OPTICAL BEAM LINE DESIGN FOR THE DUKE FREE ELECTRON LASER LABORATORY

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Abstract

In the Fall of 2000 four crotch chambers were successfully installed on the four corners of our one GeV electron storage ring facility at the Duke Free Electron Laser Laboratory (DFELL). Installation of these crotch chambers has enabled us to achieve higher optical beam power that can be used for a variety of experiments such as medical and materials science in our newly constructed Keck building adjacent to our main FEL building. In this article, the design of optical beam lines and the methodology of delivering beams to the experimental stations will be discussed.

1 INTRODUCTION

The Duke Free Electron Laser Laboratory is capable of generating beams in the range of nearly monochromatic gamma rays to high peak power infrared (IR). In this article, the design of optical beam lines for the newly constructed W. M. Keck life and science laboratory, as an extension to DFELL will be described. This design consists of a beam delivery system for:

- Extraction of broadband synchrotron radiation from one of the bending magnets,
- The Vacuum Ultra Violet (VUV) from the OK-4 undulator,
- High-Intensity Gamma Ray generated by the coherent backscattering of FEL photons and the next in-line, stored electron bunch in the orbit of the ring,
- IR beam line from the MKIII undulator.

In this article applications of these beamlines for various medical, nuclear physics, basic science and materials science will be briefly explained.

2 BEAMLINE DESIGN AND APPLICATIONS

In Spring of 1999 construction of a 13,000 SF facility was completed to host a variety of experiments with gamma ray, vacuum ultraviolet (VUV) and infrared in the area of medical, materials science and nuclear physics. This facility consists of a two-story building funded by W. M. Keck foundation. Materials science, surface physics and gamma ray experiments will be done on the first floor and the second floor has been dedicated to basic research, biology and various medical experiments. This design consists of a beam delivery system for the VUV, gamma and IR beam lines and their applications for various nuclear physics, medical and materials science experiments.

In order to deflect the beam into the experimental labs three types of mirror designs were implemented for the beamline. These mirrors are categorized according to their location.

Type I mirrors or periscope mirrors are water cooled copper mirrors and are coated with UV grade bare Aluminum. These mirrors are positioned directly in the path of UV beam line to deflect either spontaneous or the UV laser.

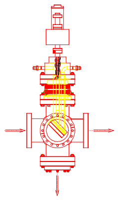

Figure 1. Periscope Mirror Assembly

Type II mirrors, also called fixed mirrors are placed in the corners of the beam line, where we would need to deflect the beam only at 90 degrees.

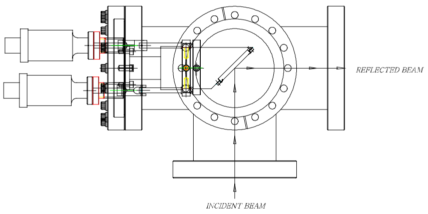

Figure 2. Fixed Mirror Assembly

Type III mirrors, or flipper type mirrors are capable of transmitting the light directly to the next user station or reflecting it at 90 degrees to the next user when the mirror is flipped at 90 degrees with the aid of a pneumatically actuated ferrofluidic seal rotation mechanism.

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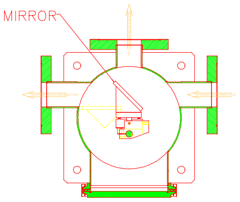

Figure 3. Flipper Tank Mirror Assembly

Some of the applications of these experimental facilities in the new expansion building of the DFELL are as follows:

2.1 Application in the time-Resolved Infrared Spectroscopy

In early spring of 2001 the installation of the beamline for the time-resolved IR Spectroscopy was completed. In this design, broadband synchrotron radiation from the South East bending magnet is used to combine with the coherent UV output of the OK4 undulator. Combination of these two light sources can be used as a pump and probe to perform broadband time resolved FTIR spectroscopy with a time resolution of 2 to 3 orders of magnitude better than currently attainable with step-scan FTIR.

To out-couple the broadband synchrotron light source from the crotch chamber, it requires focusing the broadband light through a CaF2 window that separates the ultrahigh vacuum of the storage ring from the rest of the beamline under high vacuum. Once the beam is through the window, a gold coated, off-axis parabolic mirror is used to collimate the light before transporting it to the user end-station via a series of type II fixed mirrors and a type III flipper tank mirror.

Coupling of the OK-4 UV pump pulse requires the addition of a standard optical delay line with an optical path length adjustable to 5 m in order to compensate for the estimated 15 ns delay introduced in the IR-probe pulse by the synchrotron radiation out-coupling optics. The timing of these two pulses will be adjusted with the aid of a fast Si diode photodetector placed at the location to be occupied by the sample. To get the UV pulse into the FTIR sample compartment, an anti-reflection coated, UV-transparent window must be introduced into the sample component lid. A flat mirror inside the sample compartment will reflect the UV pump beam onto the sample, spatially coincident with the IR probe beam. A long-pass filter will be placed between the sample component and the detector to block any scattered light from the UV excitation pulse and to prevent spectral aliasing when undersampling the measured interferograms.

2.2 Application in Nuclear Physics

It is possible to tune the stored electron beam in a manner which the FEL photons produced by one electron bunch to backscatter from a second electron bunch, all within the ring cavity. This will lead to an intense, linearly polarized γ-rays whose energy can be readily tuned from about 5 Mev to greater than 170 Mev. These polarized beams, combined with proper polarized targets, are ideal for nuclear physics studies such as nucleon polarizabilities and nuclear astrophysics studies in understanding the process of helium burning in stars, and in particular the oxygen-to-carbon ratio at the end of the burning.

2.3 Application in Medical Research

Our medical research scientists have been investigating UV laser-corneal interactions in various animals. In these studies 4 different laser delivery systems have been developed for use in the animal studies. Three of the four designs tested were able to cut 22% weight/volume gelatin which simulates the chemical composition of the human cornea. Additionally laser cutting of ex vivo corneas was successfully demonstrated.

2.4 Application in Materials Science

Photoemission Electron Microscopy (PEEM) has allowed the microscopic analysis of particularly semiconductor surfaces and interfaces utilizing UV laser. Recent studies have used PEEM for the analysis of p-n junctions buried interfaces, Schottky contacts and electromigration. In this technique, when the sample is illuminated with a light source, photons with an energy greater than the work function result in emission of an electron. Photoemited electrons are then accelerated in a 20 kV field and can be imaged through a multichannel plate or phosphor screen.

2.5 Application in Cell Biology

Our Cell Biology team is interested in new ways to selectively induce gene expression with high spatial and temporal resolution. Heat shock (brief exposure of cells to an elevated temperature), is a classic, non-deliterious, inducible system for expression of genes. It is based on an endogenous biological system designed to protect cells from transient thermal and other stresses. The FEL offers a unique opportunity to locally warm biological specimens that in principle could range from an individual cell to sheets of cells or even whole tissues. Local heating by the FEL beam will depend on the wavelength, beam size (cross sectional area), pulse duration and the absorption spectra of the specimen. The goals is to use existing tissue spectra to model the thermal effects of laser microbeams as a function of wavelength, beam cross sectional area and pulse duration and plan to evaluate the efficacy of these models by testing them directly using biological specimens that generate a fluorescence protein in response to activation of the heat shock promoter (the element that signals a cell to "turn on" or transcribe the gene). In this system, elevated temperature activates a heat shock promoter which in turn mediates the transcription of a recombinant (a recombinant DNA molecule is formed by joining DNA segments from different sources), chimeric "reporter" gene whose product is the fluorescent protein. Because one can accurately quantify the level of fluorescence with high spatial and temporal resolution, the fluorescent protein provides a direct readout of local heating and, in turn, local induction of gene expression, by the FEL beam.

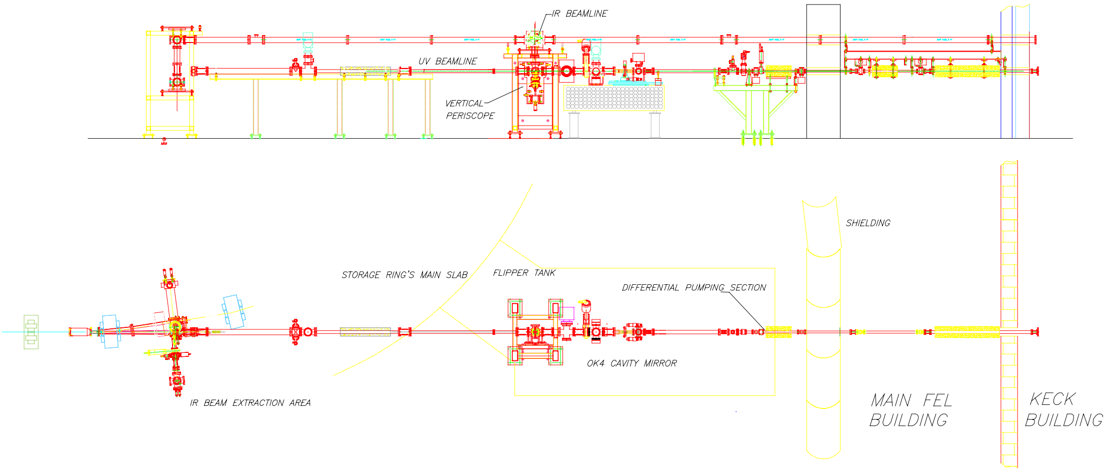

Figure 6. IR / UV Beamline In the South East Storage Ring Area

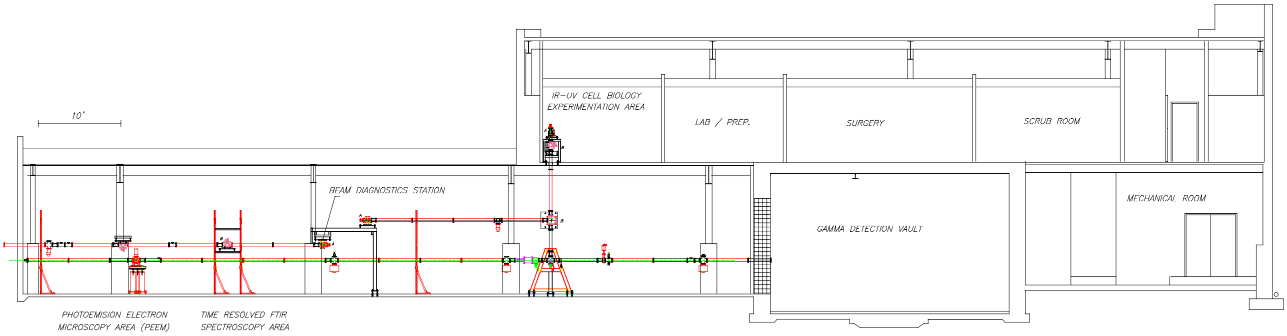

Figure 7. Side Elevation of Keck Expansion Building