

OPERATING SEMICONDUCTOR TIMEPIX DETECTOR WITH OPTICAL READOUT IN AN EXTREMELY HOSTILE ENVIRONMENT OF LASER PLASMA ACCELERATION EXPERIMENT

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Abstract

An optical readout and shielding against electromagnetic pulses (EMP) has been developed as part of the ELI Beamlines/IEAP project for hybrid silicon pixel detector Timepix and it significantly improved its resistance to electromagnetic pulses (EMP). The setup was successfully tested under vacuum at Prague Asterix Laser System (PALS) during experiments with laser pulses of energies up to 700 J and duration of 350 ps bombarding thin solid target.

We present our experience with the new setup and its description. The recorded spectrometric data were analyzed and interpreted in a context of an independent experimental campaign run in parallel.

INTRODUCTION

In the last decade the laser-driven plasma acceleration experiments are reaching higher and higher energies of accelerated particles (electrons, protons, ions and even neutrons). The laser-driven plasma acceleration provides acceleration gradients by several orders of magnitude higher (GeV/cm) than those available by RF cavities (MeV/cm). The stability of the acceleration process is still one of the main challenges for this field. Another challenge in this field is usage of semiconductor electronics beam detectors, due to extremely high EMPs produced by the laser-driven plasma. In the experiment presented in this paper we have focused on the development and testing of new optics-only setup for semiconductor Timepix [1] detector, which enables operation of the detector in extremely hostile EM environment.

TIMEPIX DETECTOR

The hybrid semiconductor pixel detector Timepix consists of a silicon sensor chip bump-bonded to a readout chip (see Fig. 1). The Timepix readout chip contains 65536 spectroscopic channels organized in a matrix of 256×256 pixels with pitch $55 \mu\text{m}$. Each pixel is equipped with its independent full spectroscopic chain including preamplifier, discriminator and digital counter. The Timepix can be operated in counting mode (counting of incoming particles), which provides precise information about flux in defined

position, Time over threshold (TOT) mode allowing the direct energy measurement in each pixel, and also Timepix mode (the counter works as a timer and measures the time when the particle is detected). For detector control and data acquisition a devoted USB interface [2] and Pixelman software [3] are used.

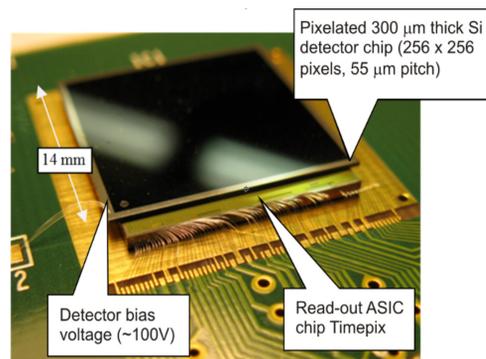


Figure 1: Timepix read-out ASIC chip with $300 \mu\text{m}$ thick silicon sensor.

TESTS AT PALS WITH METALLIC CABLES SETUP

In the first setup the detector was powered, controlled and read-out by metallic cables. Tests [4] were carried out at the PALS facility (Prague Asterix Laser System) - the high-power iodine laser system. Measurements were made with laser shots fired at the tantalum target with the Timepix detector placed inside the vacuum chamber in the vicinity of the interaction point. In view of the expected high radiation and high electromagnetic noise the detector system was double shielded. The first shield consisted of an aluminum casing, with a cylindrical tube against the active sensor chip of the detector, connected to the signal ground. The second shield, isolated from the first, consisted of lead coated plate grounded to the chamber. Also the communication and power supply cables were double shielded.

In spite of the shielding, the laser pulse still affected the power supply and reset the CPU of the USB readout interface. This problem was resolved by usage of a DC-DC converter (20V to 5V) and filtering capacitor close to the device. This solution was functional with energy of the laser shots up to about 10 J. In the case of more power-

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ful flashes the USB communication failed. This problem was fixed by disconnecting of data wires during the measurement by relay. This solution was functional with laser shots up to about 50 J (cca 150 GW), but it disabled the detector during the shots.

OPTICS-ONLY SETUP

In order to enable measurements with the detector during full power PALS shots with energies up to 700 J, the optics-only setup was prepared. This meant two modifications: the detector was powered by batteries and the control and data read-out was provided by optical fibers. We used commercial lithium AA-size batteries, which proved to be compatible with vacuum down to 10^{-6} mbar. When connected to a voltage stabilizer, a set of five batteries powered the detector for at least eight hours, providing 1.5 W in average. For control and data acquisition a commercial USB1.1 10 m long optical cable was used. At the detector side the cable contained optical converter, also powered by the batteries. The USB line consisted of four optical fibers, which were cut, equipped by new ST connectors and connected to optical fiber vacuum feed-through. The detector setup is presented in Fig. 2.

In order to provide sufficient shielding against EMP, the detector setup was housed inside a box, welded from 1.5 mm thick copper plates, see Fig. 3.

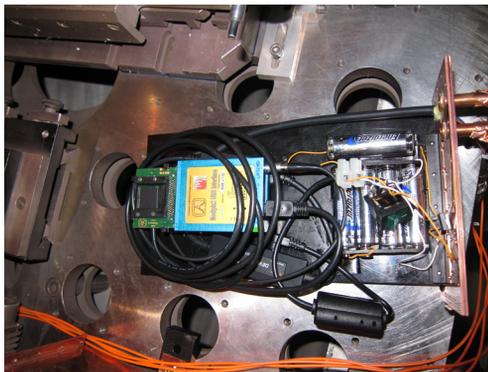


Figure 2: The optics-only setup with removed copper shielding. The Timepix detector (black square) is connected to the USB readout unit FitPix (blue), which is read out by commercial off-the-shelf USB optical cable. The optical converter (little black box) and FitPix are powered by standard Lithium batteries.

TESTS AT PALS WITH OPTICS-ONLY SETUP

The optics-only setup, described above, was tested again in vacuum chamber during experiments at PALS with laser pulse of 700 J and 350 ps focused on deuterated polyethylene foil producing intensity of 2×10^{16} W/cm², [5]. This experiment, primarily focused on neutron acceleration from thin solid targets by lasers, produced high EMPs,

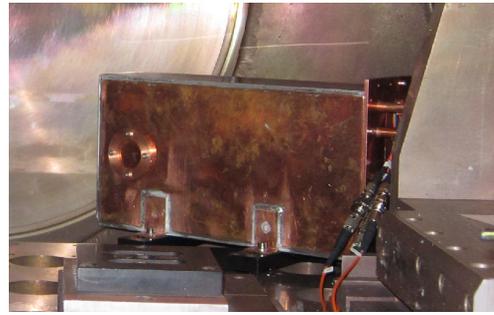


Figure 3: The copper shielding of the whole detector setup. The Timepix detector is positioned behind the round copper ring, which enables to mount different shielding windows. Only the optical cables penetrate through the shielding on the right-hand side.

which were measured. The experimental setup is shown in Fig. 4.

The distance between the target and Timepix centers was 41 cm. Few tens of laser shots were fired. This time the shielded Timepix detector worked continuously, unaffected by the harsh conditions. A typical example of signal measured by the detector is presented in Fig. 5. During this shot 7×10^7 neutrons were produced in 4π , which gives 0.1 neutron per a single detector pixel, was the detector unshielded. In addition 3×10^{12} protons with energies up to 2.5 MeV and gammas with energies up to 2 MeV were produced, [5].

Part of the detector was shielded by additional lead brick (54 mm thick from the target direction), which is apparent in Fig. 5 and related energy spectra in Fig. 6. Different shots however produced much harder gammas and the difference of signal between lead and copper shielded areas and copper only shielded areas was then almost smeared.

The EMP generated during the shots affects all unshielded electric equipment in the lab, CCD cameras inside the vacuum chamber were usually shot down. Also oscilloscopes outside the chamber were shot down by the EMP. They are hence housed in Faraday cages and powered by UPS during the shots.

For most of the shots, the rounded shielding window in front of the detector was covered by 1.5 mm copper plate. In the case of two shots this plate was exchanged for aluminum foil window 30 μ m thick. The detector still worked, but the signal in most of the pixels was saturated, due to the intensity of the radiation produced by the target.

EMP MEASUREMENTS

Given the size of the vacuum chamber diameter of 0.85 m, the electromagnetic fields maxima are expected at frequencies of hundreds of MHz. The EMP is produced mainly by hot plasma electrons, protons and gammas. For the measurement of the fields a near field loop probe with outer diameter of 23 mm was used, positioned in the vicinity of the detector, see Fig. 7. The EMP was measured in

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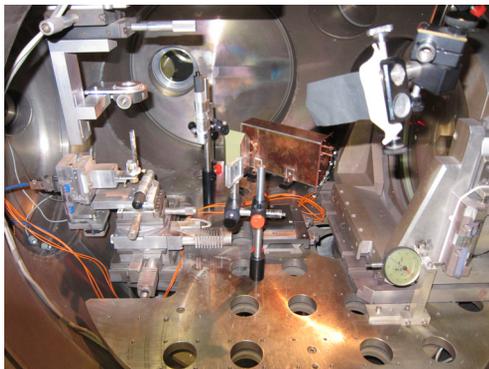


Figure 4: Experimental setup at PALS facility inside the target vacuum chamber. The PALS 700 J laser pulse is focused by the large lens on the right-hand side onto the solid target in the mount on the left hand side. In front of the Timepix copper shielded box, there is a 54 mm thick lead brick, covering half of the detector active area, as viewed from the target.

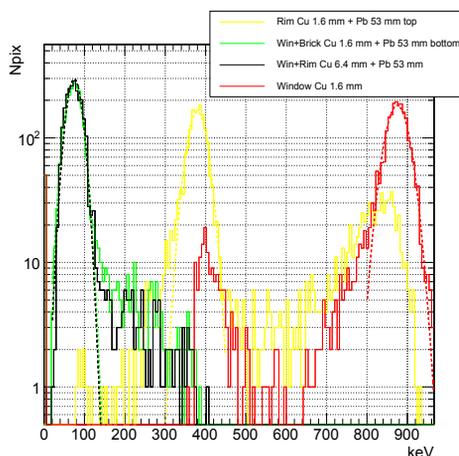


Figure 6: Energy spectra collected from areas of Timepix detector protected by various shielding materials (see the legend for details). This corresponds to detector signal presented in Fig. 5. During the shot, each pixel detected a pile-up of energy deposits from many particles. The shielded detector however survived strong radiation and electromagnetic fields (of 7 kV/m), which was the primary goal of the study.

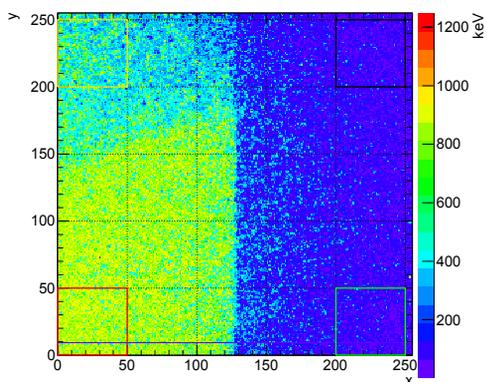


Figure 5: Signal measured by the Timepix detector during shot with laser pulse energy of 667 J. The laser pulse produced an intensive blast of neutrons, protons, ions and gammas, which were partially shielded by the lead brick (blue area on the right) and various parts of the copper detector shielding (copper window surrounded by the rounded copper ring is apparent). The colored rectangles represent areas shielded by materials described in the legend. The shielded detector withstood electric fields of 7 kV/m.

time domain with oscilloscope Tektronix TDS 2024C. The signal was attenuated by 10 m long cable and 13 db attenuator, before reaching the oscilloscope. The resulting signal is presented in Fig. 8.

In order to obtain absolute values of the EM fields, the probe (connected to the same cable and attenuator) was calibrated using wide spectral range logarithmic-periodic antenna Bilog Antenna CBL6112A, with 30 MHz - 2 GHz range, and Test Receiver Rhode&Schwarz with spectral range 9 kHz to 3 GHz. The distance between the probe,

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generating the signal, and the antenna, measuring the signal, was 1 m, corresponding to near field conditions.

Using Fourier transforms on the signal measured within the PALS vacuum chamber and applying the calibration curve of the probe, the resulting electric intensity of EMP in the vicinity of the Timepix detector is 7.6 ± 0.1 kV/m. The denoted error is statistical only. The systematic error was not quantified due to the lack of second probe, which would be needed in the near field measurements conditions.



Figure 7: The black wire loop at the top of the figure shows the antenna used for measurements of the electric fields inside the vacuum chamber. The shielding of the coaxial cable of the antenna is connected to the vacuum chamber walls.

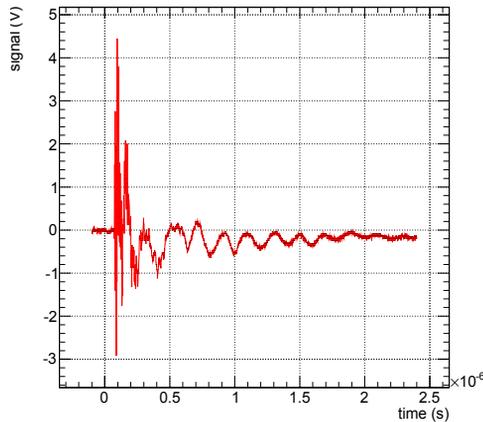


Figure 8: Uncalibrated electromagnetic field as detected by the oscilloscope after passing through 10 m long cable and 13 db attenuator. This whole chain was later calibrated to obtain absolute values of the electromagnetic fields reaching in average 7 kV/m.

CONCLUSIONS

We have presented new optics-only setup for the semiconductor Timepix detector, which enables its stable operation in electric fields of at least 7 kV/m, produced by laser pulses of 700 J and 350 ps length focused on a solid target. The previous setup with metallic cable enabled full operation of the detector only up to 10 J of laser pulse energy. The improvement is indeed significant. Moreover it is straightforward to adopt this solution to other types of detectors.

ACKNOWLEDGMENT

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