INTERACTION OF INTENSE LASER LIGHT WITH SUPER-CRITICAL DENSITY PLASMA

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Abstract

We have examined various aspects of the interaction of high intensity laser light with plasmas at and above critical density, using particle-in-cell (PIC) codes. The strongly corrugated critical density surface subsequently fragments, leading to striations which merge both spatially and temporally. Simulations of hole-boring for both linearly and circularly polarised light show marked differences between the two in the rate of hole-boring and in the channel characteristics. PIC simulations have also been carried out to explore aspects of the generation of harmonic emission at multiples of the plasma frequency, first reported at ICPP96 [1]. We find that second and third harmonic plasma emission significantly modifies the spectrum of harmonics of the incident light.

1. Introduction

The availability of ultra-short pulse lasers capable of delivering focused intensities of 10^{20} Wcm^{-2} has stimulated interest in laser-plasma interactions under conditions such that the electron quiver velocity is highly relativistic. This regime is characterised by direct consequences of the relativistic electron dynamics such as induced transparency of the laser light and by dramatic manifestations of non-linearity such as the emission of harmonics of the incident light to very high harmonic orders. The interaction is further characterised by strong fluxes of electrons of relativistic energies which are markedly dependent on the polarisation of the light. The flux of relativistic electrons in turn is one source of intense magnetic fields penetrating the overdense plasma [2]. The ponderomotive force associated with light at these intensities is powerful enough to bore a channel into the supra-dense plasma. In this paper we highlight results on high-intensity interaction physics from recent simulations.

2. Corrugation and filamentation

We first consider two-dimensional PIC simulations with light incident normally on a slab of plasma of critical density, n_c, initially uniform. In these runs the light was left-circularly polarised (LCP) in a 100fs pulse with peak intensity I = 10^{19} Wcm^{-2}. The strong ponderomotive force sweeps electrons ahead of the pulse into the plasma slab resulting in an electron density step to over $2n_c$. This step is evident from Fig.1a at t = 40fs. However by t = 60fs the light has broken through and one sees density corrugations. Corresponding electromagnetic intensity contour plots show clear evidence of striations with filaments about a wavelength across and neighbouring striations separated by about a wavelength. There is a distinct aggregation of these striations as time evolves; we see from Fig.1c,d that 7 elements at 60fs have become 5 at 100fs. This contrasts with the response of the plasma to a linearly polarised driver for which condensation of filaments is less pronounced. Mora et al. [3] have also found a similar coalescence of filaments in time but not spatially. These differences are attributable to strong inverse Faraday magnetic fields present with an LCP driver. These fields are directed along the axis and the large gradients in the induced magnetic field are strong enough to explain the effect seen in Fig.1c,d.

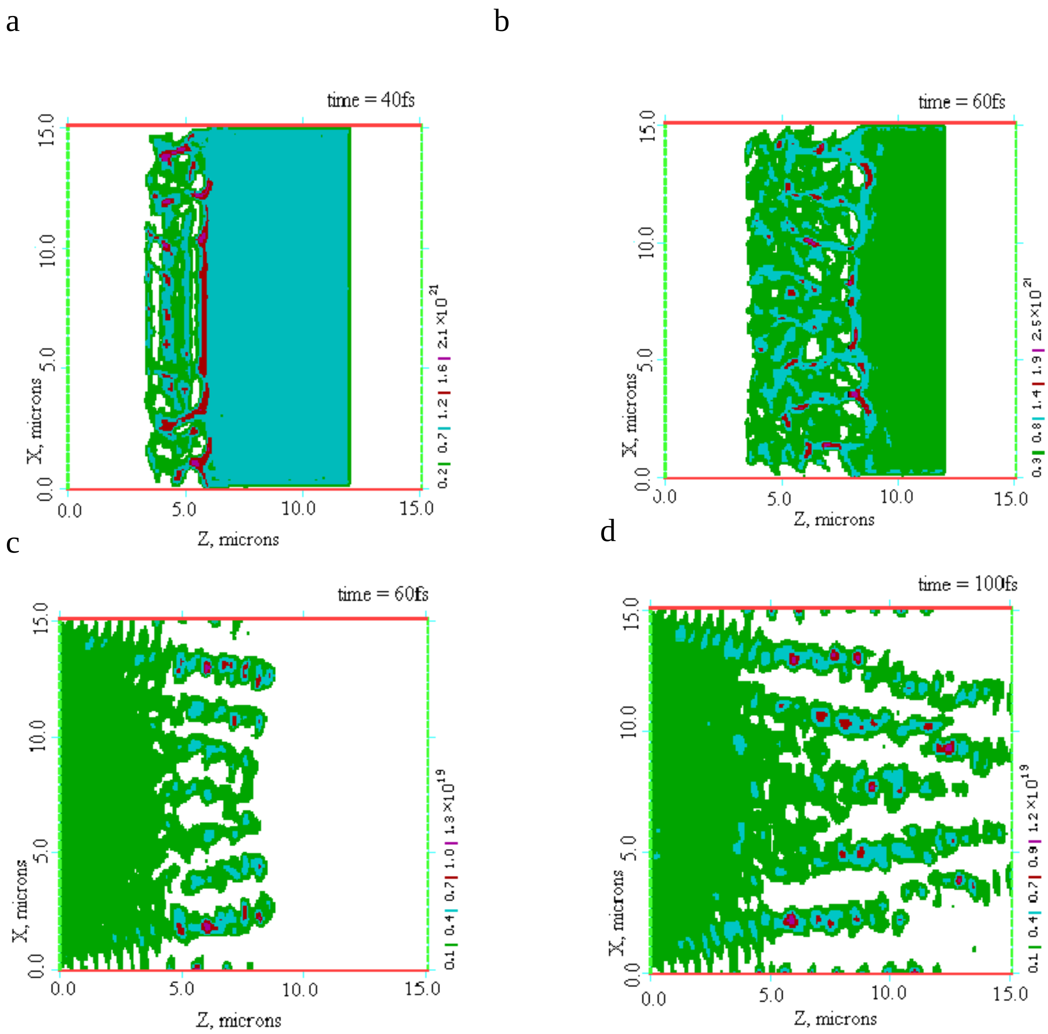

Fig. 1. Electron density contour plots (a,b top) and electromagnetic intensity contour plots (c,d bottom), for incident intensity 10^{19} Wcm^{-2}

3. Channelling into overdense plasma

We have carried out PIC simulations of the ponderomotive boring of a channel into overdense plasma for laser pulses of intensities in excess of 10^{19} Wcm^{-2} using both linearly and circularly polarised drivers. The simulation box is 10×40 μm^2 and the plasma density rises to $4n_c$ in a step with the plasma-vacuum interface at 6 μm. The initial electron temperature is 16keV and the laser pulse is of 1.2ps duration with FWHM of 4μm. The electromagnetic intensity output shows a number of interesting features. Propagation anisotropies across the pulse lead to sharp distortions at its head. Then as the light bores into the dense plasma the beam begins to bend away from the axis with displacements of a micron or more, 850fs into the run. Earlier simulations have found similar behaviour [4].

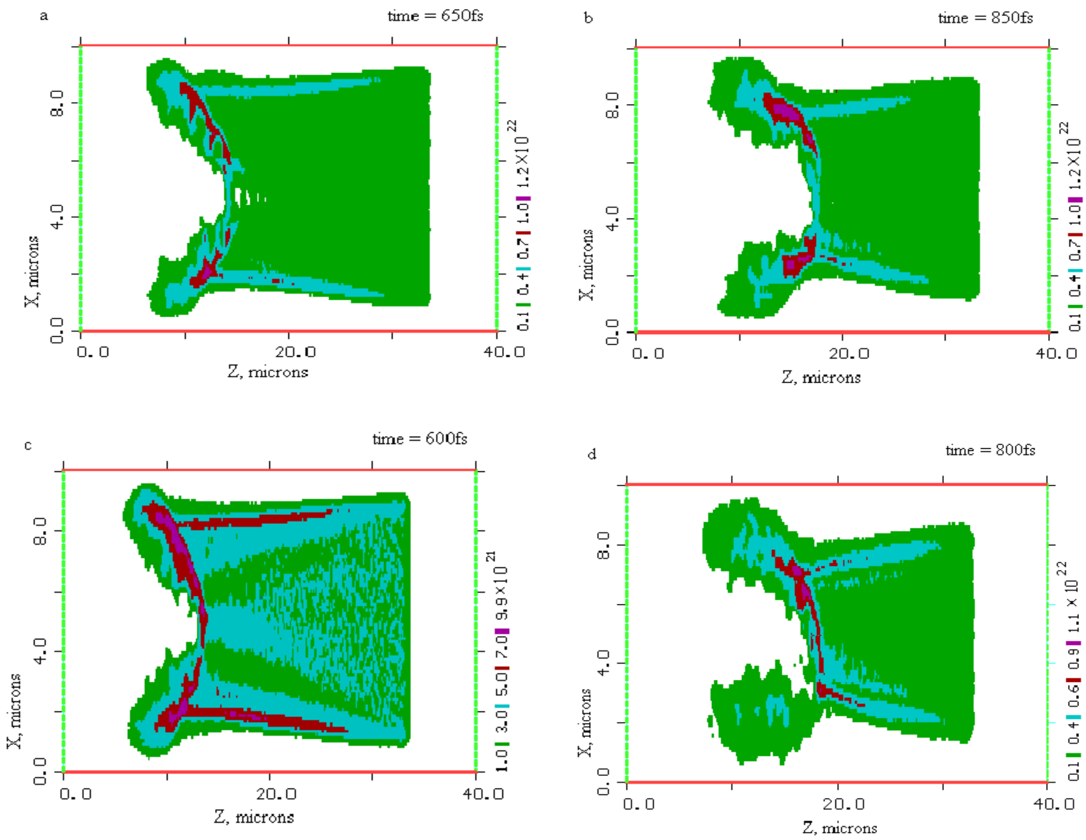

Fig. 2. Electron density contour plots from circularly (top) and linearly polarised (bottom) drivers at 3×10^{19} Wcm^{-2}

The electron density contour plots in Fig. 2 show further details of the interaction. At t = 650fs the cavity is already well developed with the delta-shaped front seen in simulations with a linearly polarised driver [5]. The front of the hole is 1.8μm wide while at the plasma-vacuum interface it is about 6μm across. Steep density gradients have developed with peak densities up to about 12 n_c at the sides and somewhat lower, ~7 n_c, at the front. By t = 850fs the hole is some 10μm deep, in keeping with a hole-boring speed of about $c/24$ from simple pressure-balance estimates. At this point the front of the hole has widened to 3.5μm across. We observed that the peak density at the front of the hole remains more or less constant at between 6-7 n_c throughout. Initially the evolution of the hole in simulations with a linearly polarised driver is similar. However at a later phase dramatic differences emerge with the channel displaying marked distortion, as shown in Fig 2d at t = 800 fs. The difference between the two polarisations again appears to be attributable to the effect of the inverse Faraday field which serves to prevent such dramatic distortions from developing.

4. Plasma harmonic emission from solid density targets

At ICPP96 Boyd and Ondarza reported the first indication of the effects of plasma line emission on the harmonic spectrum for a moderately intense light pulse incident on a plasma slab of density $30n_c$. This showed a strong plasma line centred between the 5th and 6th harmonics with a linewidth of roughly ω_0. Another feature of the spectrum was the appearance of a line at $3\omega_p/2$, about an order of magnitude weaker in intensity and somewhat broader than the plasma line. Here we show similar plasma emission from denser plasmas irradiated at higher intensities, $I \sim 10^{18}$ Wcm^{-2}. In these 1½D PIC experiments the plasma targets were two wavelengths thick. Fig. 3 shows the emission spectrum from a run in which the plasma line is again dominant with a weaker second harmonic and the third harmonic of the plasma line just detectable above the noise. Noise from the plasma emission dominates the spectrum of harmonics of the laser light, but as reported at ICPP96 some harmonic modulation of the plasma line is evident. The harmonics of the plasma line may originate either from plasmon-plasmon coupling [6] or from the very steep density gradient present. The modulation appears to derive from the interaction of the laser light with the strongly driven plasmon.

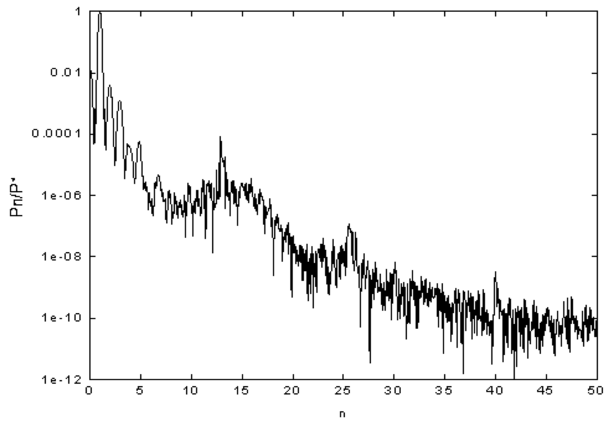

Fig. 3. Harmonic emission spectrum

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