REB-CO_2 LASER INTERACTION PROGRAM, "Σ PROGRAM", BEAT WAVE ACCELERATION

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ABSTRACT

Both Forward Raman Scattering of a 10.6 μm CO_2 laser using a foil target and a beat wave experiment with 10.6 μm and 9.6 μm lines using a gas target and an intense relativistic electron beam (REB) source are described for accelerating electrons to more than MeV energies. The former experiment achieved an acceleration of more than 1 MeV using a 45 nm CH foil and 100 J/1ns 10.6 μm laser. The latter started to accelerate 0.5 MeV REB to more than 10 MeV.

1. INTRODUCTION

There are two methods by which a laser in a plasma can accelerate electrons up to 10 MeV or more. The first is the Forward Raman Scattering acceleration using a one frequency laser such as 10.6 μm, which decays under the quarter critical density ($n_c/4$) to the forward electromagnetic wave and to the forward plasma wave of the phase velocity almost equal to the light velocity, accelerating the trapped electrons to more than MeV energies. At first, we present the Forward Raman Scattering acceleration using foil targets, since to generate a one frequency laser oscillation as well as to produce foil plasma is technically simple. In this case we observed that electrons are accelerated to more than 1 MeV. Although the accelerated electron energy increases as the plasma density is lowered, to decrease the foil target plasma density lower under 10^{18}/cc is difficult. Also the Forward Raman Scattering instability threshold increases and the number of the hot source electrons decreases as the plasma density is lowered, all of which limit the acceleration. At $n_e = 10^{18}$/cc, the energy is theoretically limited to $2\gamma^2mc^2 = 10$ MeV, where $\gamma = (1-v_{ph}^2/c^2)^{-1/2} = \omega/\omega_p$ and mc^2 is the electron rest energy, about 500 keV.

Secondly, we performed the beat wave experiment named Σ program, using 10.6 μm and 9.6 μm lines as well as a gas target which is expanded and laser-pre-ionized, providing a density of around 10^{17}/cc. Collinear 10.6 μm and 9.6 μm lasers beat and their ponderomotive force drives the plasma wave of velocity close to that of light. The situation is intrinsically the same as the first experiment, that is, the 9.6 μm laser decays to the forward 10.6 μm light and the forward plasma wave without threshold at the 10^{17}/cc resonant density. At 10^{17}/cc, γ is 10, then the energy $2\gamma^2mc^2$ obtainable for the electron becomes 100 MeV.

2. FORWARD RAMAN SCATTERING AND ELECTRON ACCELERATION

We used one 10.6 μm beam from the GEKKO VIII CO_2 laser system The output energy is 150 J in a 1 ns pulse The beam diameter is 240 mm. The focusing lens is an f/1 5. The electron spectrometers (ESM) are located at the target normal (-20 °), the laser axis (0 °) and at 45 °, as shown in Fig. 1. The spectrum of the accelerated electron temperature peaks not at the target normal but at the laser axis, that is, in the forward scattering direction

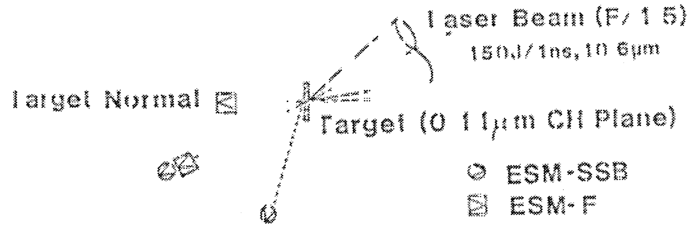

Fig 1 FRS experiment of foil targets

As shown in Fig. 2, the ESM detected the electron spectrum at the laser axis, showing that the energy extends to more than 1 MeV, whereas at 45 ° it extends only to 0.5 MeV The temperature at 0 ° is also higher than at 45 ° The threshold to accelerate electrons was 1.6×10^{14} W/cm^2, consistent with the FRS calculation.

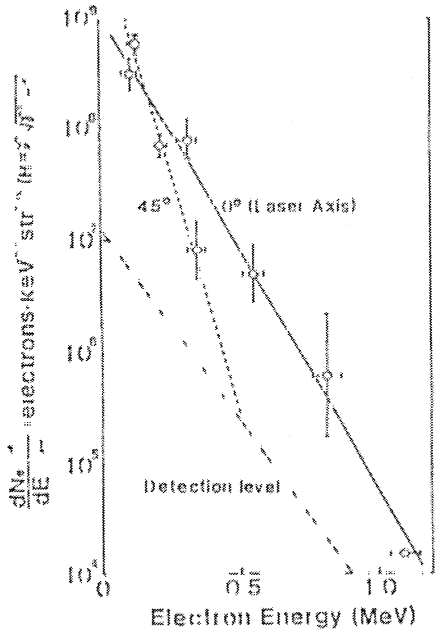

Fig 2 Accelerated electron spectrum vs ESM angle

The dispersion of the FRS shows that the plasma wave γ relating to the trapped electron energy increases as the plasma density decreases At 10^{18}/cc, γ is 3, relating to the 10 MeV electrons, but at 10^{17}/cc γ is 10 relating to the 100 MeV electrons. Similarly, Fig. 3 shows that as the foil thickness is decreased from 0 11 μm to 45 nm, the accelerated electron temperature increases from 93 keV to 120 keV. The 1 D hydrodynamic simulation HISHO requires (as shown in Fig. 4) the foil thickness to be less than 10 nm to have a density less than 10^{18}/cc and so produce higher energy electrons. However, to make such a thin foil is impossible. Therefore we pre-ionized the foil by the prepulse laser followed by the main pulse. The simulation in Fig. 4 predicts that delaying the main pulse decreases the density, but the experiment (Fig. 5) shows that the accelerated temperature decreases monotonically, implying a reduction of the source electrons and resulting in a decrease of the accelerated electron yield.

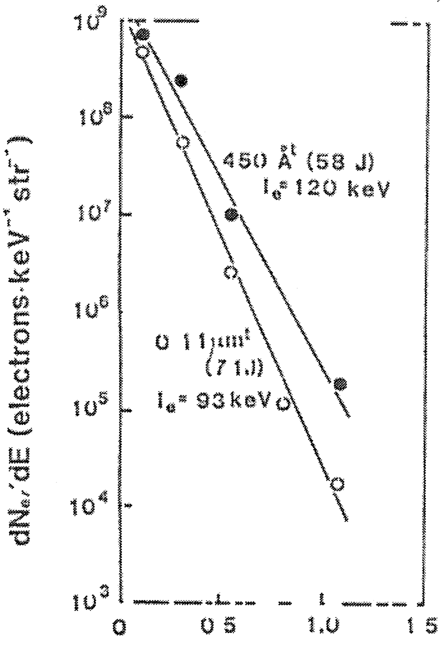

Fig 3 Accelerated electron spectrum vs foil thickness

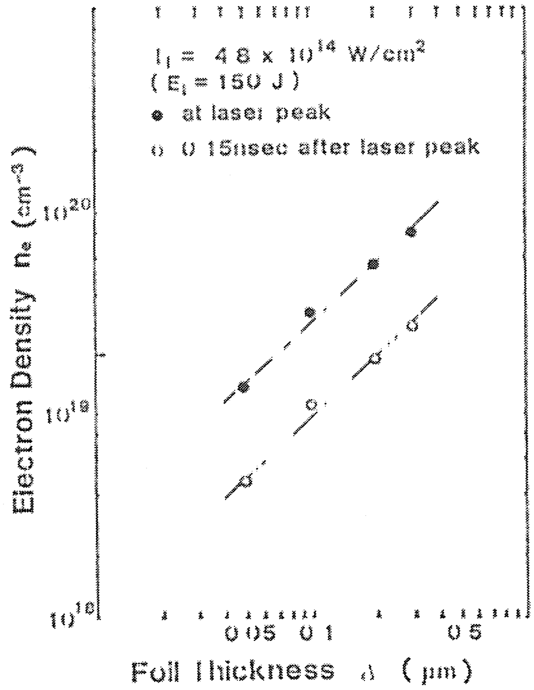

Fig 4 1-D simulation of n_e vs foil thickness

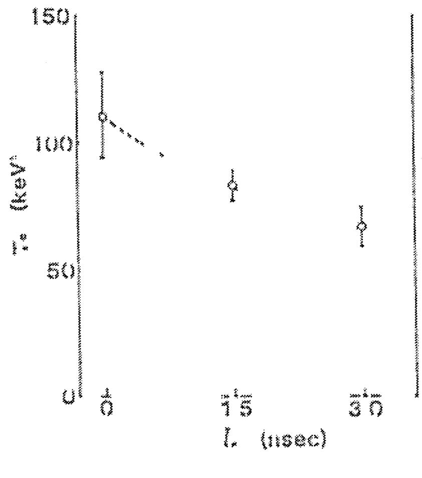

Fig 5 Accelerated electron temperature vs prepulse-mainpulse delay

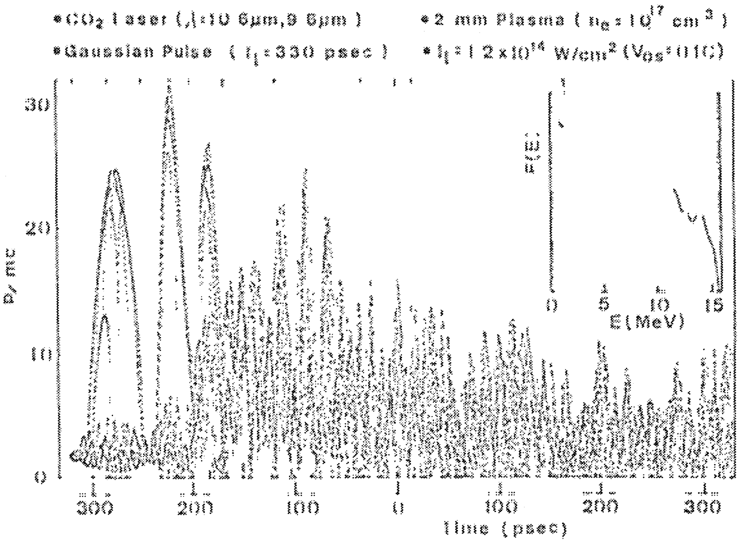

Fig. 6 Laser beat wave acceleration by the fluid-particle code

3. BEAT WAVE ACCELERATION "Σ PROGRAM"

We then planned the CO_2 laser-REB interaction program which had two objectives. The first is the FEL and the second the beat wave acceleration of REB, on which we now report the present status.

The 9.6 μm and 10.6 μm laser beat wave generates the ponderomotive force in the plasma, driving the plasma wave whose phase velocity v_{ph} agrees with the beat wave group velocity. The electric field is limited to 3×10^8 V/cm by the wave breaking. Then the potential to trap the electrons is mc^2 or $2\gamma^2mc^2$ 100 MeV in the distance of 3 mm. The fluid-particle hybrid code simulated the beat wave acceleration, as shown in Fig. 6. The fluid code calculated the plasma wave and the particle code calculated the electron beams Although the laser beam is Gaussian shaped and 300 ps long, only the initial 100 ps duration can coherently accelerate the electrons from 1 mc to 30 mc, that is, to 15 MeV. Then the plasma wave decays. The curve inserted at the top right of Fig. 6 shows the time-integrated spectrum of the initial 0.5 MeV electron accelerated up to 15 MeV. We used the same laser but at double line.

We produced the double line oscillation at 10P(20) and 9P(22), injecting a CW laser only at 9P(22) to the TEA oscillator. Figure 7 shows the systems. The 10P(20) and 9P(22) lines normally oscillate within the timing at less than 50 ns from each other. Considering the main amplifier's rise time for each line, this time difference is sufficiently small to produce the two-line 1 ns output at the main amplifier. Both lines, sliced to 1.7 ns before the TEA preamplifier, are amplified separately by two E-beam preamplifiers, and again combined in the main amplifier, whose output is 100 ~ 150 J in each 1 ns. The output beam of 240 mm diameter is directed through the wall to another room, where the laser light is focused by an f/10 NaCl lens into the OIRAN interaction chamber collinearly with the electron beam from the REIDEN III REB machine. The laser is focused to a spot of 1 mm with 2.5×10^{13} W/cm^2. Figure 8 shows the OIRAN interaction chamber connected to the laser focusing port and to the REB machine REIDEN III at the right. The latter is a pulse power machine of 0.6 MeV electrons. The beam current in the interaction region is 1 kA/100 ns.

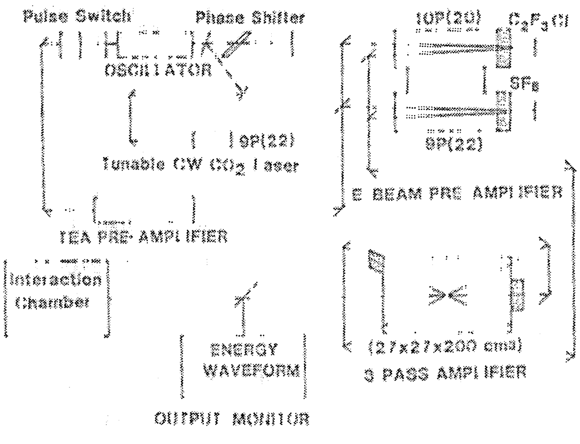

Fig. 7 Double-line operation of LEKKO VIII CO_2 laser system

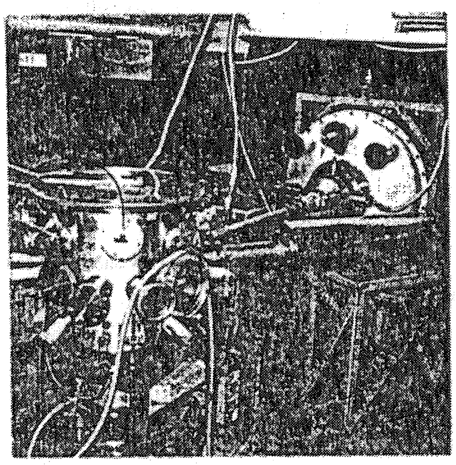

Fig. 8 Beat wave acceleration chamber OIRAN and REIDEN REB machine

Figure 9 shows the REB laser interaction region in the OIRAN chamber in which the REB is guided by a solenoidal coil of 10 kG. A puff of gas is injected at the laser focus point (interaction point) downstream of which is an electron spectrometer. The lower figure shows the REB orbit in the solenoid at and after the interaction point. The damage plate indicates that the REB diameter is less than 6 mm. The focused laser pre-ionizes the puff of gas, producing the 3mm diameter plasma, the density being close to the beat wave plasma wave resonant density 10^{17}/cc. Figure 10 shows the result of the He-Ne laser interferometry, indicating that the 1 atm N_2 gas can yield 10^{17}/cc. The laser, the REB, the guiding magnetic field and the gas-puff driver are electrically synchronized through delay pulsers. The electron spectrometer consists of the scintillator and photomultiplier array. The detectable energy range is from 3.1 MeV to 22.6 MeV with eight channels.

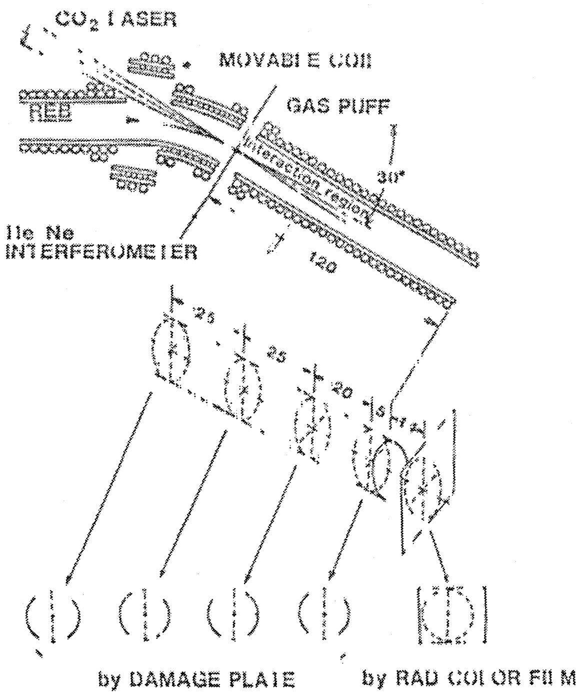

Fig 9 REB-laser interaction region and REB orbit

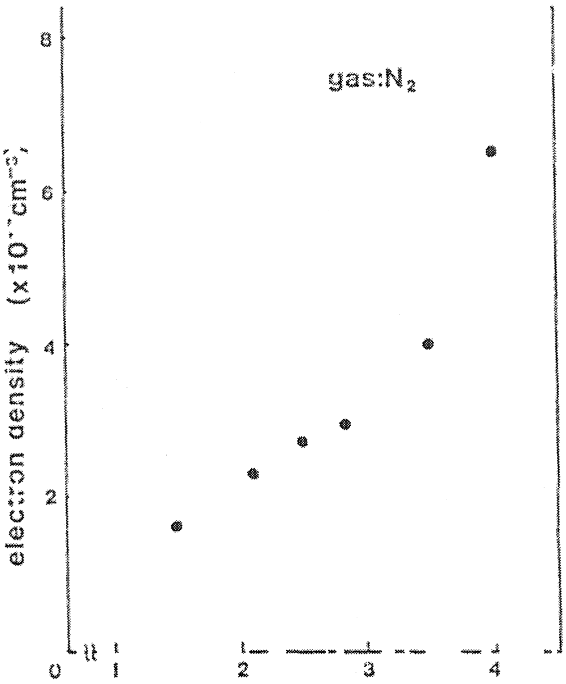

Fig 10 Electron density of gas-puff plasma vs gas-puff pressure

SUMMARY

One frequency and foil target accelerated electrons to an energy of more than 1 MeV, probably due to Forward Raman Scattering. But the plasma density and the hot electron source limit further acceleration.

The beat wave and gas target experiment) program has been started whilst the REB transport, the plasma generation and double line oscillations experiment have been completed.

* * *

Discussion

T. Katsouleas, UCLA

Do you have an estimate for when you will do the full beat-wave acceleration experiment?

Reply

No simulations have been made yet but we are now starting both simulations and experiments