Development of a Hardened THz Energy Meter for Use on the Kilojoule-Scale, Short-Pulse OMEGA EP Laser

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Terahertz radiation occupies the frequency range between microwave and infrared radiation, making it a unique pump and probe of matter that interacts with matter in neither a purely photonic nor a bulk electronic fashion.[1–3] Because of the unique nature of THz radiation, there is a large interest in high-power sources for nonlinear time-domain spectroscopy and relativistic light–matter interactions at the extremes of low frequency;[1,3] however, the generation of such THz pulses is extremely difficult with traditional methods. Recent work with laser-plasma THz generation has shown great promise in scaling THz pulses to the terawatt and >100-mJ scale using ps, kJ-scale lasers to drive solid, liquid, or gaseous targets.[1] To maximize the THz power and pulse energy, lasers with both high energy (kJ) and high intensity (>10^{18} W/cm^2) must be used. These lasers are most commonly single shot and are well known for their immense electromagnetic pulse (EMP),[4] hard x-ray,[5] and charged-particle generation.[6] The OMEGA EP laser is especially challenging due to the peak EMP field measured being one of the highest seen on any laser (~500 kV/m) (Ref. 4). This adds to the already challenging task of THz detection due to the low efficiency (average of 0.1%) of laser THz generation in these systems. All available THz detection methods rely on electronics,[2] further compounding the EMP noise issue in these experiments.

This summary outlines the development of a ten-inch manipulator (TIM)–mounted THz energy meter, known as a THz background/energy meter (TBEM), for use on the kilojoule-class OMEGA EP laser and the associated challenges with the development of this detector. The TBEM is a broadband (0.3- to 10-THz or 1-mm to 30-μm) energy meter based on THz-sensitive pyrometers and capable of detecting broadband THz pulses as weak as ~50 μJ emitted in 4π or as strong as ~2 J emitted in 4π before suffering saturation of the detection element.

TBEM is a 112.5-cm-long, 20.9-cm-wide, TIM-mounted diagnostic weighing 33.1 kg primarily due to the inclusion of 19.8 kg of tungsten radiation shielding. As shown in Fig. 1, the diagnostic consists of a light-tight aluminum chassis with a front-mounted TPX[7] (THz and optical light transmissive) lens and filter pack extending 36.8 cm from the main body. This front lens allows for THz radiation to be collected 15 cm from target chamber center, maximizing the sensitivity of the detector. In front of the lens is a removable high-resistivity silicon wafer that acts as a THz-transmissive blast shield. The filter pack attached to the front lens can hold THz filters to alter the portion of the spectrum sampled and irises to reduce the amount of THz radiation sampled while operated in the forward position. This lens and filter assembly can also be removed and the detector operated while retracted from target chamber to further protect the electronics from EMP and radiation. A schematic of the detector and the THz transmission spectrum of the optical components can be seen in Fig. 2.

THz detection is accomplished by using commercially available nanojoule-sensitive pyrometers,[8] which are commonly used for commercial and scientific THz detection. A pyrometer is a broadband-sensitive energy meter that relies on the pyroelectric

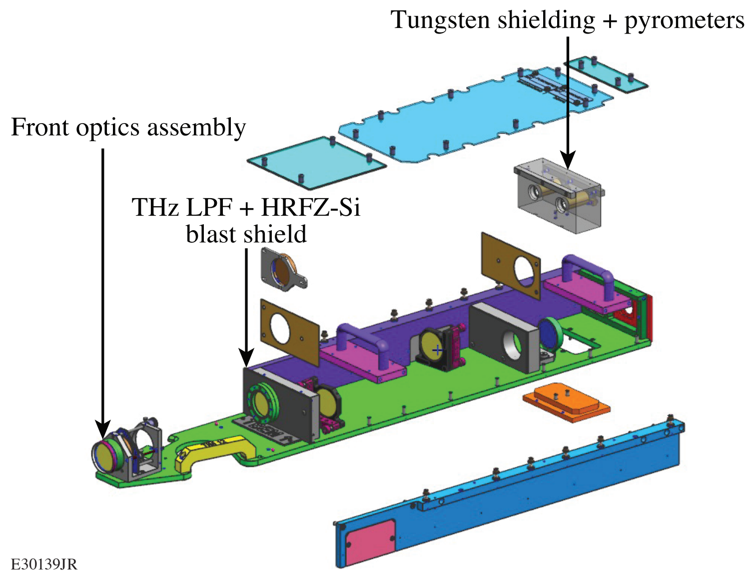

Figure 1
Expanded view of a TBEM detector assembly. LPF: low-pass filter; HRFZ: high-resistivity silicon.

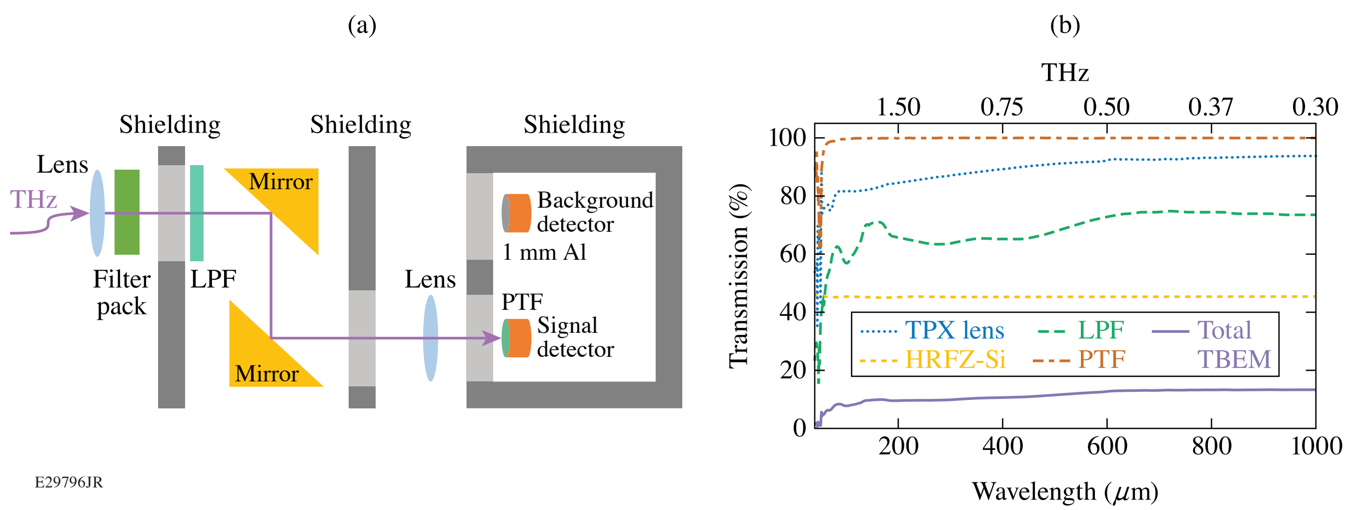

Figure 2
(a) Full optical path of the TBEM detector and (b) THz transmission of the optical components and full detector.[7,9] PTF: polytetrafluoroethylene.

effect to detect a change in energy deposition.[2,8] The sensor is built in a series of layers similar to a capacitor with two electrodes around an inner layer of pyroelectric material. One electrode is darkened to best absorb the wavelength range of interest. Upon pulsed irradiation, the pyrometer will heat up and the polarization direction in the pyroelectric material will change. A charge disparity then develops across the pyroelectric crystal, and a voltage pulse is generated that is proportional to the amount of energy deposited into the sensor.

The initial concept for TBEM was built and tested for use on the Multi-Terawatt (MTW) laser to support THz target design campaigns. The results have been extremely promising. Four campaigns were then undertaken on OMEGA EP to test the TBEM detectors with the final two campaigns showing repeatable THz detection. The first campaign did not have the full complement of radiation shielding in place and suffered from massive x-ray and EMP noise problems (Fig. 3.). The second campaign had the radiation and EMP shielding upgraded and showed more-promising results. As with MTW, it was found that using plastic target stalks reduced the noise, but in this case the reduction was not enough to observe THz signal above the background.

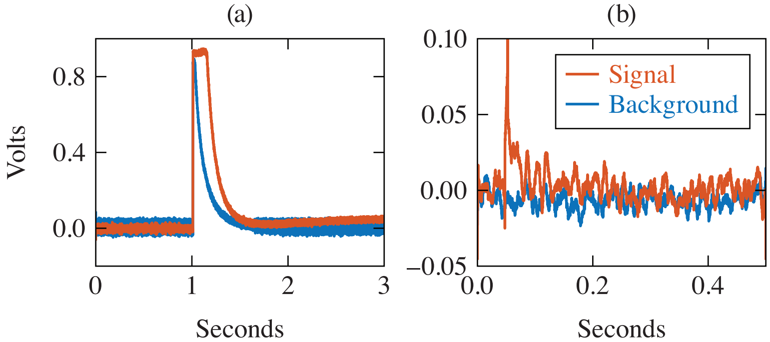

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Figure 3
Example of data taken from one TBEM on the (a) first and (b) second OMEGA EP THz campaigns with ~100 J of laser energy used (July 2021 and March 2022, respectively). EMP and x rays, caused by extremely high background noise, can be seen in (a) when there was less shielding present on the detector.

For the third and fourth campaigns, the detectors were upgraded with the full complement of tungsten shielding described above, as well as improved cable EMP shielding. THz generation was reliably detected on both foil and microchannel targets with laser energies ranging from 100 to 500 J. Example THz detections from these experiments can be seen in Fig. 4.

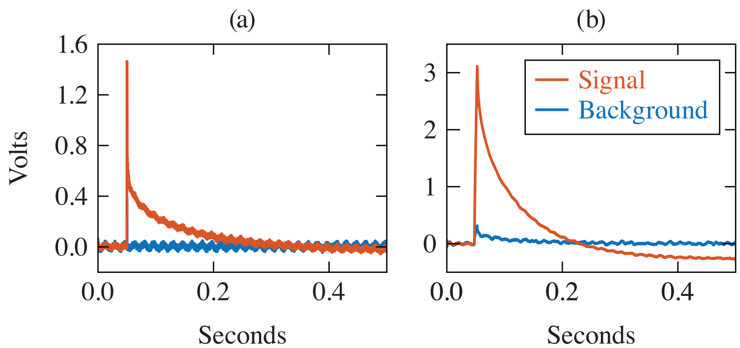

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Figure 4
Example of data taken from one TBEM on third and fourth OMEGA EP campaign (June 2022): (a) from a foil irradiated with ~100 J of laser energy and (b) from a microchannel target irradiated with ~300 J of laser energy.

The THz yields were estimated to be ~130 mJ from the foil target and ~300 mJ from the microchannel target, which are in line with the estimated generation efficiencies of these target types for the given laser energy.[1,10] The additional EMP shielding on the pyrometer wiring was found to be crucial for the most energetic laser shots.

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