(12)

PROGRESS REPORT

Contract N00014-90-K-2010

INTERACTION OF INTENSE LASERS AND RELATIVISTIC ELECTRON BEAMS WITH SOLIDS, GASES AND PLASMAS

Submitted to the
Naval Research Laboratory
Washington, D.C.

Period Covered
January 1, 1993 – June 30, 1993

Principal Investigators
Edward Ott
C. S. Liu
V. L. Granatstein

Laboratory for Plasma Research
University of Maryland
College Park, MD 20742-3511

TABLE OF CONTENTS

ABSTRACT		1
I.	INTRODUCTION	2
II.	RESEARCH IN EXCIMER LASER TECHNOLOGY	3
III.	LASER PLASMA INTERACTIONS	4
IV.	APPLICATIONS OF RADIATION AND PARTICLE PHYSICS TO SPACE AND ENVIRONMENTAL PROBLEMS	6
V.	PLASMA DYNAMICS OF SHORT PULSE PUMPED SOFT X-RAY LASERS	9
VI.	INTERACTION OF MICROWAVES WITH LONG-PULSE DISCHARGE PLASMAS	10
VII.	EXPERIMENTAL STUDIES FOR THE PROPAGATION OF AN INTENSE RELATIVISTIC ELECTRON BEAM THROUGH GAS	11
VIII.	TEMPORAL DYNAMICS IN NEURAL NETWORKS	14
IX.	WORKSHOP ON IONOSPHERIC HEATING	16
X.	DESIGN AND TESTING OF A CO-AXIAL WIGGLER MAGNET FOR FREE ELECTRON LASERS (FELS)	18

ABSTRACT

The focus of the Maryland Program is to establish strong experimental and theoretical support for ongoing programs at NRL. Areas of research which are of mutual interest are pursued by members of the University of Maryland faculty in collaboration with their counterparts at NRL. The proposal encompasses basically three broad areas of research activities. The first area deals with excimer laser technology and the interaction of high power lasers with matter (gases, solids and plasma). The second area of mutual interest involves diagnostics of intense relativistic electron beams and study of their propagation and interaction with a background gas. The nonlinear temporal dynamics in neural networks is the third area for collaboration.

I. INTRODUCTION

The present proposal in the area of plasma physics from the University of Maryland focuses on providing strong experimental and theoretical support for a variety of research programs at the Naval Research Laboratory.

There are basically three broad areas of research of mutual interest which are pursued. The first such area is high powered lasers. Under this first broad area the following projects will be pursued: (1) The collaborative development of a high powered excimer laser for application to the inertial confinement fusion program. (2) The theoretical investigation of beam smoothing techniques like induced spatial incoherence on the scattering instabilities like Brillouin and Raman. (3) The interaction of femtosecond intense laser pulses with solid targets. (The plasmas produced by these interactions can give rise to stimulated soft x-ray emissions.) (4) Novel techniques for generation of radiation with tunable frequencies. (5) The interaction of intense microwaves with long pulse discharge plasma to monitor trace and other key atmospheric species. (This work is intended to determine if plasmas can be used as artificial mirrors. This project supports a full time graduate student.)

The second broad area encompassed in this proposal deals with research in intense relativistic electron beams. The specific tasks are: (1) Development of diagnostics for studying beam characteristics and the interaction of a propagating beam with a background gas is a project that supports a graduate student. (2) Theoretical investigation of the role of relativistic electrons on ozone depletion.

The third broad area of this proposal deals with neural networks. Studies to identify and characterize the nonlinear dynamical behavior of neural networks with time varying properties is the main focus of this project.

Thus the proposal encompasses specific projects which provide a strong support for various research activities at NRL and also ensures training of graduate students who can, on graduation, pursue productive research careers at NRL.

II. RESEARCH IN EXCIMER LASER TECHNOLOGY

Contact: J. Goldhar

A. PROGRESS REPORT

During the past year we concentrated our effort on testing and improving different designs of Pockels cells with transparent electrodes. High speed switching was obtained with liquid electrodes; however, because of the need for additional thin windows between the liquid and the electro-optic crystal, half-wave voltage was over 10 kV. Also, there were serious mechanical problems in mounting of the very thin (0.2 mm) windows. In order to reduce the switching voltage requirements and to simplify the mechanical design we changed the emphasis from liquid electrolyte electrodes to plasma electrode designs. A new Pockels cell was designed and constructed and tested. Compact electrical system for plasma generation was also developed. The results from the prototype were very encouraging. Contrast ratio was observed to be greater than 2000. The turn-on time of Pockels cell was observed to be strongly dependent on the discharge plasma parameters (pressure, current, electrode structure, etc.). Proper choice of operating parameters allowed us to reduce the turn-on time to about 1 ns.

Second generation Pockels cell is almost completed now. This cell allows easy variation of the electrode structures and replacement of crystals. With the new cell, better crystals, and faster electrical pulser we expect to demonstrate additional significant improvements in the performance.

III. LASER PLASMA INTERACTIONS
Contact: P. Guzdar

A. PROGRESS REPORT

1. Over the last year we have studied the Stimulated Brillouin Scattering Instability in the strong coupling regime, in an homogeneous as well as an inhomogeneous plasma. This is motivated by present-day experiments for which the homogeneous growth rate γ_0 is comparab[illegible] to the acoustic frequency ω_s. Thus the conventional SBS theories, which require $\gamma_0 < \omega_s$ are no longer valid. We have found that in this strong coupling regime besides the usual three-wave quasimode instability which occurs at $k = 2k_0$ (where k is the wave vector of the low frequency quasimode and k_0 the wave vector for the pump wave), there is a purely growing mode for $k > 2k_0$. This new scattering regime has been coined as the Stimulated Bragg Scattering regime. It is found that in this regime a significant fraction of the unstable spectrum can be blue shifted by flows with a mach number of unity. This may explain recent observations on blue shifted SBS spectra.

For an inhomogeneous plasma, we find that the convective amplification factor in the strong coupling regime turns out to be the same as the amplification factor for conventional SBS. This is because during the growth phase the growth rate decreases like $t^{-1/3}$ (where t is time). As a consequence the mode is in the strong coupling regime for a finite time after which it reverts back to the usual SBS regime. The implications of this study is that the bandwidth of the pump will have no effect on the amplification factor similar to Raman case.

B. FUTURE WORK

We will extend our 1D work on SBS to 2D. This will allow us to study the effect of ISI on this instability. Furthermore, we will also include the effect of ponderomotive self-focussing or filamentation on this instability. A comparison of SBS in the presence and absence of filamentation will allow for a better understanding of present-day data.

C. PAPERS PRESENTED AT MEETINGS

1. Convective Amplification and the Effect of Bandwidth on SBS in the Quasimode Regime, P. N. Guzdar, C. S. Liu and R. H. Lehmberg, 23rd Annual Anomalous Absorption Conference, Wintergreen, VA, 21-25 June 1993.

D. PUBLICATIONS AND REPORTS

1. Induced Spatial Incoherence on the Convective Raman Instability, P. N. Guzdar, C. S. Liu and R. H. Lehmberg, Phys. Fluids B **5**, 910 (1993).

2. Stimulated Brillouin Scattering in the Strong Coupling Regime in Homogeneous and Inhomogeneous Plasmas, P. N. Guzdar, C. S. Liu and R. H. Lehmberg (in preparation).

IV. APPLICATIONS OF RADIATION AND PARTICLE PHYSICS TO SPACE AND ENVIRONMENTAL PROBLEMS

Contact: K. Papadopoulos

A. PROGRESS REPORT

Research Projects

The following were accomplished during the previous contract period.

1. Remote Spectroscopy of the Atmosphere Using Microwave Breakdown [K. Papadopoulos, G. M. Milikh, W. Ali and R. Shanny, submitted to *J. Geophys. Res.*, 1993]

A novel method for remote optical diagnostic of the atmosphere at heights 30-60 km is proposed. The method relies on the measurements of optical emissions of atoms and molecules of minority species excited by electron impact during and following an ionizing RF pulse injected from a focused ground based transmitter. Free electrons produced in the breakdown region are the exciting agents for the atmospheric target molecules. The mixing ratio of the minority species can then be measured by either detecting the direct emission from allowed transitions, or utilizing lidar techniques to measure the excitation level of metastable states. Computer simulations of the intensity of expected emission, based on kinetic theory of air breakdown, have been developed. It is shown that the requirement for a principal system in terms of effective radiation power and frequency are consistent with the state of the art in microwave and detection technology.

2. Triggering HF Breakdown of the Atmosphere by Barium Release [K. Papadopoulos, G. M. Milikh and P. Sprangle, *Geophys. Res. Lett.* **20**, 471-474, 1993]

RF ionization rates for mixtures of air with barium are computed using a Fokker-Planck code. It is shown that there is an optimum mixing ratio of barium to air, significantly lower than unity, which maximizes the ionization rate for a given value of incident RF power density and frequency. Rocket injection of barium at a selected height reduces significantly the RF breakdown threshold for the mixture, and allows atmospheric and ionospheric breakdown at selected heights using the radiation from powerful HF radio facilities. The possibility of field experiments using currently available or projected HF heaters is discussed.

3. Kinetic Theory of Runaway Air-Breakdown [R. Roussel-Dupre, A. V. Gurevich, T. Tunnell and G. M. Milikh, submitted to *Phys. Rev.*, 1993]

The kinetic theory for a new air breakdown mechanism advanced in a previous paper [A. V. Gurevich, G. M. Milikh and R. Roussel-Dupre, Runaway Electron Mechanism of Air Breakdown and Preconditioning During a Thunderstorm, *Phys. Lett. A*, **165**, 463, 1992] is developed. The relevant form of the Boltzmann equation is derived and the particle orbits are computed. A numerical solution of the Boltzmann equation, assuming a spatially uniform electric field, is obtained and the temporal evolution of the electron velocity distribution function is described. The results of our analysis are used to estimate the magnitude of potential x-ray emissions from discharges in thunderstorms.

4. Nonuniform Runaway Air-Breakdown [A. V. Gurevich, G. M. Milikh and R. Roussel-Dupre, submitted to it Phys. Lett. A, 1993]

Structure of an individual runaway pulse stimulated by a seed energetic electron is studied. The approach is based on the fluid model, which is corrected by comparison with the results from the kinetic calculations and yields the stationary spatial distribution of the electron beam in the thunderstorm atmosphere. The polarization electric field, as well as the intensity and pulse width of the corresponding breakdown current are estimated.

5. Thunderstorms as a Limiting Factor of the Atmospheric Halocarbon Abundance [K. Papadopoulos and G. Milikh]

The halocarbons are manufactured in large quantity. These species are generally fairly stable in the troposphere and can therefore be transported toward the stratosphere, where they are eventually dissociated by UV radiation. The product of their dissociation is the chlorine radicals which start to destroy the stratospheric ozone as soon as they appear. When halocarbons dissociated in the troposphere, the products react with the chemicals and finally are rained out. An effective means the halocarbon destruction in the troposphere can be lightning. The previous estimates [NAS report 1976] concluded that lightning cannot be a sufficient sink of halocarbons. Nevertheless, since this estimate was rather approximate and some effective mechanisms of halocarbon destruction were missed, we have reexamined the problem. In our model we treat a lightning channel not just as a region of fully ionized plasma, but also consider a surrounding halo of low ionized plasma, produced by the shock wave. In the extended lightning channel following mechanisms of halocarbon distribution are taken into account: thermal decomposition, dissociation caused by electron attachment, and oxidation by radicals produced in the lightning stroke. The effectiveness of each of these mechanisms is estimated. The global sink of some halocarbons associated with thunderstorms is also evaluated and compared with the industrial source of these species.

B. PROPOSED WORK

Energetic particles due to solar flares and cosmic rays precipitating in the Earth's atmosphere strongly affect the composition of the atmosphere, troposphere, stratosphere and mesosphere. These interactions can possibly be the explanation of the recently reported correlation between the Earth's warming trend and the solar activity (Friis-Christensen and Lassen, *Science* **254**, 698, 1991). It is the objective of this part of the research to determine the physical processes responsible for the observed correlation, and identify novel diagnostic instrumentation using coherent em sources, to provide the necessary data. In particular, we will examine:

1. Effects Initiated in the Troposphere

These effects are associated with the thunderstorm appearance modulated by the solar activity. A further lightning can be sink or source of some atmospheric constituents controlling the thermal balance. Proposed investigations include:

a. studying the correlation between solar activity and the frequency of thunderstorm appearance on the global scale. This investigation will be based on the existing observations. Observations made during 2-3 decades are required.

b. studying a lightning effect on the atmosphere constituents which are responsible for the thermal balance. This will be made on a local, as well as on the global basis. The last model will allow to evaluate the global basis. The last model will allow to evaluate the global temperature changes.

2. Effects Initiated in the Middle Atmosphere

These effects are associated with the precipitation of relativistic magnetospheric electrons modulated by the solar activity. The relativistic electrons produce odd nitrogen and odd hydrogen, both of them are involved in the catalytic destruction of the ozone layer. Proposed investigations include:

a. modeling of the ozone depletion caused by the relativistic electrons, and estimating of a net reduction in the heating rate of the atmosphere.

b. since the reduction of ozone concentration changes the absorption of solar UV emission at given altitude, the downward propagation of the atmospheric perturbation will be considered.

3. Novel Instrumentation

Under this part we will identify appropriate microwave, laser and passive systems utilizing high power sources under development at NRL to monitor trace and other key atmospheric species.

V. PLASMA DYNAMICS OF SHORT PULSE PUMPED SOFT X-RAY LASERS

Contact: H. M. Milchberg

A. PROGRESS REPORT

In the past year, our group has demonstrated, for the first time, the optical guiding in a plasma of an intense optical pulse over distances considerably in excess of a Rayleigh length. Currently, we are observing guiding up to 70 Rayleigh lengths. We have measured the beam exiting from the guide and find that the plasma guide supports modes very much like an optical fibre, except at intensities many orders of magnitude higher.

The many applications of this result are just beginning to be investigated in our lab: coherent and incoherent soft x-ray generation via recombination lasing and high harmonic generation (HHG). A differential pumping geometry and a gold mirror/XUV spectrometer arrangement have been aligned for these measurements.

Construction has begun on a new Ti:Sapphire femtosecond laser system, which has been designed to produce 150 mJ in a 100 fs pulse (1.5 Terawatts). Focused to less than 10^{-6}cm^2, this will yield intensities in excess of 1.5×10^{18} W/cm^2. This system produces peak powers in excess of 250 times greater than our current dye-based system.

B. FUTURE WORK

In the next year we plan to exploit our guiding results in the area of x-ray sources, as described above, by investigating the processes of high harmonic generation and recombination-generated population inversions. A number of schemes for phase matching are currently being attempted in the harmonic generation experiments, whiie assorted gases are being used to maximize population inversion in Li-like ions. In parallel, we have written computer codes to solve the nonlinear wave propagation equation (for use with the HHG experiments) and to simulate the plasma dynamics of the recombining plasma channel.

VI. INTERACTION OF MICROWAVES WITH LONG-PULSE DISCHARGE PLASMAS

Contact: W. W. Destler

A. PROGRESS REPORT

During the last part of FY 1989, the Charged Particle Physics Branch (Code 4750) of the Plasma Physics Division at NRL and the Charged Particle Beam Laboratory at the University of Maryland agreed to work together on problems of mutual interest in the general area of high power particle beams and related areas. Under this agreement, Mr. Joseph Gregor pursued an M.S. thesis at NRL in which he developed and tested a sensitive magnetic spectrometer and an intense beam emittance meter both of which are intended to be used in the NRL atmospheric beam propagation program. This work was summarized in Mr. Gregor's thesis and both of these diagnostics are available for use in experiments at the University as well.

During FY 1993, Mr. Gregor, working under the joint supervision of Prof. W. W. Destler and Dr. R. Meger of NRL, began a Ph.D. thesis study of the interaction of microwaves with long-pulse discharge plasmas.

B. PROPOSED RESEARCH

During the next fiscal year, Mr. Gregor's thesis studies will be continued. These studies will include resea[illegible]n long-pulse discharge plasma formation under varying conditions of ambient gas pressure and composition, and microwave reflection, transmission, and absorption in such plasmas. This work is intended to determine if plasmas can be effectively used as microwave reflectors in some applications.

Mr. Gregor will work directly with Charged Particle Physics Branch research personnel on this project

VII. EXPERIMENTAL STUDIES FOR THE PROPAGATION OF AN INTENSE RELATIVISTIC ELECTRON BEAM THROUGH GAS

Contact: M. J. Rhee

A. BACKGROUND

Propagation of an intense relativistic electron beam through a gas without an external focusing magnetic field is possible.[1] In a gas, the electron beam creates a conductivity channel which neutralizes the beam space charge. Propagation distance, however, can be limited by the resistive hose instability,[2,3] which allows growth of transverse ($l = 1$) motion of the beam and eventually destroys the beam. It is possible to reduce the growth rate of this instability by tapering the beam radius from head to tail.[4] This is known as "beam radius tailoring." There are two outstanding issues that are associated with beam conditioning: (1) how to generate a beam that has a tailoring profile that will allow stable propagation and (2) the interaction of the beam with the background gas distribution.

Many techniques have been proposed to generate a radius-tailored electron beam. One technique involves using a Fast rise-time Focusing Coil (FFC).[5] In this technique, the beam head is allowed to expand due to the beam emittance, when the axial magnetic field in the FFC is low. As the magnetic field in the FFC is ramped up, the beam body and tail are focused. This produces a radius tailored beam at the end of the FFC. Such a radius tailored beam can be passed through a scattering foil to produce an emittance-tailored beam, so that the radius tailoring is preserved during propagation. The result is a beam that has a larger head than the original beam radius and a body and tail with the radius roughly the same as the original beam radius.

Another technique uses an IFR (ion-focused regime) cell, which is filled with gas, to provide beam radius tailoring. The beam head flares due to the beam emittance, while the beam tail is focused by the beam-induced ion channel and the beam self-magnetic field.

Hose instability results from the interaction of the beam current with the beam-induced background-conductivity distribution. Propagation distance and hose growth are influenced by a number of factors associated with the beam and the background gas. The beam produces a conductivity channel in the gas with a certain radial density profile. Return currents are driven in this channel, which can be significant even at large radius.

Regardless of how successfully instabilities are suppressed, there will still be a limit to the effective propagation distance of an electron beam. In the case where instabilities are not significant, the distance is limited by gas scattering. The beam expansion is called Nordwieck expansion, the length scale of which is characterized by the Nordwieck length L_N. Experimental determination of L_N can provide information about the beam effective current, which is the net current within the beam radius, and the beam emittance.

B. PROGRESS REPORT

The operation of the FFC radius tailoring cell has been characterized with an electron beam.[5] We investigated the effect of a time-varying current in the FFC on the beam radius tailoring. Time-resolved electron beam radius measurements were performed using a streak camera viewing a fast scintillator.[6] We measured the beam energy,[7] current, and emittance before the FFC; these measurements were used as the inputs for computer simulations that were performed and were compared to my experimental results.

Since beam radius measurements are essential to these experiments, algorithms were developed to analyze the data from a streak camera and from a framing camera. These algorithms were implemented in applications that run under Microsoft[8] Windows to allow relatively easy analysis of all data that is collected. This now enables objective analysis of the data without bias, such as may be introduced by selecting data for analysis or by analyzing data interactively.

C. PROPOSED WORK

The effects of the beam propagating through a background gas will be studied. This is important for leading to an understanding of long-range propagation and the effects of beam conditioning. The experiment would be designed to study the beam over a distance that is long compared with the length scale of interest L_N, as described above. The electron beam in these experiments will be the one produced by the SuperIBEX accelerator: 4 MeV, 15 kA, and 40 ns.

Diagnostics will be used that will provide measurements of the beam radius as a function of time and position. Cherenkov foils will provide current-density profile information; this will be time-resolved by viewing with a streak camera and a fast framing camera. This will also provide a direct measurement of the beam radius. Measurements will be taken at different locations on the same shot to avoid problems associated with shot-to-shot variation.

Experimental measurements, proposed here, of the beam during propagation will be helpful for future work. This work may include extending the propagation distance of beams to relatively large distances, for various applications.

REFERENCES

1. R. B. Miller, *An Introduction to the Physics of Intense Charged Particle Beams*, Plenum Press, New York, 1982.

2. E. P. Lee, "Resistive hose instability of a beam with the Bennett profile," Phys.

Fluids **21** (8), 1327-1343 (1978).

3. H. S. Uhm and M. Lampe, "Theory of the resistive hose instability in relativistic electron beams," Phys. Fluids **23** (8), 1574-1585 (1980).

4. R. F. Fernsler, R. F. Hubbard, and S. P. Slinker, "Conditioning electron beams in the ion-focused regime," Phys. Fluids B **4** (12), 4153-4165 (1992).

5. D. J. Weidman, M. J. Rhee, R. F. Schneider, K. T. Nguyen, and R. A. Stark, "Radius tailoring of an intense relativistic electron beam using a fast rise-time focusing coil," to be published in Appl. Phys. Lett. **61** (1993).

6. NE102A from NE America or ND120 from National Diagnostics.

7. D. J. Weidman, M. J. Rhee, and R. F. Schneider, "Time-resolving electron energy spectrometer," Rev. Sci. Instrum. **62** (2), 548-549 (1991).

8. "Microsoft" is a registered trademark of Microsoft Corporation.

VIII. TEMPORAL DYNAMICS IN NEURAL NETWORKS
Contact: Judith Dayhoff

A. PROGRESS REPORT

Neural networks have proven to be highly useful tools in signal processing, control, and pattern recognition. Paradigms such as the multi-layered perceptron, competitive learning, and adaptive resonance have been applied to diverse applications areas and have shown demonstrated results for real-world problems. Although their capabilities are known, most networks in use today are static networks, capable only of processing static patterns – patterns that do not incorporate temporal variations and time-varying parameters as part of the distinguishing features to be recognized. Furthermore, most networks do not contain nonlinear dynamic properties such as limit cycles, oscillators and chaos, as well as transitions between complex attractors. The addition of more complicated nonlinear dynamics to neural networks appears to be a key area of research because of its promise to enhance the limited computational capabilities of static neural networks.

An adaptive threshold (AT) neural network was developed and its dynamic behavior was studied. Processing units in the network perform incoming sums and then apply a squashing function whose horizontal position is adapted to adjust its threshold. Thresholds are adjusted based on a recent past history of neuronal activation. A recently active unit adjusts its threshold upwards and a recently inactive unit lowers its threshold. The network was found to be capable of prolonged oscillations and can enter modes where irregular activity occurs for an indefinite period of time. Preliminary analysis of the activity of the network was performed, including traces of the variance over the entire network over a period of time. Variance increased initially and then leveled off as the network entered a prolonged period of irregular activity. Oscillations across the entire network were characteristic of networks with low weight values, and more complex patterns of activity emerged as weights were increased. These activity patterns open possibilities for overcoming the limitations in the capabilities of static networks, as complex trajectories, activation patterns, and chaos-like behavior was observed and could eventually be utilized for pattern recognition and computation.

B. WORK STATEMENT

This research project is to identify and characterize dynamic behavior of neural networks, with respect to time-varying properties, attractors, and chaos. We have developed an adaptive threshold (AT) neural network that produces prolonged complex activity including limit cycles, coupled oscillations, and irregular activity patterns with chaotic properties. We intend to explore the dynamics of this network and to experiment with its potential for producing useful computations.

We intend to vary weights along interconnections to study the impact of different weight matrices on the dynamic properties of the network. The entire weight matrix can be multiplied by a factor g that can be varied, and a comparison made between the operations of the resulting networks. When thresholds are not adapted, small g values result in a fixed point attractor or a set of limit cycles for the network. When g is increased, there is eventually a rapid transition to chaotic behavior for the network. The impact of variations in weight values is a subject of new research, as well as methods for performing computations via the relationship between weights and limit cycles. Different sets of weights and initial conditions are expected to lead to different limit cycles; computations could then be performed by starting with explicit sets of weights and observing the resulting limit cycles. Such a scenario has advantages over previously developed static networks because of the diversity of trajectories that can lead to the same limit cycles and the possibilities for moving from one limit cycle to another.

The impact of adaptive thresholds on the dynamic behavior of the network will also be studied. Two types of adaptive threshold models are to be used: a local threshold adaptation rule and a global threshold adaptation rule. The local adaptation rule leads to a network of individual oscillators. We will study how these oscillators couple and when they may produce chaotic behavior. The global adaptation rule fosters the development of spatially isolated limit cycles. We will study how these limit cycles arise and how to control which limit cycles the network enters into. The potential for processing, generating, and recognizing spatiotemporal patterns by means of network activation patterns will be explored.

IX. WORKSHOP ON IONOSPHERIC HEATING
Contact: K. Papadopoulos

A workshop on "Research Topics and Opportunities Using Ionospheric Heaters" was held at East West Center of the University of Maryland on June 18, 1993. The main subject was the identification of research opportunities and needs that are attractive for investigation using the HAARP ionospheric heater and associated diagnostics. Of particular interest were basic and exploratory research opportunities leading to applications of interest to DOD and other government agencies; to potential dual use (military/civil) applications; and to address environmental issues such as global warming and global change. Highly leveraged cooperative or collaborative programs exploring the HAARP facility and diagnostic complement in conjunction with ionospheric research capabilities and facilities in other countries are of particular interest.

A summary of the specific areas, both experimental and theoretical, that need to be addressed and the agenda of smaller working groups was discussed in this workshop. These issues are discussed below:

1. Diagnostic issues – HF diagnostics.

    1.1 Possible use of HAARP transmitter as a receiving antenna.

    1.2 Possible addition of a "big" receiving antenna to be used as interferometer. Needed of resolution fir 100-300 m size F-region inhomogeneities.

    [A. Gurevich and P. Bernhardt]

2. Possible use of satellites and dedicated satellite as diagnostic platforms for remote optical sensing, top side ionosonde, and in situ F-region diagnostic.

    2.1 Dedicated inexpensive satellite ($\leq$ 4 M).

    2.2 Frequency of overflights, instrumentation, number of satellites required for better coverage.

    2.3 Target of opportunity satellites (MIR-2, RAIDS).

    [H. Carlson, EWC]

3. Atmospheric chemistry and environmental studies.

    3.1 Utilization of diagnostics complement in passive mode.

3.2 Active mode - probe emissions on the ground, balloon, RPV, and satellites.

[M. Keskinen, G. Milikh]

4. Field aligned scattering.

   Possible use of the large volume of artificial irregularities generated by the HF heater to reflect HF, UHF, VHF signals.

   4.1 Remote environmental probing (sea state - ice thickness).

   4.2 Emergency communications in Alaska.

   [EWC]

5. Use of HAARP as a radar at 8-10 MHz frequency for magnetospheric probing and for planetary and solar astronomy.

   [EWC, A. Gurevich, M. Keskinen]

6. ELF/VLF generation and propagation in D-region, stratosphere, and ionospheric wave guide. Potential utility for atmospheric and magnetospheric diagnostics.

   [EWC]

7. Requirements for studies of strong turbulence in F-region.

   [EWC, A. Gurevich]

8. Magnetotelluric studies using ULF/ELF/VLF generated by HAARP.

   [EWC, A. Gurevich]

Timetable

Major meeting, or smaller group meetings (September 1993).

Draft of the research program (December 1993).

X. DESIGN AND TESTING OF A CO-AXIAL WIGGLER MAGNET FOR FREE ELECTRON LASERS (FELS)
Contact: V. I. Granatstein

A new and advantageous configuration for producing the wiggler magnetic fields required for free electron lasers will be investigated. The field will be produced by a solenoid inside of which is placed a co-axial structure of periodic iron rings. This type of wiggler magnet is named "Coaxial Hybrid Iron" (CHI) wiggler. This new design promises to have many advantages over older ones; for example, due to the co-axial configuration, the FEL would use an annular electron beam thereby avoiding and focusing problems which exist with planar electron beams.[1]

During the first year, a study of all the possibilities and advantages of this new design will be carried out using computer electromagnetic codes such as POISSON/PANDIRA and SCRIBE. This will allow one to evaluate design options and to make an optimum choice of design parameters such as wiggler period and accelerating voltage. A prototype of the CHI wiggler will then be constructed and tested, and its performance will be compared with the predictions of the computer code calculations. Magnetic probe assembles will be constructed or adapted for these measurements.

In the out years, a free electron laser operating at microwave frequencies and using the CHI wiggler will be developed and evaluated. This project will be carried out by a graduate research assistant (J. M. Taccetti) under the guidance of Professor V. I. Granatstein. It will be carried out in collaboration with scientists at the Naval Research Laboratory (Dr. Robert Jackson and Dr. D. E. Pershing) and will make use of NRL furnished equipment and NRL laboratory facilities.

REFERENCES

1. V. L. Granatstein et al., "Experimental and numerical results on a millimeter-wave free electron laser amplifier," Nucl. Instrum. Meth. Phys. Res. A **331**, (1993) 122.