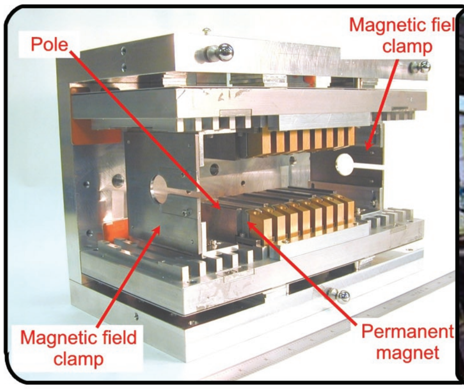
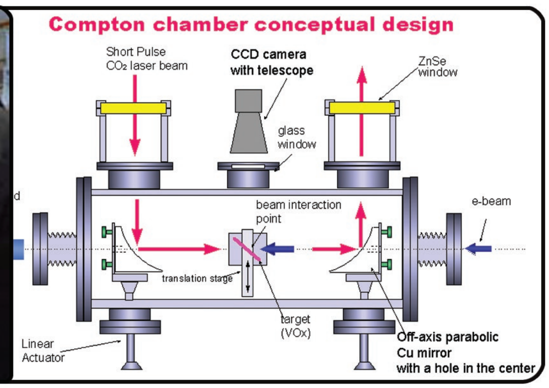
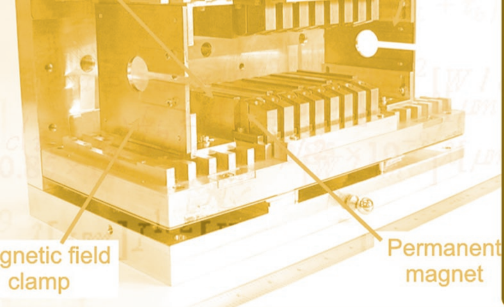
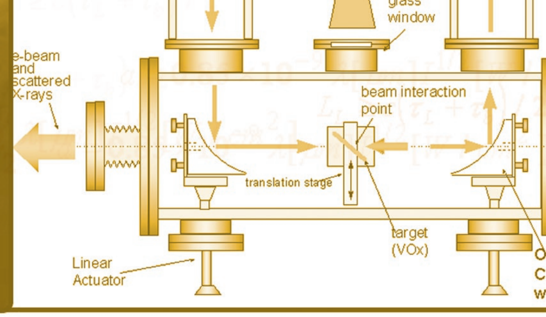
ATF Experiments







Active/Approved Experiments

Completed/ Terminated Experiments

Feasibility Studies

Photocathode R & D:

Spokesperson: AE09. T. Rao, BNL. (1992 -)

In the past decade, RF injectors have been used as high brightness electron sources for free electron laser and accelerator research. A novel component in this injector is the photocathode, which is incorporated into the RF cavity and acts as the source of the electrons. The ease with which the electron bunch parameters such as the charge, the current, the current density, and the spatial and the temporal profile could be modified is a major advantage of these injectors. The complexity of the injector is determined primarily by the choice of the photocathode material and the laser system that drives the photocathode. The photocathode materials that have been used so far could be broadly categorized into two types, namely cesiated metals and semiconductors or simple metals. The cesiated materials typically have a very large quantum yield and hence require a simpler laser system to drive it. This advantage is offset by the delicate nature of the material. Its susceptibility to contamination reduces the lifetime to a few days or hours and necessitates use of complex preparation techniques and vacuum levels exceeding 10-9 Torr. The metal cathode, on the other hand, is relatively insensitive to contamination and has a very long lifetime, but has low quantum yield.

The research at the Instrumentation Division has focused on various methods to improve the quantum yield of metal photocathodes. A wide variety of techniques such as in situ surface ablation, energy transfer via surface phonons or multi photon process, optical field enhancement, surface field enhancement, and Schottky effect have been tested and shown to improve the quantum yield. More than a dozen metals have been tested for their photoelectric properties as well as laser induced damage properties.

Quantum efficiencies of various metal photocathodes were measured in the linear and the nonlinear photoemission regimes as shown in the graph. It is expected that the nonlinear process will be more advantageous at high intensities before laser damage initiated. Behavior of these metals under RF fields has been investigated in an ongoing experimental program at the Accelerator Test Facility in collaboration with scientists from NSLS. Recent experiments with bulk Mg, ion sputtered Mg and bulk Cu indicate that current densities of 40 kA/mm2 could be obtained without damaging the metal surface. This is the highest current density reported so far from macroscopic metal electron emitters. We have also established a preparation technique for reliable cathode performance.

Currently, our laboratory is the only facility where metal photocathode research is being done for this application. These results are used extensively world wide in choosing the cathode materials. A number of research academic and commercial institutions such as UCLA, CERN, Argonne National laboratory, MIT, Grumman-Northrup have been using metal cathodes based on this research.

GENERATION OF HIGH BRIGHTNESS ELECTRON BEAMS

The future electron colliders require bunches of very high brightness electron beams to provide the high luminosity beams required by these machines. The short wavelength Free Electron Lasers (FEL) also require electron beams with high current and emittance comparable to the wavelength. The research in the Instrumentation Division in the generation of such high brightness electron beams follow two parallel paths, RF injectors and pulsed power guns.

In a typical electron beam, if the transport at high energy is designed carefully, the emittance and the brightness of the electron beam is dominated by its momentum and energy distribution at the source, namely the cathode. The electron emission from the cathode is modified by the field seen by the electrons within the cathode. This field is a combination of the surface field due to the applied RF and the space charge field due to the electrons in the vicinity of the cathode. The velocity distribution of the emitted electrons and hence the transport of the electrons are also affected by this dynamic field. An ongoing experimental program that investigates the electron emission and the properties of the electrons at the cathode in a RF injector is in place at the ATF. This is a collaborative effort between scientists from Instrumentation Division and the NSLS.

At the ATF, the emitted charge was measured as a function of the RF phase at which the laser illuminated the cathode. A dynamic model that takes into account the variation of the field in the emission regime and its impact on both emission and transport of subsequent electrons is currently being developed. When completed, this model would provide the temporal shape and momentum distribution of the electrons at the source, and can be used to optimize the laser parameters to reduce the longitudinal emittance. With this dynamic model, the electrons can be characterized accurately for the first time at their source. These characteristics can be used as the input parameter for the beam transport, and optimal parameters for the laser beam can be determined. The emittance growth in the injector could be minimized with such a laser beam and the brightness of the electron beam could be improved significantly. From a practical point of view, this research has also led to the development of surface preparation technique for achieving highest quantum yield and reliable performance from the cathode.

Experimental test of Beam Position Monitor for Linear Collider

V. Balakin, A. Bazhan, P. Lunev, I. Skarin, V. Vogel, P. Zhogolev; **BINP-Protvino, Russia** V. Yakimenko; **ATF BNL-Brookhaven, USA**; A. Lisitsyn ; **SSIE "Istok"-Moscow, Russia**

Abstract

Prototype of beam position monitor (BPM) for next linear colliders developed and constructed by Branch of the Budker Institute of Nuclear Physics have been tested in the BNL Accelerator Test Facility using a 45 MeV, 0.5 nC single bunch beam. The test set-up consisted of three BPMs, which were mounted on three precision movers with 0.3 m m resolution in both (horizontal and vertical) directions for displacement calibration. The detection electronics allowed to take and process data pulse to pulse independently in horizontal and vertical positions in each BPM. Tests BPMs and detection electronics in lab showed that the potential resolution of the BPM system on the BNL ATF beam was less then 0.1 micron. But jitter at ATF BNL appeared to be about 25 m m that is why we had to reduce the output signals from BPMs by 30 dB to conform dynamic range of detection electronics and jitter. So the limit on resolution of 1.9 m m has been obtained directly with ATF beam in these condition. Several tests were made with 10 dB attenuation. And the first results of these data analysis show that in this case resolution was 0.2 m m.

INTRODUCTION

For preservation of the beam emittance on next-generation of linear colliders the high accuracy of aligning of magnetic elements and accelerating structures is required.

So the sensitivity of BPMs for linear colliders have to be better than 0.1 m m [1]. The simplest and effective microwave BPM is circular cavity, excited in TM_{110}-mode by an off-axis beam [1,3,7,8].

The measured amplitude of transverse mode is proportional to the beam offset and bunch charge:

$$P = \frac{\omega^2}{2Q} T^2 M^2 r' (k\Delta x)^2 q^2 .$$

Where q means the beam charge,

M=sin(kh/2)/(kh/2) - beam transit time factor;

$T = \exp\left(- \frac{\omega^2 \sigma_z^2}{2c^2} \right)$-space factor;

r ' -normalized transverse shunt impedance;

Q - loaded quality factor.

Phase of the oscillations depends on beam offset direction.

One of the main problems is the large amplitude of the fundamental and others symmetrical modes exciting in resonant cavity by beam independently of it's offset. These modes must be dumped. Thermal noise and noise of electronics determine another limit of resolution. Calculations and laboratory tests of BPM prototype and detection electronics showed that the potential resolution is better than 0.1 m m (for BNL ATF beam).

The aim of the experiment described in this paper was testing the complete BPM system in a real beam of accelerated particles. The experiment was made in the BNL ATF using it's 45± 1 MeV, 0.25? 0.5 nC single bunch beam with longitudinal size 5 - 10 ps

CONCLUSIONS

Complete resonant BPM system has been tested at ATF BNL using real beam, which had position, angle, intensity and energy jitter. In these conditions the resolution of 0.2 m m was obtained. Three independent BPMs were used to exclude position and angle jitter. For absolute BPMs calibration precision movers were applied.

Achieved resolution isn't the limit for these BPMs. It's value was determined by experiment condition.

Dynamic range of used in the test electronics wasn't enough for measurements with real beam jitter. Therefore BPM output signal was attenuated.

Time of laser pulse in RF gun was not absolutely stable relatively of accelerating RF signal, which was used as the reference signal for phase measurements. That is why "beam phase" has jitter relatively reference oscillations and it is the cause of additional jitter noise in the output signal of phase detection electronics. And this jitter couldn't be excluded using three BPMs.

Beam trajectory through BPMs was not absolutely rectilinear because the magnetic field has influence on moving charged particles. And even in the constant magnetic field (for instance the earth field) trajectory deflection from line isn't abiding. It depends on beam energy. So energy jitter in accelerator cause mistakes in resolution determination using three BPMs.

So to improve observing BPM system resolution we suppose increase dynamic range of detection electronics for conformation with real beam jitter, add to BPM system reference cavity for measurements of phase shift between reference line and real phase of the beam, to take in to account the influence of magnetic field on beam trajectory through BPMs.

Study of Compton Scattering of Picosecond Electron and CO2 Beams:

Spokespersons: T. Kumita, Tokyo Metropolitan University, and I. Pogorelsky, BNL. [Waseda University, KEK, UCLA, Princeton U.] (1998 -)

Abstract

We report the first results of high intensity x-ray generation using Inverse Laser Compton scattering. This experiment was carried out by a US-Japan collaboration at the Brookhaven National Laboratory (BNL) Accelerator Test Facility (ATF) in September 1999.The ATF is an accelerator and beam physics user facility. The 3.5 ps x-ray pulse at 6.5 keV, containing ~10^7 x-ray photons was generated by interacting 60 MeV, 0.5 nC electron bunches and CO_2 laser pulses with the peak power of 600 MW.

Introduction

High intensity, short pulse and compact x-ray sources are required in various fields of the scientific, industrial and medical research. To meet these demands, R&D on the next generation light sources has been initiated in several laboratories [1]. One of the most promising approaches to ultra-bright pulsed x-ray sources is the Laser Synchrotron Source (LSS). It is based on inverse Compton scattering via interaction between pulsed high power laser beams with pico-second relativistic electron bunches.

One of the attractive features of the laser Compton scattering is easy control of polarization of the produced high energy photons that duplicates polarization of the applied laser beam. This method have been proposed to generate circularly polarized g -rays in the prospective polarized positron source for Japan Liner Collider [2].

The US-Japan collaborative experiment on ultra-bright x-ray generation using inverse Compton scattering was performed at the Brookhaven Accelerator Test Facility (BNL-ATF). This experiment takes advantage of the availability of a high-brightness 60 MeV electron RF linac and high peak power CO_2 laser. The CO_2 laser, with it's long wavelength (ten times longer than solid state lasers), is a good choice for the LSS driver because it can generate large numbers of x-ray photons for a given laser energy. In this communication, we report the first results of this experiment.

Summary

We report results of the intense x-ray generation using inverse Compton scattering of CO_2 laser pulses from relativistic electron bunches. The generated number of x-ray photons was 5´ 10^6 photons/pulse and 2´ 10^{18} photons/second. We believe that this is the strongest x-ray yield observed so far in the proof-of-principle LSS experiments. This is achieved due to the availability of a combination of the high-brightness picosecond electron beam, the high mid-IR photon flux CO_2 laser at the BNL ATF and the use of a backscattering configuration. Upon completion of the ongoing ATF CO_2 laser upgrade to the terawatt power and proposed electron bunch compression to femtoseconds we plan to demonstrate LSS with the x-ray yield of the order of 10^{10} photons/pulse and flux up to 10^{23} photon/sec.

Ultra-fast Detection of Relativistic Charged particles by Optical Techniques:
AE23. Spokesperson: T. Tsang, BNL. [Montclair State University, Univ. of Pittsburgh]. (1998 -)

It is well known that the response time of the polarizability of optical crystals is in the femtosecond regime. If the electric field produced by the relativistic charged particles, both positive and negative charged particles, can be probed by such crystals, the passage of these particles could be detected with unprecedented temporal resolution, limited only by the bandwidth of the associated electronics. This scheme also has an added benefit of removing the detector from the vicinity of the interaction region, reducing the real space required near the beam line.

Experiments are done using the electron beam at the Accelerator Test Facility to examine the temporal shape of the electron induced polarization. A short 7 ps duration, 50 MeV electron beam passes at the vicinity of an electro-optical crystal, thereby induce a large polarization field on the crystal. The perturbed field induced by the electron beam will be probed with a highly polarized optical beam. After converting the optical phase change into light intensity variation, the transient electric field can be measured during the passage of the electron beam.

In one verison of the apparatus, the light field propagates at 45 degree to the principle axis of the crystal. The electron beam induced signal is measured to be less than 1 ns limited by the bandwidth of the photoreceiver.

In another verison of the apparatus, a free space Mach Zehnder interferometer is employed to probe the electron induced phase change. The electro-optical signal is sent to a streak camera. Less than 40 ps fast optical transient is measured.

Several variations of the apparatus are planned to lower the temporal resolution to the femtosecond regime. Upon the success of these initial experiments, the project may be expanded to the construction of a real detector. If successful, this idea could lead to the development of particle detectors with temporal resolution in the femtoseconds and spatial resolution of a few microns which would be highly useful in both hadron and lepton colliders.

A SASE-free Electron Laser Experiment, VISA, at the ATF Linac:

AE24. Spokespersons: J. Rosenzweig, C. Pellegrini, UCLA, I. Ben-Zvi, BNL. (1998 -)

Summary

We present a proposal of a SASE-FEL experiment, VISA, to be done at the ATF linac using a 4m long undulator, to study the FEL collective instability regime, including saturation, start-up, time dependence and spectral and angular characteristics of the radiation. The experiment will use a complete set of diagnostics tools to allow a detailed comparison of the experimental results with the theory and the simulation codes. The experiment is being proposed by the VISA group, a BNL-LLNL-LANLSSRL/ SLAC-UCLA collaboration. The experiment is part of a program to demonstrate the feasibility of short wavelength, UV to X-ray, FELs based on the SASE collective instability regime. This program has received the highest priority from the Birgenau panel, which has recently presented a report to DOE on future needs and development of synchrotron radiation sources in the USA. This top priority has been confirmed by the fact that the Basic Energy Sciences division of DOE has already provided the funding needed to carry out VISA.

The experiment will be done in the wavelength region 0.5 to 0.8 ?m, where sophisticated optical diagnostics is available. To reach this wavelength region using a conventional permanent magnet undulator it will be necessary to raise the ATF linac energy to 70-100 MeV. The energy upgrade has already been planned, and the order for a new klystron has already been placed. The four meter long undulator has been designed, and the order for the permanent magnets needed has also been placed. The energy upgrade and the undulator construction are the two elements defining the time scale for the experimental program. According to our schedule the undulator and the energy upgrade will be completed before the end of September 1998. Our goal is to obtain initial experimental results before the end of 1998, and a complete set of results before the end of Spring 1999.

Introduction

Short wavelength free-electron lasers based on Self Amplified Spontaneous Emission in the high gain, collective instability regime, are being developed by several groups, for wavelength regions from the UV to the X-rays. Several experiments have been done recently in the IR to visible at Orsay, BNL, UCLA, and LANL1,2,3,4,5,6,7,8, to demonstrate the SASE mode of operations, measure its most important parameters and compare the results with theory and simulation codes. Although these results agree with theoretical expectations they do not yet provide a complete test of the theory, even in the IR or visible wavelength. The VISA experiment is designed to fill this gaps and provide a complete test of the SASE-FEL theory in a wavelength region between 1 and 0.5 micrometers.

The main goals of the experiment are:

1. Reach saturation in Self Amplified Spontaneous Emission
2. Measure radiation pulse intensity and intensity fluctuations vs. undulator length and charge
3. Determine startup noise, looking at possible new effects, as quantum effects
4. Measure radiation spectrum and time structure
5. Measure radiation transverse distribution
6. Verify diffraction limited properties
7. Measure electron bunch charge density and pulse length
8. Benchmark SASE-FEL codes like Ginger, TDA3D, etc.

The choice of parameters for the VISA experiment has been based on these main choices:

- 1 to 0.5 ?m wavelength for easier radiation diagnostic
- Modular undulator with strong focusing quadrupoles, length shorter than 4m, as determined by space availability, to reach saturation and measure charge and undulatorlength dependence of a SASE-FEL
- Complete electron beam and radiation diagnostics to allow an accurate comparison between, theory, codes and experimental data.

The present schedule for the experiment aims to obtain initial results during 1998, and a complete set of data by Spring 1999. Because of the easy availability of advanced photon diagnostics at a wavelength shorter than 1?m, it is convenient to do the experiment in the wavelength region 1-0.5 ?m. However the present ATF linac energy is not large enough to reach this wavelength using an undulator with a period of a few centimeters. For this reason this experiment requires to raise the linac energy from the present value of 45 MeV up to 85 MeV. In addition a beam line matching section has to be built in front of the undulator. The undulator construction and linac upgrade define the time scale, and we are planning to have this work completed in 5 months, before the end of September 1998. This proposal describes the proposed experimental system, the present status of design of the components, and the requested time schedule.

To organize the work and manage the construction of all the components the following task group have been formed, with the group leader indicated:

a. Undulator and undulator instrumentation, R. Carr
b. Linac upgrade, I. Ben-Zvi
c. Beam line and electron beam instrumentation, XJ Wang
d. Radiation Instrumentation, M. Babzien
e. Utilities and space problems, J. Skaritka
f. Simulations, H-D. Nuhn
g. Experimental program, C. Pellegrini

Laser Driven Cyclotron Autoresonance Accelerator:
AE25. Spokesperson: J. Hirshfield, Omega-P/Yale (2000-)

INTRODUCTION

Omega-P, Inc. has carried out analytical and computational studies of a novel accelerator-driven electron acceleration mechanism *LACARA*, with support in 1999-2000 under a SBIR Phase I grant from High Energy Division, Department of Energy. This study led to a Phase II proposal to DoE, currently pending, to support a proof-of-principal experiment at Brookhaven National Laboratory Accelerator Test Facility. Obviously, acceptance of this proposal by the ATF User's Committee is also required. This document is intended to provide background information to enable the Committee to reach a considered judgement on this project. Included here are excerpts from the Phase II proposal submitted to DoE.*

SIGNIFICANCE AND BACKGROUND INFORMATION, AND TECHNICAL APPROACH

Under Topic 11a in the 1999 SBIR Program Solicitation entitled *Advanced Concepts and Technology for High Energy Accelerators—New Concepts for Acceleration,* grant applications were sought to develop new or improved acceleration concepts to provide very high gradient (>100 MeV/m for electrons) acceleration of intense bunches of particles. Omega-P, Inc. submits this proposal in response, describing Phase II of a three-phase program to develop a laser-driven cyclotron autoresonance accelerator (*LACARA*). The analysis carried out during Phase I confirms that *LACARA* (*a*) can provide an acceleration gradient in one stage of the order of 100 MeV/m, (*b*) can accelerate continuously along a 150-cm length in vacuum using an available laser, and (*c*) can accelerate in a vacuum with good uniformity all electrons within a millimeter-length bunch.* The Phase I analysis has been applied to the experimental parameters available at Brookhaven National Laboratory Accelerator Test Facility (BNL-ATF), where experiments to confirm the analysis using a prototype *LACARA* are proposed for Phase II.

Electron acceleration using intense lasers has engendered significant attention within the accelerator research community. This interest stems from the enormous optical electrical field strengths E that can be obtained with a focused laser, i.e. of the order of $E = 3\times10^{-9}\sqrt{I}$ TV/m, where the intensity I is in $\mathrm{W/cm^2}$. Since compact terawatt focused lasers can have $I > 10^{18}\ \mathrm{W/cm^2}$, field strengths of the order of TV/m are possible. Of course, since this field is transversely polarized, it cannot give much net acceleration to a charged particle directly, so an indirect means must be employed to achieve net acceleration. The basis upon which *LACARA* rests is cyclotron resonance, using an axial static magnetic field. The magnetic field can be adjusted to allow transverse deflections of electrons that move along a helical path to be synchronous with the rotating transverse electric field of a circularly-polarized laser beam, thereby allowing the field to do work on the electrons.

LACARA is a laser-driven accelerator that operates in vacuum. It does not require a pre-bunched beam; nevertheless all injected electrons can enjoy nearly the same acceleration history. *LACARA* is operated without a tight laser focus, so the Rayleigh length can be 10′s of cm for a 10.6 μm laser wavelength, and continuous acceleration in vacuum over several Rayleigh lengths can take place. Phase bunching—but not spatial bunching—occurs in *LACARA*, which explains how all injected electrons can experience nearly the same accelerating fields, since circularly-polarized laser radiation is used. Furthermore, the effective group velocity in *LACARA* exceeds the particle's axial velocity, so operation with strong pump depletion is possible without causing undue energy spread for the accelerated beam. It is shown that *LACARA* is not limited to being a "γ-doubler" (as is its microwave counterpart *CARA*), because the relativistic energy factor

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*The preliminary analysis underlying *LACARA* is presented in a forthcoming publication entitled "Laser-driven cyclotron autoresonance accelerator with production of an optically-chopped electron beam," by J. L. Hirshfield and Changbiao Wang, *Phys. Rev.* E **61**, June 2000 (to be published and appended herein.)

$\gamma = W/mc^2$ can be increased by more than a factor-of-two in a single stage. This is because stalling of the electron beam in the axial magnetic field can be avoided. (In this expression, W is the electron rest energy plus kinetic energy, and mc^2 is the rest energy.) Another feature of *LACARA* is the relatively low level of magnetic field required for the cyclotron resonance interaction when a CO_2 laser is employed. For the prototype *LACARA* demonstration proposed here for operation at BNL-ATF, the magnetic field required is only 6 T, a field that can be obtained using a cryogen-free superconducting magnet system available from a number of industrial vendors.

During Phase I, efforts were directed towards a detailed study of *LACARA*, using computational tools available to Omega-P, Inc. The main goal is to develop a design for the prototype *LACARA* based on parameters of experimental facilities available at BNL-ATF, including an rf linac to provide a 50 MeV beam to be accelerated, and a high-power CO_2-laser to drive the acceleration. It is necessary in Phase II for Omega-P to procure a high-field solenoid magnet, specifications for which evolved during the Phase I study. Some compromise in specifying the parameters of the magnet is necessary on account of budgetary limitations, but this is not expected to prevent confirmation of the underlying principles of *LACARA*, and for quantitative comparison between performance and theoretical predictions. A presentation by Omega-P is scheduled for June 1-2, 2000 before the BNL-ATF Steering Committee, to request approval for the installation and test of a prototype *LACARA*, contingent upon approval by DoE of the Phase II project. A letter from Dr. Ilan Ben-Zvi, Head of ATF, expressing strong interest in *LACARA*, is enclosed in this proposal.

ANTICIPATED BENEFITS

The physics underlying laser-based acceleration provides a wide range of fertile problems that continue to motivate a not-insignificant number of research workers. Still, none of the schemes for acceleration under study has yet produced a beam with low enough energy spread and emittance to be considered suitable as one stage out of many in a machine for nuclear or high energy physics experiments, even assuming that multi-stage operation is perfected. A single stage should be capable of uniformly accelerating a bunch containing a significant number of electrons (1 nC, for example), with a gradient of the order of 100 MeV/m, and producing a beam with an acceptable emittance (<5 mm-mrad, for example). These attributes are anticipated for *LACARA.* Efficiency is an oft-overlooked but critical parameter, since the energy per pulse that will be available in a laser beam is not unlimited. For example, for a 1 Joule laser pulse, energy conservation sets a limit of 100 MeV that can be gained by $6\times10^{10}\eta$ electrons per pulse, corresponding to 10η nC, where η is the efficiency with which laser energy is imparted to the electrons. For $\eta = 10^{-3}$, only 10 pC can be accelerated; however, for $\eta \geq 0.5$, as is shown below to be possible in *LACARA*, over 5 nC can be accelerated. This is a critical issue, since energy consumption by an eventual high energy accelerator with acceptable luminosity dictates that a reasonable level of efficiency for the driver is a *sine qua non*. Additional potential advantages of *LACARA*, as compared with other laser-based accelerator schemes, include the absence of any material medium in or nearby the accelerating region. In some vacuum accelerator schemes, nearby mirrors with apertures or surfaces that support surface waves are required. It has been shown that these surfaces can suffer permanent damage within a short time when illuminated by intense lasers. Or, when solid dielectric loading is used to provide for wave slowing, breakdown limits in the dielectric will limit the acceleration gradients. And in the inverse Cerenkov laser, where a low-pressure gas fill is used to provide the wave slowing, a small degree of ionization of the gas could be sufficient to cause a significant change in the index of refraction of the medium; this leads to loss of synchronism between the radiation and the accelerated electrons. This recitation of concerns, already thoroughly discussed in the literature, is not meant to imply that such problems cannot be overcome; rather it is to draw attention to issues that are not inherent to a vacuum accelerator such as *LACARA*.

These advantages for *LACARA* may thus provide a basis for electron and positron accelerators using powerful lasers, to be designed and built to take advantage of the high electric fields lasers provide, to generate an accelerated beam with a small energy spread and low emittance, and to transfer laser pulse energy to the beam with high efficiency. Laboratory proof of these virtues in the SBIR Phase II project proposed here by Omega-P could open the door towards realizing a high-gradient electron/positron accelerator free of many irksome features of other laser-based schemes. The potential market for the large number of magnets and optical stages of *LACARA* needed to provide a beam of interest to the high energy physics community is very large indeed, and represents a highly attractive future business opportunity.

Electron Beam Pulse Compression Based Physics at the ATF:

AE26. Spokesperson: J. Rosenzweig, UCLA (2000-)

Information coming soon.

Structure-based Laser Driven Acceleration in a Vacuum:

AE27. Spokespersons: Y. C. Huang, National Tsinghua Univ., Taiwan and Vitaly Yakimenko, BNL (2000-)

The goal of this proposal is to experimentally confirm electron acceleration from a laser-driven accelerator structure in a vacuum. The project takes advantage of the 75 MeV electron beam and the CO2 pulse laser at ATF. Due to the high electron energy and the long laser wavelength, the accelerator structure can be as large as 10 cm, consisting of 5 accelerator cells. The predicted electron energy gain ranges from 190 keV to 1.35 MeV. The uncertainty arises from laser-induced material damage as a function of the laser pulse width. The experimental result of this project is to answer the question of the possibility of vacuum laser-driven particle acceleration in a solid structure. The first goal of this proposal is to measure the laser damage thresholds on various CO2 optics materials as a function of the laser pulse width. Once the optimal material and the laser pulse width are determined, the accelerator structure will be designed, fabricated and optically tested at National Tsinghua University, Taiwan. The laser-driven acceleration experiment is to be carried out at the ATF facility, Brookhaven National Laboratory, USA. The experimenters include Y.C. Huang, the principal investigator, Y.H. Chen, the postdoctoral research associate of Huang's group, and two graduate students from Huang's group. The amount of beam time needed is approximately three weeks near the end of the proposal period. The funding if primarily from National Science Council, Taiwan, with the possibility of joint supports from other agents in the US.

Particle Acceleration by Stimulated Emission of Radiation (PASER):

AE30. Spokesperson L. Schachter, Technion, Israel. (2002-)

The interaction of electromagnetic radiation with free electrons in the presence of an active medium has some appealing outcomes. When an electron moves along a vacuum channel in a dielectric material it may cause radiation to be emitted provided that its velocity is greater than the phase velocity of an electromagnetic plane wave in the medium - this is Cerenkov radiation. What a remote observer measures as electromagnetic energy comes at the expense of the particle's kinetic energy, in other words, the particle is decelerated. For a better understanding of the deceleration force, one has to examine the field distribution in the vicinity of the particle. Ignoring for a moment the presence of the dielectric, a point charge generates in its rest frame of reference an electrostatic field which transforms in the laboratory frame into an infinite spectrum of evanescent waves. As these waves hit the discontinuity between the vacuum channel and the dielectric, a so called secondary field is generated. This is the reaction of the medium to the presence of the charged particle. It is the action of this secondary field which *decelerates* the electron and it was demonstrated that if instead of a passive dielectric medium, an active medium is used, the action of this secondary field may cause the particle to *accelerate*.

An additional way to examine the proposed acceleration scheme is to consider the microscopic processes. As indicated above, attached to a moving charge there is an infinite spectrum of evanescent waves; these can be viewed as a spectrum of virtual photons continuously emitted and absorbed by the electron. These photons impinge upon the excited atom which is conceived here as a two level system in its upper state. Since the spectrum of waves attached to this particle includes the resonance frequency of the medium, a photon with the adequate energy may stimulate the atom. As a result, two correlated photons are emitted: one is virtual as the initial one and the other is a real photon. Since the two are practically *identical*, the real photon is absorbed by the moving electron causing to the latter's acceleration. The inverse process is also possible: if the virtual photon encounters an atom in the ground state and excites it, the moving electron loses energy - thus it is decelerated. We may expect net acceleration only if the number of atoms in the excited state is larger than these in the lower state i.e. the population is inverted. From the description above the acceleration force is a result of stimulated radiation therefore, we call this scheme PASER which stands for Particle Acceleration by Stimulated Emission of Radiation. This scheme may be conceived as the *inverse of Frank-Hertz effect*; for the regime of Frank-Hertz experiment namely, one electron-atom collision (in average), the phenomenon was demonstrated experimentally by Latyscheff and Leipunsky in 1930 - the accumulative process is yet to be proven experimentally in the framework of the PASER experiment at Brookhaven National Laboratory.

A bunch of electrons moving in an active medium excites a wake that is amplified by the medium. The intense radiation field generated in this process reduces the population inversion and as a result, the field-medium interaction reaches saturation. It was shown that the accelerating gradient at saturation may reach the 1GV/m level before the medium is ionized. When ionization occurs, higher gradients may develop provided that we excite resonant states of a partially stripped atom. In fact, we determined the set of equations which describe the dynamics of electrons in the presence of a wave propagating in an active medium. Simulation results indicate that even when virtually all the energy is drained from the medium, electrons remain trapped by the accelerating wave. While in previous studies simplifying assumptions on the geometry of the micro-bunch as well as the length of the macro-bunch were made, recently we considered the effect of the active medium on a *finite length* train of micro-bunches including the dimensions of each micro-bunch.

The PASER experiment to be performed at Brookhaven National Laboratory aims to demonstrate this result experimentally. Specifically, a 70 MeV electron beam is modulated in a wiggler by an intense CO_2 laser pulse. The modulated electron pulse is then injected into a mixture of a CO_2:N_2:He which is excited by a 200nsec long discharge – if mirrors would have been attached then this cell could have form a laser.

Multi-bunch Plasma Wakefield Acceleration at ATF:

AE31. Spokepersons T. Katsouleas and P. Muggli, Univ. Southern California [BNL] (2004 -).

Background and Motivation:

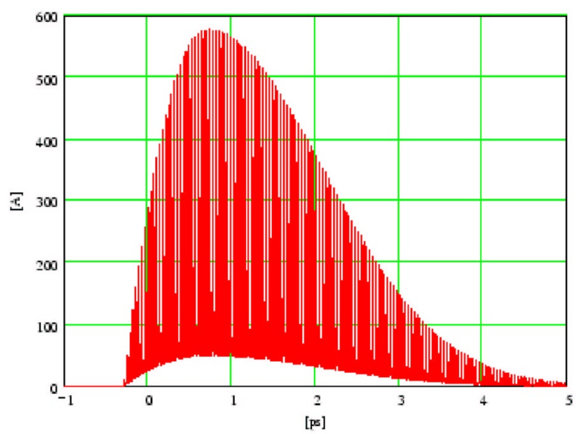
- Several recent PWA experiments have shown promise w/ single bunches
  - E-162 at SLAC: 280 MeV 1.4, e- and e+
  - ANL: ~ 15 MeV/30cm, >50% beam energy extracted
  - ATF: 6 MeV/cm. Focus and acceleration phases
- Realizations require multi-bunches
  - Afterburner: 2
  - NLC Afterburner: many

Building on Recent Success:

- ATF Plasma Wakefield Experiment
  - Single bunch
  - Low plasma density
- ATF STELLA Experiment
  - IFEL-modulated bunches at 10.6

Strategy: Use 1st stage of STELLA to drive multi-bunch PWA

- Current profile from STELLA stage 1:



Experimental Design

Adapts ATF PWA setup of Yakimenko et al.:

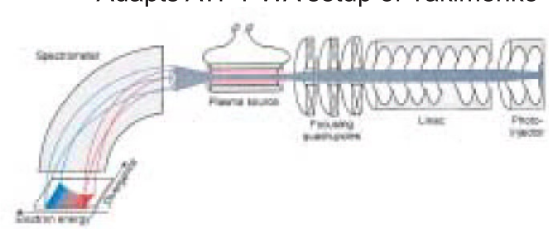


FIG. 1 (color). Schematic diagram of the plasma and electron beam interaction experiment.

- Plasma moved to second stage STELLA IP
- Capillary discharge increased from 10^16 to 10 ^19 cm^-3

Summary

- Multi-bunch wakefields can lead to energy exchange of several MeV in a mm scale plasma
- Multi-bunch PWA viability can be demonstrated
- Multi-bunch issues can be explored
  - Phasing and resonance
  - Self-modulation enhancement
  - Hosing and other instabilities can be explored

Laser Wakefield Acceleration Driven by a CO_2 Laser:

AE32, Spokesperson W. Kimura, STI Optronics (2004 -).

Background

- STELLA program successfully demonstrated important capabilities relevant to laser accelerator systems
  - Staging of microbunches and rephrasing with optical waves
  - Monoenergetic acceleration of microbunches
  - High trapping efficiency
- STELLA used inverse free electron laser (IFEL) for convenience
  - Device is well understood, relatively easy to control
  - Has inherent scaling limit, process becomes inefficient at high γ

Overview of STELLA-LW Experiment

- Phase I Program
  - Demonstrate LWFA at 10.6 μm inside capillary discharge
  - For 1.2 cm long plasma length, predict ~7-8MeV energy gain
- Possible future phases of Program
  - Demonstrate microbunching using LWFA buncher
  - Demonstrate staging between LWFA buncher and LWFA accelerator
  - Demonstrate high-trapping efficiency, monoenergetic acceleration
- Long-term goal of Program
  - Demonstrate ≥ 100 MeV energy gain using CO_2 laer-driven LWFA
  - Accelerate ≥ 5x 10^8 electrons with narrow energy spread
  - Addresses challenge given by D. Sutter in 1992 AAC Workshop

Conclusions

- STELLA-LW experiment will apply the STELLA basic approach to laser wakefield acceleration
  - STELLA-LW collaboration represents a strong, well-balanced team
  - ATF has already demonstrated key components of experiment
- STELLA-LW (Phase I) will be first to:
  - Demonstrate LWFA driven by a CO_2 laser beam
  - To use CTS on a capillary discharge
  - To operate at ~10^16 cm^-3 plasma density in a capillary discharge
- STELLA-LW (Phase I) will lay foundation for more advanced LWFA experiments
  - Demonstration of LWFA buncher and generation of microbunches
  - Staging of LWFA Devices

Ultimately, demonstration of 100-MeV LWFA-driven laser linac

Far Infrared Radiation Source:

AE08. Spokesperson J. Walsh, Dartmouth. [Oxford, BNL]. (1992 - 1994)

Information coming soon.

Laser Grating Accelerator Experiment:

AE03 Spokesperson: R. Fernow, BNL. [Princeton, LANL]. (1992- 1996)

The grating accelerator is one of the schemes that has been proposed for utilizing the enormous peak power available from lasers to accelerate electrons to high energy. In principle the accelerating gradient could be much larger than what is presently available with RF linacs. The basic reference to this idea is R.B. Palmer, A laser-driven grating linac, Part. Acc. 11:81-90, 1980. The basic principle is to use the periodic grating surface as a structure to support longitudinal, accelerating field components. The source of these fields is the incoming, focused electromagnetic wave from the CO2 laser beam. Cylindrical optics are used to produce a line focus along the electron beam direction. The electron beam transverse dimensions must be small compared to the wavelength of the laser radiation (10 fm) over the entire interaction region. Various types of structures will be investigated in the experiment. Besides flat, 2-D gratings, we will examine the accelerating properties of “foxhole” and “colonnade” structures. These structures have been manufactured using silicon etching with metallic coating. They can also be made from LIGA techniques. We could also measure the accelerating fields on the vacuum side of a crystal undergoing total internal reflection. The proof of principle experiment will use a 50 MeV beam from the ATF with a normalized emittance of 2x10-8 m-rad. This should produce a 1 fm beam radius at the experiment and give a 3 mm interaction length. A laser power of 1 GW should produce an accelerating field greater than 1 GeV/m on the grating surface. This would produce an energy gain of 3 MeV.

This experiment was formally withdrawn in September 1996

Inverse Cherenkov Acceleration:

AE06. Spokesperson: W. Kimura, STI Optronics. [UCSB,BNL]. (1992-1997)

The Inverse Cherenkov Laser Accelerator experiment at the Accelerator Test Facility is located on Beam Line number 1.

In the first laser accelerator scheme to be tested at the ATF, we start with a radially polarized CO_2 laser beam. The conversion of the linear polarization to radial polarization is done an optical circuit containing spiral phase shifters, an optical device that changes the light delay as a function of the azimuthal angle.

Using an axicon, the laser beam will be converged to the e-beam axis inside of an interaction gas cell. Because of the wave-front inclination, a longitudinal component of the electric field will be developed.

By filling the interaction cell with hydrogen, the phase-matching condition is satisfied, and the injected electron bunch propagates in phase with the optical field and experiences an acceleration. This process is opposite to that of coherent Cherenkov radiation, thus the designation "Inverse Cherenkov Acceleration" (ICA).

The radially polarized laser beam is converged by the axicon to produce a cylindrically symmetrical interference pattern. The longitudinal component of the electric field has a maximum along the axis. The width of this maximum under the conditions of the ATF experiment is 400 microns, about the same as the diameter of the e-beam.

Design Parameters for ICA Experiment:

- Cherenkov Angle [mrad]------------------20
- Phase Matching Gas----------------------H2
- Gas Pressure [atm]-----------------------1.7
- Interaction Length [cm]-----------------20
- Electron Beam Diameter [mm]--------------0.2
- Net Acceleration (@ 0.6 GW) [MeV]--------3.7
- Predicted Acceleration (@50 GW) [MeV]---36

In the first ICA run using a 0.7 GW CO_2 laser beam, up to 3.5 MeV peak acceleration has been observed. Up to 12 MeV acceleration over a 20 cm interaction distance is predicted by computer simulations for 5 GW of delivered laser power. These figures are subject to experimental verification in the next ICA runs, scheduled through the end of 1995.

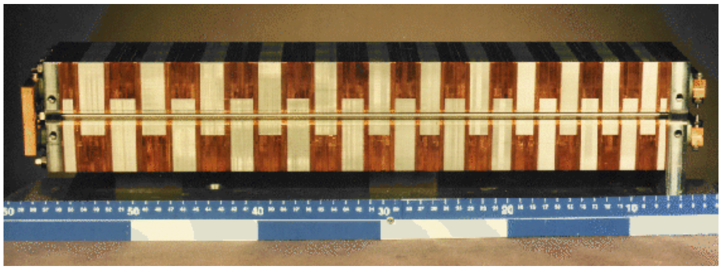
Inverse FEL Accelerator:
AE02. Spokesperson: A. van Steenbergen, BNL. [Yale, Columbia]. (1992-1997)

EXPERIMENTAL RESULTS

An IFEL accelerator module has been successfully tested at the Accelerator Test Facility.

The experiments makes use of the 50 MeV linac beam and high power (2 10^{11} W) CO_2 laser beam of the ATF in conjunction with a fast excitation (300 micro-sec pulse duration) variable period wiggler.

Fast Excitation Wiggler for the IFEL Experiment at the ATF

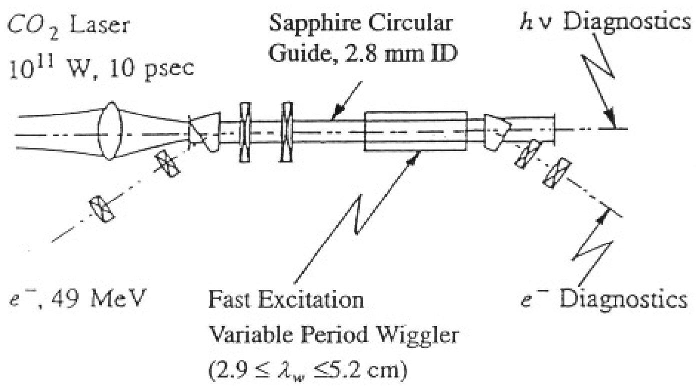


The wiggler makes use of alternating stacks of Vanadium Permandur (VaP) ferromagnetic laminations, periodically interspersed with conductive, nonmagnetic laminations, which act as eddy current induced *field reflectors.* A typical period length taper for the IFEL experiment is lambda = 3.0 - 5.0 cm, d lambda/dz = 4%. Other wiggler parameters are: B_max =14 kG (I = 6 kA) and maximum field variation pole-to-pole, ({\Delta B}/B)_rms = 0.2%.

The CO_2 laser beam will be transported through the IFEL interaction region by means of a low loss (alpha=0.2 dB/m) dielectric (sapphire) circular waveguide of 2.8 mm i.d. and 1 m long.

The IFEL design is supported by the development and use of 1D and 3D simulation programs.

Schematic Diagram for the IFEL Experiment at the ATF



Parameters for the IFEL Experiment at the ATF

Electron Beam	
Injection energy	48.9 MeV
Exit energy	87.95 MeV
Mean accelerating field	89 MV/m
Current, nominal	5 mA
N (bunch)	6×10^{9} e^{-}
I (max)	100 A
$\Delta E/E$ ($1\ \sigma$)	$\pm 3 \times 10^{-3}$
Emittance ($1\ \sigma$)	7×10^{-8} m-rad
Beam radius	0.3 mm
Wiggler Parameters	
Wiggler length	0.47 m
Section length	0.6 m
Period length	2.86-4.32 cm
Gap	4 mm
Field (constant B mode)	1.25 T
Horiz. max. amplitude	0.17-0.22 mm
Laser parameters	
Power	2×10^{11} W
Wavelength, λ	10.2 μm
Max. Field	1.36×10^{4} MV/m
Guide loss par. α	0.025 m^{-1}
Field attenuation/section	0.13 dB
Pulse length (FWHM)	6 ps

Study of Spiking Phenomena in FELs:

AE11. Spokesperson: T. Marshall, Columbia. [BNL] (1992 - 1997)

The microundulator BNL FEL Oscillator setup is the device used by Columbia University to study spiking in short wavelength FELs.

It has been observed that, when a Free Electron Laser oscillates at high power, a set of sidebands appears located near the laser carrier wavelength. These sidebands result from an instability, and have been examined theoretically by analytic theory as well as numerical simulations in the past. The cause of the instability has to do with the slippage of the faster light wave in front of the more slowly moving bunched electrons in the FEL, which provides a feedback mechanism for the growth of parasitic waves on the carrier. The appearance of a complicated spectrum suggests that narrow temporal pulses might be produced, and indeed numerical work suggests that the FEL micropulse (~ 5 ps long) can break up into a series of regularly spaced or chaotic sha rp, narrow pulses ("spikes") at high intensity. We have proposed to study sideband and spiking radiation as they may occur in the visible FEL facility at the ATF in Brookhaven.

The motivation to study such spiking is as follows. One can show that the location of the sideband is about 1.5% away from the carrier; thus the spectrum is about 10E13 Hz wide, and pulses as narrow as 100 fs could result by Fourier transform. Such high intensity narrow pulses could be useful if they are regularly spaced. On the other hand, other applications might require the suppression of spiking. Therefore, it is useful to determine if such spiking appears in the ATF FEL, and what mechanisms or conditions affect the phenomenon.

The FEL should produce a high intensity carrier at about 500 nm wavelength at a level > 100 MW/cm2 inside the optical resonator. At thus level, simple estimates from analytic theory show that sidebands -- spaced about 1.5% from the carrier -- should grow at a rate somewhat smaller than the carrier itself. Thus, a few passes after the carrier reaches saturation level, the sidebands should appear. The first part of the experimental program consists in observing sideband radiation with a spectrometer. This instrument can also be used to study how the sideband develops throughout the FEL macropulse. In addition, we have a 1D numerical program which has computed the sideband growth spectrum under conditions appropriate to the ATF FEL.

If sidebands are found, there is motivation to study the time-dependent structure of the radiation pulses, especially the spikes. At first, a streak camera, with a resolution of 1 ps, will be used to measure the temporal width. We also plan to combine streak camera with spectrometer to study the frequency content across the optical micropulse. For the observation of the optical spikes which can be as short as 100 fs, our streak camera will not be sensitive enough to observe it. We plan to build an optical autocorrelator to observe the spikes. The study of the correlator construction is currently underway. Once spiking is detected, operating parameters of the FEL can be changed in order to understand what physics favors regular spiking.

New Generation Photocathode RF Gun Test Program:

AE15. Spokesperson: R. Miller, SLAC. [BNL]. (1994 - 1997)

Information coming soon.

Room Temperature, pulsed Microwiggler:

AE12. Spokesperson: H. Haus, MIT. [BNL] (1992 - 1997)

Information coming soon.

Micro-undulator FEL Experiment:

AE01. Spokesperson: I. Ben-Zvi, BNL. (1992 - 1997)

The microundulator FEL experiment at the Accelerator test Facility is located on Beam Line number 3. This set-up is used by a number of experiments. The BNL FEL Oscillator experiment will use a dc superconducting electromagnet wiggler.

MIT has an experiment on the same line that will use a pulsed electromagnet. The period and length of the MIT microundulator have been chosen to be the same as the BNL superconducting device. This will lead to an interesting comparison of the two short period devices under otherwise identical conditions.

Finally, Columbia University will use the microundulator FEL to study spiking in short wavelength FELs.

Parameters:

- Electron beam energy: 49.5 MeV
- Peak current: 50 amp
- Emittance: 7 pi mm mrad (normalized rms)
- Undulator period: 0.88 cm
- Number of periods: 68
- Length of undulator: 60 cm
- Peak magnetic field: 0.473 Tesla
- Mirror spacing: 367.65 cm
- Power outcoupling: 5%
- Optical wavelength: 0.5 microns
- Mirror radius of curvature: 188.72 cm
- Rayleigh range: 30 cm
- Waist radius: 0.22 mm
- Spot size on mirror: 0.136 cm

Optical Diagnostics:

Spontaneous Emission Diagnostics

The single-pass undulator radiation is expected to have a central energy density of 2.2 pJ per mrad**2 per nC of electron beam charge. This energy will be confined to a cone of approximately 1 mrad**2 in the forward direction at the f undamental wavelength of 530 nm. This results in a spot size at the FEL optical- diagnostics table of 15 mm. This spot is expanded (lense L1) and focussed (lense L6) onto three diagnostics: (1) a low light imaging CCD camera (CAM2), (2) a fast time response (few ns) photodiode (PD2) to measure the micro-pulse by micro-pulse energy variation, and (3) the entrance slit of an imaging spectrometer (SPEX).

High Power FEL Diagnostics

The outcoupled laser light is expected to have a maximum energy of 10 uJ and a spot size of 30 mm at the FEL diagnostics table. The light is split twice (BS3 and BS4) to divide it between the imaging spectrometer (SPEX), a fast photodiode (PD1), and a Joule meter (J1) for absolute energy calibration.

Nd:YAG Transport

The same Nd:YAG laser that produces the high-brightness electron beam is frequency- doubled and mode matched to the VFEL resonator cavity so that it may be used to align the FEL cavity and test the various diagnostics described above. Lenses L4 and L5 provide the mode matching. PH1 is a 400 micron pinhole for spatial filtering. The beam is sent to the FEL cavity via BS1 where it is used for cavity length adjustment. After reflecting from the resonator mirrors the returning beam is used to align and test the diagnostics in the high power FEL line.

High Gain Harmonic Generation FEL:

AE10. Spokesperson: L.H. Yu, BNL. [ANL] (1992 - 2001)

Currently there are two possible paths to high-power, single-pass short-wavelength FELs: SASE and HGHG. The HGHG technique seems to offer an order-of-magnitude better bandwidth, a signal free of noise, improved wavelength stability and a shorter wiggler but seems to be limited to longer wavelengths than SASE.

In recent years there has been an enhanced interest in the generation of coherent, short pulse Free-Electron Laser (FEL) radiation. In particular there is interest in single-pass devices, such as Self-Amplified Spontaneous-Emission (SASE). At Brookhaven National Laboratory we have been pursuing a different approach to short wavelength FELs. We call this approach High-Gain Harmonic Generation (HGHG).

In HGHG, a seed laser is used to modulate the energy of an electron beam in a 'modulator' wiggler. The energy modulation is converted to spatial bunching in a dispersive section that follows the modulator. The bunched beam is introduced to a wiggler tuned to the desired harmonic of the seed. The radiation at the harmonic wavelength starts as a coherent spontaneous signal, which quickly changes to exponential regime growth, and, if the wiggler is long enough can reach saturation. Tapering may follow to extract more energy.

HIGH GAIN HARMONIC GENERATION:

The FEL operates as an amplifier of a coherent signal, generated by a seed laser, thus:

- -No need for resonator mirrors
- -The wiggler is shorter as compared to startup from spontaneous noise (SASE).
- -The bandwidth is narrower as compared to startup from spontaneous noise (SASE).
- -High wavelength stability is provided by the seed laser (the wavelength does not depend on the electron beam energy)
- -Adjustable pulse length through the seed. No need to change the electron pulse length.
- -Precise chirping is possible through the seed laser. Possibility of femptosecond pulses through optical compression.
- -Flexible pulse format: Single pulses, bursts, veto etc.

MINOS Beam Monitoring Detectors:

AE28. Spokesperson: M. Diwan, BNL.[FNAL, Northwestern, Pittsburgh, Wisconsin, CERN]. (2001-2001)

Information coming soon.

Smith-Purcell Effect Experiment:

AE13. Spokesperson: J. Walsh, Dartmouth. [BNL, Univ. of Colorado] (1994 - 2004).

Principle of Smith-Purcell Radiation

Smith-Purcell radiation occurs when a charged particle passes close to a periodically varying metallic surface. In the most simple terms one can imagine that an electric dipole is formed from the beam particle and its image in the metal. Since the surface height is periodic, the dipole oscillates and thus produces radiation at a wavelength determined by the period, particle velocity, and angle of emission of the radiation.

Description of the Experiment

The experiments were conducted with a 2.8 MeV/c electron beam from the ATF RF gun. The beam shape was measured using a phosphor coated beam flag at the grating location. The beam charge could be measured using a Faraday cup located downstream of the grating. A series of blazed gratings were used with periods around 1 cm. The distance of the beam to the grating surface could be remotely adjusted. The optical collection system consisted of a remotely rotatable plane mirror, off axis parabodial mirror, and a light pipe. The wavelength of the radiation was determined with a Czerny-Turner monochromator. The radiation power was measured with a liquid helium cooled InSb bolometer.

Experimental Results

This experiment detected Smith-Purcell radiation over the wavelength range from 0.6 to 6.0 mm. The wavelengths of the measured Smith-Purcell radiation agree with theoretical predictions. The emitted power from the electron beam is expected to peak in the forward direction (small angles with respect to the beam direction). The experiment observed this forward peaking for the first time in Smith-Purcell radiation. The radiation was detected with grating period to wavelength ratios as high as 16. The measured intensities were much higher than those predicted from incoherent emission.

Future Plans

A new experiment is under construction to measure Smith-Purcell radiation in the wavelength region 10 - 100 microns using the high energy, 50 MeV beam from the ATF linac.

STELLA:

Staged Electron Laser Acceleration. AE20. Spokesperson: W. Kimura, STI Optronics. [BNL, UCLA, Stanford, Yale, UCSB] (1997 - 2004)

Motivation and Main Achievements:

Laser-driven electron accelerators (laser linacs) offer the potential for enabling much more economical and compact devices with very high acceleration gradients.However, the development of practical laser linacs requires accelerating a large ensemble of electrons together (“trapping”) while keeping their energy spread small (“monoenergetic”).This has never been realized before for any laser acceleration system until the STELLA experiment.**We have demonstrated for the first time efficient, monoenergetic trapping and acceleration of electrons via laser acceleration.**

The STELLA Concept:

The basic concept utilized by STELLA is to first group the electrons within the electron-beam (*e*-beam) into microbunches. Briefly, the initial *e*-beam energy is distributed uniformly over all phases of the accelerating electromagnetic wave (i.e., laser beam optical field).A sinusoidal energy modulation is imparted onto the *e*-beam using the intense electric field of the laser beam.This accelerates some of the electrons and decelerates others.The fast electrons are allowed to catch up with the slow ones resulting in grouping (“bunching”) of the electrons into tiny clusters (“microbunches”). These microbunches can then be efficiently trapped and accelerated by a second laser acceleration device while maintaining a narrow energy spread.This process of trapping and acceleration by a second device is fundamental to staging multiple laser acceleration sections, which is necessary for enabling high net energy gains.Microbunching and staging were first demonstrated in an earlier precursor experiment

. Description of Experiment:

The basic STELLA concept can be applied to many different laser acceleration schemes.For experimental convenience, inverse free electron lasers (IFEL) were chosen as the laser acceleration mechanism.An IFEL is a free electron laser operating in reverse.The laser beam co-propagates with the *e*-beam within the gap between a pair of parallel-facing magnet arrays called an undulator.Depending on the sign of the laser field seen by an electron, it will be accelerated or decelerated.

Figure 1 shows a schematic layout of the experiment.It consists of two IFELs driven by a single laser beam from the ATF CO_2 laser.The first IFEL (IFEL1) is called the buncher and causes the sinusoidal energy modulation.The second IFEL (IFEL2) is referred to as the accelerator. This IFEL traps and accelerates the microbunches.A bunch compressor or chicane is located between IFEL1 and IFEL2. The chicane has both a fixed magnetic field (i.e., permanent magnets) and a variable magnetic field (i.e., electromagnets).The fixed field forces the electrons to travel through a “V-shaped” trajectory in which the faster electrons generated by IFEL1 traverse a shorter path than the slower ones, thereby causing the electrons to bunch at the entrance to IFEL2. This creates a train of microbunches separated by 10.6 μm with individual bunch lengths of ≈1 μm (equivalent to ≈3 fs). Control of the phase delay between the microbunches and the laser field in IFEL2 is achieved by adjusting the variable field of the chicane. This enables resynchronizing the microbunches with the accelerating portion of the laser field by slightly delaying when the electrons exit the chicane. Usage of the chicane also makes the entire system more compact with a total length of 1.2 m from the entrance of IFEL1 to the exit of IFEL2. At the end of the experiment is an energy spectrometer for measuring the electron energy spectrum.

In IFEL1 the gap separation is uniform along the undulator. IFEL2 uses a tapered undulator where the gap separation decreases by 11% towards the end of the undulator. Tapering is important for achieving high trapping efficiency and sufficient energy gain to separate the accelerated electrons from the background electrons.

Stimulated Dielectric Wakefield Accelerator:

AE19. Spokesperson: J. Hirshfield, Omega-P Inc. and Yale University and T. Marshall, Columbia University. (1997-)

We report on the experimental demonstration of a novel acceleration technique, proposed in 1999, which might deliver high acceleration gradients as required by future linear colliders. This technique utilizes constructive superposition of wake-fields produced in a dielectric-lined waveguide by short (psec) drive bunches which excite a broadband frequency spectrum having more than a hundred eigenmodes and thereby synthesize a high-amplitude accelerating field. This experiment is compared with a related experiment by a group at the Argonne National Laboratory where the wake field consisted of a few tens of eigenmodes. We find that the axial accelerating electric field has a sharply- peaked profile with very narrow footprint as desired, and we demonstrate that fields of two bunches have been successfully superimposed. Our observational technique has two important advantages: a) the wake field period can be established with excellent accuracy; b) agreement between theory and experiment can be verified when the bunch spacing is different from the wake field period.

We report the development of a nondestructive technique to measure bunch rms-length in the psec range and below, by measuring the high- frequency spectrum of wake field radiation which is caused by the passage of a relativistic electron bunch through a channel surrounded by a dielectric. We demonstrate both experimentally and numerically that the generated spectrum is determined by and sensitive to the bunch rms-length, whereas it is insensitive to the axial and longitudinal charge distribution. Measurement of the millimeter-wave spectrum determines the bunch rms-length in the psec range, and this has been done using a series of calibrated mesh filters. We have developed the analysis of the factors crucial for achieving good accuracy in this measurement, and find the experimental data are fully understood by the theory. We point out that this technique also may be used for measuring fsec bunch lengths, using a prepared planar wake field microstructure. Further details can be found here.

We also report on the theoretical and numerical investigation of the quantitative behavior of the dielectric wake field accelerator performance (such as the efficiency, accelerating gradient, and energy spread) vs. the dielectric wake field accelerator parameters (e.g. the inner and outer radii, the dielectric constant, the longitudinal shape of a drive/test bunch, the bunch rms- length, etc) for the case of the cylindrical multimode monolayer dielectric wake-field accelerator. Having analyzed over 2,000 cases we reach conclusions about the quantitative behavior of the MM- DWA performance, affected by changes in the structure and/or bunch dimensions, as well as the dielectric material. In particular, we have found an important scaling law that provides a straightforward way to connect changes in the DWA performance with changes in the DWA parameters.

ODR/OTR:

Spokesperson: Ralph Fiorito, Approved: 2001. Completed 2002.

Introduction

OTR interferometry is a proven method for measuring the rms emittances of relativistic electron beams with energies ranging from 15-100 MeV [1]. In this technique two parallel thin foils, oriented at 45 degrees with respect to the electron beam, produce forward and backward directed OTR. When the distance between the foils is comparable to the vacuum coherence length $L \sim g^2 l$, interference fringes are observed whose visibility is a function of the rms beam divergence.

Scattering in the first foil of the interferometer limits this method to beam energies above about 10 MeV. When the energy of the electron beam falls below about 10 MeV and the rms divergence of the beam is smaller than about 0.05/g, it becomes very difficult to design a foil with less scattering than the divergence of the beam. To overcome this limitation, we plan to use a *perforated* first foil as shown in Figure 1. The total output light intensity distribution observed is the coherent sum of the intensities of ODR and OTR produced by the unscattered and scattered portions of the beam.

By proper choice of the first foil thickness, the inter-foil spacing, the size, number and spacing of the holes and the band pass of the imaging optics, interference fringes from the unscattered electrons can be seen above the background light produced from the scattered portion of beam. The rms divergence of the unperturbed beam can be measured from the visibility of the interference fringes. In addition, the orthogonal (x, y) components of the divergence can be separately obtained by observing polarized interferences when the beam is focused to either an x or y waist condition

Experiment

The experiment proposed for ATF is

(1) to use conventional OTR interferometry to measure the beam divergence and

(2) to compare the results of the divergence measurements using (1) to that obtained using ODR-OTR interferometry.

Conventional OTRI and ODR-OTRI can be both be done by using a common fixed distance two foil system, with part of the first foil containing a small (several beam diameters) perforated section.

One, multiple position actuator will be used to expose the beam to three positions different sections on the first foil:

a) a cut away section, which will allow the beam to pass through without generating any forward direction OTR or ODR from the first foil; this sectuib will allow us to optically align the interferometer with the help of an upstream laser which is available on the ATF beam line

b) a solid section of the first foil which will be used to generate conventional two foil OTRI

c) a perforated area on the first foil which will be used to generate ODR-OTRI .

The second foil, which will be a mirrored surface, is parallel and at fixed distance (35-70 mm) with respect to the first foil. The actuator and foils will be housed in a six inch cube commonly used and available at ATF. The ATF cooled CCD and Spiricon LBA500 image frame integrator will be synchronized to the beam and used to acquire and accumulate images of the angular distribution of the OTRI/ODR-OTRI with sufficient signal to noise, so that the interferences will be clearly visible above background. Image subtraction of the background will also be performed. This method has been commonly used by us in previous OTRI measurements [1]. The charge per macropulse on ATF is equivalent to that of beams with which we have had previous experience and success in these types of measurements.

We estimate approximately one or two hours of beam time per experimental run and two or three experimental runs will be sufficient to complete our proof of principle experiments. The position of the experimental cube will be placed such that the beam can be focused (x and y) to a waist condition at the site of the interferometer. A pair of quadrupoles and steering magnet will therefore be placed upstream of the diagnostics cube. We will work with the ATF staff and scientific users of the ATF beamlines to find a position which will minimally impact other experiments and which in fact may serve to provide useful data for their experiments. Our diagnostic foil system will be completely retractable to allow complete uninterrupted passage of the beam when it is not in use.