100 MeV Laser Accelerator Demonstration and 1 GeV Baseline Design Development

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DESCRIPTION OF PRESENT EXPERIMENT

2.1 INTRODUCTION

The acceleration of relativistic electrons using the inverse Čerenkov effect was first demonstrated at Stanford University in 1981.²⁻¹ Later, Fontana and Pantell²⁻² developed an improved configuration for the inverse Čerenkov acceleration (ICA) process. Their basic scheme is shown in Figure 2-1. A radially polarized laser beam is focused by an axicon onto the e -beam traveling through a gas-filled interaction region. The light intersects the e -beam at the Čerenkov angle θ_c , where $\theta_c = \cos^{-1}(1/n\beta)$, n is the index of refraction of the gas, and β is the ratio of the electron velocity to the speed of light.

This configuration has several important advantages over the geometry used during the Stanford experiments. First, it produces a more efficient coupling of the laser energy into the e -beam. Second, the transverse electric field components from the laser beam are focused axisymmetric about the e -beam. This helps mitigate some of the detrimental effects of gas scattering by channeling the electrons in the longitudinal direction.²⁻³ This same effect can also focus the e -beam using the inverse Čerenkov effect. Third, the potential problem of laser-induced gas breakdown may be less of an issue. This is because when the radially polarized laser beam is focused by the axicon, its profile in the interaction region follows a $J_1(r)$ Bessel pattern, where r is the radial distance away from the longitudinal z -axis. The $J_1(r)$ Bessel function is zero at $r = 0$ and maximum at a finite distance away from the z -axis. Hence, gas breakdown, if it should occur, will tend to be located in a circular region away from the e -beam. (The situation is actually much better than this because the laser energy in this circular region is also distributed along the entire interaction length, thereby lessening the chance for gas breakdown.) As will be discussed later in Section 5, a radially polarized laser beam focused by an axicon also has important advantages for laser acceleration of electrons in a vacuum.

The goal of our present program is to demonstrate improved laser acceleration using the Fontana and Pantell configuration. Our experiments will be performed on the Accelerator Test Facility (ATF) located at Brookhaven National Laboratory (BNL). This facility features a 50 MeV linac fed by a Nd:YAG (4 ω) laser-driven photocathode e -gun. It will be upgraded to 65 MeV in the near future. The ATF also has a high peak power

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Figure 2-1. Arrangement for the inverse Čerenkov interaction. The electrons travel parallel to the z-axis and the laser beam consists of a radially polarized field that passes through an axicon and converges at an angle θ_c onto the z-axis. L is the interaction region length.

CO₂ laser, which was developed for laser acceleration studies. The scientist responsible for the ATF CO₂ laser, Dr. Igor Pogorelsky, is actually a member of our ICA experiment team and he is being entirely supported through funds from our program.

The ATF is in its final stages of preparations before being available for the Users and their experiments. Both the Nd:YAG and CO₂ lasers are operational, with the Nd:YAG laser being used regularly to drive the photocathode. This same laser is also used to slice out the variable pulse lengths (10 ps - 100 ps) from the CO₂ laser oscillator. An update on the status of the ATF CO₂ laser system is given in Appendix A.

The ATF RF *e*-gun has surpassed several of its original design goals. Its design and achieved characteristics are listed in Table 2-1.

Table 2-1. ATF RF *e*-Gun Characteristics

	<u>Design</u>	<u>Achieved</u>
Energy, MeV	4.6	4.6
Repetition rate, Hz	6	6
Electron pulse charge, nC	1.0	2.0
Electron pulse length (rms), ps	2.5	4.9
Peak current, A	160	106
Energy spread (rms), %	0.3	0.4
Emittance ($\gamma\sigma_x\sigma_{x'}$), mrad	7×10^{-6}	4×10^{-6}
Beam brightness, A/m ²	3×10^{12}	7×10^{12}

The *e*-beam requirements for the ICA experiment are not stringent so that the *e*-gun characteristics listed in Table 2-1 are well within the needs of our experiment. (This is one advantage of ICA over some of the other laser acceleration approaches which have more stringent *e*-beam requirements.) The ATF has produced 50 MeV beam and plans to deliver the beam to the experimental hall where the ICA experiment is located in December 1992.

The present ICA experiment was divided into two phases. Phase I was to examine certain experimental issues in preparation for Phase II. Phase I was successfully completed in the spring of 1992. Phase II is to perform the actual laser

acceleration experiments on the ATF e -beam. We are currently waiting for the availability of the e -beam so that we can begin our Phase II experiments.

In this section, the theory and experimental hardware for the present program are described. The results of the Phase I experiments are presented, and an update on the Phase II experiment is given.

2.2 COMPUTER MODEL DEVELOPMENT AND PREDICTIONS

2.2.1 Brief Description of Model

A Monte Carlo computer simulation of the ICA process was developed²⁻³ based upon earlier models developed at the University of California, Santa Barbara and at Stanford University. The model includes all relevant physics and is more versatile than the earlier models in its ability to simulate many different experimental conditions. It also uses a more accurate characterization of the optical field as the laser beam propagates through the interaction region.

The model includes Rutherford scattering caused by the gas and e -beam windows, straggling, and other inelastic losses suffered by the electrons. It is designed to model axicon focusing and can handle any arbitrary optical field distribution coming into the axicon. Thus, it can analyze the affects of experimentally measured beam profiles. Diffraction and interference effects of the laser beam are included using a fast Fourier transform (FFT) technique. Electron beam characteristics such as emittance, energy spread, and width are also included.

Another distinguishing feature of the STI model development was the amount of validation performed on it. Wherever possible, the model was checked against available experimental data. In particular, the accuracy of its scattering predictions was verified by comparing with empirical-based scattering formulas and with experimental data obtained by Pantell at Stanford.²⁻⁴ The model was also run to see if it could predict the Stanford ICA experiment. Its predictions are in excellent agreement with the Stanford results.

2.2.2 Model Predictions for Phase II Experiments

The basic parameters for the ATF ICA experiment are listed in Table 2-2.

Table 2-2. ATF ICA Experiment Parameters

Electron beam mean energy	50 MeV
Electron beam energy spread	0.2 MeV
Electron beam angular divergence	1.2 mrad
Electron beam diameter in gas cell	0.18 mm
Čerenkov angle	20 mrad
Hydrogen gas pressure	1.7 atm
Gas cell window thickness	2.1 μm diamond
Laser wavelength	10.2 μm
Laser peak power	5 -50 GW delivered
Laser pulse duration	30-100 ps
Laser beam outer diameter	1 cm
Axicon inner hole diameter	0.05 cm
Interaction length, L	20 cm
Distance between gas cell mirrors	30 cm

For our simulations of the experiment we assume, conservatively, that various optical losses and inefficiencies will result in 1/2 of the laser output power being delivered into the interaction region. Thus, if the laser peak output power is 100 GW, then the simulation is run at a value of 50 GW for the laser input parameter. For the other conditions listed in Table 2-2, this results in a prediction of nearly 80% energy gain over the 50 MeV *e*-beam (i.e. ~ 38 MeV). This prediction is shown in Figure 2-2. For our interaction length of 20 cm this corresponds to an acceleration gradient of ~ 190 MeV/m.

Note in Figure 2-2 that because the electrons are uniformly distributed in phase over the light wave, the spectrum displays a full range of particle energies. For efficient acceleration a prebunched *e*-beam would be used whose phase is selected for optimum acceleration only. This subject of prebunching is discussed more in Section 3.3. (The asymmetry evident in the spectrum is also explained in Section 3.3.)

(a)

(b)

Figure 2-2.

Monte Carlo model predictions for the ATF ICA experiment of the e -beam energy spectrum. (a) Laser off. (b) Laser on, 50 GW delivered to interaction region. The rest of the parameters are: e -beam energy = 50 MeV, $\theta_c = 20$ mrad, $L = 20$ cm, laser beam OD = 1 cm, e -beam focused to $r = 0.18$ mm, $P = 1.71$ atm hydrogen, and the e -beam windows are $2.1 \mu\text{m}$ thick diamond.

As explained in Appendix A, the present ATF CO₂ laser system output power is limited to ~10 GW. Theory predicts that the maximum energy gain is simply proportional to the square-root of the laser peak power. Hence, if we assume only 5 GW of laser peak power is delivered to the interaction region (i.e., 0.5 x 10 GW), then the maximum acceleration is reduced by 10^{1/2} or from ~38 MeV to ~12 MeV. Our model results confirm this case in Figure 2-3. As can be seen, this still results in significant energy gain that can be easily detected by an electron energy spectrometer.

2.3 DESCRIPTION OF EXPERIMENTAL APPARATUS

2.3.1 Optical System

Figure 2-4 shows a schematic layout of the Phase I optical system. The ATF CO₂ laser beam is transported along the ceiling of the experimental hall to our 4'x8' optical table where it is directed downward to the surface of the table as shown in the upper right-hand corner of Figure 2-4. It is then sent through a 2X expansion telescope that increases the beam diameter to ≈2 cm. Next, it is directed into the radial polarization converter optical system.²⁻⁵ This is an improved version of the techniques developed earlier during this program.²⁻⁶ After leaving the converter system, the radially polarized laser beam goes through a beam reduction telescope, which reduces its diameter to ≈1 cm. Finally, the beam is sent into the gas cell where the ICA process occurs (details of the gas cell are shown later).

Also depicted in Figure 2-4 are the cw CO₂, GaAlAs diode, and HeNe lasers used for aligning our optical system. The cw CO₂ laser (Synrad, Model 48G-1-115W) is grating tunable and is adjusted to lase at 10.2 μm to simulate the ATF CO₂ laser when it runs on an isotopic gas mixture. The diode laser (GALA, Model 078-04-1) lases at 780 nm. It has a much shorter coherence length than the cw CO₂ laser and, therefore, mimics the short coherence length of the short pulse ATF CO₂ laser. This is very important when adjusting the optical path lengths of the radial polarization converter system.²⁻⁷

A photograph of the Phase I experimental hardware is shown in Figure 2-5. Located underneath the optical table is the control panel of the gas manifold system for filling and evacuating the gas cell. This specially designed system is portable for remote control of the gas system (necessary during the Phase II experiments) and has built-in safety features to ensure safe handling of the hydrogen gas.

(a)

(b)

Figure 2-3. Monte Carlo model predictions for the ATF ICA experiment of the e -beam energy spectrum. This simulation assumes 1/10 the delivered laser peak power as assumed in Figure 2-2. (a) Laser off. (b) Laser on, 50 GW delivered to interaction region. The rest of the parameters are the same as in Figure 2-2.

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Figure 2-4. Schematic plan view of the ICA experiment optical system. The entire system is located on a 4' x 8' optical table. Not shown is the electron beamline hardware that is connected to the gas cell (see Figure 2-10).

Figure 2-5.

Photograph depicting the ICA experiment optical system shown in Figure 2-4.

To the right of the optical table is the personal computer used for data analysis and below table is the gas manifold system.

To the right of our table in Figure 2-5 is the personal computer (PC). Contained within the PC is a video data acquisition system which features a frame grabber board that can be connected to either a regular CCD camera or an IR-sensitive camera. The IR camera is used extensively when diagnosing the radially polarized CO₂ laser beam. The software, written in C, is capable of acquiring single shot data and analyzing the stored image.

Figure 2-6 is a photograph of the radial polarization converter system. It is based upon a double-interferometer. A detailed explanation of the system is given in Ref. 2-5 (see Appendix D).

A plan view and photograph of the gas cell is shown in Figures 2-7 and 2-8, respectively. The cell is fabricated from a single piece of aluminum and, therefore, has no welds. The walls are 1" thick and both the lid and bottom are 1.25" thick. This type of construction was used for two reasons. First, it provides maximum safety (the cell was hydrostatically tested to 70 psi) and eliminates possible gas leaks through aluminum welds. Second, it provides an optically rigid platform for the optics inside the cell and the gas cell *e*-beam windows, which must all be precision aligned to each other to ensure good spatial overlap of the focused laser beam and *e*-beam. There is also a large observation port along the top of the cell.

As can be seen in Figure 2-7, the laser beam enters the cell through a ZnSe window. It reflects off a 45° mirror and is sent to the axicon mirror. This 45° mirror has a 0.5 mm diameter hole drilled through it at 45° to its surface for the *e*-beam to travel through. The axicon mirror also has a 0.5 mm diameter hole drilled through its center normal to its surface. An axicon mirror rather than a lens (as shown earlier in Figure 2-1) is used because of the higher damage threshold (approximately 10X better) of reflective metal optics rather than transmissive optics. The axicon is cut with a 10 mrad apex angle, which will result in a Čerenkov angle of $\theta_c = 20$ mrad.

The laser beam reflects off the axicon and is focused down onto the *e*-beam traveling from right to left in the Figure 2-7. After interacting with the *e*-beam, the spent laser beam reflects off the 45° mirror and exits the gas cell. This spent beam can then be further analyzed using optical detectors located outside the gas cell (see Section 2.3.4). The *e*-beam windows consist of a 2.1 μm thick diamond film deposited on a silicon substrate. Details of the *e*-beam windows are described in Section 2.3.2.

Figure 2-6. Photograph of the radial polarization converter system.

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Figure 2-7. Schematic plan view of the gas cell where the ICA interaction occurs. The laser beam focusing angles are exaggerated for clarity.

Figure 2-8. Photograph of the outside of the gas cell.

Figure 2-9 shows the location of the ICA experiment in the ATF experimental hall. Our optical table, which contains the entire optical system, is positioned just downstream from the Grating Accelerator experiment. The small rectangular box in the lower left-hand corner of our table represents the gas cell (c.f. Figure 2-4). The laser beam from the ATF CO₂ laser is delivered to our experiment through a portal hole near the ceiling in the concrete shielding that separates the experimental hall from the CO₂ laser room. Downstream from our table is located the electron energy spectrometer.

2.3.2 Electron Beamline System

Figure 2-10 is a drawing of the ICA electron beamline system attached to the gas cell. The gas cell position relative to the beamline will be surveyed in with the aid of special surveyor's targets attached to the cell body. On both ends of the cell are a bellows and pop-in phosphor screen. Gate valves on the ends of the beamline permit breaking into the bellows in order to access the *e*-beam windows. The design of the *e*-beam window holders actually permits the entrance *e*-beam window to be replaceable from inside the gas cell rather than needing to open up the beamline. For changing the exit *e*-beam window it will still be necessary to break into the beamline; however, experience during the Stanford ICA experiments showed that it is the entrance window which is most susceptible to radiation damage from the *e*-beam. Thus, being able to change the entrance window without breaking into the beamline will help expedite matters. Fortunately, as explained later, our *e*-beam window holder design protects the window seals from direct electron impact, thereby making the windows much less susceptible to radiation damage.

Upstream of the gas cell are a pair of steering magnets for control of the *e*-beam transverse position. We are using a standard BNL trim magnet design (BNL Drawing No. SLS-17.17-1-5). A photograph of the beamline system is shown in Figure 2-11.

Figure 2-12(a) is a schematic drawing of the gas cell window manufactured for us by Crystallume, Menlo Park, CA. It consists of a 2.1 μm thick diamond film deposited on a 0.36 mm thick silicon substrate sealed to a stainless steel holder with C7-W Armstrong epoxy. A <1 mm x 1 mm portion of the silicon substrate has been etched away in the center leaving only the diamond film through which the electrons will pass. The window was pressure and vacuum tested at the manufacturer to verify its ability to withstand the required pressure differentials. The results are summarized in Table 2-3.

Figure 2-9. Schematic plan view of the ATF experimental hall showing the location of the ICA experiment on Beamline #1 and relative to the ATF CO₂ laser.

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Figure 2-10 Schematic drawings of the plan and side views of the ICA electron beamline system. The electrons are traveling from left to right.

Figure 2-11. Photograph of the ICA beamline system.

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Figure 2-12. (a) Schematic drawing of the diamond film *e*-beam window. The diamond film is 2.1 μm thick. (b) Basic design for the entrance *e*-beam window holder. This holder is inserted into the end of the gas cell (see Figure 2-7).

Table 2-3. Electron Beam Window Pressure Test Parameters

<u>Test</u>	<u>Pressure (psid)*</u>	<u>Number of cycles</u>
Proof pressure	47.9	5
Pressure cycle	32.3	5000

*Note, the nominal operating pressure during the ICA experiments is 25 psi.

Even at nearly 2X the nominal operating pressure, the window did not break. (It is not known how high of pressure is required to break the window.) After the preceding pressure cycling tests, the window was leak checked and had no measurable leak. Thus, these diamond windows have demonstrated the required mechanical strength.

The only weak point of this particular window design is the use of epoxy for sealing the silicon substrate to the stainless steel holder. Past experience at Stanford showed that organic adhesives, such as epoxy, have severely limited lifetimes if the *e*-beam strikes the adhesive. For this reason a metal seal is preferred; however, the Crystallume window design cannot be easily modified to accommodate a metal seal. Fortunately, during normal ICA operation the *e*-beam will be traveling through the center of the window, roughly 6 mm away from the epoxy. However, during alignment of the *e*-beam through the gas cell, the beam can easily strike the epoxy if the adhesive is unprotected. Fortunately, there are straightforward methods for protecting the epoxy from direct impact by the *e*-beam.

Figure 2-12(b) shows a drawing of the gas cell *e*-beam input window holder which holds the window and is inserted into the end of the gas cell as shown in Figure 2-7. The epoxy is protected by a lead iris plug positioned in front of the *e*-beam window. The length of the lead iris (2.5 cm) is chosen to not only stop most of the 50 MeV electrons, but also to attenuate the secondary radiation produced when the electrons are stopped by the lead.

Some secondary radiation (x-rays and γ -rays) will still reach the epoxy. Fortunately, similar diamond windows manufactured by Crystallume using the same epoxy have been successfully used at BNL under high radiation environments.²⁻⁸ These windows were constantly irradiated for 14 days with γ -rays from a Co-60 source for a total absorbed dose of 1×10^5 rad. The window remained leak-tight after this exposure.

During Phase I the e -beam window durability was successfully tested and the results are discussed in Section 2.4.3.

2.3.3 Diagnostics

With regard to the optical system, there are a number of different diagnostics being used. As mentioned earlier, an IR video camera is used to obtain images of the CO₂ laser beam. This is used for verifying the proper alignment of the radial polarization converter and, as explained in Section 2.3.4, for aligning the spatial overlap of the laser and electron beams.

The output pulse energy of the ATF CO₂ laser beam is sampled using a Molelectron J25 pyroelectric joulemeter. Its output is sent into a Molelectron JD501 joulemeter digitizer that sends the pulse energy information directly to our PC. Hence, the laser peak power delivered to the gas cell can be automatically measured during each shot.

With regard to the electron beam diagnostics, the e -beam position within the interaction region is determined using phosphor screens inside the gas cell (see Section 2.3.4). The electron beam energy will be measured using a spectrometer magnet system specifically design for the ATF.²⁻⁹ It features a video output that can be directly stored and analyzed by our PC.

An example result of a code simulation for the spectrometer output under the conditions of the ICA experiment is shown in Figure 2-13. The bottom distribution is for the laser off with energy dispersion oriented along the horizontal direction. The spectrometer quadrupoles have been adjusted to give the narrowest spectrum in the horizontal direction to help compensate for scattering of the e -beam caused by the e -beam windows and phase matching gas. (Scattering effects are included in the simulation.) This makes the vertical distribution large, but the width in the vertical direction is not important for the ICA experiment.

The top distribution in Figure 2-13 is with the laser on (laser peak power = 5 GW delivered). There is a dramatic change in the distribution, which should be easily measured. Note the resolution of the spectrometer is roughly 25 keV. This is much higher than needed for our experiment; hence, even less than perfect ICA interactions should be observable. Thus, the spectrometer will also be a useful tool when fine tuning the experimental parameters (see below).

Figure 2-13. Preliminary simulation of the electron energy spectrometer output for the ICA experiment. This does not represent an optimized case. Top figure is with the laser on; bottom figure is with the laser off. Energy dispersion is in the horizontal plane with each symbol representing roughly 25 keV.

2.3.4 Spatial and Temporal Alignment of the Beams

Ensuring that the laser and electron beams are spatially and temporally overlapped inside the gas cell is a critical task during the Phase II experiments. Within the interaction region, the laser focal spot is ~ 0.4 mm in diameter. The e -beam will be focused down to this size or slightly less inside the gas cell. It is important that the beams remain overlapped over the 20-cm interaction region.

Spatial overlap of the beams is detected using the optical imaging system shown in Figures 2-14 (plan view) and 2-15 (side view). Two remote-controlled phosphor-coated screens are located inside the gas cell. One is near the axicon mirror; the other is near the 45° mirror. Light emission from these screens is relay-imaged to video cameras via a remote-controlled translating lens system. When imaging the upstream screen (Screen #2), the lens is farthest from the gas cell. When imaging the downstream screen (Screen #3), the lens is closest to the gas cell. Note that a periscope system is used to direct the light to the relay lens positioned 8 inches above the table top (see Figure 2-15). This is to avoid interference with the radial polarization converter system (see Figure 2-4).

Unfortunately, the light emission from the phosphor screen is not bright enough to be sensed by the IR video camera. Thus two cameras are used, an IR and a standard CCD, to visualize the laser and e -beam images, respectively. The phosphor emission from Screens #2 and #3 are detected by the CCD camera whose output is stored in our PC. Thus, the position of the e -beam within the gas cell is known at two points. The IR camera is used to detect the CO_2 laser beam spatial distribution within the axicon focal region. When imaging the laser light, the phosphor screens are swung out of the laser beam path; however, the relay lens still images the laser light at the screen's position along the e -beam path. In order to compare the CO_2 laser beam position at these two locations with the e -beam positions stored in the PC, a HeNe laser (see Figure 2-14) that can be seen by both cameras is used as a common reference image. By adjusting the remotely controlled micrometers on the axicon and 45° mirrors inside the gas cell, the laser beam position can be made to overlap the e -beam position at the two locations, thereby ensuring the beams are overlapped over the entire interaction region.

The HeNe alignment laser shown in Figure 2-14 and its associated mirrors is also used to align the gas cell, the optics inside the cell, and the beamline. Some of the mirrors are on kinematic mounts that permit the mirrors to be positioned where the beamline

Figure 2-14. Schematic plan view of the ICA relay imaging system for the gas cell internal screens.

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Figure 2-15. Schematic side view of the ICA relay imaging system for the gas cell internal screens.

bellows are located (see Figure 2-10). This HeNe laser system is also used to calibrate images seen by the CCD and IR video cameras.

Temporal synchronization will be performed in two steps. First, various detectors are available at the ATF to sense the passage of the e -beam pulse. These will be used to estimate its arrival time in the gas cell. (Recall the e -beam pulse is 6 ps long.) A fast HgCdTe photodetector will be used to detect the ATF CO₂ laser pulse at a location on our optical table. With careful measurements of the path lengths for both beams from their respective temporal detectors to the center of the gas cell, the time delay needed to obtain temporal overlap can be estimated. Fortunately, for this initial synchronization it is only necessary for the 6-ps e -beam pulse to lie somewhere within the 1 to 3-cm long (i.e., 30 to 100-ps) laser pulse. Once this occurs a change in the electron energy spectrum should be detected by the sensitive spectrometer magnet (see Section 2.3.3). The second step is to use the spectrometer output to help fine tune the temporal overlap by optimizing the signal seen by the spectrometer.

2.4 EXPERIMENTAL RESULTS OF PHASE I EXPERIMENTS

A summary of the accomplishments during the Phase I experiments are listed below.

2.4.1 Optical System Tests

- 1) Demonstrated conversion of the linearly polarized ATF CO₂ laser beam into a radially polarized beam using the double-interferometer system. Because of the short coherence length of the laser beam, it was important to show that the phase of the double-interferometer system could be adjusted properly.
- 2) Determined that the radially polarized laser beam focused by the axicon inside the gas cell is stable, and has acceptable position and angle tolerances.
- 3) Measured the $J_1(r)$ Bessel pattern in the axicon focal region and found it agreed with theory (see Ref. 2-5 in Appendix D).
- 4) Performed optical damage tests on the spiral-phase-delay plate (see Ref. 2-5), which is the optic in our system most sensitive to laser damage, and determined that its damage threshold for 100-ps laser pulses is >190

mJ/cm². This value corresponds to the same fluence on the optic if the laser were to produce 100 GW of peak power. Thus, damage of optical components should not be a problem during the ICA experiments. (Note, damage thresholds tend to increase with shorter laser pulse lengths, so that a 10-ps laser pulse will have a higher damage threshold than the 100-ps pulse.)

2.4.2 Nonlinear Effects

Possible nonlinear effects, such as gas breakdown and stimulated Raman generation, caused by the high peak power laser beam being focused by the axicon in the hydrogen gas are discussed in Appendix B and estimated not to be an issue for the conditions of the ATF ICA experiment. During Phase I we observed no laser-induced gas breakdown in hydrogen gas for laser peak powers at the ~2 GW level for a laser pulse length 100 ps. Although this does not represent the 50 GW case, we believe the estimations made in Appendix B are still valid and do not expect problems with gas breakdown during the Phase II experiments.

In summary, during the Phase I experiments we did not observe any unusual phenomena when the ATF CO₂ laser beam was focused inside the gas cell.

2.4.3 Electron Beam Window Lifetime Tests

As mentioned earlier, the durability of the diamond film *e*-beam window seals during exposure to the *e*-beam was of concern. To verify that our window holder design (see Figure 2-12) protected the window adequately, during Phase I we performed *e*-beam exposure tests of a sample window. The window was sealed in a holder similar in design to the holder shown in Figure 2-12(b) with a lead plug shielding the window from direct *e*-beam impact. The window was held under vacuum during the tests with a 1-atm pressure differential across the window.

Since the ATF 50-MeV *e*-beam was not ready yet, we exposed the sample window to the National Synchrotron Light Source (NSLS) 70-MeV *e*-beam for a total of 12 hours. This corresponded to roughly 100X more exposure than expected during the ATF ICA experiments. The sample window was still leak-tight after this test. Therefore, we are confident that the *e*-beam windows will survive exposure to the ATF *e*-beam allowing us to perform the ICA experiments without worry of window failures.

2.5 PHASE II EXPERIMENTS

As mentioned earlier, we are currently waiting for the ATF e -beam to be available for our Phase II experiments. The Phase II hardware has been installed at the ATF and will be fine tuned as we wait for the e -beam. Our experiment will be the first major laser acceleration experiment to use the e -beam, and the ATF staff have been working very hard to get the e -beam to us as soon as possible. Since the linac has only recently been commissioned, one can expect some delays while they debug their system, but we have been told that the e -beam may be available to us in December 1992. If we are able to run in December, we plan to submit an addendum to this proposal with any experimental results.

The main objectives of the Phase II experiments are to: 1) verify the timing and spatial overlap between the electron and laser pulses; 2) examine the e -beam energy spectrum as a function of laser peak power, gas pressure, and timing between the electron and laser pulses; and 3) compare the experimental results with model predictions.

Our plans for the remainder of the current program are to conduct three runs with the ATF e -beam and laser, with an optional fourth run if needed. The first run is anticipated to be primarily for debugging our system. Our primary objectives should be reached during the second and third runs.

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