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Ultra-High-Intensity experiments at ultra-high-contrast

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Introduction

In this talk, we will demonstrate that the contrast of high intensity laser pulses is a key issue for many problems dealing with high-field-physics interacting with solid-matter density. Experiments based on this idea can serve as benchmarks for theories and models.

As a proof, we will discuss the interaction of an Ultra-High-Contrast, Ultra-Intense, 50 fs laser pulse with overdense plasma through two examples: i) the generation of high order harmonics pulses where the swing between linear and relativistic conversion regime will be demonstrated and ii) the proton acceleration from ultra-thin foils where the perfect symmetry of both faces will be demonstrated, as well as the dominant role of the *p* component of the electric field.

High Order Harmonics generation from oscillating mirrors

It is known from several experiments that when a laser pulse is focussed onto a solid target, high order harmonics (HHG) can be generated. The condition for a specular emission (in contrast with an emission over 2 π) is the absence of a low density pre-plasma expanding in front of the surface. A very high laser contrast is then required to investigate this physics if the intensities are roughly greater than 10^{17} W/cm^2 (assuming an "ordinary" contrast in the 10^6 and a typical damage threshold of the solid target in the 10^{11} W/cm^2).

For the last 30 years, many models have been proposed to explain HHG from plasmas, but clear experimental validations have so far remained scarce. Recent results tend to support two generation mechanisms, *Coherent Wake Emission* and *the Relativistic Oscillating Mirror* process. We present new and strong experimental evidence for these two mechanisms, and show that they lead to harmonics with very different properties, thus enabling to distinguish unambiguously between them.

Coherent Wake Emission (CWE)

As recently demonstrated in [1], Brunel electrons [2] are involved in harmonic generation through the recently proposed "Coherent Wake Emission" process, efficient down to intensities of a few 10^{15} W/cm^2 . In this model, periodic bunches of "Brunel" electrons trigger plasma oscillations at different depth in the density gradient of the target. Because this light emission is triggered once every optical cycle by returning Brunel electrons, the emitted spectrum consists of harmonics of the incident frequency.

Relativistic Oscillating Mirror (ROM)

When the laser intensity is increased further, beyond a few 10^{18}W/cm^2 , and if the temporal contrast is high enough (in our case, better than 10^{10} [3]), the laser-driven motion of the plasma surface becomes relativistic, leading to strong Doppler shifts of the laser light. As this oscillating surface chases the retreating optical phase-fronts, it compresses the reflected electromagnetic field, distorting it from its original sinusoid. Since this phase-distortion repeats itself with the periodicity of the driving laser field, harmonics of the incident frequency then appear in the reflected beam. This is the so-called "relativistic oscillating mirror" process, which was identified theoretically more then a decade ago [4].

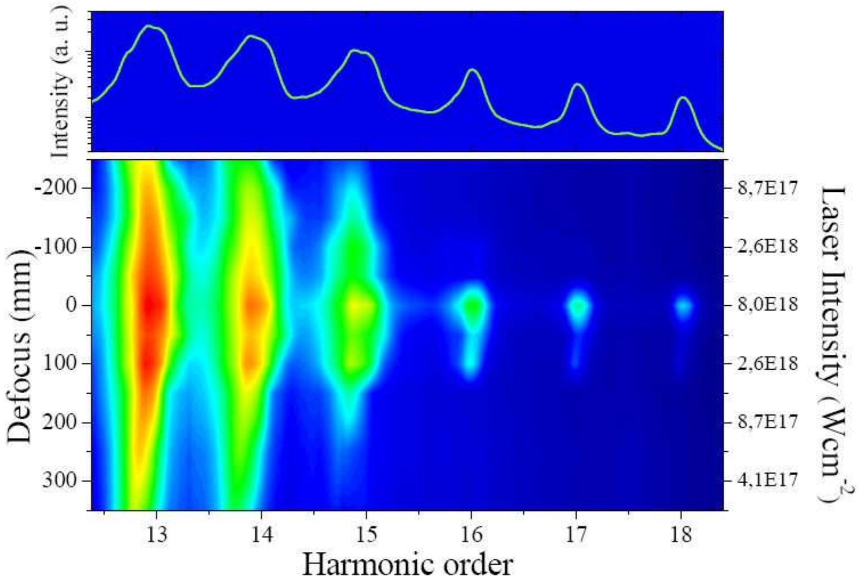

Figure 1 : Harmonic spectrum dependency on the laser intensity. Harmonic spectra obtained on plastic are plotted in logarithmic scale as a function of distance between the target surface and the laser best focus.

Experimental validation of both models

Predictions of the CWE model are a cut-off of the harmonics spectra at the maximum plasma frequency of the target and a quasi-linear behaviour with the incoming intensity. On the opposite, in the ROM regime, the position of the spectral cut-off depends on the laser intensity [5] and can be much higher then in CWE. In addition, a strongly non-linear dependence of the harmonic signal with the laser intensity is expected.

This is illustrated in Fig.1, which presents the intensity dependence of the harmonic spectrum from a plastic target, measured by varying the distance between the target surface and the best focus of the laser beam. CWE is a quasi-linear conversion process, the overall efficiency of which depends only weakly on laser intensity. Thus, harmonics below order 15 vary very weakly with changing laser intensity, and are still clearly present below the relativistic threshold. On the contrary, harmonics beyond order 15 vanish sharply and almost simultaneously as soon at the target is moved away from the best focus. They are only observed for intensities approaching 10^{19} W/cm^2.

Proton acceleration from ultra-thin foils

Up to now, most of the published works deals with protons emerging normally to the opposite side of thin foils with respect to laser direction, then emitted in the Forward laser Direction (FWD). Protons originating from the laser side surface, then emitted in the Backward laser Direction (BWD), were usually found much less energetic. We will demonstrate here that the influence of the laser contrast, determining the presence or not of a large scale and smooth gradient plasma expanding in front of the surface, throw new light on the acceleration mechanisms and is decisive to shape the BWD emission characteristics.

We report here a study of proton acceleration using thin Mylar foils of different thickness as targets, under low (10^6) and ultra-high 10^{10}) laser contrast conditions (respectively "LC" and "HC" in the following).

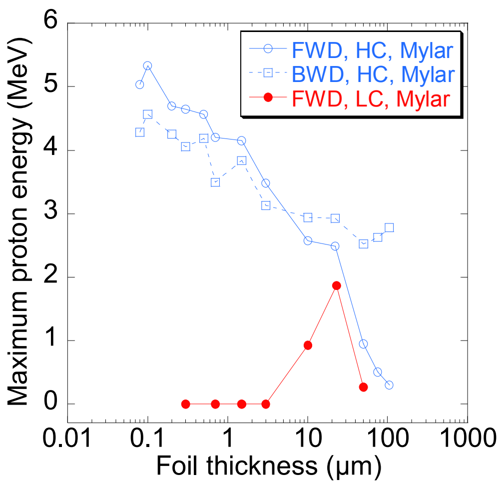

Figure 2 : Variation of maximum proton energy as a function of target thickness of FWD and BWD emission for laser contrast of 10^{10} (510^{18} W/cm^2) and 10^6 (10^{19} W/cm^2)

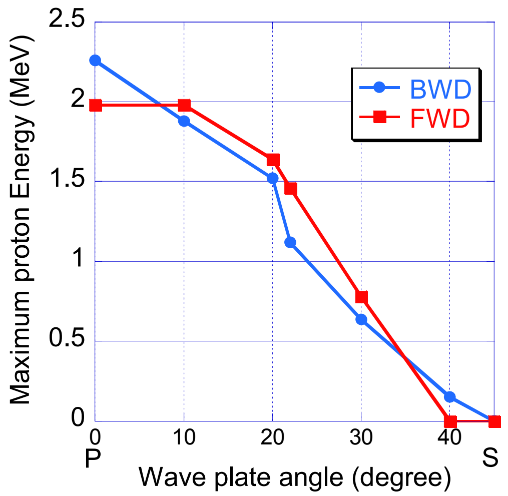

Figure 3: Variation of maximum proton energies as a function of laser polarization in the HC case.

We show on figure 2 simultaneous single shot measurements of proton emission behind the target in the laser direction (FWD) and in front of the target, opposite to laser direction (BWD). We observe for HC shots that, increasing the target thickness from 80 nm to 20 µm, BWD and FWD energies present a twin behaviour decreasing together from 5 MeV to 3 MeV. Above this thickness, the BWD beam keeps constant around 2.5 MeV whereas the FWD vanishes exhibiting the same behaviour than in the LC case. These results suggest a totally symmetrical electron confinement on both foil sides. We have also measured simultaneously the beam profiles in both directions using radio-chromic films. Beam divergences are found to be around 4° for 2 MeV protons.

We have also study the laser polarization influence on the ionic acceleration mechanism. Obviously, because p and s -polarized pulses refer to a well defined plane (or a very sharp gradient), this study is meaningful under HC conditions only. Indeed, the models found in the literature, even if some of them must be carefully used in the case of very short pulse durations, assume that the only ponderomotive force (independent on the laser polarization) accounts for the initial electronic energy absorption. Looking at the figure 3, we see that there is no acceleration for a s polarized pulse whereas it goes to a maximum for p polarization. We conclude that only the p component of the electric field is active to accelerate ion beams in contrast with models employed so far.

Conclusions

We believe that these results contribute to a better understanding of a new interaction regime: ultra-high-intensity at ultra-high contrast (UHI@UHC) at solid matter density. Just as HHG in gases has been instrumental in providing a comprehensive understanding of basic intense laser-atom interactions, HHG on solid density plasmas as well as proton acceleration will be unique tools to better understand many key features of laser-plasma interactions in the relativistic regime.

[1] F. Quéré et al, *Phys. Rev. Lett. 96 (2006), 125004*
[2] F. Brunel, *Phys.Rev.Lett. 59 (1987), 52*
[3] A. Levy et al, *Optics Letters, 32, (2007), 3*
[4] S. Bulanov et al, *Phys. Plasmas 1 (1994), 745*
[5] T. Baeva et al, *Phys. Rev. E, 046404 (2006)*