THE BNL*)-NRCC**)-AECL***) LASER GRATING ACCELERATOR EXPERIMENT

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ABSTRACT

A collaboration has been set up to take advantage of the unique capabilities of a laser developed by NRCC to explore the feasibility of acceleration of particles in the electric fields established over the surface of a grating by a laser beam. This report will review the history of the collaboration, discuss the characteristics of the equipment which is available to conduct the experiment, and present a timetable for experimental activities.

INTRODUCTION

In the course of his early investigations into the use of lasers for particle acceleration[1,2], Palmer identified the need for a high-energy picosecond laser. At the time, no such laser existed, but in 1983, Corkum reported[3] on a technique to generate and amplify picosecond laser pulses at 10.6 μm. The laser is rather complex and immobile, and it became clear, during a visit to the NRCC laboratory by Palmer in the spring of 1984, that any experiment which sought to make use of this unique facility would have to be located in close proximity to the laser. A relatively small, portable electron linac would therefore be required as an injector to a grating accelerator.

A suitable linac was available, manufactured in Ottawa by Atomic Energy Canada Radiochemical Company. Further inquiries with AECL Research Company's Chalk River Nuclear Laboratories interested members of the Physics Division in the proposed experiment, and contributed a second possible injector linac and a sophisticated detector to the rapidly maturing collaboration. All elements necesary for a successful experiment seemed to be present, and the first formal meeting of the collaboration was held in Ottawa on September 6-7, just prior to this workshop. The principal investigators are, from BNL: R.B. Palmer and J. Claus; from NRCC: P.B. Corkum and N.K. Sherman; and from AECL: J.W. Knowles and L.W. Funk.

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OBJECTIVES

The objectives of this experiment, shown in schematic outline in Fig. 1 are as follows:

(1) determine the intensity threshold for damage to a copper grating with picosecond 10.6 μm pulses,

(2) demonstrate electron acceleration while keeping the laser intensity below the damage threshold,

(3) study the performance of the grating accelerator as a function of various laser and injector parameters,

(4) increase the optical intensity to, and beyond, the damage threshold,

(5) examine plasma physics issues relating to formation and development of a plasma grating, and

(6) accelerate electrons over a plasma grating to determine the maximum achievable accelerating gradient.

The objectives are listed in order of increasing difficulty, and naturally the later objectives may be modified by experience from the earlier ones.

LASER

The laser is shown schematically in Fig. 2, taken from Ref. 3. The picosecond pulse is switched out of a 100 ns pulse from a hybrid CO_2 oscillator using fast semiconductor switches energised by a picosecond pulse from a synchronously mode-locked dye laser. The 10.6 μm picosecond pulse is then regeneratively amplified in a high pressure TE CO_2 laser. The pulse length is continuously variable from 2 to 60 ps, and an output pulse energy of 10 mJ has been achieved. An additional high pressure CO_2 gain module has been ordered which is expected to increase the pulse energy to 100 mJ. The amplified short pulse can be focused down to a diffraction limited spot.

This laser is capable of generating accelerating gradients of 300 MeV/m over a grating area of 0.2 cm^2, even if there is no gain from resonant interaction of the laser beam and the surface, while remaining below the threshold for surface damage. The pulse repetition frequency is 0.5 s^{-1}, limited by thermal dissipation in the final amplifier.

INJECTOR

Two different linacs are being considered as possible injectors for the experiment. The first of these is a 10 MeV standing-wave electron linac built by Atomic Energy Canada Radiochemical Company, who are in the business of providing products for the radiotherapy market. This linac is identical to that used in the THERAC-25 [4]), a 25 MV x-ray, 5-25 MeV electron beam cancer therapy unit, but operated in a different mode and at higher currents, since only 10 MeV is required. It has the advantage that it can be obtained as a complete package, with rf system, cooling and controls.

The second choice is a 6 MeV standing-wave electron linac designed and built by CRNL[5]). This is a slightly more compact unit, but it has the disadvantage that more work would be necessary to assemble the auxiliary packages, although it would still be possible to plug the smaller linac into the 10 MeV unit package. In addition the higher energy unit promises to allow a slightly longer acceleration distance before the electrons fall out of synchronism with the accelerating fields.

Both linacs operate at an rf frequency of 3 GHz, and are driven by 2.5 MW magnetrons with a nominal pulse length of 5 μs and a pulse repetition frequency of up to 300 s^{-1}. The operating pulse repetition frequency for the experiment will be 1 s^{-1}, to match the laser capability. With their standard thermionic diode guns, both linacs have unnormalised transverse output emittances of about 0.1 π cm•mrad.

There exists a possibility that a high-current (≈ 5 A), short pulse (≈ 3 ns) thermionic triode gun of the SLAC design[6]) could be incorporated in either accelerator, which would improve the transverse matching by reducing the output emittance from the figure quoted above, and enormously improve the signal-to-noise ratio by increasing the fraction of electrons injected which are illuminated by the laser beam.

In spite of such efforts at improving the transverse and longitudinal match between the injector linac and the grating, the grating acceptance is likely to be so small that nearly all the injected electrons will collide with the grating, or cross the grating before or after the accelerating laser pulse arrives, or suffer deflection or deceleration, rather than acceleration. These considerations impose severe constraints on the resolution and noise rejection of the detector.

DETECTOR

The detector which is being made available for this experiment is a bremsstrahlung monochromator[7], designed and built by a CRNL-University of Toronto-University of Illinois collaboration. It is based on the original University of Illinois design and has been used with the Illinois cw microtron for (γ,γ) and (γ,f) measurements. It consists of a dispersive 90° bending magnet (see Fig. 3 from Ref. 7) followed by an analysing magnet operated in the energy loss mode for tagged photon studies. For the laser grating accelerator experiment, the grating will be substituted for the radiator in the figure and the analyser will be operated in the energy gain mode. The limit of energy resolution is 14 keV for 3.5 MeV electrons[7] and is not expected to be much more than 30 keV at 10 MeV. Experiments on the cw microtron are coming to a halt in preparation for a major facility upgrade, and the detector could be made available early in 1985.

TIMETABLE

The installation and commissioning of the new laser amplifier module is expected to be completed late this year. The linac and detector are expected to be available in January 1985. We expect that installing, commissioning and linking of all these systems should be complete by April 1985, at which point the experimental program could begin. We have allocated a period of six months for the first series of experiments, after which time progress would be assessed, and plans for further work reviewed.

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REFERENCES

1) R.B. Palmer, "A Laser-Driven Grating Linac", Particle Accelerators 11, 81 (1980).

2) R.B. Palmer, Laser Acceleration of Particles, Ed., P.J. Channell, AIP Conference Series 91 (1982).

3) P.B. Corkum, "High-power, Subpicosecond 10-μm Pulse Generaton", Optics Letters 8, 514 (1983).

4) T. Taylor, G. Van Dyk, L.W. Funk, R.M. Hutcheon and S.O. Schriber, "THERAC-25: A New Medical Accelerator Concept", IEEE Trans. Nucl. Sci., NS-30, 1768 (1983).

5) R.M. Hutcheon, L.W. Funk, B.A. Gillies, S.B. Hodge, P.J. Metivier and S.O. Schriber, "A Compact 6 MeV Pulsed Electron Accelerator", IEEE Trans. Nucl. Sci., NS-30, 1418 (1983).

6) R.F. Koontz, "CID Thermionic Gun System", Proceedings 1981 Linear Accelerator Conference, Eds. R.A. Jameson and L.S. Taylor, LA-9234C (1982).

7) J.W. Knowles et al., "A High-Resolution Bremsstrahlung Monochromator for Photo-Nuclear Experiments", NIM 193, 463-483 (1982).

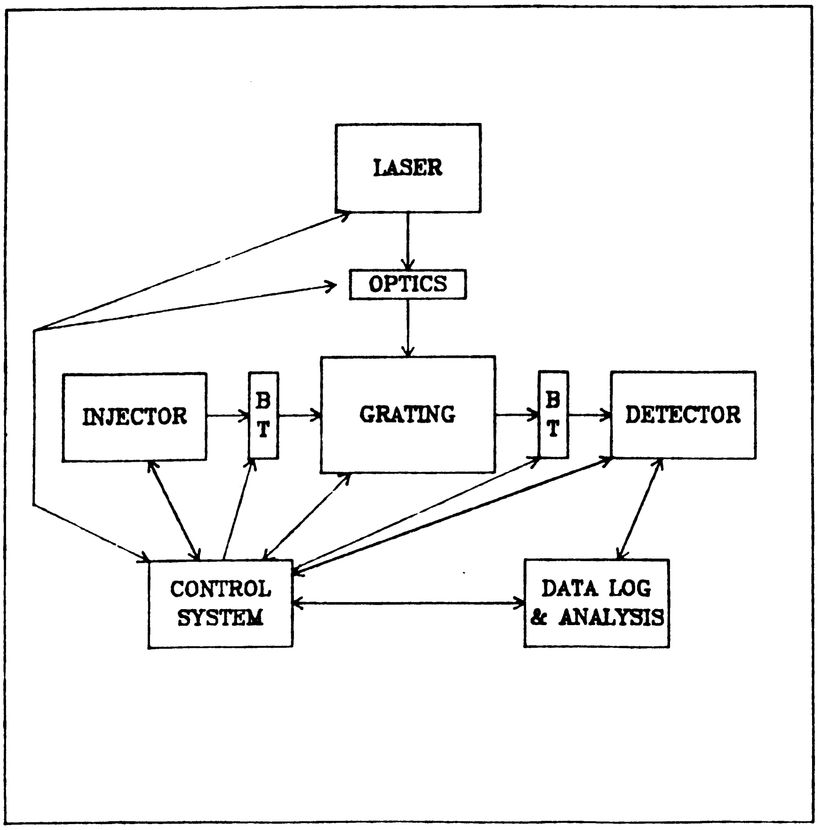

Fig. 1 : Experiment schematic

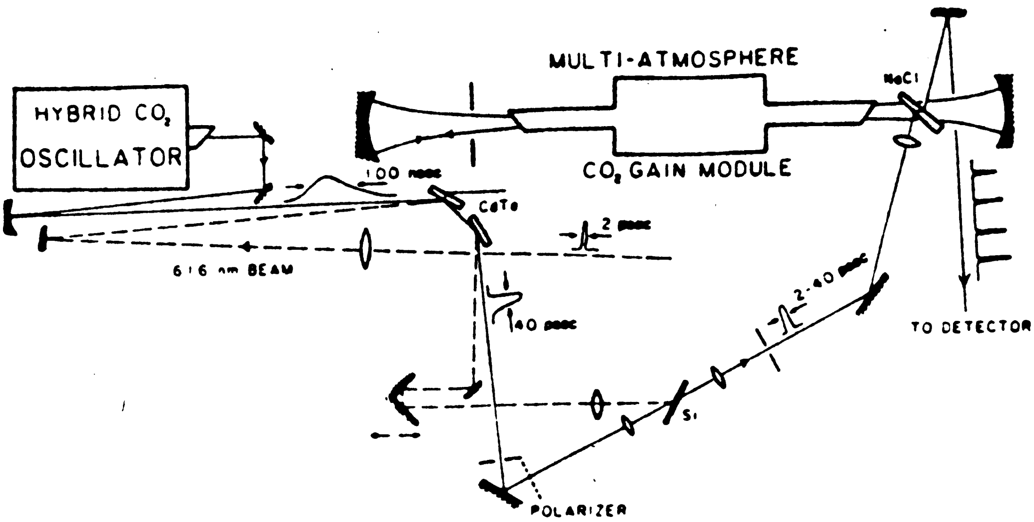

Fig. 2 : Schematic of the laser configuration

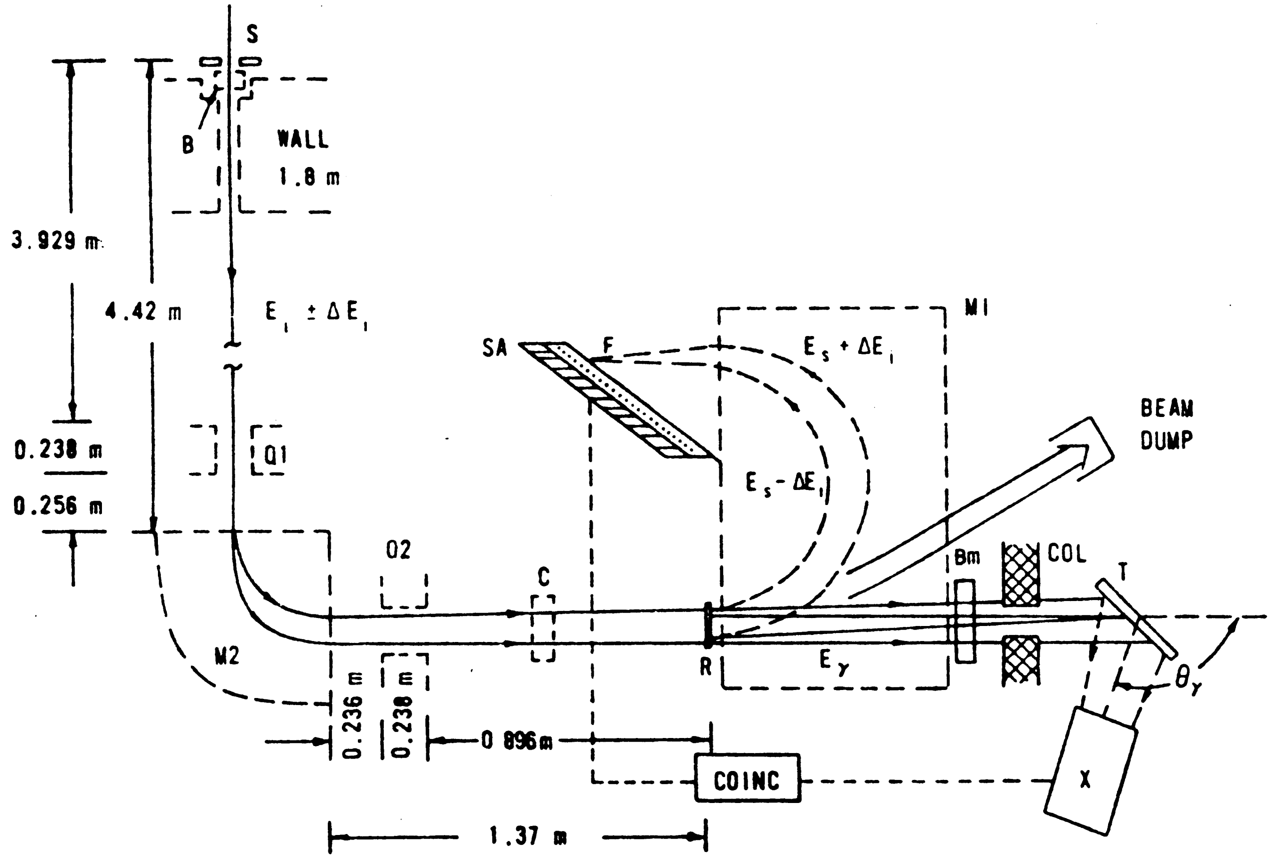

Fig. 3 : Schematic of the photon monochromator, as used for tagged photon experiments, showing reference slit S behind a shielding wall; a beam transport consisting of quadrupoles Q1, Q2, 90° magnet M2 and steering coils B and C. Electrons of energies $E_i \pm \Delta E_i$ are incident on a converter foil R. The bremsstrahlung from R proceeds through a lead collimator COL and a photon flux monitor B_m and is incident on a target T. Radiation emitted by T is detected in a NaI (Tl) counter X shown at $\theta_\gamma \approx 135°$ to the incident beam. Scattered electrons of energies $E_S \pm \Delta E_i$ are focused by magnet M1 at F onto the detector, a multi-wire proportional chamber in front of an array of scintillators (SA). In this experiment, the conventer foil R would be replaced by the grating and the flux monitor, collimator, target NaI(Tℓ) counter and coincidence detector would be removed.