MEASUREMENT OF HOT ELECTRON TRANSPORT IN OVERDENSE PLASMA VIA SELF INDUCED GIANT MAGNETIC PULSES

S Mondal\(^1\), V Narayanan\(^1\), Amit D Lad\(^1\), Saima Ahmed\(^1\), S Sengupta\(^2\), A Das\(^2\), Z M Sheng\(^3\), P K Kaw\(^2\), G Ravindra Kumar\(^1\)

\(^1\)Tata Institute of Fundamental Research, 1-Homi Bhabha Road, Colaba, Mumbai-400005, India
\(^2\)Institute of Plasma Research, Bhat, Gandhinagar - 382428, India
\(^3\)Institute of Physics, CAS and SJT University, P. R. China

E-mail: msudipta@tifr.res.in

Abstract. Spatial and temporal resolved ultrashort (8ps) multimegagauss (65 MG) magnetic field has been measured in plasma produced on Al-coated BK-7 glass by the interaction of a relativistic intensity laser (4x10\(^{18}\) W/cm\(^2\), 30 fs) using pump-probe polarimetry. The 2D profile of magnetic field is captured using a CCD camera. Mapping of this magnetic field maps the transport of relativistic electrons in the plasma. The magnetic field profiles indicate filamentary behavior (Weibel-like instability). Particle in cell simulation are used to explain the result obtained.

1. Introduction

The largest terrestrially available magnetic fields are generated by interaction of solid targets with ultrashort super intense laser pulses (> 10\(^{18}\) W/cm\(^2\))[2, 3, 4]. Since the origin of the magnetic field is directly related to the electron transport, the study of this magnetic field has attracted considerable attention as it can map electron transport properties inside the plasma. In recent years lasers capable of producing intensity 10\(^{19}\) W/cm\(^2\) in many laboratories and are driving electrons in relativistic regime [6]. There is increasing interest in development of laser driven high energy particle accelerators, short pulse x-ray sources, neutron sources and fast ignition scheme for inertial fusion. Understanding electron transport is important for all these studies. There are many simulations [7, 8] on electron transport and giant magnetic fields produced inside plasma but the experiments are fewer and in particular spatial resolved dynamics of the magnetic field inside the plasma has not been studied.

In this experiment we monitor electron transport in the plasma by measuring self generated magnetic field. Light from an ultra-short super intense laser pulse (I\(~ 5 \times 10^{18}\) W/cm\(^2\), \(\tau = 30\) fs) is used to create a dense, hot plasma and launch the electron jets and the polarization change of a weak, time delayed probe beam is used to monitor the magnetic field.
2. Experimental setup

Experiments are performed using a table-top terawatt Ti:sapphire CPA laser, which can deliver 30fs, 10 Hz pulses of 600mJ each at 800 nm central wavelength. The schematic of the experimental setup is shown in the fig. 1. The p-polarized pump beam is focused at an angle of 40° with respect to the target normal with a f/4 off-axis parabola on an Al coated BK-7 glass target. The target was placed inside a vacuum chamber of pressure 10^{-5} torr and was mounted on a computer controlled xyz-θ precision stage so that every laser pulse irradiates a fresh spot on the target. The pump spot size on target is 20 µm. The pulse energy on target is 120mJ, giving a peak intensity ∼ 5 × 10^{18} W/cm^2.

The thickness of the Al-coating on the BK-7 glass is kept much larger than the skin depth (δ_s ∼ c/ω_p) at 800nm (∼ 100nm). So the incident pump laser interacts only with the Al coating and creates plasma on Al layer and the generated hot electron can ionize the glass and propagate through the resulting hot medium. We extracted 10 percent of the main beam and converted to second harmonic (2ω) and used as probe so that it can penetrate and sample the over dense region (4 times the critical density n_c) for 800nm of the plasma. At critical density most of the laser light is absorbed and hot electrons are expected to be generated. One more advantage of using 2ω probe is noise from pump can be filtered. We kept probe intensity very low 10^{12}W/cm^2 and weakly focused on the target so that probe does not modify the plasma and can sample larger area. The probe sense magnetic field in the plasma and its polarization state changes, acquiring ellipticity (Cotton-Mouton effect[1]). The probe is delayed by high precision translation stage(Akribis). The spatial overlapping of two pulses is monitored by a CCD camera coupled to high zoom video microscope lens. The temporal matching of the two pulse is done by looking at the reflectivity of probe as a function of time delay.

The reflected probe is divided into two parts for simultaneous measurements by two detectors. One arm has a photo-multiplier tube to measure space integrated ellipticity and other a CCD camera to measure spatially resolved ellipticity. We measure the reflected probe signal from plasma with parallel and crossed position of the analyzer at different time delays and derive time dependent ellipticity.

3. Result and Discussions

From the ellipticity we can calculate magnetic field. We can write β(t) = (e^2/m_ec^3ω_n_c) ∫ n_e(l,t)B^2(l,t)dl to derive B-field from ellipticity [2, 4]. From the spatially inte-
grated ellipticity data the magnetic field is deduced assuming a spatially uniform B-field over the entire crosssection and an exponential density gradient $n_e(x) = 4n_e^{400} \exp(-x/L(t))$, where $L(t)$ is the plasma slab length, $4n_e^{400}$ corresponds to the turning point of 400nm probe at normal incident. Where $L(t) = L_0 + v_{exp}t$, where $L_0$ is 1 μm, $t$ is time delay and $v_{exp}$ is the expansion velocity of the plasma critical surface estimated to $5 \times 10^6$ cm/sec from Doppler shift measurement of the reflected probe from plasma. For the spatially resolved data (from the CCD), we get the ellipticity for each pixel by doing the above procedure for that pixel and get 2D spatial map of magnetic field at critical surface of 400nm probe.

![Figure 2](image)

**Figure 2.** Space integrated time resolved (a) ellipticity and (b) magnetic field

Fig.2(a) shows the space integrated ellipticity of as captured in photomultiplier tube and fig.2(b) shows the magnetic field derived from this ellipticity. Integrated magnetic pulses is 7 ps long in time and maximum magnetic field is around 65 megagauss at the critical surface of the probe (400nm).

![Figure 3](image)

**Figure 3.** Space and time resolved magnetic field
Fig. 3 shows the x-y profile of the B-field as captured by the CCD camera. These are the first ever measurements of the simultaneous space and time resolved magnetic field.

The 2D profile of the B-field is not cylindrically symmetric but it has structure on it which indicates the current distribution which is responsible for this magnetic field has structure, i.e. the current distribution is filamentary. This filamentary behavior of the current distribution was known in 2D and 3D PIC simulations in much earlier time, but experimental evidence of dynamics of this current filamentation, which is known as Weibel instability, is observed first time as it happens.

We have run 2D PIC simulation for our experimental condition for long time. The peak magnetic field is about the same magnitude of the experimental value. We are improving the simulation to understand our results better.

![Figure 4. 2D PIC simulation of the magnetic field](image)

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