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MILLIMETER WAVE FREE ELECTRON LASER AMPLIFIERS: EXPERIMENTS AND DESIGNS*

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ABSTRACT

Free electron laser amplifiers are investigated as sources of high-average-power (1 MW) millimeter to submillimeter wave radiation (200 GHz - 600 GHz) for application to electron cyclotron resonance heating of magnetically confined fusion plasmas. As a stepping-stone to higher frequencies and cw operation a pulsed amplifier ($\tau_{pulse} \simeq 80$ ns) at 98 GHz is being developed. Status is reported on this experiment which investigates linear gain amplification with use of a sheet electron beam (transverse cross section = 0.1 cm × 2.0 cm, $V_{beam} = 440$ keV, $I_{beam} \simeq 10$ A) and short-period wiggler ($l_w = 0.96$ cm) and with expected output of 140 W. Predictions of gain and efficiency from a 1-D universal formulation are presented. Beam propagation results, with wiggler focusing as a means of sheet beam confinement in both transverse dimensions, through the 54 cm (56 period) pulsed electromagnet wiggler are discussed. Peak wiggler fields of 5.1 kG on-axis have been achieved.

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INTRODUCTION

The University of Maryland is developing a free electron laser (FEL) amplifier for application to electron cyclotron resonance heating (ECRH) and profile control in magnetically confined fusion plasmas. The advantages of the FEL include its potential for significant power in the 200 GHz to 600 GHz range and its inherent tunablity. Development of this source is proceeding in three stages: (1) demonstration of stable, confined sheet electron beam propagation through amplifier relevant wiggler lengths, (2) demonstration of linear gain amplification at 98 GHz using a sheet electron beam and a short-period wiggler ($l_w = 0.96$ cm), and (3) development of a proof-of-principle tapered amplifier at 98 GHz with parameters (e.g. $P_{out} \sim 1$ MW, $\eta \sim 20\%$) relevant to an eventual source. This short paper will briefly discuss the first two stages of our amplifier development.

SHORT-PERIOD WIGGLER MAGNET AND SHEET BEAM PROPAGATION

An experimental effort is underway to study sheet electron beam transport through amplifier relevant lengths. Previous work has successfully demonstrated sheet electron beam propagation through planar electromagnet wigglers of modest length.[1] In particular, propagation through 10 cm (10 periods with $l_w = 1$ cm) has shown the wiggler magnet to sufficiently focus a sheet beam (~ 500 keV, 7.2 A, 65 A/cm^2), in the narrow transverse dimension and to provide virtually 100% transport efficiency. No beam instabilities were observed in these approximately 35 ns pulsed experiments. In contrast to this work, the eventual ECRH source device calls for interaction lengths of 2 - 3 m, and it is toward these lengths that our beam propagation effort is directed.

Similar to our previous magnet designs, the present wiggler consists of copper meander path windings with laminated silicon steel pole pieces. The design employs a two-layer (two turns per pole) configuration which minimizes stray magnetic fields. In particular, stray fields at the wiggler

sides and from the two energizing current feeds are reduced. As a means of increasing the overall interaction length, the wiggler is designed in a modular fashion with 19 periods per module. Three of these modules have been constructed resulting in an overall interaction length of 54 cm (56 periods). Preliminary measurements indicate up to 5.1 kG pulsed, magnetic fields on-axis. Higher field values are possible since the data indicates that the iron poles have not fully saturated. For an adiabatic beam entrance to the wiggler magnet, we have reduced the volume of iron in the first two wiggler poles. This results in a one-wiggler period entrance taper. Numerical modelling of sheet beam propagation as well as witness plate photos of the beam indicate that this taper is satisfactory. Generation of the sheet electron beam is from a cold (field emission) cathode connected to a pulse-line accelerator. A machined slit within the anode serves to aperture the beam forming a sheet. Typically, the beam dimensions are 0.1 cm × 2.0 cm.

In the past, at overall interaction lengths of 10 cm, no effort was made to provide for side or wiggle plane focusing. However, for these propagation experiments, with a total length of 54 cm, side focusing can not be ignored. Our proposed mechanism of side focusing is an offset pole technique. The iron poles, on both the top and bottom wiggler halves, will be alternatively offset in the wide transverse dimension. Measured magnetic field profiles in this dimension indeed indicate a vertical field displacement, with opposite polarity at the two sides. Minimal influence was measured in the central regime of the magnet. It is anticipated, and verified by numerical beam modelling, that this side field displacement will focus straying electrons back into the central region.

LINEAR GAIN AMPLIFIER AT 98 GHz

An amplifier is under development which is intended to demonstrate linear gain at 98 GHz and which will employ the short-period electromagnet wiggler discussed above. Parameters for this pulsed amplifier as well as a design for a cw ECRH source are given in Table 1. A peak power of 140 W is anticipated, as predicted by a 1-D universal formulation[2], after 54 cm of interaction length.

	1 cm Wiggler	Design Goal
frequency (GHz)	98	280
V_{beam} (MV)	0.44	1.0
I_{beam} (A)	10.0	5.8
S_{beam} (cm^2)	0.1 x 2.0	0.1 x 2.0
$B_{w,0}$ (kG)	3.4	10.0
l_w (mm)	9.6	10.5
$a_{w,0}$	0 30	0.98
S_{wg} (cm^2)	0.32 x 4.0	0.52 x 3.0
P (W) @ 54 cm	140*	—
P_{sat} (kW) @ 71 cm	—	68†
Gain (dB/cm)	0.39	0.26

* 1 W input power

† 1 kW input power

Table 1: Parameters of the linear gain amplifier at 98 GHz and, for comparison, a design goal for ECRH application.

REFERENCES

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