

# Multi probes measurements at the PALS Facility Research Centre during high intense laser pulse interactions with various target materials

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**Abstract.** During the interaction of high intense laser pulse with solid target, a large amount of hot electrons is produced and a giant Electromagnetic Pulse (EMP) is generated due to the current flowing into the system target–target holder, as well as due to the escaping charged particles in vacuum. EMP production for different target materials is investigated inside and outside the target chamber, using monopole antenna, super wide-band microstrip antenna and Moebius antenna. The EMP consists in a fast transient magnetic field lasting hundreds of nanosecond with frequencies ranging from MHz to tens of GHz. Measurements of magnetic field and return target current in the range of kA were carried out by an inductive target probe (Cikhardt J. *et al.* Rev. Sci. Instrum. **85** (2014) 103507).

## 1 Introduction

When high intense laser pulse interacts with a solid target a strong electromagnetic pulse (EMP) is generated. The main sources of EMP are the return target current flowing through the target holder and the charged particles escaping into the vacuum; both these EMP sources are directly connected with hot electrons escaping the plasma [1-8]. To obtain a complex data set on this process, various probes are employed for observation of return current and EMP emission during 3TW PALS laser pulse-target interaction experiment. While the target current probe (T-Probe) allowed us to determine occurred current onto the target as well as magnetic field around the target holder, loop antennas and linear antennas were employed for measurements of electric field and magnetic field both inside and outside the interaction

chamber.

The escaping electrons generate up to hundreds kV potential at the target and 10kA current flows from the target to the ground [9-12]. The return current, that compensates the net positive target charge, generates an electromagnetic pulse because the system target-target holder is in first approximation a linear antenna emitting toroidal radiation pattern in the far-field and more complex field pattern in the near field zone [13-20]. The charged particles moving inside the target chamber produce the Lenard-Wiechert potentials with radiative and non-radiative electric and magnetic fields depending on their both velocity and acceleration [21-24].

The generated EMP is a transient pulse lasting hundreds nanoseconds which is much longer than

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laser pulse target interaction [25-28]. The frequencies range from MHz to tens GHz.

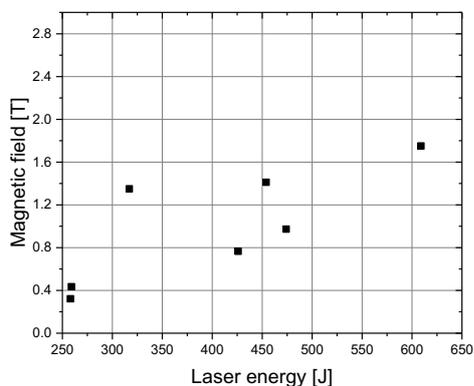
EMP propagates in all directions and it resonates at the resonant frequencies of the target chamber that acts as not efficient resonant cavity with many leakages (e.g. big glass windows) [29]. The presence of the EMP inside the vacuum chamber as well as in the experimental hall can cause problems with sensitive diagnostics, sophisticated data acquisition systems and, in some case, even disruptions of electronic devices can occur.

The generation of this harmful EMP depends on laser pulse characteristics, target material and shape of the target chamber as well as accessories located within it.

This contribution reports measurement carried out at PALS facility and it is focused on characterizing the magnetic field using different antennas.

## 2 Method and results

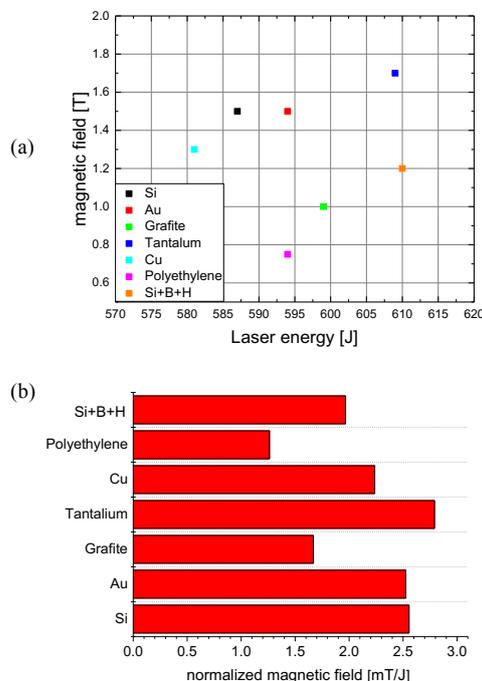
The employed target current probe [20] makes it possible to measure magnetic field at 5 mm distance from the target holder, which is generated only by the neutralizing target current. Fig.1 shows the increase of the magnetic field associated with target-holder current with the enhancement of the laser energy.



**Fig.1** Laser pulse energy dependence of magnetic field produced by return target current which was detected by the inductive target probe at 5mm distance from the target holder. Target material was Tantalum.

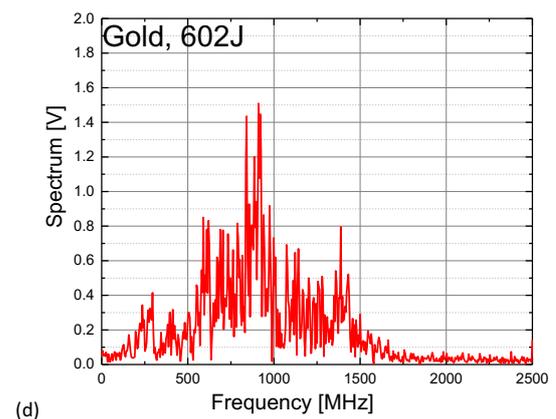
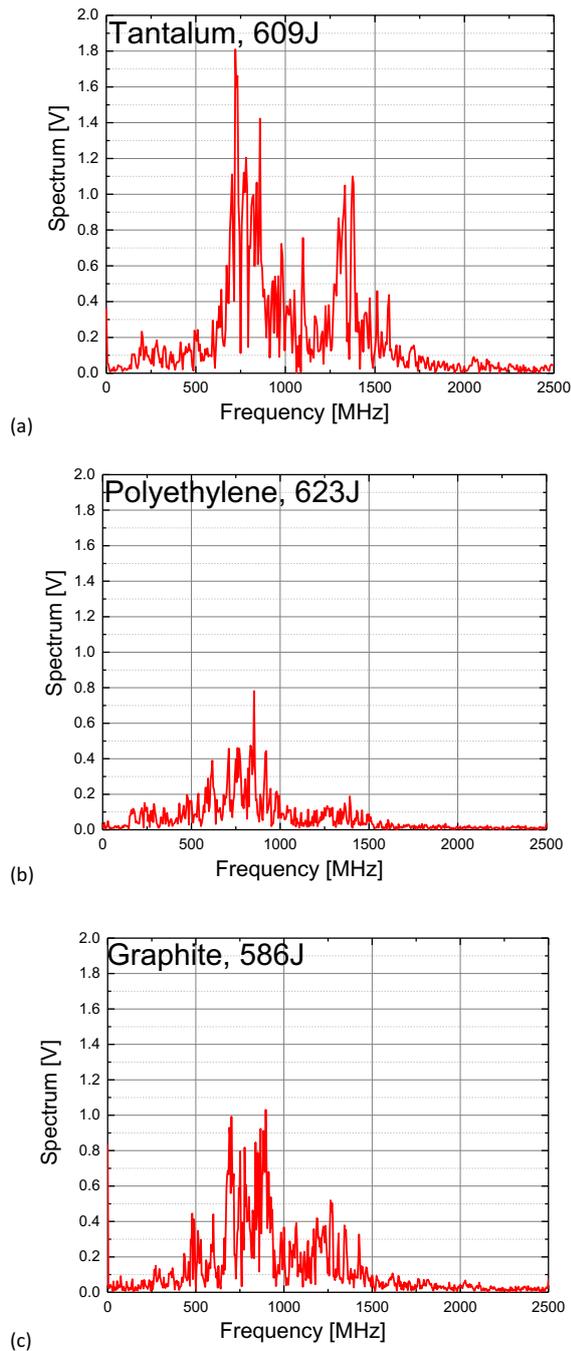
The measurements of magnetic field generated by only the return current for different target materials, were carried out by using the target current probe [20] and they are presented in Fig.2(a). The magnetic field was normalized to the laser energy  $E_L$ , see Fig.2(b). The target material influence on the return target current is also affected by the amount of impurities chemisorbed on the irradiated target surfaces which significantly contribute to the

emission of hot electrons [18]. For this reason, the study of the relation between target material and hot electron emission should be performed with perfectly cleaned targets and under ultra-high vacuum conditions.



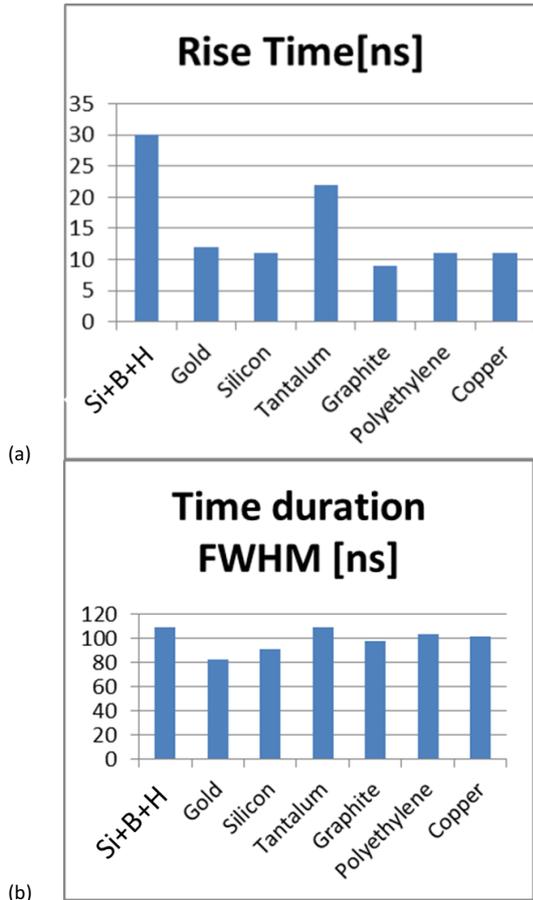
**Fig.2** (a) Magnetic field at target holder, measured by the T-Probe, for different target materials. (b) Normalized magnetic field with  $E_L$ .

Moebius antennas were used outside the interaction chamber and placed at 3m distance from the PALS spherical chamber wall. The highest EMP signal was detected when the Moebius antenna was placed in front of the glass window (40 cm in diameter) serving as an input window into the chamber for the laser beam. The typical EMP signals and frequency spectra were collected for different target materials. The spectra have two dominant peaks, one between 500MHz and 1GHz and another between 1GHz and 1.5GHz. Although at the moment it is not clear the correlation of the EMP spectra with the target materials, one can presume the influence of the target surface impurities as hydrocarbons on the emission of hot electrons and consequently on the EMP intensity, as Fig.3 shows. The tantalum target exhibits the highest amplitude of the first peak (see Fig. 3a) probably denoting big amount of hydrocarbon impurities on its surface [9]. This clearly exceeds the EMP amplitudes registered for polyethylene and graphite targets.



**Fig.3** Frequency spectra of EMP emitted by interaction of laser pulse with various target under similar conditions (laser energy 586 – 623 J) detected by Moebius antenna outside the interaction chamber at 3m distance from the glass window. (a) Tantalum, (b) Polyethylene, (c) Graphite and (d) Gold.

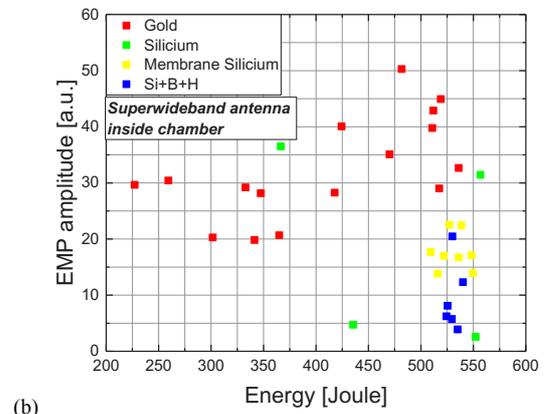
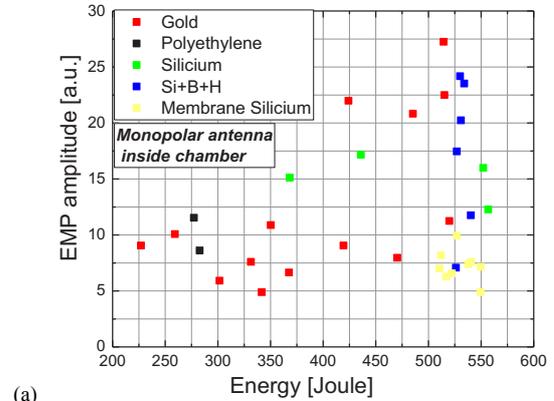
Double exponential fits [14] were carried out for each detected EMP signal and both the time duration and rise time duration of the magnetic flux were determined; the mean values of rise time and FWHM time duration over 10 shots are collected in Fig.4. The rise time is a parameter that reflects the rate of charge particles emission from target and it can be directly connected with both the atomic structure of the target material (e.g. atomic number) and the absorption of impurities on the target surface. In the case of Graphite target, the magnetic flux rise time reaches a very low value of only 8 ns while for the case of Tantalum and Si+B+H [30] the highest values are reached. In the case of Copper, Silicon, Gold and Polyethylene the rise time is very similar. The time duration of the FWHM has a minimum for Gold at 81ns and a maximum for Tantalum, Polyethylene and Si+B+H [30] at about 110ns. The FWHM time durations of magnetic flux for different target materials are very similar and it is probably due to the same geometry of the used target chamber that plays an important role for the determination of the signals decays [19].



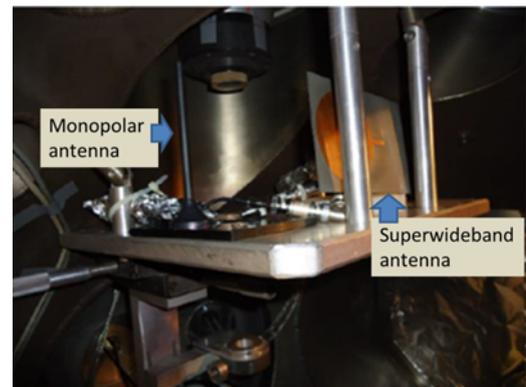
**Fig.4** Mean rise time (a) and mean FWHM time duration (b) of EMP for different target materials.

The signal acquisitions carried out by linear monopole antenna [31] and super wide-band antenna [32] placed both inside the interaction chamber, above the target at 30cm from it, and protected by a thick stainless-steel slab, as from Fig.5(c), are shown in Fig.5(a) and in Fig.5(b), respectively. It is well known that it is very difficult to get reliable measurements of EMP by conductive probes when high intensity and energetic lasers are used [1-10, 12]. In fact, big fluctuations were present shot by shot on the measurements, due to background noise on the oscilloscopes caused by bad EMC-shielding of the scope and by spurious coupling of EMP with outside conductor of the coaxial cables. To resolve these problems, it was necessary to use a delay line to clean the signals, as described in references [33, 34]. Fig. 5 shows the laser energy dependence of the EMP amplitude for various target and antennas. For energies higher than 400 J, high values of EMP were obtained for gold target, and this is in good agreement with results from Fig. 2a achieved by T-probe. Unfortunately, we were not able to get reliable results from these probes for all the other materials

studied, and for example for Tantalum. A clear and more complete comparison of absorbed EMP for other target materials, will be thus performed in future experimental campaigns [34].



(b)



**Fig.5** EMP amplitude for monopolar antenna (a) and SWB antenna (b) inside the experimental chamber; picture of the SWB magnetic antenna and linear antenna placed inside the target chamber at 30cm above the laser target interaction point (c).

### 3 Conclusions

In this work the results of EMP measurements are shown for different probes. The T-Probe allows us to measure the magnetic field produced only with the return target current. It was shown how the magnetic field increases with the laser pulse energy, as the target current scales with the laser intensity as  $\sqrt[3]{I\lambda^2}$  [20]. The analysis of the collected data for various materials, show that EMP spectra have two dominant peaks which change in their ratios based on the target material; however their dependence is not yet understood. Nevertheless the influence of hydrogen or carbon impurities on the emission of hot electrons and, thus, on the EMP intensity seems to be evident. The EMP rise time and duration (FWHM) was determined for each of the calculated magnetic flux. Average over 10 shots shows that Graphite presents the lowest rise time while Tantalum and Si+B+H targets shows the highest ones. For different target materials, the time duration at FWHM is very similar and it is related to the common target chamber structure that induces similar decaying of the EMP pulses. Measurements performed by conductive antennas inside the chamber suffered of high background noise, but it was possible to find a suitable solution and reliable results were eventually achieved, which are in rough agreement with those from T-probe. More complete characterization and comparison of results for different target materials can be performed in future experimental campaigns.

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