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White Paper: The T-camera

The principle of operation of T-camera is based on the property of thermochromic liquid crystals (TLC) to change color when heated. The molecular structure of TLC changes with temperature, producing a change in the material's optical properties hence, by imaging the TLC surface with a color video camera one can determine the temperature map of the surface (see Figure 1).

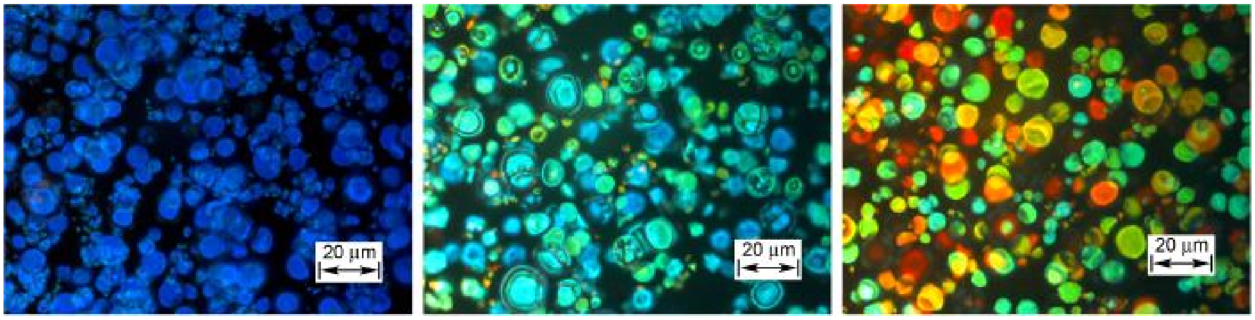

Figure 1: Change in encapsulated TLC molecules color with temperature.

TLC materials have been in use as a CO_2 laser diagnostics for decades, but as a very rough gauge of laser beam position, not as a user friendly or calibrated tool. Inspired by the use of the TLC sheets as an alignment tool at the Accelerator Test Facility (ATF) at Brookhaven National Laboratory, RadiaBeam decided to develop the T-camera as a fully featured, broadband beam profiler. The prototype development was funded by an NSF SBIR grant. The latest version is pictured in Figure 2.

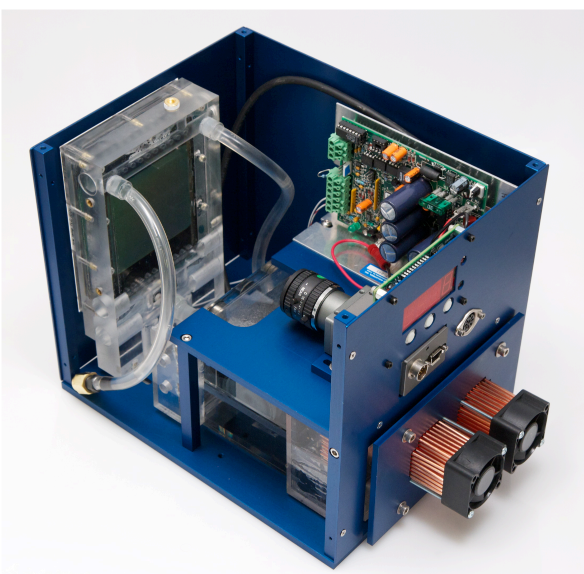

Figure 2: A photograph of the latest version of the T-camera prototype, with cover removed.

Table 1: T-camera Specifications

Parameter	**Value**
Wavelength Range	0.5 µm - 500 µm
Spatial Resolution	250 µm
Active Area	5x4 cm (20 cm^2)
Sensitivity	100 µJ/cm^2 @ λ=120 µm
Footprint	20x25 cm
Resolution	250 µm; 200x160 pix
Dynamic Range	6 bit
External Trigger	Yes (CCD)
Rep. Rate	up to 10 Hz
Control Interface	IEEE 1394

The T-camera prototype specifications are presented in Table 1. Since the TLC response is purely thermal, there is no fundamental limitation on the wavelength range in which the T-camera is sensitive, and the very same device can be used to image radiation beams in a very broad spectral range, depending only on the limits of the absorber attached to the TLC sheet.

Thus, the T-camera can image from millimeter range to UV. Our intended primary application for the T-camera, however, is imaging of FIR, sub-millimeter and millimeter wave sources, since sensitive and inexpensive solid state detectors already exist in the visible to UV range. The main features of T-camera differentiating it from the state-of-the-art pyroelectric viewers optimized for the same spectral range are:

- High sensitivity in a pulse regime;
- Large field of view (FOV);
- Inexpensive, easily replaceable components.

The input radiation beam is delivered towards the sensitive layer, which is a thin absorptive material on which a TLC sheet is attached. The other side of the sensitive layer is attached to a thermally stabilized transparent water chamber that allows for back-view geometry. A computer controlled system is used to maintain the temperature within the range where a particular TLC material exhibits the strongest optical response to a minimal change in temperature. By imaging the illuminated TLC sheet with the CCD camera, one can obtain a transverse profile of the incoming radiation beam (see Figures 3 and 4).

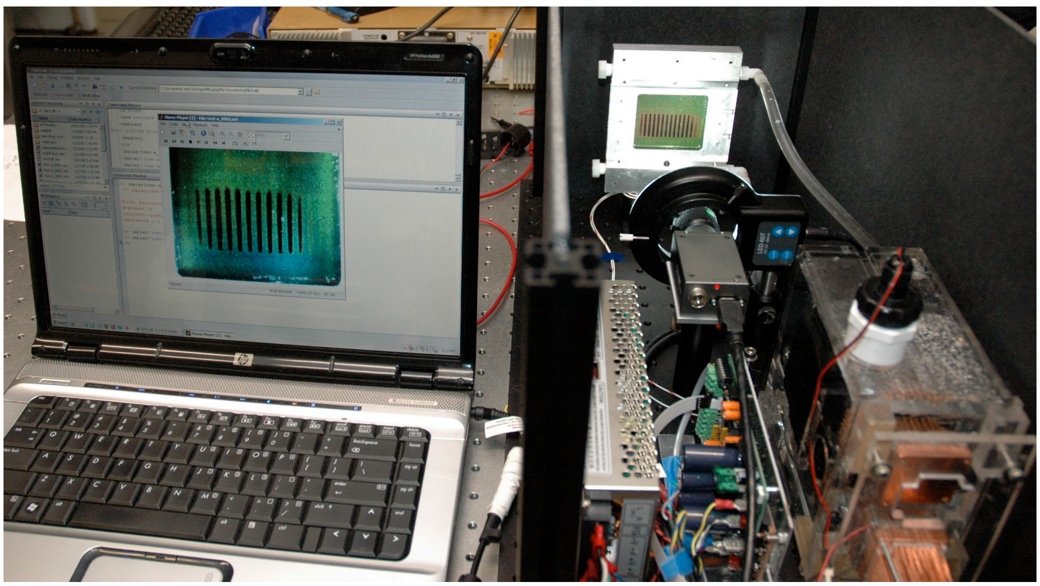

Figure 3: T-camera beta prototype with some parts removed for clarity. A thermal image is visible on a large TLC (thermochromic liquid crystal) layer. Note that the current prototype is much more compact (see Figure 2 above).

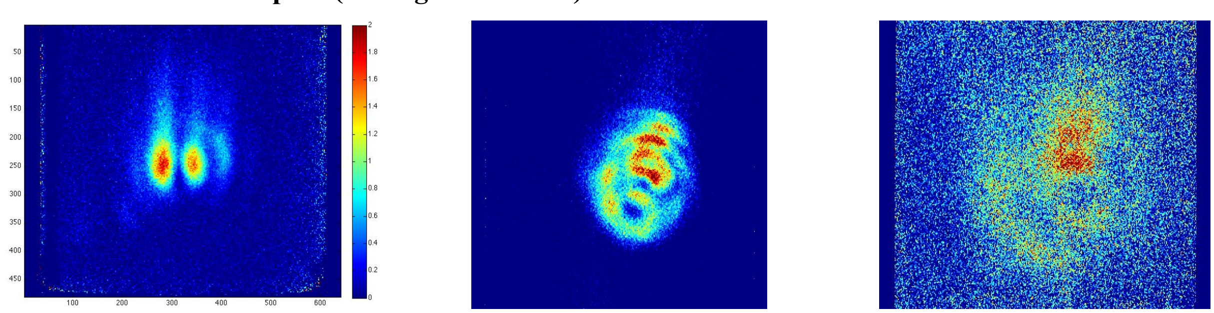

Figure 4: T-camera images of different THz sources. Left: the UCLA CW THz source (15 mW, 112μ). Middle and right: UCSB FEL-based pulsed THz source (middle: 116.5μ, 2.9mJ, 16μs; right 196μ, 3.3mJ, 12 μs).

The observation of the change in color on the TLC layer of the sensor element is performed with a color CCD camera. The camera currently used was chosen for its small footprint and its IEEE 1394 interface (compatible with most computers for ease in image acquisition).

To properly interpret and manipulate the image as well as to control the temperature stabilization of the camera, proprietary image analysis and camera control software was developed at RadiaBeam. The RGB image is converted to hue, saturation, intensity (HSI) space. The saturation and intensity channels are discarded and only the hue is converted to temperature; this requires the camera specific calibration polynomial to executed. Each hue pixel is passed through the calibration polynomial to obtain the temperature. This sophisticated image processing along with ultra high temperature stabilization allows for sensitivity enhancement of two orders of magnitude or more; making this product extremely competitive in the THz detector market. Other features include background subtraction, artificial high/low frequency noise filters, and gamma, gain, black level adjustments. The image extraction and analysis software is self-contained, uses a user-friendly graphical user interface, and has cross-platform compatibility, see Figure 5.

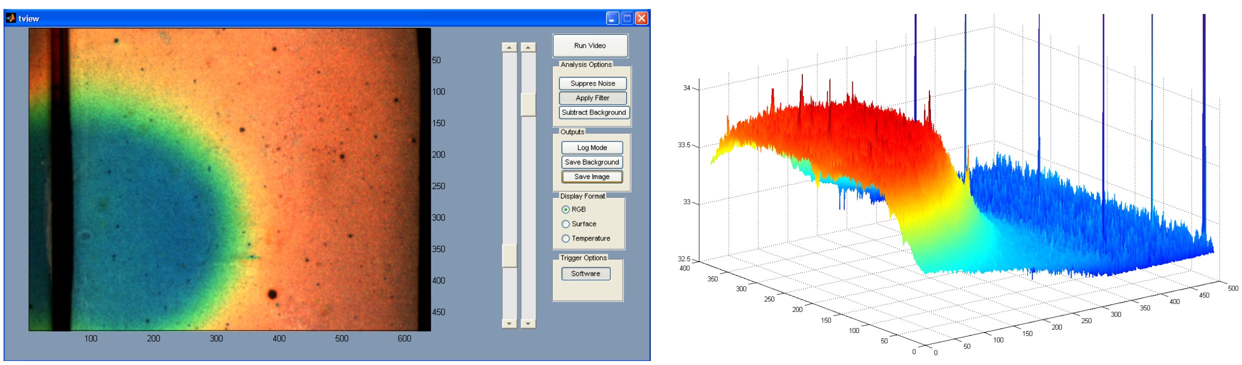

Figure 5: Left: Screenshot of GUI developed for T-camera. The GUI controls both image processing as well as Temperature Feedback of the system. Right: 3D intensity plot from the Image acquisition software (part of GUI). Spurious spikes are artifacts of Hue in image and can be accounted for (subtracted) in data analysis.

A new version of the T-cam has been recently developed and demonstrated at IRMMW-THz 2010 conference. The new version of the T-cam was designed to be more compact and user friendly as well as more thermally stable, see Figure 5. RadiaBeam is continuing development and working to further improve the design, which includes even greater size reduction, component optimization and extensive thermal simulation.

For more information about the T-camera, please contact RadiaBeam's President:

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