Modeling of Electro-Magnetic Pulses generated by high intensity lasers

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Abstract

High intensity laser pulses are used in inertial fusion experiments for diagnostics purposes and for fuel ignition. They however present a danger by generating EMP (Electro-Magnetic Pulses) which disturb or destroy the electronics devices and diagnostic. The EMP are generated after the laser shot and their strengh is related to the charge created on the target after the shotWe present here a model predicting the charge of the target depending on the laser and target parameters. It is compared with the experimental data and detailed numerical simulations.

The EMP present a serious danger in laser matter interaction experiment. They are especially important in the case of picosecond pulses with energies exceeding a level of a few joules. It was observed in experiments that such pulses are producing EMP pulse in the gigahertz domain with the amplitude exceeding 100 kV/m inside the interaction chamber. The origin of such pulses is explained by the return current induced by the positive charge left on the target after the intense laser pulse. The theoretical model proposed recently in Ref. [1] has been compared with experiments, which provided the important elements of the EMP generation mechanism. It is confirmed that the EMP amplitude is proportional to the quantity of electrons ejected during the laser interaction [2]. It was demonstrated that the target charge is proportional to the laser pulse intensity. The target is settle on a support which behaves as an antenna during the charge relaxation toward the mass. The EMP is emitted all along this relaxation as it is qualitatively shown in figure 1.

Here, we present a simple model which allows to quantify the charge induced on a solid target after a high intensity laser shot of a pico- or sub-picosecond duration. The principal elements of the model are the following: the laser pulse transfers its energy to some electrons of the target, accelerating them to relativistic energies. A part of these hot electrons spreads and dissipates in the target while other electrons are ejected from the target in the vaccum chamber. model

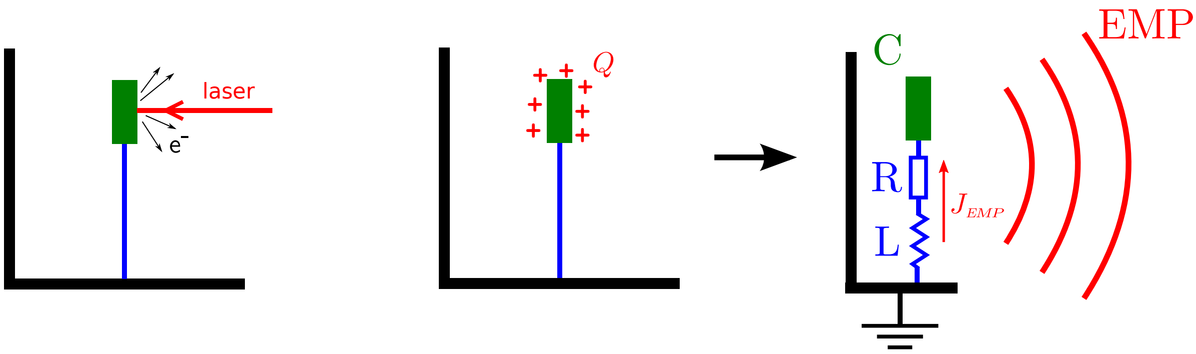

Figure 1: Schematic view of EMP emission by high intensity laser.

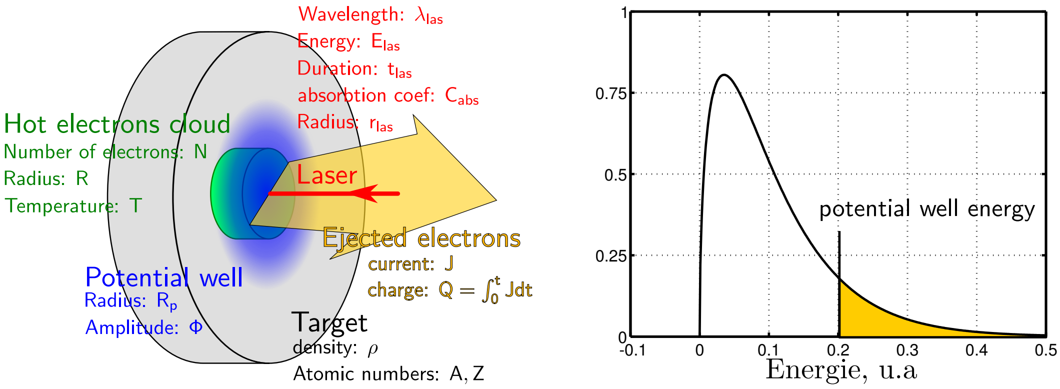

Figure 2: a) Target scheme, b) Maxwell-Juttner distribution function of hot electrons

provides an estimate for the quantity of ejected electrons which corresponds to the amount of positive charge left on the target. The first part of the model describes the hot electrons cloud in the target by using several simplifications detailed in figure 2a). . We assume that the hot electrons have a Maxwell-Jüttner energy distribution and they move in every directions. The cloud's temperature and density are supposed to be homogeneous. The cloud volume increases with time while its energy is decreasing in the target due to the collisions with cold electrons. Moreover, the hot electron number is reducing due to the hot electrons ejection and cooling. The second part of the model describes the hot electrons ejection conditions. The ejected hot electrons leave a positive potential at the surface of the target. This potential corresponds to a well which prevents the ejection of other hot electrons if their energy is not sufficiently high, see figure 2b). The potential of the well depends on the number of ejected electrons and the distribution of the positive charge on the targe surface. The ejection current of hot electrons increases the positive charge while the return current of the cold electrons spreads it over a larger surface.

For the given laser energy and the focusing conditions, the model describes different regimes depending on the pulse duration t_{las} with respect of the hot electron collision time in the target.

For a given laser energy and very short pulses, the total number of hot electrons created by the laser Q_{tot} is low but their energy is high because of the high laser intensity. There is not enough hot electrons to build a deep potential well for such highly energetic electrons. As a consequence, almost all the heated electrons may leave the target. Thus the final charge of the target is approximately equal to Q_{tot}. Thus, in the quasi-instantaneous ejection regime (noted 1 in figure 3) the fraction of ejected hot electrons decreases while the laser pulse duration t_{las} is increasing. The hot electrons become then less energetic and more numerous. Then the potential barrier becomes more efficient. This quasi-instantaneous regime ceases to exist if the mean hot electron energy becomes smaller than a mean potential well without accounting for the charge redistribution.

In the intermediate regime,noted 2 in figure 3, the ejection is limited by the potential well and it stops completely when the hot electrons are cooled in the target. The cloud energy and the potential well are linked by an evolution equation. This intermediate regime is operational if the cooling time t_{cool} is larger than the laser pulse duration t_{las}.

For laser pulses durations t_{las} greather than t_{cool}, the hot electrons cloud is in a quasi-stationary regime: the number of hot electrons created by the laser is equal the number electrons cooled in collisions. This is the third regime, noted 3, in figure 3, the energy dissipation and the hot electrons ejection are compensated by the laser which brings energy by heating new electrons. The well potential at the target surface is also almost constant during the laser pulse: it has two compensated contributions. The current of hot ejected electrons increases the well depth while this positive charge spreads across the target surface and decreases the well depth. Those two contributions compensate within a logarithmic accuracy. As the ejected current is inversely proportional to the laser pulse duration, the ejected charge is almost independent on the laser duration while it increases with the laser pulse energy.

Although the model is rather simple, it accounts for the major physical effects and agrees well with the experimental data. It presents a useful tool to predict the charge of a target after a laser shot and to explore the physical phenomena related to the EMP generation. It has also an interest for the generation of strong magnetic fields by laser providing estimated for the charge evolution during the laser pulse.

References

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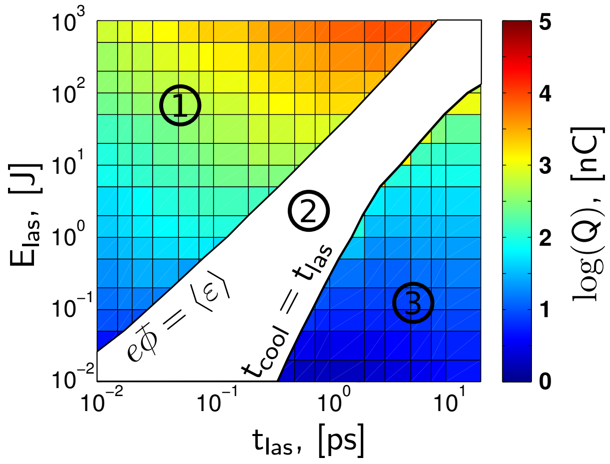

Figure 3: Domain of validity for the tree regimes of hot electron ejection depending on the pulse duration t_{las} and energy E_{las}. The other parameters are : the laser wavelength $\lambda_{las} = 800$nm, the laser focal spot radius $r_{las} = 7.5\ \mu$m and the laser-to-electrons conversion efficiency $C_{las} = 0.4$.

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