnetic chicane. In the first cascade stage, the undulator taper is matched to the chirp of the electron beam at the current spike to produce the initial enhanced self-amplified spontaneous emission (ESASE) [3] pulse. The bunch is then delayed relative to the pulse by a second magnetic chicane, allowing the radiation to slip pass the initial lasing region to be overlapped with a fresh slice of the bunch and be amplified in the second cascade stage (Fig. 1).

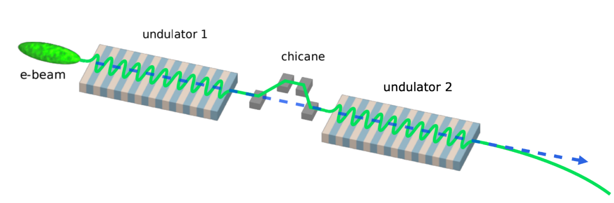

Figure 1: Schematic of the two-stage cascade.

PRELIMINARY RESULTS

The XLEAP project has experimentally demonstrated the generation of soft x-ray pulses with hundreds of microjoules of energy using cascaded amplification in two FEL stages at LCLS, the highest energy shots having over 300 µJ of pulse energy. These higher energy pulses also have sufficient bandwidth to have sub-femtosecond duration near the fourier transform limit (Fig. 2). Previous XLEAP configurations have been within a factor of 2 of the fourier transform limit [1].

In the electron beam phase space, energy loss from reamplification in the second stage is seen as the lasing spike in the head of the beam (Fig. 3). The ESASE pulse is initially lased at the current spike near the center of the beam, and is then slipped ahead to the fresh, non-chirped head of the beam. Energy loss from lasing in the head is visible for the higher energy shots, indicating that amplification of the ESASE pulse is taking place.

CONCLUSION

The preliminary results suggest we can deliver a high power, sub-femtosecond duration soft x-ray mode at LCLS. This set-up is scalable to the upcoming high repetition rate at LCLS-II. Future work will use angular streaking [4] of the experimental soft x-ray pulses to reconstruct the temporal profile of the x-ray pulses and characterize peak power. Additionally, the broadening of bandwidth with pulse energy is characteristic of superradiant lasing (Fig. 4). It is

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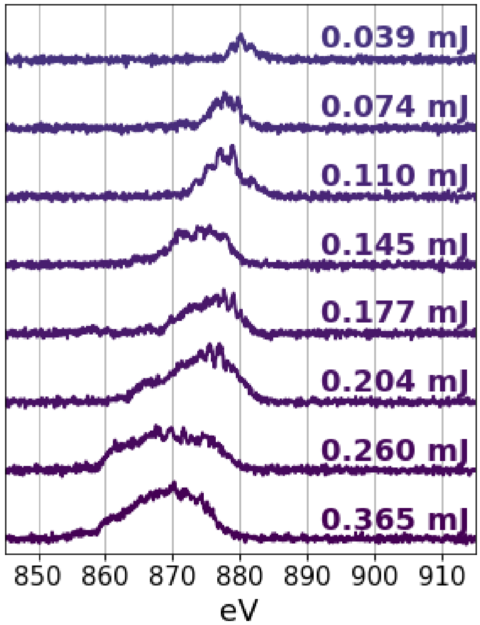

Figure 2: Example spectra are shown for shots with different pulse energies. The highest energy shots have sufficient bandwidth for generation of sub-femtosecond pulses.

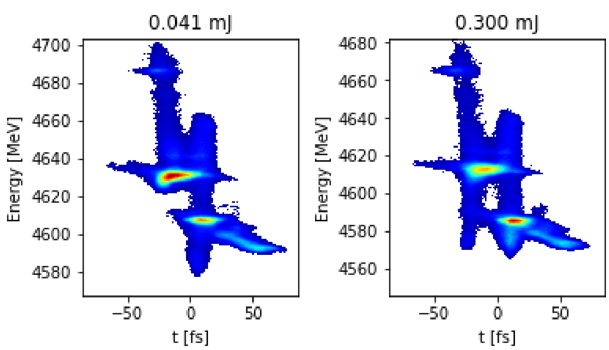

Figure 3: Electron bunch time-energy phase space distribution after the undulators. Energy loss from reamplification in the second stage is seen as the lasing spike in the head of the beam (head on the left).

of interest to further study the lasing process in the second stage through start-to-end simulations.

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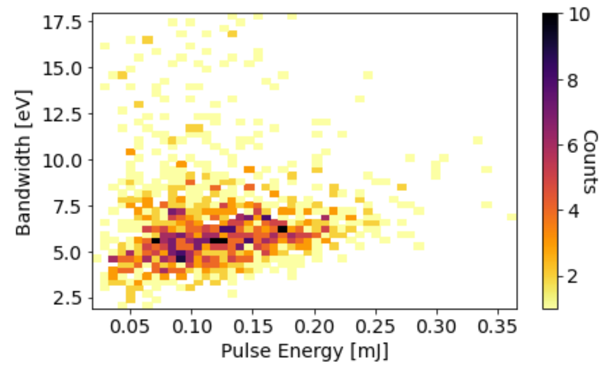

Figure 4: Distribution of bandwidth and pulse energies.The broadening of bandwidth with pulse energy is characteristic of superradiant lasing.

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