Strong electromagnetic pulses generated in high-intensity fs laser interaction with thin foil targets

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The process of laser-target interaction at high laser energies and high intensities may lead to generation of strong electromagnetic pulses (EMP), with the frequencies in the GHz range. Such pulses strongly interfere with the electronics used to collect data and manipulate targets and hence pose a serious threat to safe and reliable operation of the high energy and high intensity laser facilities [1,2]. There are several physical processes that may result in the EMP generation, but a complete quantitative understanding of this phenomenon is still lacking. The mechanisms of EMP generation in the case of fs laser pulses interacting with thick targets (~3 mm) were studied in a systematic way at the ECLIPSE laser facility at CELIA, Bordeaux, where thick targets made of various metals and dielectrics were irradiated by laser pulses of the energy on target in the range 30-100 mJ and duration 30-1000 fs [3,4]. A special "lollipop" target was used, which facilitated measurement of the neutralization current and determination of the total charge generated on the target.

In this note we report results of an experiment at the ECLIPSE facility which extended these studies to the case of thin (μm scale) targets that are common in laser ion acceleration experiments. We used custom made targets which also had the "lollipop" form, but were capable of supporting thin foils pasted in holes 1 mm in diameter, thus enabling a close comparison between GEMP generation off thick and thin targets. Measurements were taken with the laser pulse energy on target being varied in the range 45 mJ – 93 mJ, and the duration of the pulse was varied in the range 39 fs - 1000 fs. The FWHM of the laser spot on target was found to be 10.50 μm. The full laser pulse was found to have a 5 ns pedestal, with the contrast 8×10^{-6} at 150 ps before the peak for the shots 41-59, and 1.5×10^{-6} for the shots 60-184. We used the SOPHIE experimental chamber. The following targets were used: (a) a massive Cu "pill" 10.1 mm in diameter and 1.0 mm thick; (b) pure Al foil 6.0 μm thick, placed between two Cu pills, each 10.1 mm in diameter and 0.50 mm thick, with 10 holes 1 mm in diameter for shots; (c) an Al foil 6.0 μm thick, with 0.3 μm layer of polystyrene on the rear side (the expectation was that such a layer would increase the number of the TNSA protons), pasted on the rear side of a Cu pill 10.1 mm in diameter and 1.0 mm thick, with 10 holes 1 mm in diameter for shots; (d) a microdot target with Al disk 120 µm in diameter and 6.0 µm thick, placed on a 0.5 µm Ps foil, pasted on 10 holes 1 mm diameter in a Cu pill 10.1 mm in diameter and 1.0 mm thick, intended to mimic the behaviour of mass-limited targets. Several probes placed inside and even outside the chamber were used to monitor the electromagnetic field and obtain a good characterization of the generated EMP. Signals registered by the electromagnetic probes were recorded using two high-performance oscilloscopes: 6 GHz bandwidth, 20 GSa/s and 4 GHz bandwidth, 10 GSa/s.

The target neutralization current was measured by inserting the target stalk into a 50 ohm mount that was connected via a shielded cable to the oscilloscope. The temporal dependence of the target neutralization current is very similar for all thick and thin foil targets, with the sole difference in the maximum value (representative curves are shown in Fig. 1). In Fig. 2 we show the maximum value of the target neutralization current as a function of the laser pulse energy, for the pulse duration close to 40 fs. The values that are measured for the thick Cu target are quite stable from shot to shot, and they are consistent with the direct energy proportionality, as first observed in [3]. However, the absolute values recorded in our experiment are somewhat higher than in [3,4]. We attribute that effect primarily to the difference in the ns laser contrast: experiments reported in [3,4] were performed with the pedestal of 2 ns duration and the level of contrast 10^{-7}, whereas in our measurements the pedestal was 5 ns long and the level of contrast was 1.5×10^{-6}@150 ps for AlPs targets and 8×10^{-6} @150 ps for the pure Al foil. The maximum value of the neutralization current for thin foil targets shows larger shot-to-shot variation, so we display only the scatter plot for the data. The values for thin foil targets also follow an increasing

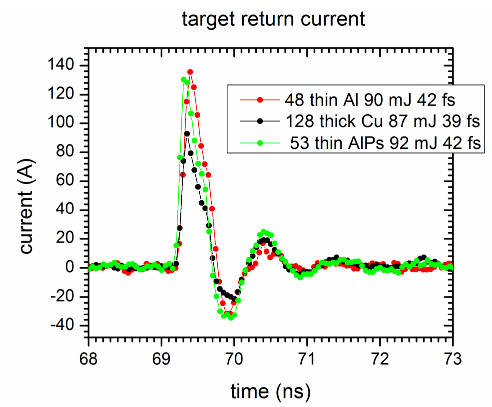

Fig. 1 The target neutralization current as a function of time for three shots representative of a bigger sample.

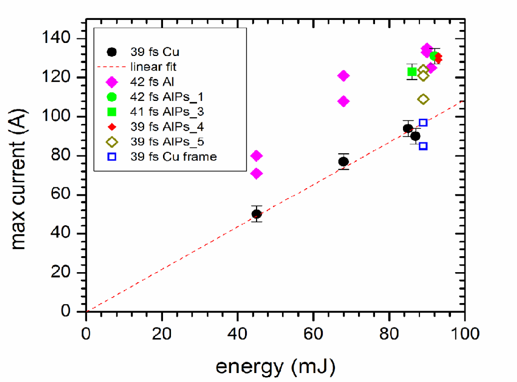

Fig. 2. The maximum value of the target neutralization current as a function of the pulse energy, for the pulse duration close to 40 fs. The dashed line represents a linear fit to the data for the thick Cu target, with the intercept constrained to 0.

trend with the laser pulse energy, and they are approximately 50% higher than for the thick Cu target, which may be attributed the fact that electrons may be ejected from a thin foil both in the reverse and in the forward direction. Furthermore, the data points for the pure Al target lie systematically above the points for the AlPs target; we attribute that to the level of contrast in various shot series and the fact that the layer of Ps on the rear of the target may reduce the number of escaping electrons and hence the target charge.

Concerning the shots on the microdot targets, in most of them the return current and the level of EMP were indeed substantially smaller than for the thin foil targets, but there was also a much bigger shot-to-shot variation. The target alignment to put the laser spot in the middle of a microdot proved to be a challenge. However, the idea of using microdot targets to reduce EMP certainly shows promise and deserves further study.

In order to measure the magnetic field generated in the process of laser-target interaction we used among others the Prodyn RB230 B-dot probe, connected to a Prodyn BIB-100G balun to provide unbalanced, symmetrized signal. This probe was located 214 mm behind the target, 55 mm to the right and 41 mm above the target and its orientation throughout the experiment was to record the tangential component of the magnetic field (referring to natural cylindrical coordinates in the experimental chamber). The data on the time derivative of the tangential component of the magnetic field is displayed in Fig. 3 for three shots representative of the thick Cu, thin Al foil and thin AlPs foil targets. The displayed shots correspond to energies close to 90 mJ and duration approximately 40 fs.

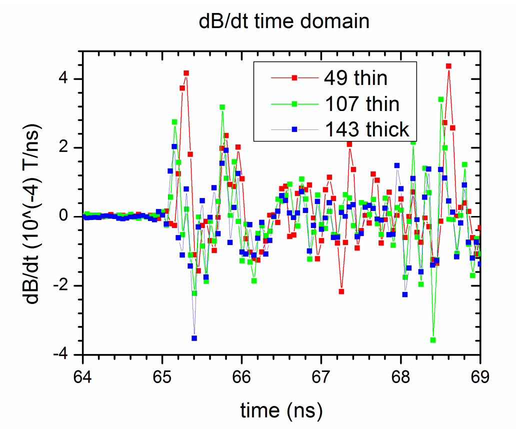

Fig. 3 The data for the time derivative of the tangential component of the B-field at the initial stage of the EMP signal, as obtained from the B-dot1 probe, for three representative shots: 49 (thin Al, 90 mJ, 42 fs), 107 (thin AlPs, 86 mJ, 41 fs), 143 (thick Cu, 85 mJ, 39 fs).

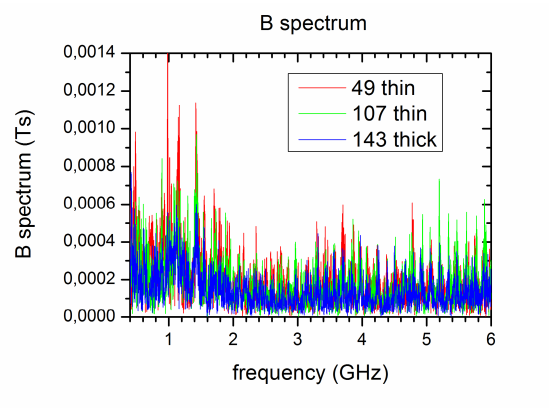

Fig. 4 The spectrum of the tangential component of the B-field, as obtained from the B-dot1 probe, for three representative shots: 49 (thin Al, 90 mJ, 42 fs), 107 (thin AlPs, 86 mJ, 41 fs), 143 (thick Cu, 85 mJ, 39 fs).

The EMP generated from the thin AlPs target is stronger than the EMP from the thick Cu target, while the EMP from the thin Al target is stronger than EMP from the thin AlPs target, as could be expected from the return current. All three signals have a very characteristic shape, consisting of an initial very narrow spike, followed by a more gradual decay lasting approximately 400 ns. These spikes turn out to be a very characteristic feature of the signals recorded by the B-dot. There is qualitative difference between the initial spikes originating from thick and thin targets: the spikes from the thin targets are "positive", while the spikes from the thick targets are predominantly "negative".

In Fig. 4 we show the spectrum of the tangential component of the magnetic field, extracted from the discrete Fourier transform of the B-dot signal for the three shots mentioned above. The spectra shown in Fig. 4 are characterized by three maxima: near 1 GHz, 1.2 GHz and 1.4 GHz, which are broad and overlapping for the thick target, but take the shape of high narrow spikes for thin targets, particularly for the pure Al target. The broad structure around 1 GHz is due to the signal generated by the target support system acting as a dipole antenna. We also see a pattern of closely spaced narrow spikes extending into the multi-GHz range, which are related to excitations of high-frequency eigenmodes of the experimental chamber.

Summarizing, the EMP generation has been studied in the interactions of laser pulses of up to 92 mJ of energy and at least 39 fs duration with thin foil (~μm) targets has been studied in a setup that allows for easy comparison with the thick targets that are better understood. It is found that compared to thick targets the thin foil targets give rise to visibly larger target neutralization current and the EMP signal, by 30% or more.

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