1 Introduction

Free Electron Lasers (FEL) are devices that use the electron beams passing through a transverse periodic magnetic field so that electromagnetic radiation is amplified. The electrons can have energies ranging from keV's to MeV's. Periodic magnetic field is produced by alternating poles (north-south-north-south...). So by changing the separation between the poles so called wiggler period it is possible to design any kind of laser. Also even for a fixed wiggler period just by changing the energy of the electrons it is possible to tune the wavelength. Because of the convenience and the quality of the laser FEL's are being accepted as the next generation light (X-ray) sources.

As we will see in the theory section, the expression for the gain of the FEL consists of two additive parts: one starts from the noise and produces a density modulation in the electron bunch (leading eventually to Self Amplified Spontaneous Emission (SASE)). The second component depends on the initial conditions in which electrons are organized, for example when the FEL is seeded by a radiation.

The High Gain Harmonic Generation (HGHG) [1-2] experiment is an alternative approach to the SASE case where we seed the electrons by a radiation and amplify the harmonics of the seed radiation. There are a number of advantages to this approach as compared to SASE. The radiation is fully coherent and the spectrum may be an order of magnitude narrower. The central wavelength is determined by the wavelength of the seed radiation (which can be very stable) and not by the energy of the electron beam (which may be less stable). There are other advantages that are related to the seed laser. One is that the pulse may be made much shorter than the electron beam pulse width.

1.1 Structure of the Dissertation

In the 2nd chapter of the dissertation, I will be reviewing the basic theory of the single-pass high-gain FEL's. The Free Electron Laser was first proposed in 1970 by John

Madey [52]. In his original proposal Madey actually described the device with a quantum-mechanical theory. Then it was discovered that the device could be accurately described by the classical theory [53,54]. To describe the dynamics of the FEL, Colson treated the electrons individually, and this approach has been proven to be more powerful for computing both analytically [55] and with computers [54]. In years there were many developments in the theory. The theory of high gain single pass FELs was mostly developed by the National Synchrotron Light Source (NSLS) FEL group, especially by Dr. Li Hua Yu and Dr. Sam Krinsky. The complete theory was only available as a hand written lecture notes and some articles. We thought it would be beneficial to include the theory in the dissertation to have a better understanding of the HGHG experiment.

In chapter 3, I will be describing the Accelerator Test Facility (ATF) in Brookhaven National Laboratory (BNL). ATF has been established to produce high brightness electron beams and high power short pulse laser beams for user to enable investigation into electron-laser interactions as well as experiment into physics of beams. The facility consists of a radio frequency (RF) photocathode electron gun, two SLAC type Linear Accelerator, and three experiment beam lines. The laser system consists of a gigawatt Nd:YAG laser system to produce photoelectrons and a gigawatt CO_2 laser to investigate electron-laser interactions.

In chapter 4, I will be describing the optical transport system of the experiment, which includes the CO_2 laser, He-Ne alignment laser and the FEL transport lines.

In chapter 5, the SASE measurement will be described. The result of the energy, spectrum and gain measurements will be presented.

In chapter 6,7,8 the HGHG experiment will be described. This experiment is the first demonstration of the HGHG process and will open up a new perspective to produce X-ray FELs. The energy, spectrum and pulse length measurements of the HGHG output will be presented and compared with the SASE case.

In chapter 9, the harmonic content of the HGHG measurement and its results will be presented.

In chapter 10, the steering of HGHG beam by the electron beam steering measurement will described.