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STUDIES ON THE INTERACTIONS OF A PROBE ELECTRON BEAM WITH RELATIVISTIC PLASMA WAVES*

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Abstract

Results of a numerical study which models experiments on a low energy electron beam probe of relativistic plasma waves are discussed. The plasma wave modifies the electron beam cross section and energy distribution. Qualitative results of current experiments on the optical breakdown of Helium and Argon gas by CO_2 laser light in a plasma shutter are presented.

1 INTRODUCTION

Many research groups have demonstrated that the high gradient acceleration of electrons using relativistic plasma waves is possible over short distances. An important parameter for plasma wave acceleration is the amplitude of the accelerating longitudinal electrostatic fields. The results of previous numerical studies suggest that a perpendicularly injected electron beam may be a convenient and sensitive diagnostic of the wave's accelerating fields. The plasma wave's longitudinal fields deflect the electrons, thus distorting the beam's cross section in direct proportion to the magnitude of the longitudinal fields. Those studies focused on using 1.5 MeV [1] and 50 keV [2] electron beams to measure plasma waves having fractional amplitudes, a_w, in the range of 2.5 to 25%. However, in many laboratories performing basic studies on plasma wave acceleration techniques, waves that have fractional amplitudes of 1.0%, or less, are common. A lower energy electron beam probe would be more sensitive and convenient for experiments involving these lower amplitude waves.

In the following are discussed the results of numerical simulations of the interactions of 5 keV to 50 keV electron beams with relativistic plasma waves that have fractional amplitudes in the range of 0.1% to 1.0%. These simulations model an experiment being constructed to compare this electron beam diagnostic with the more commonly used Thomson scattering diagnostic. Part of the experimental effort is to develop a plasma shutter for shortening laser pulses, and qualitative results of recent tests of this device are presented.

2 NUMERICAL SIMULATIONS

The simulations were performed using a 3-D relativistic particle trajectory code which was originally used to model the acceleration of injected electrons by relativistic plasma waves [3], and to model the radiation emitted by an electron beam passing through a plasma wave undulator [4]. For the present simulations, the electron beam energy was varied from 5 keV to 50 keV and the energies were converted to the appropriate relativistic γ. The beam's width and length were approximately 0.5 mm and 10.0 mm, respectively. Uniform and Gaussian random number generators were used to select the electrons' initial positions and momenta in the longitudinal and transverse directions, respectively. The relativistic plasma wave's phase velocity corresponded to a gamma phase, γ_p, of 9.7. In laser plasma beatwave experiments this γ_p could be generated by beating the 10.6 μm and 9.6 μm lines of a CO_2 laser. The amplitude of the plasma wave was varied from $a_w = n_1/n_o = 0.1\%$ to 1.0 %, where n_1 = the density fluctuation and n_o = the background density. The plasma wave propagates in the +z direction and a beam of 5000 electrons is injected transversely through the wave in the +y direction [2]. After the electron beam exits the plasma wave, it drifts approximately 10 cm at which point the positions of the individual electrons are recorded. Figure 1 shows the initial cross section of the electron beam for all simulations. Figure 2 is an example of the cross section of a 5 keV electron beam that has passed through a plasma wave having $a_w = 1\%$. The width of the beam in the z direction, or "spot width", is plotted versus n_1/n_o for various beam energies in figure 3. Figure 3 shows that the lowest energy electron beam is most sensitive to the plasma wave, as expected.

The plasma wave also induces an energy spread in the beam. Figure 4 shows the original energy of the monoenergetic electron beam along with a histogram of the number of electrons in the final energy bins. This shows that electrons gain and lose energy, consistent with the model that electrons sample both accelerating and decelerating fields as it passes through the plasma wave [3]. The final energy spread shown in figure 4 is appoximately 0.03%. Additional sorting of the results was performed to determine the location of the accelerating electrons in the beam and it was found that the electrons that gain and lose the most energy are the ones that are deflected the most. This energy spreading is being analyzed to determine its suitability as an additional diagnostic of the plasma wave.

3 THE PLASMA SHUTTER

The experiment to test this electron beam diagnostic of plasma waves will use CO_2 lasers to create the plasma waves. A plasma shutter will be used to remove the long energetic trailing edge of the CO_2 pulse. The optical breakdown of the CO_2 laser pulse in a gas chamber filled

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with either Helium or Argon has been studied. The chamber is a ~3.5 cm long, ~3.8 cm diameter, cylinder with windows for transmitting CO_2 and YAG laser light, and with ports for a vacuum pump and a pressure gauge.

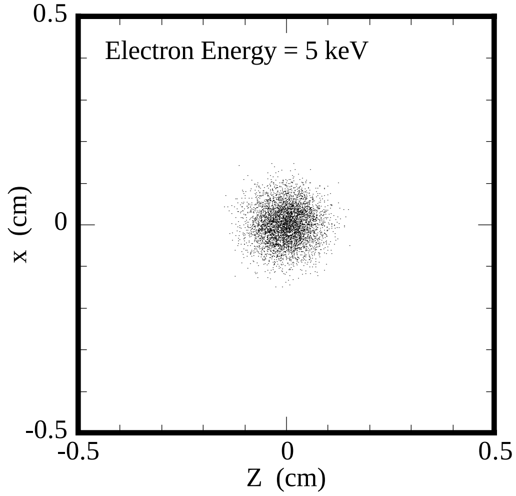

Figure 1: Initial cross section of the electron beam. The beam moves out of the page in the simulation.

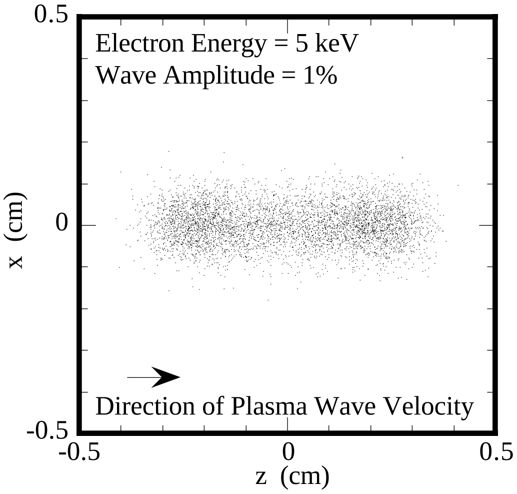

Figure 2: Final cross section of the beam.

The laser (~10^{12} W/cm^2) is focused into the chamber using f/1.7 optics, and the laser energy is measured using a pyroelectric Joulemeter. The pressure is measured using a capacitive manometer and is held steady using a computer controlled leak valve. Figure 5 shows laser energy transmitted versus gas pressure, and indicates the pressure at which breakdown occurs and also the amount of energy transmitted after breakdown. The results suggest that the CO_2 laser breaks down at ~ 30 Torr in Argon and at ~ 105 Torr in Helium, as expected in cascade ionization [5]. The results show, qualitatively, that a larger fraction of the CO_2 laser energy is transmitted when Helium is used as the fill gas in the plasma shutter. Additional tests are underway to use other gases, to study triggering the breakdown using a separate YAG laser and to measure the breakdown time.

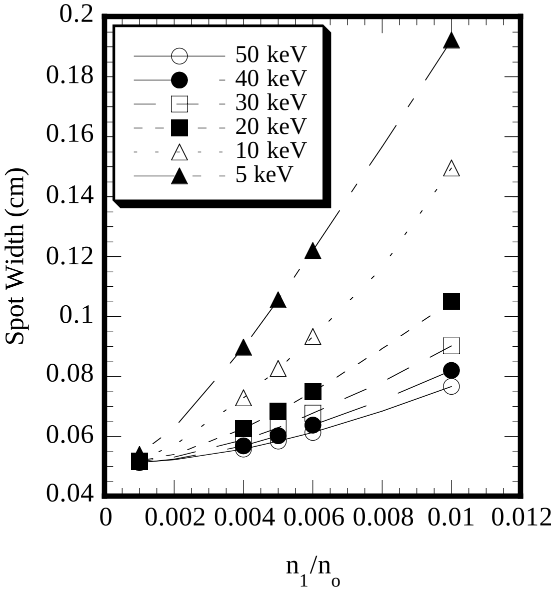

Figure 3: Plot of cross section (spot width) versus fractional plasma wave amplitude for several electron beam energies.

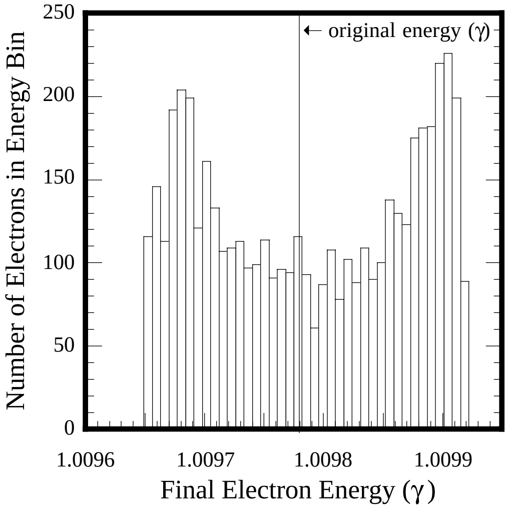

Figure 4: Initial beam energy and histogram of final beam energies.

4 CONCLUSIONS

Recent numerical simulations reveal the relative sensitivity of low energy electron beams to the electrostatic fields in relativistic plasma waves. These simulations also provide a qualitative picture of the induced energy spreading and the distribution of the accelerated and decelerated electrons within the beam. Initial results indicate that the plasma shutter is capable of controlling a CO_2 laser beam pulse.

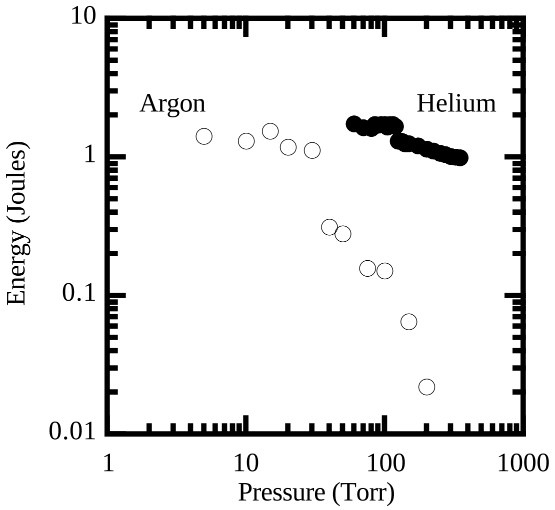

Figure 5: CO_2 laser energy transmitted in the plasma shutter filled with Argon and with Helium, versus pressure.

5 REFERENCES

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