

# The University of Maryland Free-Electron Laser

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## 1. Introduction

The Maryland Infrared Free-Electron Laser (MIRFEL) is under construction at the University of Maryland. MIRFEL, based on the Advanced Energy Systems CIRFEL, is a source of far-infrared (FIR) light for physics, medical, and materials science research. A project to investigate vibrational modes in DNA is currently planned. MIRFEL construction will be complete by early 2001. This paper discusses the design and planned applications for MIRFEL.

## 2. MIRFEL Design

MIRFEL is being constructed from the Compact Infrared Free-Electron Laser (CIRFEL), which was originally built to develop applications-focused research FELs [1], and which first lased in 1996 [2]. MIRFEL has a number of unique attributes ideally suited for FIR research, including high peak power (> MW), high average power (~2 W), short pulse radiation (5 ps), and rapid tunability. Another important feature is the 7 ns pulse separation. Unlike FELs with sub-nanosecond pulse spacing, the pulse spacing in MIRFEL is long enough to allow samples to cool or relax between pulses. Furthermore, MIRFEL incorporates a ps-pulsed Nd:YLF photocathode drive laser that is phase locked to the electron beam and FEL optical output. The drive-laser can produce harmonics at 1.047, 0.524, 0.349, and 0.262  $\mu\text{m}$ , and can be used for experiments in conjunction with the primary FEL output.

The main components of the FEL are the electron accelerator, photocathode electron source, UV drive laser, RF power system, and the FEL wiggler and optics. Because MIRFEL was built as an FEL and is not a retrofitted accelerator, it has a very compact footprint. The entire FEL, exclusive of the drive laser and RF system, occupies a space of only 8' x 12'. The other component sizes are modest as well, totaling about 52 square feet. Such compact FELs can be easily and inexpensively sited at places such as Universities and medical institutions.

## 3. Accelerator

The MIRFEL accelerator is a high-brightness electron source capable of producing electron pulses with energies up to 14 MeV and peak currents in excess of 150 A.

The accelerator consists of two separate units, the gun and the booster. The gun is a 9-MeV, 20 cm long, 3 1/2 cell Sband structure. A 6 mm diameter Mg disk serves as a photocathode [1]. Afterwards, the photocathode will be upgraded to an LaB<sub>6</sub> disk.

Downstream from the gun is a 2-cell booster cavity, identical to the central two cells of the gun. This booster can raise the electron energy to 14 MeV. RF power is provided by a single ITT 2960 klystron system with feed forward control [3].

The macropulse in the gun consists of a train of micropulses, each 5 - 10 ps long, with a micropulse repetition rate of 142.8 MHz. The macropulse is 10  $\mu\text{s}$  long, and has a repetition rate of up to 10 Hz [4]. The expected normalized rms emittance is 5  $\mu\text{m}$  with 1 nC per bunch

## 4. Wiggler and Optical Cavity

In the original CIRFEL configuration, the accelerator was connected to the wiggler through a 90-degree bend. The optical cavity mirrors were totally reflecting, and light was outcoupled through a hole in the downstream mirror. A smaller hole in the upstream mirror was used for alignment by a HeNe laser [5].

The new MIRFEL configuration will abandon this geometry. Instead, the wiggler and optical cavity will be colinear with the accelerator and beamline. This will provide a more compact and rapidly tunable system. The electron beam will enter and leave the optical cavity through small holes in the cavity mirrors.

The two currently available MIRFEL wigglers are of a well-proven, robust design developed at LANL and used there and at Princeton. The first was used to demonstrate lasing in the 8 - 20  $\mu\text{m}$  region at Princeton. This is a 73 period permanent magnet wiggler, with the length of each period measuring 13.6 mm. The wiggler gap is 6 mm, and the RMS wiggler parameter ( $a_w$ ) is 0.20 [1]. This wiggler has been successfully tested here at Maryland using the taught wire technique, and will be the first wiggler installed at MIRFEL (Phase I).

A second permanent magnet wiggler, having 50 periods of length 10 mm, will be tested and installed at a later date. It is believed that this wiggler will allow increased output power and shorter wavelength output light [2]. A 3-cm period wiggler for lasing at 50-150  $\mu\text{m}$  will also be constructed (Phase II).

## 5. Applications

Prohofsky [6], Lilley [7], and Lim [8] claim that two mechanisms control the chemical reactions of large biomolecules in living organisms: molecular structure and vibrational dynamics. While biomolecular structure (i.e. the DNA double helix) is relatively well understood, a complete understanding of vibrational dynamics has not been experimentally determined. Grasping the dynamics is thought

to be the key to understanding fundamental processes such as DNA replication and protein interaction.

Large biomolecules move primarily in vibrational modes. These "accordion-like" vibrations along the backbone of the DNA involve thousands of base pairs. These vibrations are predicted to be involved with energy transfer through the DNA, including determining points for DNA melting. DNA also undergoes conformational changes where the strands bend into different shapes[9]. It has been shown that some DNA-protein interactions require specific conformations of DNA[7] and that DNA conformations can help modulate chemical reactions as they occur[8].

Laser light is extremely useful for studies related to DNA interactions, because it can serve as both a trigger to initiate reactions and a time resolved probe to monitor the outcome of those reactions. MIRFEL is extremely well suited to perform these tasks as most biologically relevant chemical reactions can be initiated with light between 3  $\mu\text{m}$  and 30  $\mu\text{m}$ ; many of the vibrational modes in complex molecules fall in the far infrared spectrum between 30  $\mu\text{m}$  and 200  $\mu\text{m}$ [10].

The laser can be used to generate vibrational modes through interaction with electric dipoles inside the DNA double helix structure. Under normal conditions, a dipole in the presence of an electric field feels a torque,  $\mathbf{L} = \mathbf{p} \times \mathbf{E}$ , and will rotate accordingly. The dipoles in the DNA will feel the same torques when exposed to laser light. The flexible bonds between these dipoles allows sections of the DNA to rotate and initiate vibrational modes inside the molecule. Therefore, the applied E-M field from MIRFEL will be able to drive the different vibrational modes and conformational changes within the DNA.

While the long term goal of exploring DNA dynamics is to determine exactly how or if certain conformational changes play a role in gene expression, we must first build a larger experimental database of knowledge about DNA dynamics. In the past, some experiments used optical, ultraviolet, or x-ray sources to conduct these types of studies, but optical and UV light is easily scattered by organic material. Additionally, the same material can be easily damaged by x-ray radiation [11]. Some researchers used weak infrared sources, but the high absorption of infrared light in water was difficult to overcome. The radiation from MIRFEL is nondestructive and is not scattered by organic material. Capable of producing megawatts of peak power, MIRFEL would be a prime candidate to gather more data regarding the existence of these modes using Fourier Transform Infrared (FTIR) Spectroscopy.

The next step would be to determine if infrared pulses from MIRFEL could produce effects resulting in downstream gene expression. In order to accomplish this task, we plan to bring together four groups at the University of Maryland: the Department of Electrical and Computer Engineering, the University of Maryland Biotechnology Institute, the Institute for Plasma Research, and the Department of Radiation Oncology (at the University of Maryland, Baltimore). In preliminary studies, alterations in DNA as a result of MIRFEL radiation could be calculated

using DNA fingerprinting to detect changes in chromatin conformation. Detecting functional alterations will be accomplished by gene expression profiling (Clontech Atlas (r) 1.2).

## 6. Conclusion

As MIRFEL nears completion in 2001, the University of Maryland will gain a unique light source. MIRFEL's frequency range, optical power, and pulse separation allow it to be used effectively in experimental investigations of DNA dynamics, a field that has never been fully explored. This research, to be conducted in an interdisciplinary setting will make important contributions to genetics while helping to demonstrate the utility of Free Electron Lasers to the scientific community as a whole.

## References

- [1] I.S. Lehrman, et al. Proc. SPIE 2522 (1995) 451.
- [2] I.S. Lehrman, et al. Nucl Instr. and Meth. A. 393 (1997) 178.
- [3] R. Hartley, I.S. Lehrman, J. Krishnaswamy. Nucl. Instr. And Meth. A 375 (1996) ABS22
- [4] I.S. Lehrman, et al. Nucl. Inst. And Meth. A 358 (1995) ABS5.
- [5] I.S. Lehrman, et al. 1995 PAC Conf., May 1-5, Dallas, TX, 1995.
- [6] Prohofskey, E. Statistical mechanics and stability of macromolecules : application to bond disruption, base pair separation, melting, and drug dissociation of the DNA double helix. New York, N.Y. : Cambridge University Press, 1995
- [7] D. Lilley ed. DNA Protein: Structural Interactions. New York: Oxford University Press, 1995.
- [8] M. Lim, T. Jackson, and P. Anfinrud. "Ultrafast rotation and trapping of carbon monoxide dissociated from myoglobin." Nature Structural Biology. 4.3 (1997): 209-214.
- [9] L.L. Van Zandt, and VK Saxena. Physical Review A 39.5 (1989): 2672-2674.
- [10] D.D. Dlott, and M.D. Fayer. IEEE Jour. Of Quan. Elec. 27.12 (1991): 2697 – 2713.
- [11] GS Edwards. Optical Engineering. 32.2 (1993) : 314-319.