3rd Asia-Pacific Conference on Plasma Physics, 4-8,11.2019, Hefei, China

Wakefields in Plasma: Particle Acceleration and Terahertz Generation

Pallavi Jha

Professor (retired), Department of Physics, University of Lucknow, Lucknow, India.

prof.pjha@gmail.com

Longitudinal and transverse wakefields generated by the propagation of short laser pulses in preformed plasma is an important mechanism that finds applications in plasma based particle acceleration schemes as well as Terahertz (THz) radiation generation. When short, high intensity laser pulses propagate in underdense plasma, the ponderomotive force arising due to the intensity gradients in the laser pulse, pushes the plasma electrons away from the region of high intensity. The displacement of electrons creates a local charge separation, with the massive ions forming a stationary background. The electrostatic restoring force generated by the space charge tends to restore the perturbed plasma electron density distribution, leading to oscillatory electron motion inside and behind the laser pulse. These plasma oscillations follow the laser pulse in the form of a wakefield [1].

The acceleration of charged particles by plasma based accelerators utilizes the concept of generation of plasma waves or longitudinal wakefields either driven by an electron beam as in the plasma wakefield accelerator (PWFA), first proposed by Fainberg in 1956 [2] and observed experimentally by Rosenzweig et. al [3], or by an intense laser pulse. Tajima and Dawson [4] were the first to propose the concept of laser-plasma based acceleration technique which included laser wakefield accelerator (LWFA) and the plasma beat wave accelerator (PBWA). The former uses the concept of acceleration of externally injected electrons by wakefields generated by compact, short, high intensity laser pulses propagating in plasma while the latter uses two conventional long (~100 ps) laser pulses of modest intensity (~10^{14}-10^{16} W/cm^2). Another laser - plasma based accelerator system is the self-modulated laser wakefield accelerator (SMLWFA), in which enhanced acceleration of the charged particles is achieved via resonant self-modulation of the laser pulse [5].

Another laser-plasma based application of great interest is the emission of terahertz radiation via laser plasma interaction [6]. The first experimental observation [7] of laser-plasma-produced THz emission was reported in 1994. It was attributed qualitatively to laser-driven electron plasma oscillations. It is well known that mode conversion between electron plasma waves and their electromagnetic counterparts can occur in plasma under certain appropriate conditions. For example, when a laser pulse propagates obliquely through a tenuous inhomogeneous plasma, THz emission with a frequency nearly that of the plasma is produced, provided the plasma density increases with distance along the laser propagation direction [8]. Laser field ionization resulting from propagation of a short laser pulse in a gas target can also lead to THz emission, if the leading and trailing edges of the incident laser pulse are highly asymmetric as in the case of a frequency-chirped pulse [9]. THz emission occurs since a high transverse net current is produced. Such transverse currents can also be generated in pre-ionized plasma. The possibility of THz radiation generation due to transverse wakefields produced by propagation of short laser pulses in magnetized, homogeneous plasma has also been reported [10].

This presentation will focus on the theory of wakefield generation via laser-plasma interaction. Analytical studies of two applications based on such wakefields in plasma, namely, laser wakefield acceleration (LWFA) and terahertz radiation generation in magnetized-plasma will be discussed. Simulation studies validating the possibility of terahertz radiation emission by wakefields in magnetized plasma [11,12] will also be presented.

References:

[1] Kruer, W.L., "The Physics of Laser Plasma Interaction" (Addison-Wesley, Redwood City) (1988).
[2] Fainberg, Y. B., "The use of plasma waveguides as accelerating structure" Proc. Symp. CERN **1**, 84 (1956).
[3] Rosenzweig, J.B., Cline, D.B., Cole, B., Figueroa, H., Gai, Konecny, W.R., Norem, J., Schoessow, P., and Simpson, J. “Experimental observation of plasma wakefield acceleration,” Phys. Rev. Lett., 61, 98 (1988).
[4] Tajima, T. and Dawson, J.M., "Laser electron accelerator" Phys. Rev. Lett. **43**, 267 (1979).
[5] Esarey E., Schroeder C.B. and Leemans W. P., "Physics of laser-driven plasma-based electron accelerators", Rev. Mod. Phys. 81, 1229 (2009).
[6] Liao, G.-Q., and Li, Y.-T., "Review of Intense Terahertz Radiation from Relativistic Laser-Produced Plasmas", IEEE Trans. Plasma Sci., 47 (6), 3002 (2019).
[7] Hamster, H., Sullivan, A., Gordon, S. and Falcone R. W., "Short-pulse terahertz radiation from high-intensity laser-produced plasmas", Phys. Rev. E. 49(1), 2725, (1994).
[8] Sheng, Z.-M., Mima, K., Zhang, J., Sanuki, H., "Emission of electromagnetic pulses from laser wakefields through linear mode conversion", Phys. Rev. Lett. 94, 095003 (2005).
[9] Wang, W.-M., Sheng Z.-M., Wu, H.-C., Chen, M., Li, C., Zhang, J., Mima, K., "Strong terahertz pulse generation by chirped laser pulses in tenuous gases", Opt. Express 16, 16999 (2008).
[10] Jha, P., Saroch, A., and Mishra, R. K., "Generation of Wakefields and terahertz radiation in laser–magnetized plasma interaction" Europhys. Lett., 94**,** 15001 (2011).
[11] Jha, P. and Verma, N. K., "Numerical and simulation study of terahertz radiation generation by laser pulses propagating in the extraordinary mode in magnetized plasma",Phys. Plasmas, 21, 063106 (2014).
[12] Saroch, A. and Jha, P., "Simulation study of terahertz radiation generation by circularly polarized laser pulses propagating in axially magnetized plasma" Phys. Plasmas, 24, 124506 (2017).