Overview of NEPTUNE Facility

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The Neptune Laboratory at UCLA is being used for 2nd generation experiments on the plasma beat wave acceleration of electrons. For this purpose 10 ps electron bunch produced by a photoinjector will be injected in the plasma beatwave driven by a 100 ps two-wavelength TW CO2 laser pulse. Up to 100 MeV acceleration is expected in the plasma with low energy spread of the beam, since the electrons have to be prebunched at the exact wavelength of the plasma wave.

beat wave acceleration (PBWA) of electrons. Here, a two-wavelength laser beam (frequencies ω_1,ω_2) resonantly drives up a longitudinal electron plasma wave of frequency $\omega_p \approx \Delta\omega \approx$ \$$\omega_1 - \omega_2$, providing a field strength of GeV/m and, therefore, accelerate an injected electron beam at this very high gradient. This concept was successfully realized using two-wavelength pulses in the $10\mu m$ range and a net acceleration 30 MeV was reported for a 1 cm long plasma [1]. The second generation plasma accelerator experiments are those which begin to deal with the practical spatial and temporal aspects of the plasma accelerator structure and its control. The primary goal of Neptune is to inject high-quality electron bunches into a laser-driven PBWA and explore ideas for extracting a high-quality $\Delta mathrmE$/E $<$ 0.1, $\varepsilon <$ 10π mm-mrad, high-energy (³$100MeV$) beam from a plasma structure operating at about 1 THz and accelerating gradient of 3 GeV/m.

At present the state-of-the-art two-wavelength, terawatt CO_2 laser system based on multistage amplification of a 100 ps pulse is built and fully characterized. The system is capable of producing 100 ps pulses with energy 100 J [2]. The CO_2 laser chain includes a two-wavelength hybrid TEA master oscillator, an UV-preionized, 8-atm regenerative amplifier, and a 2.5-atm electron-beam-controlled large-aperture amplifier. A short, low-power seed pulse at $10\mu m$ is switched out from the nanosecond master-oscillator output by use of a semiconductor switching system driven by a 100-ps pulse Nd:YAG laser. This active optical switching also provides the synchronization of the short $10 - \mu m$ pulse and an electron bunch from a photocathode RF gun illuminated by the fourth harmonic of the same Nd:YAG laser pulse. The Neptune RF gun and linac produce 10 MeV, 10 ps electron bunches with emittance of 6 mm mrad [3].

For PBWA, electrons from the photoinjector are injected in a plasma accelerating structure. A 4-cm long plasma in H_2 is obtained at resonant conditions for a CO_2 laser operating at 10.3 and $10.6\mu m$; this resonant density is $9.4 \times 10^{15} cm^{-3}$. The large diameter ($w_0 = 200mm$) and long period (1 THz) of the accelerating structure relative to the injected electron bunches will facilitate both transverse and longitudinal beam loading into the plasma. Longitudinal relativistic plasma waves driven by TW $10-\mu m$ pulses are detected and studied by collinear Thomson scattering with a green optical probe beam. Based on the Thomson scattering it is found that the plasma wave amplitude is around 20%. A simple model of the plasma wave growth and subsequent electron acceleration suggest that 100 MeV electrons will be observed. To meet ΔE/E $<$ 0.1 requirements for the energy spread in the second phase of experiments, the electrons have to be prebunched at the exact wavelength of the plasma wave. Several methods have been considered for such phase-locking: a plasma klystron technique for prebunching the electrons into the buckets of the plasma wave; CO_2 gating of the photoinjection optical beam for phasing the electron microbunches to the plasma wave; an IFEL prebunching driven by a THz seed radiation phase-locked to the electromagnetic beatwave [4]. Theoretical modeling have shown that IFEL prebunching is a versatile method to phase-lock electrons and the plasma accelerating structure with a period of $330\mu m$. However, this scheme requires a high-power seed $330\mu m$ signal phased to the electromagnetic beatwave. Difference frequency generation between two CO_2 laser wavelengths in a nonlinear crystal is suggested to use for production such a radiation pulse. Analysis have shown that MW

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pulses at $330\mu m$ could be generated both in birefringent and quasi-phase matched nonlinear materials. Experimental study of feasibility of this method is in progress.

Besides PBWA of electrons several other experiments are planned at the Neptune Facility: plasma wake field generation and acceleration, IFEL acceleration using TW CO_2 laser pulses, a plasma lens experiment, and study of Cherenkov radiation from a magnetized plasma.

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References

[1] M.J. Everett *et al.*, Nature **368**, 527 (1994).
[2] S.Ya. Tochitsky *et al.*, Optics Lett. **26**, 813 (2001).
[3] S.G. Anderson *et al.*, Advanced Accelerator Concepts 2000, AIP Proceedings, Melville, New York, **569**, 487 (2001).
[4] C.E. Clayton, L. Serafini, IEEE Trans. Plasma Sci. **24**, 400 (1996).