LA-UR- 97-1743

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CONF-970503--252

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Submitted to:

1997 Particle Accelerator Conference
Vancouver, B.C., Canada
May 12-16, 1997

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A HIGH-POWER COMPACT REGENERATIVE AMPLIFIER FEL

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Abstract

The Regenerative Amplifier FEL (RAFEL) is a new FEL approach aimed at achieving the highest optical power from a compact rf-linac FEL. The key idea is to feed back a small fraction (<10%) of the optical power into a high-gain (~10^5 in single pass) wiggler to enable the FEL to reach saturation in a few passes. This paper summarizes the design of a high-power compact regenerative amplifier FEL and describes the first experimental demonstration of the RAFEL concept.

1 INTRODUCTION

Self-amplified spontaneous emission (SASE) has been demonstrated experimentally in the mm-wave, far-ir and mid-ir regions.[1] Recent interest in SASE has shifted toward shorter wavelengths as this provides the basis of the fourth generation light sources emitting coherent tunable radiation in the deep uv and x-rays. Existing designs of x-ray SASE FELs, however, call for very long wigglers (tens of meters).[2]

One way of reducing the wiggler length is to use optical feedback to synchronously inject the optical power from one pass back to the front of the wiggler to seed the optical buildup of subsequent passes. We called this idea the regenerative amplifier FEL (RAFEL). With a large single-pass gain, the amount of optical feedback can be quite small, e.g. <10%. Since mirrors can easily provide that kind of reflectivity, even in the deep uv and x-ray regions, a small amount of optical feedback translates into substantial saving in the number of gain lengths needed for saturation. Furthermore, this approach allows us to control the output frequency and amplitude and to use a strongly tapered wiggler for improved extraction efficiency. Compared to traditional FEL oscillators, the RAFEL outcouples >90% of the intracavity power, thereby reducing the risk of optical damage while maximizing system efficiency. The RAFEL output efficiency is essentially equal to the FEL extraction efficiency.

2 EXPERIMENTAL SETUP

The RAFEL concept was implemented on the compact Advanced FEL test stand at Los Alamos with the philosophy of a simple system design and minimum number of components. The key components of the RAFEL experiment include a high-current, high-brightness electron linac, a high-gain, high-efficiency wiggler and an optical feedback loop. Figure 1 schematically depicts the RAFEL experimental setup. As details of the RAFEL experimental implementation have been reported elsewhere,[3] only the pertinent parameters of the RAFEL experiment are summarized in this paper (see Table I).

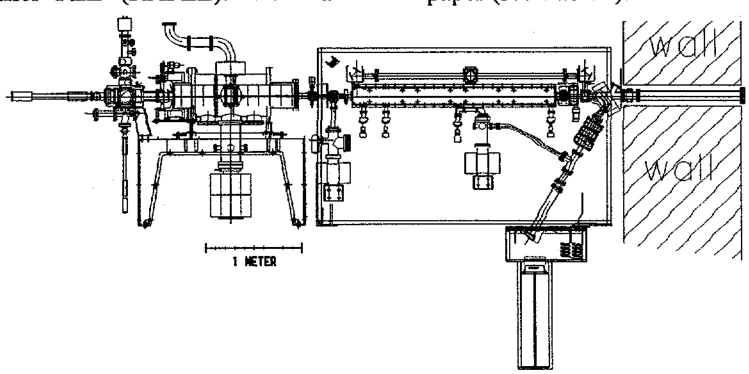

Figure 1. Experimental setup of the regenerative amplifier FEL.

integrated over an 8 μs macropulse (~900 micropulses) was 0.35 J. If the Fresnel loss of the ZnSe vacuum window is accounted for, we have generated 0.5 J of 16 μm light over 8 μs, corresponding to a 60 kW average power over the macropulse. Since these results were obtained with 3 nC electron bunches, we deduced 1% of the beam power was converted to FEL light.

Unlike an FEL oscillator, the RAFEL has a large feedback cavity detuning curve with a fwhm ≥ 1 mm (Fig. 4). The optical buildup near saturation exhibits a large gain (~X6 assuming 66% cavity loss), although this is much less than the small-signal gain which we could only infer from the SASE measurements. As there are two pulses in the feedback cavity, two sets of micropulses build up from different initial conditions and achieve saturation at different times (Fig. 5). Because of the large outcoupling, the cavity ringdown is fast: the FEL power drops by a factor of 3 in successive passes (Fig. 6). From the ringdown measurements, we estimated that the present outcoupling is less than 66%. This outcoupling differs from the expected 90% partly because of the smaller hole in the output mirror.

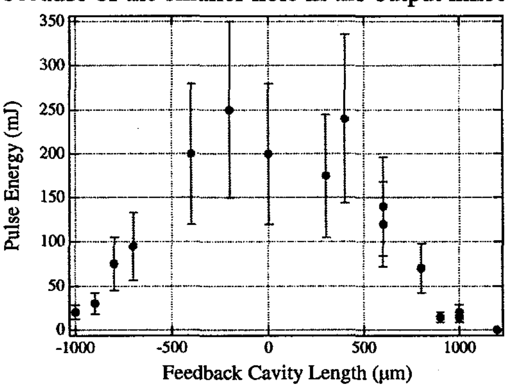

Figure 4. RAFEL feedback cavity detuning curve

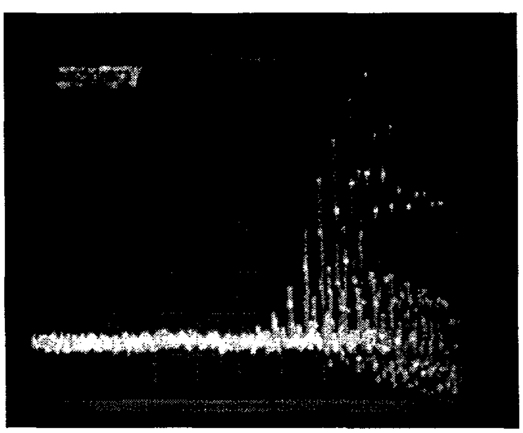
Figure 5. Fast buildup of RAFEL to saturation.

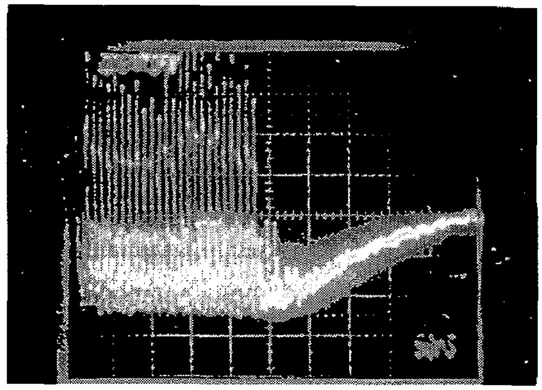
Figure 6. RAFEL ringdown shows optical power decaying by a factor of 3 in successive passes.

4 CONCLUSION

We have demonstrated for the first time the regenerative amplifier FEL concept. A single-pass gain greater than 500 was inferred from the plot of SASE intensity versus charge. The RAFEL produced 0.5 J per macropulse at 16 μm, corresponding to 60 kW average power, over an 8 μs macropulse, and a 1% output efficiency. Experiments are in progress to characterize this new regime of FEL operation.

5 ACKNOWLEDGMENTS

The authors thank Roger Warren, Claudio Pellegrini, David Goldstein, Kara Hayes, Michael Weber, Scott Volz, John Plato, Richard Lovato, Claude Conner, and Robert Wheat for their support. This work was conducted under the auspices of the US Department of Energy, supported (in part) by funds provided by the University of California for the conduct of discretionary research by LANL.

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