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Relativistic proton emission from ultrahigh-energy-density nanosphere generated by micro-bubble implosion

M. Murakami[1], M.A. Zosa[1], A. Arefiev[2], J.K. Koga[3], Y. Nakamiya[4]

[1] Osaka University, [2] US San Diego, [3] Kansai Photon Science Institute, [4] Extreme Light Infrastructure - Nuclear Physics

e-mail: murakami-m@ile.osaka-u.ac.jp

In the past quarter century, the chirped-pulse-amplification (CPA) technique has increased the laser intensity more than ten mil- lion times. Consequently, diverse research via laser-matter interactions has been pursued. Examples include fast ignition and high energy particle acceleration for electrons and ions with respect to different applications. These studies have been conducted under the relativistic electron regime, corresponding to the laser intensity I_L with 10^{18}<I_L (W cm^{-2}) <10^{22}.

We have investigated laser intensity scaling for accelerated proton energy and attainable electrostatic field using microbubble implosion (MBI) [1,2]. In MBI, the bubble wall protons are subject to volumetric acceleration toward the center due to the spherically symmetric electrostatic force generated by hot electrons filling the bubble. Such an implosion can generate an ultrahigh density proton core of nanometer size on the collapse, which results in an ultrahigh electrostatic field to emit energetic protons in the relativistic regime. Three-dimensional particle-in-cell (PIC) and molecular dynamics (MD) simulations are conducted in a complementary manner. As a result, underlying physics of MBI are revealed such as bubble-pulsation and ultrahigh energy densities, that are higher by orders of magnitude than, for example, those expected in a fusion-igniting core of inertially confined plasma. MBI has potential as a plasma-optical device, which optimally amplifies an applied laser intensity by a factor of two orders of magnitude, and thus MBI is proposed to be a novel approach to the Schwinger limit.

The aim of this paper is not to precisely address this uniformity problem or to enumerate detailed numerical simulation results, but rather to construct a simple semi-analytical model, which encapsulates the important features obtained from multi-dimensional simulations. Not only can this model easily visualize the underlying physics of this novel phenomenon but also define the limiting performance. For example, it can approximate the extent of approaching the Schwinger limit within the framework of the idealized one-dimensional (1D) scenario. Our goal is to show that MBI holds promise as a unique plasma-optical device to generate ultrahigh fields, which remarkably exceed an applied laser field by orders of magnitude, and resultant energetic protons in the relativistic regime.

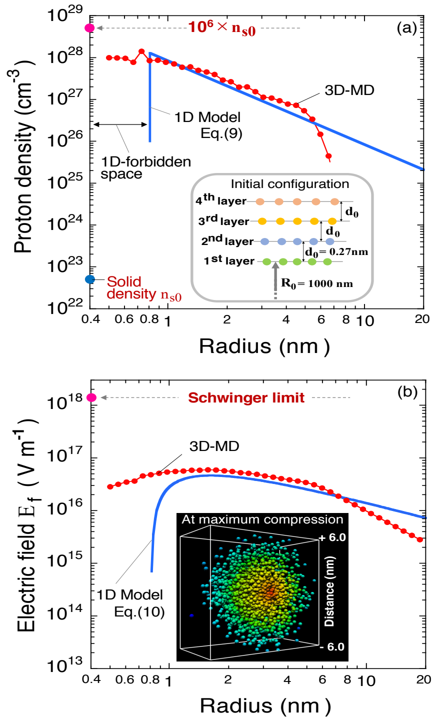

Fig.1 (a) Comparison of the proton density at the maximum compression between the 3D molecular dynamic simulations and the 1D model. Fixed parameters are R_0 = 1μm, n_{i0} = 5 × $10^{22}$$cm^{-3}$ assuming Λ ≪ 1. The curve labeled "3D-MD" is obtained using the innermost four layers as shown in the inset. (b) Comparison of the electrostatic fields between the simulations and the model. The inset shows the proton distribution around the center (color-coded in accordance with the distance from the center).

References

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