THz Beam Measurement
A Practical Primer

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Outline

• THz Range available to the user
  – Wavelengths and Frequencies
• Tools to Image THz beams
• Optics- Type and Sources
• Cameras and Other Sensors
• Results
What is the THz Band?

300 GHz (1000 um) to 30 THz (10 um)

Courtesy- Advanced Light Source-Berkeley, CA
Measurement is Key to Success

If You Cannot Measure it, You Cannot Control it

“If you can't describe what you are doing as a process, you don't know what you're doing.”

W. Edwards Deming (1900-1993)
How is THz measured?

- **Single element detectors- Pyroelectric**
  - Acceptable for the Wavelength/Frequency Range
  - Does not yield any information about spatial energy

- **Array detectors-Pyroelectric or Bolometer**
  - Pyroelectric- more stable-larger pixels (100 µm)
  - Microbolometer- less stable-smaller pixels (25 µm)

- **Power/Energy meter**
  - Only displays power or energy
Simple Block Diagram for Measurement
THz Detectors

• Pyroelectric
  – Based on LiTaO$_3$ crystal

• Can be single element or array
  – Array has 124 x 124 100 um pixels
  – Up to 100 images per second
  – Sensitivity is 2.2 µw/cm$^2$ or 70 µJ/cm$^2$

• Good Response across entire ban
Microbolometers

- Generally Ferroelectric or Vanadium Oxide
- Not as stable baseline as Pyroelectric
- Sensitive to environmental temperature changes
- Smaller Pixels (25 µm) than Pyroelectric (100 µm)
Optics- The Missing Link

• For imaging **sources**, optics not necessary
  – UNLESS- beam is too big for array

• For imaging scatter from **target**, optics are required
  – Same as in photography

• Optics have different characteristics
  – Polyethylene, Picarin* & Silicon most popular
    *Microtech Instruments, Inc.
Optics- Characteristics

Polyethylene

- Offers the best performance at frequencies below 1 THz and above 7 THz
- Not transparent in visible and near-IR
- Polymer not hard like glass optics- has variations- may cause aberrations in imaging
  - Available in 2” (50 mm) diameter biconvex or spherical 60 mm focal length
Optics- Characteristics

• Polished Tsurupica (Picarin)
  – Tsurupica is highly transparent in THz and visible spectral ranges
  – Refractive index of Tsurupica is the same for THz and visible light (n=1.52)
    – Available as Plano-convex, aspheric, Bi-convex, and spherical in 30 and 45 mm sizes, with focal lengths from 50-180mm (other focal lengths available on order)
Silicon Lens

- Silicon Lenses
  - “Harder” than polymer lenses
  - Can be machined to better tolerances
  - High purity Si results in less Aberrations
  - Very High Refractive Index in THz region results in losses & possible internal reflections
Other Optics

- Gold-coated parabolic, ellipsoidal or toroidal mirrors
- For beam sizing – not imaging, (unless they are spherical)
- Off–axis paraboloids most common and easiest to use
- Relatively inexpensive
Imaging Results

- Typical set up including Polarizer
- Beam Image

Courtesy - Thomas Jefferson National Accelerator Facility
THz Beam Profile Near a Focus

Measured

Calculated

Courtesy- Thomas Jefferson National Accelerator Facility
Frequently Asked Question:

- Q: So, how DOES a Bolometer measure THz energy, when its bandwidth ends much lower?
- A: Bolometers are thermal sensors
  - Any photons absorbed will produce temperature rise and thus a signal.
  - Absorption efficiency at long wavelengths not great for VOx microbolometer arrays, but is definitely higher than PY III.
  - Drawback - pixel size is well below the diffraction limit in THz spectrum
Summary

• Imaging THz SOURCES is well understood, and can be done with pyroelectric cameras.

• Imaging of TARGETS can be done by bolometers, providing care is taken when using them.

• Because human eye responds logarithmically, they are acceptable for image interpretation.
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