# High-Power THz Sources for High-Energy-Density–Physics Applications

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## Summary


- THz radiation provides a unique probe and pump[1,2] for HED matter, but there are currently no available options at large HED facilities
- THz probes can provide measurements of dc conductivity, while THz pumps can alter the structural state of materials
- A suite of THz capabilities are being developed for use on HED and plasma-physics experiments


HED: high energy density

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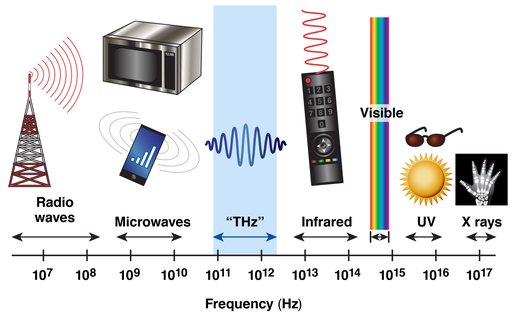
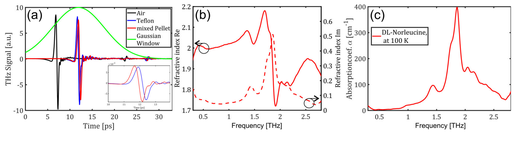
## THz Radiation

- THz radiation typically referrers to electromagnetic radiation that lies between 0.1 and 10 THz[1]




- THz radiation is considered "quasi-optical" and can act in ways similar to both microwaves and optical light[1]
- THz is currently used as a powerful diagnostic for materials science via time-domain spectroscopy (TDS)[1]
- THz-TDS is used for dc measurements of conductivity, a non-contact temperature probe, and a method of identifying chemical structures *in situ*[1]

### Example THz-TDS Measurement of an Amino Acid




J. Neu and C. A. Schmuttenmaer, J. Appl. Phys. 124, 231101 (2018).

- These measurements provide unique measurements into HED materials[1,3,4]
- Powerful THz sources have recently been developed that can drive nonlinear phenomena in materials[2,5]
- None of these unique sources or detectors are available at the Laboratory for Laser Energetics

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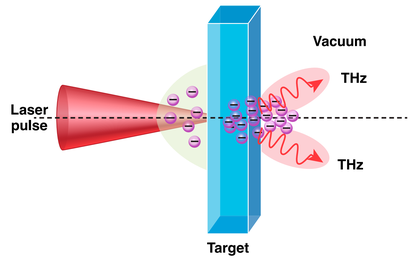
## OMEGA EP THz Source

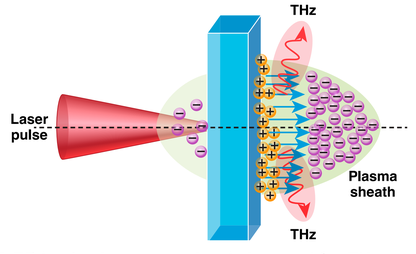
Comparison of THz Sources[2]

| THz generation source | Peak power (GW) |
|---|---|
| Nonlinear crystal | 5 |
| Particle accelerator | 1.5 |
| Air plasma | 1 |
| Metal foil plasma | 36 |
| OMEGA EP metal foil plasma | ~700 |

- Recent experiments have shown that high-intensity laser irradiation of thin foils can generate THz radiation with ~0.1% efficiency[2,5]
  - recent experiments on the Vulcan laser generated ~50 mJ of THz radiation in a single cycle pulse[2,5]
- The mechanism of generation is two part
  - coherent transition radiation (CTR) is generated when hot electrons exit the target foil




  - incoherent THz radiation is then generated when the electrons are attracted toward the foil and oscillate




- OMEGA EP in short-pulse mode will be used for THz generation in July of 2021
  - the estimated peak yield is ~500 mJ of THz radiation, making OMEGA EP the strongest source of THz radiation available
  - the target material, target pulse length, and laser intensity will all be varied to better optimize the generation of THz radiation
  - preliminary experiments will be carried out on the MTW laser to better determine target design
  - intensity and energy scans will also be performed on MTW to fully study THz source scaling

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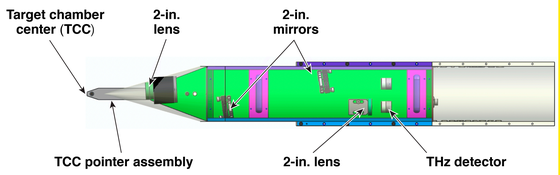
## THz Diagnostic Development

- Two separate THz diagnostics are under development to support future THz campaigns

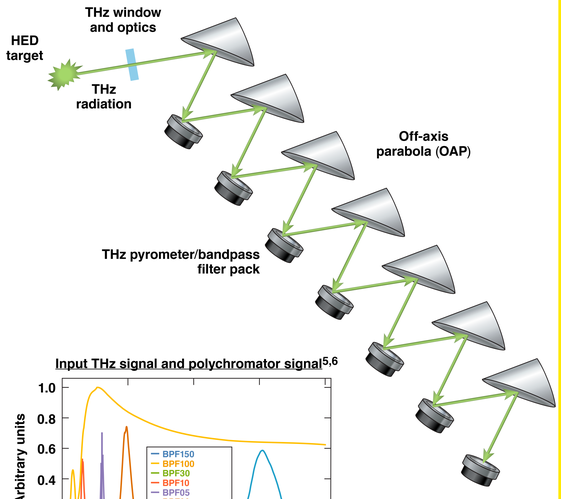
THz Background/Energy Meter

- The first step in developing THz radiation capabilities will be to measure the broadband THz background during laser compression experiments and act as an energy meter for THz source development
- The detector utilizes a THz sensitive pyrometer behind a series of mirrors, filters, and radiation shields to ensure that only THz radiation impacts the detector
  - it will be able to detect broadband sources with 4$\pi$ emission as low as ~40 $\mu$J with options to go lower




THz Polychromator

- A polychromator using multiple bandpass filters and the same THz pyrometers to provide rough spectral information is also in development
- The polychromator will sample the spectrum at seven points in the current design




Input THz signal and polychromator signal[5,6]

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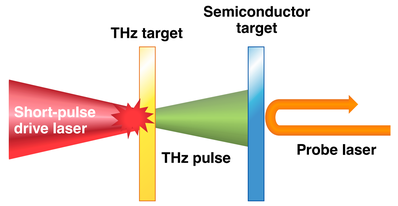
## Future Plans

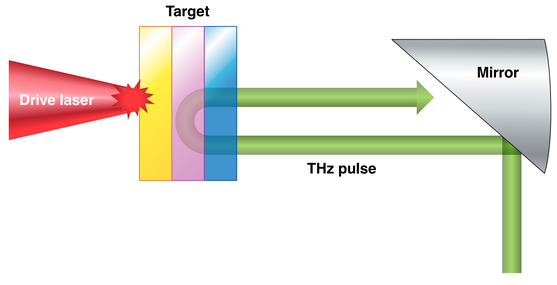
- Driving targets with high-intensity THz radiation
  - high-intensity, short-pulse THz radiation can provide quasi-static dc fields in excess of 100 MV/cm onto targets[2,5]
  - these extreme fields can drive matter into unique states and efficiently accelerate charged particles

High-Power THz




- Develop a THz-TDS system on OMEGA EP[3,4]
  - single shot THz-TDS has already been shown
  - commercial THz-TDS systems are available and meet the specifications needed to perform THz-TDS on relevant time scales for HED experiments[6]
  - coupling to OMEGA EP will require precise co-timing

THz-TDS

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## References


[1] Y.-S. Lee, *Principles of Terahertz Science and Technology* (Springer US, Boston, MA, 2009).

[2] G. Liao *et al.*, Proc. Natl. Acad. Sci. 116, 3994 (2019).

[3] G. T. Noe *et al.*, Opt. Express 24, 30,328 (2016).

[4] Kim, K., Yellampalle, B., Glownia, J., Taylor, A. and Rodriguez, G., 2008. Measurements of Terahertz Electrical Conductivity of Intense Laser-Heated Dense Aluminum Plasmas. Physical Review Letters, 100(13).

[5] S. Herzer *et al.*, New J. Phys. 20, 063019 (2018).

[6] https://www.tydexoptics.com


E29223

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