58.

Chen

STATUS OF LASER ACCELERATOR WORK

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The paper summarizes the recent work of the UCLA Laser Accelerator Group, whose senior personnel are C. Clayton, T. Katsouleas, W. Mori, and Profs. F.F. Chen, J.M. Dawson, and C. Joshi. The group studies new ideas theoretically, by computer simulation, and, eventually, by experimentation. Details and references can be found in a review article[1] and need not be given here.

I. Concepts

1. Beat-wave accelerator. Two laser beams beating at the plasma frequency are used to excite plasma waves with relativistic phase velocity. Electrons injected and trapped in the potential troughs can be accelerated to multi-GeV energies in distances 10^3 times shorter than usual.

2. Wake field accelerator. An electron bunch traveling through a plasma leaves a wake which is basically a large amplitude plasma wave. Electrons injected into this wake can be accelerated to perhaps 100 times the energy of the original bunch. No lasers are necessary, but a large accelerator is needed for testing this scheme.

3. Plasma lens. A relativistic particle beam normally has an electrostatic field that cancels the pinch effect of its magnetic field. By passing the beam through a plasma, the electric field can be neutralized, allowing the pinch effect to focus the beam much more strongly than in conventional quadrupole lenses. Simulations bear this out.

4. Plasma wiggler for FEL's. The large radial electric field of a plasma wave created for instance, by beat-wave excitation can be used as a high-frequency wigger for a free-electron laser. To overcome problems of ponderomotive defocusing, we propose to use the field between two plasma waves excited 180° out of phase.

5. Linear light source. By combining a plasma wiggler with a compact linear accelerator [(1) or (2)], one can, in principle generate intense, coherent x-ray bursts in the 10 to 100 femtosecond range. Such a device would have many advantages over conventional synchrotron light sources.

Nonlinear Phenomena in Vlasov Plasmas
F. Doveil Ed., Editions de Physique, Orsay, 1989

II. New theory

1. Beam loading. The energy in a plasma wave can be transferred efficiently to the accelerated particles if the bunch has a triangular shape; that is, its density varies linearly in space or time. In that case, each particle inside the bunch sees the same electric field. Simulations show that about 75% efficiency can be achieved with almost zero energy spread.

2. Relativistic wavebreaking. The limiting amplitude of a plasma wave is well known if the plasma is cold or non-relativistic. Removing both these limitations greatly increases the complexity of the analytic problem, but a formula for warm, relativistic wavebreaking has now been found.

3. New ways to manipulate photons.[2] The beat-wave accelerator mechanism can also be applied to photon packets if one pushes them with a fast-moving density front. It is found that the light *frequency*, not intensity is increased. In another scheme, a light packet moving through a gas is trapped if one can photo-ionize the gas inside the packet to a density above critical for it. Again, the light which leaves is increased in frequency. In addition, a strong dc magnetic wiggler field is left behind.

III. Experiments

1. Beat-wave excitation.[3] Using CO_2 laser beams at 9.6 and 10.6 microns, we have successfully excited, detected, and analyzed plasma waves of about 3% amplitude, with electric fields of order 1 GeV/m.

2. Mode coupling.[4] During beat-wave excitation, stimulated Raman and Brillouin scattering also occur. These produce additional light waves as well as short-wavelength ion and plasma waves. We have sorted out the various interactions caused by these waves. In particular, we find that the coupling of the beat wave to ion acoustic waves causes lost of energy to spatial harmonics. This is the dominant saturation mechanism at low intensities.

3. Harmonic generation.[5] As electron plasma waves grow in amplitude, their wave shapes sharpen and their spectrum develops harmonics. These have been measured for plasma waves excited by SRS. The amplitudes agree with theory.

4. Electron acceleration.[6] Demonstration of beat-wave electron acceleration is being carried out with a new

apparatus centered around a large CO_2 laser capable of simultaneous production of 9.6 and 10.3 micron lines with about 30 J per line in 400 psec pulses. Intensity is about 7 x 10^{14} W/cm^2 per line over 1 cm. The plasma of 5.8 x 10^{16} cm^{-3} density is produced by a theta pinch. A small linac injects 1.5 MeV electrons along the laser beam axis. The electron spectrometer can detect single electrons at the expected final energy of 10-20 MeV.

5. Helicon wave sources.[7] A small experiment has been set up to study other plasma sources suitable for accelerator applications. RF excitation of helicon waves has been found to be very efficient up to 10^{13} cm^{-3} density. We have verified the wave resonance and are extending the technique to higher densities.

6. Four-wave mixing.[8] An experiment on degenerate four-wave mixing was done in a plasma using two CO_2 pump beams at 180° and a probe beam at 2.4°. A phase-conjugate scattered beam is found to retrace the path of the probe beam. All beams are at the same frequency, but they could be distinguished by changing the polarizations. The scattering is done by a static ion perturbation produced in the plasma by the ponderomotive force of the beat pattern. It is found that the density modulation is greatly enhanced by the localized heating of the beat pattern.

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