LA-UR- 89-17

CONF 8808171

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405 ENG-36

Received by OSTI

FEB 0 6 1989

TITLE: **PROPOSED EXTENDED TUNING RANGE FOR THE LOS ALAMOS MID-INFRARED ADJUSTABLE, COHERENT LIGHT EXPERIMENT (MIRACLE) FACILITY**

LA-UR--89-17

DE89 006550

AUTHOR(S): **A. H. Lumpkin, P-15**

D. W. Feldman, R. W. Warren, W. E. Stein, J. M. Watson, AT-7

J. E. Sollid, B. E. Newnam, CLS-6

J. C. Goldstein, X-1

W. J. Johnson, AT-5

SUBMITTED TO: **The 10th International Free Electron Laser Conference, August 29 - September 2, 1988, Jerusalem, Israel**

MASTER

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

[illegible]

PROPOSED EXTENDED TUNING RANGE FOR THE LOS ALAMOS MID-INFRARED ADJUSTABLE, COHERENT LIGHT EXPERIMENT (MIRACLE) FACILITY

A. H. Lumpkin, D. W. Feldman, J. E. Sollid,
R. W. Warren, W. E. Stein, B. E. Newnam, J. C. Goldstein,
W. J. Johnson, and J. M. Watson

Los Alamos National Laboratory
Los Alamos, NM 87545

Abstract

The Los Alamos Free-Electron Laser (FEL) Facility has been in operation as an oscillator in the 10μm wavelength regime since 1983. Operations from 10 to 45μm have been recently demonstrated which would provide a new applications capability: A Mid-Infrared Adjustable Coherent Light Experiment (MIRACLE) Facility. We propose to extend this tunability from 3 to 160μm by upgrading the injector, accelerator, and resonator cavity. Potential applications in material science (high-temperature superconductors) and biophysics (DNA spectroscopy) for this wavelength regime are briefly addressed.

I. INTRODUCTION

Broadband wavelength tunability is one of the most attractive features of a free-electron laser (FEL). Our efforts at Los Alamos have been concentrated on high power operations at 10μm [1], although tunability had beer demonstrated from 9 to 35μm previously [2]. A projected extension of this range from 3μm to 160μm would provide a needed complement to the existing FEL applications research facilities in the U.S. that operate in the visible, (Stanford SCA), the few micron (Stanford Mark III), and the sub millimeter regimes (University of California at Santa Barbara).

Recently, we demonstrated the tunability of our Mid Infrared Adjustable, Coherent Light Experiment (MIRACLE) Facility and extended our operations to 45μm. We used copper mirrors with a 1-mm-diameter outcoupling hole in one of the mirrors. The present ZnSe windows (λ cut off at 22μm) on the end of the cavity and the Hg:Ge detector (sensitivity to 15μm) constrained our experiment. We therefore relied on detection of the first, second, and/or third harmonics of the FEL output as we varied the electron beam energy. Extraction of energy from the electron beam was monitored on our electron spectrometer as well as by the optical measurements.

We propose to change the cavity window to allow longer wavelength transmission (diamond is one candidate), obtain a zinc or copper-doped Germanium detector for extended wavelength coverage, and modify our IR spectrometer for operations at the longer wavelengths. We would then tune to longer wavelengths and ultimately establish an optical path up to the user laboratory.

Potential applications in material science and medical physics for this wavelength regime will be addressed.

II. EXPERIMENTAL CONSIDERATIONS

A. Experimental Procedures and Results

The Los Alamos FEL is an RF-linac-driven oscillator that has been operated nominally at about 10.6μm since 1983 [1]. The e-beam pulse structure (and hence the optical beam) consists of a 100-μs long macropulse with about 2000 micropulses of 10 to 20-ps duration separated by 46 ns. The nominal operating parameters are given in Table I. The present experimental beam line is shown in Fig. 1. The injector, two accelerator sections, the 60° achromatic bend, the wiggler, and resonator cavity are indicated.

Recent improvements in operational capability are described elsewhere in this Conference [3,4]. In particular, the optical bandwidth of 0.3% was at the transform limit; wavelength chirping was achieved by a prescribed e-beam energy slew within a macropulse; sideband suppression was demonstrated by both length detuning and Littrow grating techniques [5]; copper mirrors provided broadband tuning and a higher intracavity power capability than the ZnSe mirrors allowed; and the extraction efficiency determined from the optical output and e-beam spectral effects agreed.

With this strong foundation and motivated by the potential applications described in Section III, we decided to test the broadband tunability of the system again in April, 1988 Using the two copper mirrors for the cavity, one of which had the 1-mm diam hole for coupling the radiation through the ZnSe window we had the following results:

1) Lasing was observed from 10 to 45μm as evidenced by detecting the fundamental, second harmonic, or third harmonic optical output and/or the electron beam spectral effects.

2) We demonstrated transport of charge through the wiggler at energies as low as 5 MeV (corresponding to $\lambda \sim 150\mu m$) by reducing the field in both accelerators A and B and by using the second accelerator as a decelerator.

3) We observed a dramatic increase in detected optical power when the fundamental wavelength was about $30\mu m$. These features were consistent with lasing on the third harmonic ($10\mu m$ where the detectors and windows are optimized). A more thorough investigation of this aspect was performed just after the Conference and the laser operated on the third harmonic down to $3.4\mu m$.

Limitations in this preliminary experiment included the liquid helium cooled, Hg-doped germanium detector's insensitivity to wavelengths longer than about $18\mu m$, the ZnSe window transmission cutoff at $\sim 22\mu m$, and vignetting of the large optical modes by the structures of the resonator cavity (including the wiggler gap itself). Nevertheless, the obtained broadband tuning over a factor of $4^1/_2$ is notable as shown in Fig. 2. The solid circles indicate a few of the actual wavelengths generated based on the FEL resonance relation and the e-beam energies measured in the electron spectrometer located after the wiggler. In addition, the figure shows the projected longer wavelength operation one could obtain with e-beam energies down to 5 MeV. The curvature of the solid curve is due to the wavelength's $1/_{\gamma^2}$ dependence.

B. Proposed Modifications

We envision several modifications to the experiment that would dramatically improve our capabilities. The Phase I modifications are mostly the detectors, windows, and wiggler gap. The Phase II major modifications involve changing the injector to a photoinjector, the addition of a third accelerator, and reduction of the geometrical aperturing in the resonator cavity.

In Phase I, which will have partial financial support from internal institutional funding, we foresee the following:

1. Detectors: At least one Zn-doped Ge detector that is sensitive to about $45\mu m$ will be procured to supplement the Hg doped Germanium detector Also our pyroelectric devices can be used over the extended wavelength range once the ZnSe window is replaced.

2. Windows: The resonator window for coupling the radiation out to the external detectors will be changed to diamond or TPX, both of which should transmit to 100μm.

3. Vignetting: The wiggler gap will be enlarged to accommodate the larger modes of the longer wavelength radiation. Minor beamline changes will be made where possible. A set of simulations is on hand as described below.

4. Slippage: For wavelengths longer than 50-60μm, we can use the nonisochronous 60° bend as a magnetic debuncher to lengthen the micropulse temporal width to 20-30 ps. Alternatively, we might reduce the wiggler's length.

Our efforts will be guided by FEL numerical simulations. Table II shows a summary of long-wavelength calculations for the present facility. Cases involving nominal wavelengths of 10, 50, 100 and 150μm were considered. The electron energy, the wiggler half-gap, the peak wiggler field parameter (A_w), the empty cavity loss, and the small signal gain are shown. The actual wavelength value for maximum small signal gain is in the first column. The calculations were performed with a single pass simulation code, and it was assumed that the cavity was not a limit and that the mirrors were larger than the mode size. It was found that the vignetting losses due to the wiggler aperture itself define the losses when all other apertures are removed. Of the two possible strategies of shortening the wiggler or opening the gap, the latter was chosen as a first try.

The gap was adjusted to keep the losses to about 20%, and the effects on the wiggler fields as the gap was opened were calculated. In all cases tabulated, the gain was shown to be sufficiently greater than the losses so that lasing would be expected. These results were added to Fig. 2 as the triangles and complement the lower-energy beam transport demonstration. In practice, the actual mirror sizes and the 60° bend magnet gap may have to be changed since they cause additional losses. Changes to these would have to be under Phase II.

In Phase II, a photoelectric injector, a third accelerator tank, and a new isochronous 60° bend are the main modifications planned under another base program. The improved emittance provided by the injector and acceleration up to 35-40 MeV should allow lasing on the fundamenal at 3 to 4μm. It is expected that the micropulse duration adjustment needed for very long wavelength tuning will be handled by altering the length of the laser micropulse that drives the photocathode. Use of larger mirrors (perhaps 30-cm diam) in the resonator cavity would require extensive, but straight forward, mechanical modifications to the beamline.

III. POTENTIAL APPLICATIONS OF THE MIRACLE FACILITY

Although there are a number of potential applications for which FELs have been considered, the wavelength regime from 3 to 160μm has its own special set. Space limitations preclude a full discussion, so one example each from materials science and biophysics is cited.

A. High-Temperature Superconductors (HTSCs)

It has been proposed and discussed separately at this conference [6], that an infrared FEL could be tuned across the energy gap of a HTSC sample for $T<T_c$. Reflection and transmission measurements done as a function of irradiation wavelength and temperature should determine the gap magnitude. The FEL's monochromatic, coherent, and polarization features should simplify the analysis procedures used so that a two-angle reflection measurement could characterize the complex index. The FEL would be a unique probe in this regard. This source also avoids the complications of broadband irradiation of the sample. Only the Phase I modifications are needed for this experiment for a $T_c \sim 100$K sample and assuming an energy gap of $3^1/_2$ kT_C.

B. DNA Spectroscopy

A number of vibrational modes have been observed or calculated for DNA structure. Some of these would be accessible depending on the FELs range. In particular, the region from 200 to 1000cm^{-1} (10 to 50μm) includes part of the biologically significant region described by Van Zandt, [7]. Spectroscopy effects due to temperature, salinity of solutions, binding of drugs, etc. would be studied. The micropulse structure would be useful in determining lifetimes of vibrational modes with large bandwidth. These studies would provide tests of the present modeling capability for these systems.

IV. SUMMARY AND CONCLUSIONS

In summary, the proposed modifications to the Los Alamos FEL should allow wavelength tunability from 3 to 160μm (3333 to 62 cm^{-1}). This extended MIRACLE facility would fill the existing wavelength gap among the operating FELs internationally. Specific application to high-temperature superconductors and DNA spectroscopy are envisioned. Successful experiments in either one of these proposed applications would herald a significant, new research technique in that field.

REFERENCES

1. R. W. Warren, B. E. Newnam, W. E. Stein, J. G. Winston, R. L. Sheffield, M. T. Lynch, J. C. Goldstein, M. C. Whitehead, O. R. Norris, G. Luedemann, T. O. Gibson, and C. M. Humphry, "First Operation of the Los Alamos Free-Electron Laser Oscillator," Proceedings of the International Conference on Lasers 83, pp. 316-320 (1983).

2. Brian E. Newnam, et al., IEEE Journal of Quantum Electronics, Vol. QE-21, No. 7, 867, (1985).

3. R. W. Warren, et al., "Near-Ideal Lasing with a Uniform Wiggler," these Proceedings.

4. D. W. Feldman, et al., "High Extraction Efficiency Experiments with the Los Alamos Free-Electron Laser," these Proceedings.

5. J. E. Sollid, et al., "Sideband Suppression in the Los Alamos Free-Electron Laser using a Littrow Grating," these Proceedings.

6. Alex H. Lumpkin, "Potential Application of the Los Alamos Free-Electron Laser: High-Temperature Superconductors," these Proceedings.

7. L. L. Van Zandt, V. K. Saxena, and W. K. Schroll, "Biological Significance and Insignificance of DNA Vibrations," to be published.

FIGURE CAPTIONS

Fig. 1. Schematic layout of the present Los Alamos Rf-linac-driven Free-Electron Laser.

Fig.2. Observed and potential broadband tuning aspects of the Los Alamos FEL. Solid circles show lasing wavelengths demonstrated or inferred from harmonic production. The triangles represent the results of FEL simulations assuming the wiggler gap is the critical aperture.

TABLE I

NOMINAL FEL PROPERTIES AT 10 MICRONS

Bandwidth: $\Delta\lambda/\lambda$	~0.3%
Micropulse Duration:	10-15 ps
Pulse Separation	46 ns
Macropulse	10-100μs
Polarization	Linear (~100%)
Focusability	Diffraction Limited
Power (Peak)	10 MW
Power (Ave.)	1W

Basic Equation:

$$\lambda_L = \frac{\lambda_W}{2\gamma^2} \quad (1 + 1/2\,(A_W)^2)$$

where

$\lambda_W = 2.73$ cm	wiggler period
$\gamma = 42$	Lorentz factor
$A_W = 0.76$	wiggler field parameter

TABLE II

Summary of long-wavelength calculations for Los Alamos FEL Facility

Optical Wavelength (μm)	Electron Energy (γ)* (Mev)	Wiggler $1/_2$ Gap (cm)	Peak Wiggler Field (a_W) (g)	Empty Cavity Loss** (%)	Small Signal Gain (%)
10.3	21.5 (42.0)	0.44	3000 (.76)	3	68
51.4	9.4 (17.9)	0.55	2329 (.59)	21	260
102.7	6.2 (12.0)	0.78	1387 (.35)	21	135
153.9	4.9 (9.7)	0.94	949 (.24)	22	95

*The current was 100A, $\Delta\gamma/\gamma = 1.3\%$ all cases, $\epsilon_n = 171\ \pi$ mm-mr (90% emittance; $\epsilon_{rms,n} = 1/_4\ \epsilon_{90,n} = 43\ \pi$ mm-mr), single wavefront calculations only (cw, no pulse effects).

**The assumed reflectivity of the mirrors in all cases was 97%; the losses represent the effect of aperturing by the wiggler gap -- a <u>circular</u> aperture of the $1/_2$ gap size as radius was assumed.

PRESENT LOS ALAMOS FEL

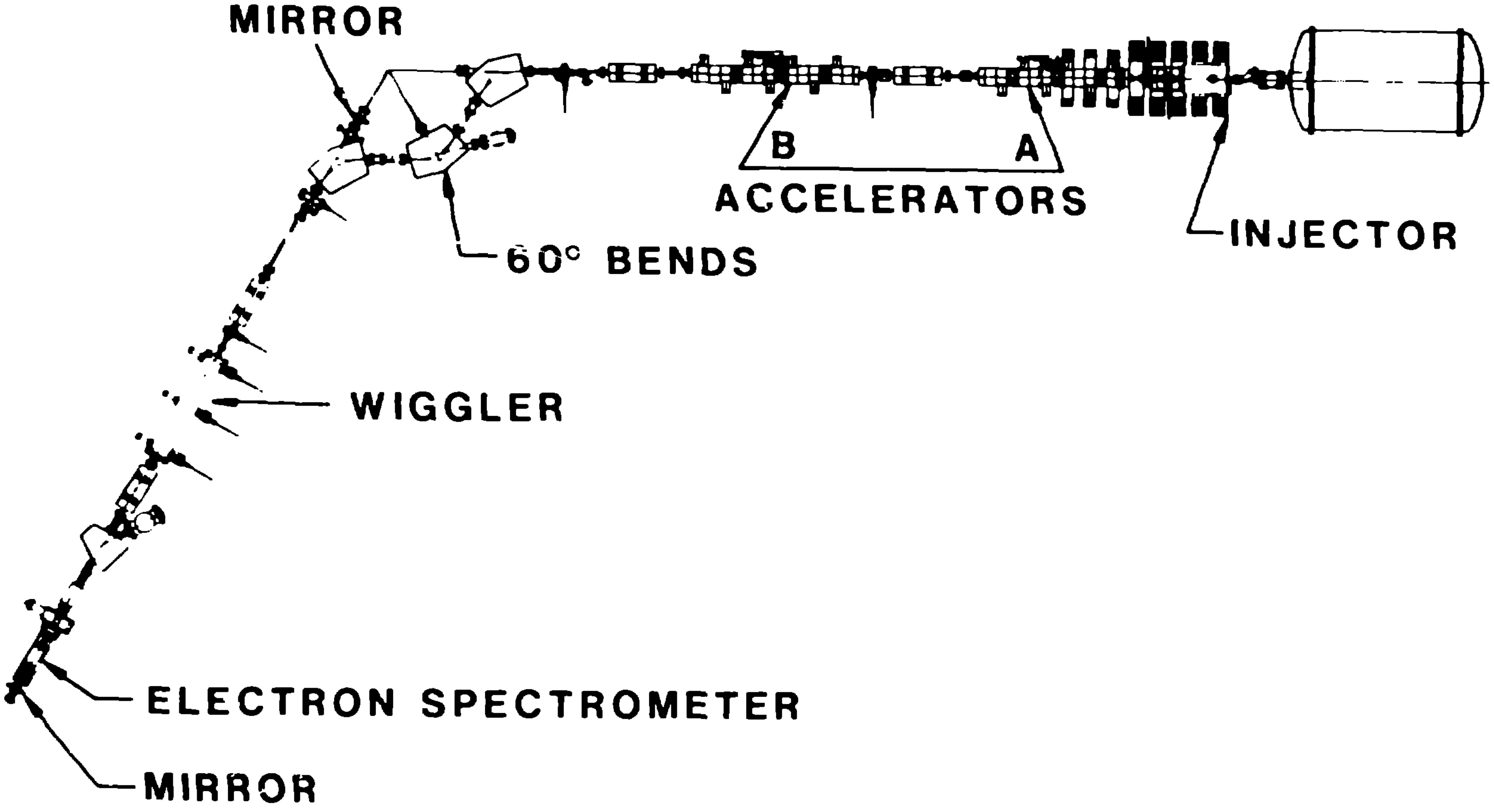

Fig. 1

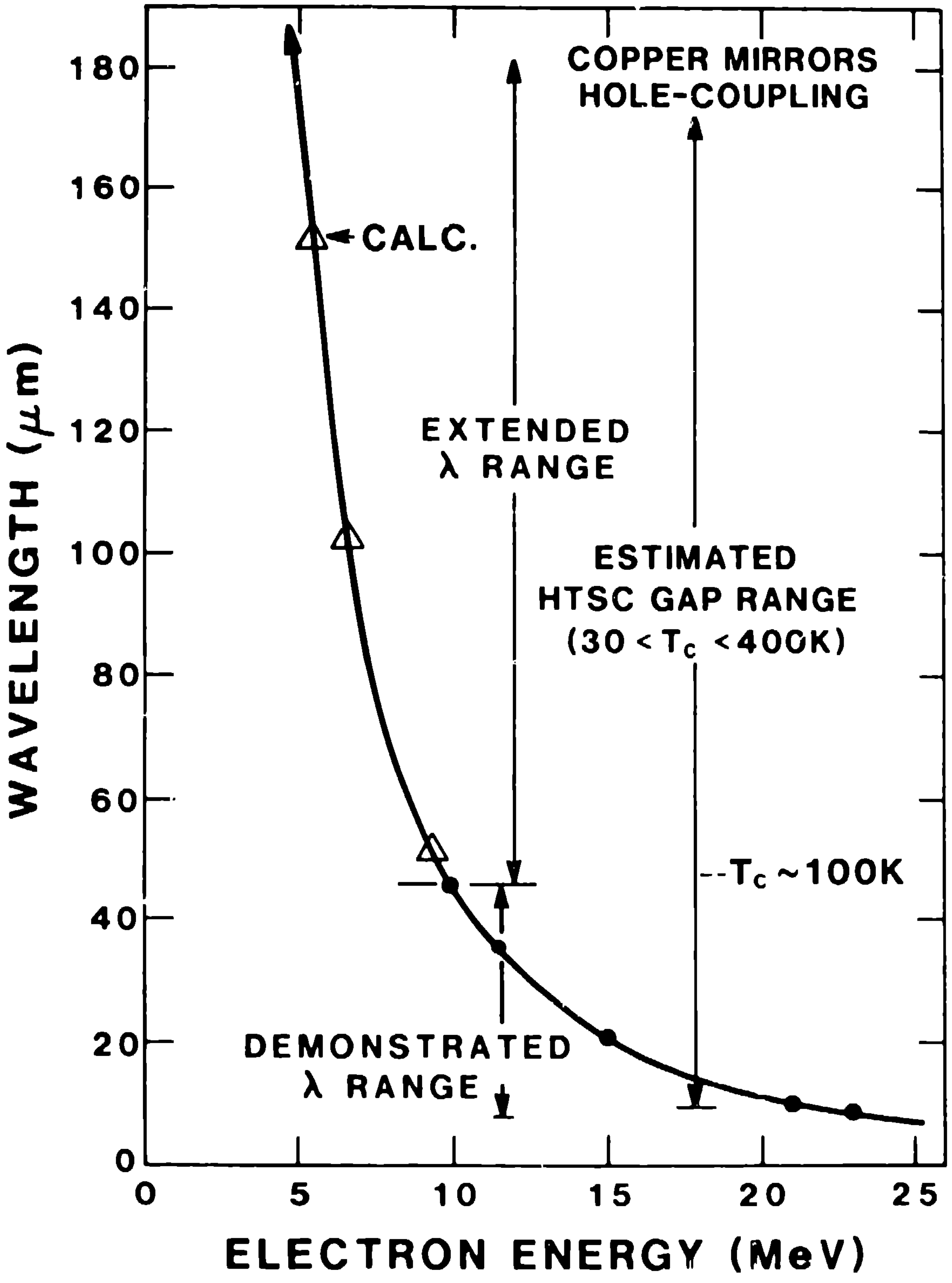
WAVELENGTH (μm)
ELECTRON ENERGY (MeV)
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
CALC.
EXTENDED
λ RANGE
COPPER MIRRORS
HOLE-COUPLING
ESTIMATED
HTSC GAP RANGE
(30 < Tc < 400K)
--Tc ~100K
DEMONSTRATED
λ RANGE

Fig. 2