Feasibility Studies of a Compact mm-Wave Linac FEL*

A. Nassiri, R. L. Kustom, Y.W. Kang, and J. Song

Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439, USA

1 Introduction

Short wavelength FELs impose stringent requirements on the quality of the electron beams. The key factor in obtaining a single-pass UV or x-ray FEL is the generation of small emittance electron beams with ultra-high brightness. The pioneering work at Los Alamos National Laboratory in the last decade has resulted in a dramatic improvement in the production of high electron beam brightness and small beam emittance using rf photocathode gun. The lower bound on the emittance of a 1-nC bunch without any emittance compensation is on the order of 3 π mm-mrad. This is well within the emittance requirement being considered here. Although the original R&D work at Argonne [1], in collaboration with the University of Illinois at Chicago and University of Wisconsin-Madison, has produced encouraging results in the area of rf structure design, x-ray mask fabrication, and LIGA processing (Lithography, Electroforming, and Molding), the goal to prove feasibility has not yet been achieved. In this paper, we will present feasibility studies for a compact single-pass mm-linac FEL based on LIGA technology. This system will consist of a photocathode rf gun operated at 30 GHz, a 50-MeV superconducting constant gradient structure operated at 60 GHz, and a microundulator with 1-mm period.

2 FEL parameters

The mm-wave linac-based FEL under feasibility study will consist of a $3\frac{1}{2}$-cell photocathode rf gun operated at 30 GHz, a 5-meter-long superconducting constant gradient structure operated at 60 GHz, and a 2-meter-long microundu-

*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

lator with 1-mm period. The FEL main design parameters are summarized in Table 1.

3 Photocathode rf gun

The rf gun considered for design studies here is a 30-GHz $3\frac{1}{2}$-cell side coupled structure. The gun is designed to operate in the π-mode phasing on the beam axis. A 30-GHz structure will allow us to reach a very high peak electric field in excess of 500 MV/m at the cathode. The gun is designed to produce electron beams with energies up to 6 MeV. The rf power is fed from a single waveguide which couples power directly to cells 2 and 3. MAFIA [2] numerical codes including particle-in-cell simulations were used to model the 30-GHz rf gun. The initial simulation results indicate that the beam rms emittance is between 3 and 7 π mm-mrad depending on the initial rf phase. The chosen photocathode material is copper with a cathode quantum efficiency of 0.01%. A 15-GHz $3\frac{1}{2}$-cell model was fabricated for cold model rf measurements. The results are reported in [3].

4 Accelerating structure

To relax the rf power requirement, we are are considering a 60-GHz superconducting constant gradient structure fabricated by the LIGA process. For a planar constant gradient structure, the cell-to-cell coupling must be controlled. Since the LIGA process requires that the the structure to be fabricated as a single piece on a wafer, the cell-to-cell coupling adjustment can be done by varying the cell width and length with a constant depth within the structure. A $\frac{2\pi}{3}$ traveling wave is chosen as the accelerating mode. The 5-meter structure is composed of fifty standard 10-cm-long sections. For a 60-GHz structure a 1-mm aperture height can be used for the required coupling to obtain a constant gradient with $b = 4.4$ mm, $g = 1.266$ mm, and $t = 0.4$ mm, see Figure 1. For a 60-cell section the shunt impedance is 200 $\frac{\Omega}{m}$ and the required group velocity normalized to the speed of light is in the range of 0.096 to 0.022 [4].

5 Microundulator

An undulator of period 1 mm has been designed. The undulator consists of a silver conductor embedded in poles and a substrate of nickel-iron. The undulator will be fabricated by the LIGA process to improve the fabrication accuracy. Silver is chosen as a conductor for its high electrical conductivity and its softness. Nickel-iron is chosen for its high permeability and suitable mechanical properties. A shortened (2-period) version of the undulator was modeled using the eddy-current numerical code ELEKTRA [5]. The silver and nickel-iron were treated as different vector-potential regions. The surrounding "air" was treated as a combination of vector-potential and magnetic scalar-potential regions as needed for consistency with the current specifications. Simulation results indicate that within the midplane, the field is fairly uniform transversely across the central region and, with the slotted poles, most of the current remains in the silver. A ten-times (10-mm period) model was designed using 1010 steel for the substrate and insulated copper wire for the conductor. Stainless steel spacers held the top and bottom halves in the correct relative positions. The model was driven with a current of 10 A from a DC power supply. This gave a peak field of 25.5 G, in agreement with the 26.6 G predicted by a 2-D computation. The full undulator design and the initial measurements are reported in [6].

6 Acknowledgements

We would like to thank G. Waldschmidt and T. Berenc for their invaluable help and hard work on the design simulations and cold model rf measurements.

References

[1] A. Nassiri, et. al., A 50 MeV mm-Wave Electron Linear Accelerator System for Production of Tunable Short Wavelength Synchrotron Radiation, *Proceedings of the IEEE International Electron Device Meeting* (Washington DC, December 1993).

[2] R. Klatt, et. al., MAFIA, A Three-Dimensional Electromagnetic CAD System, *1986 Linear Accelerator Conference Proceedings* (Stanford, CA, 1986).

[3] A. Nassiri, et. al., A Photocathode RF Gun Design for a mm-Wave Linac-Based FEL, *Proceedings of the 1995 Particle Accelerator Conference* (Dallas, TX, May 1995).

[4] Y. W. Kang, et. al., A Constant Gradient Planar Accelerating Structure for Linac Use, *Proceedings of the 1995 Particle Accelerator Conference* (Dallas, TX, May 1995).

[5] The 3-D eddy-current code ELEKTRA is a trademark of Vector Fields, Ltd., Oxford, UK.

[6] L. R. Turner, A. Nassiri, F. E. Mills, S. Kim, and A. Feinerman, A Micro-Undulator Fabricated by LIGA Processes, *14th International Conference on Magnet Technology* (Tampere, Finland, 11-16 June, 1995).

Table 1
Basic 300-nm Linac FEL Design Parameters.

Beam energy	50 MeV
Peak beam current	600 A
Beam pulse length	3 ps
Normalized rms emittance	3 π mm-mrad
Micropulse charge	1.8 nC
λ_u	0.3 cm
Magnetic field, B	0.7 T
Deflection parameter, K	0.196
λ_{FEL}	300 nm
FEL parameter, ρ	7×10^{-4}
L_{sat}	4.3 m
L_{gain}	20 cm
L_{und}	5 m

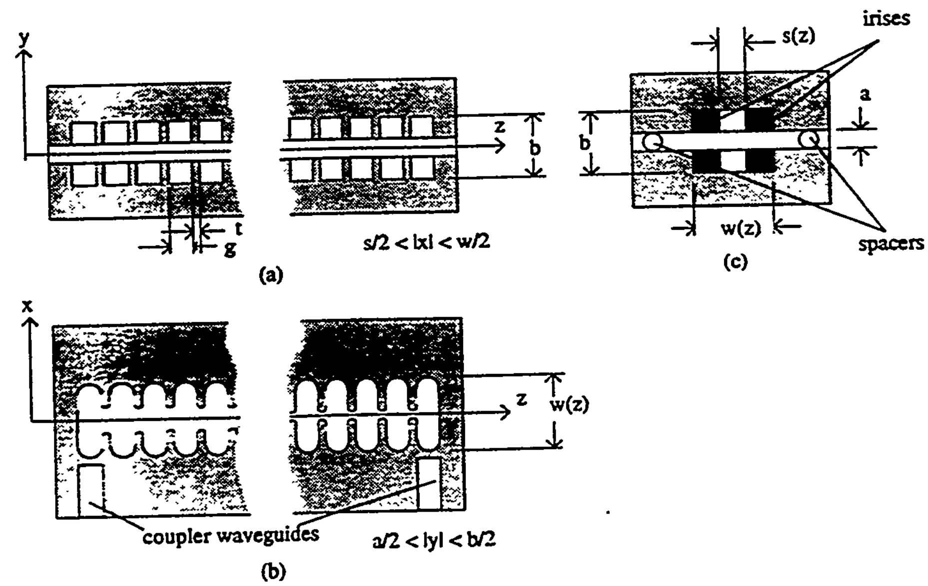

Figure 1 - A constant gradient planar cavity structure with cuts in irises