

TERAHERTZ CAMERA DEVELOPMENT STATUS*

R. Tikhoplav[#], G. Travish, UCLA, Los Angeles, CA 90095

G. Andonian, A. Murokh, M. Ruelas, RadiaBeam Technologies, Marina del Ray, CA 90292

T. Shaftan, V. Solovyov, BNL, Upton, NY 11973

Abstract

We describe our effort in the development of a low cost, wide-band detector/camera for generation of spatially resolved images of radiation beams in a multi-spectral range of wavelengths, from IR (infrared) to THz (terahertz). The detector (T-camera) utilizes a TLC (thermochromic liquid crystal) film as the sensitive element in a temperature controlled chamber and a CCD detector array and can be used as a powerful diagnostic for terahertz sources such as a synchrotron or an FEL.

INTRODUCTION

During the last decade there has been tremendous progress in the field of THz science. The previously unexploited "THz gap" of the electromagnetic spectrum, which includes far infrared (FIR) and sub-millimeter waves, was actively explored through developments of new sources, detectors and technologies [1]. The possibility of practical applications of THz radiation became apparent in many areas ranging from far-infrared astronomy and time-resolved THz spectroscopy [2] to skin cancer diagnostics [3], and other medical applications as well as detection of explosives and biohazards [4]. With the development of synchrotron sources spanning over a wide range of wavelengths as well as tunable FIR free-electron lasers [5], THz camera (T-cameraTM) becomes an important tool to cover sub-millimeter range of the radiation spectrum.

Even though there exist detectors of THz radiation, they are complicated units produced in small quantities, that require sophisticated handling, and are generally very expensive. A good example of such a device is the liquid He cooled bolometer [6]: which is large, fragile, time-consuming to operate, not very friendly to ESH policies and pricy. T-cameraTM, on the other hand, offers a number of attractive features such as low cost, portable, fast, works in different laboratory conditions, large active area, no other THz diagnostics at this price has.

T-CAMERA PRINCIPLE OF OPERATION

The principle of operation of T-cameraTM is based on the property of thermochromic liquid crystal (TLC) to change its 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.

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[#] rodion@ucla.edu

The TLC materials have been in use as a CO₂ laser diagnostics for decades, but not as a user friendly or calibrated tool, but rather as a very rough gauge of laser beam position. The idea of T-camera has originated at the Accelerator Test Facility (ATF) at Brookhaven National Laboratory in 2001 [7], where a Peltier cooled TLC sheet coupled with CCD camera were successfully utilized to co-align a red alignment laser and 10.6 μm CO₂ beams at ATF for the high gain harmonic generation (HG) experiment [8]. That work was a foundation to the present

Table 1: T-camera Specifications

Parameter	Value
Wavelength range	10 μ -500 μ
Spatial Resolution	100 μ
Active Area	25 cm ²
Sensitivity	50 mW/cm ²

efforts at RadiaBeam Technologies to develop T-camera imaging device commercially. The main features of T-camera differentiating it from the state-of-the-art pyroelectric viewers are high dynamic range, large field of view (FOV), and inexpensive, easily replaceable components.



Figure 1: CAD drawing of target holder with redesigned lighting fixture. Two LED bars are located at each side of the holder (in green).

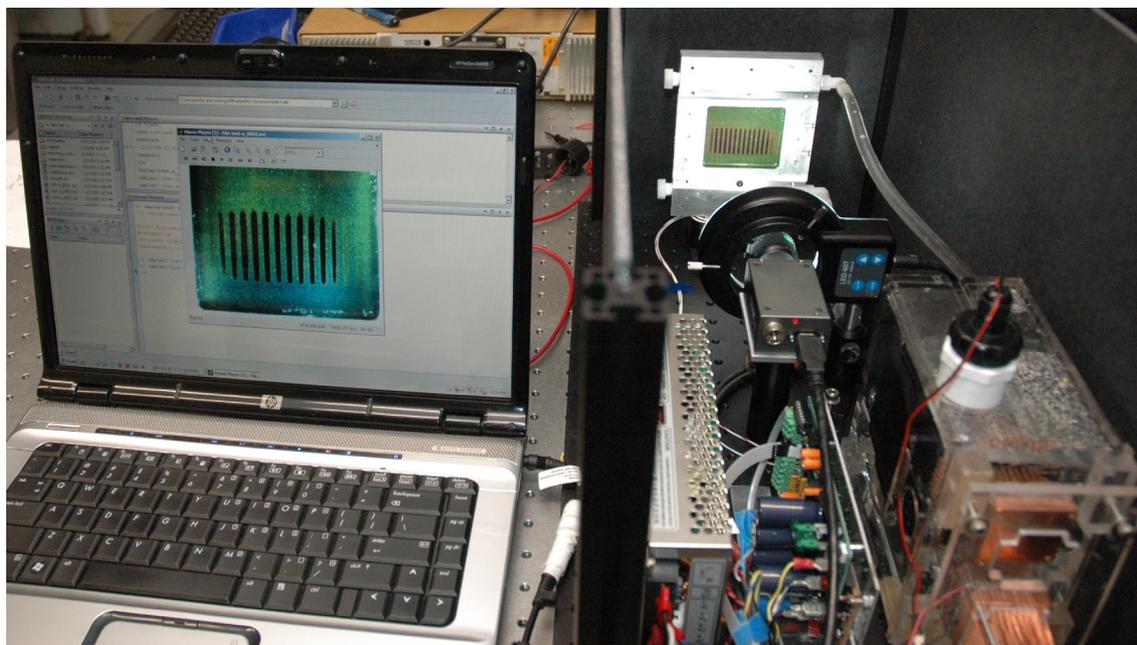


Figure 2: T-camera beta prototype with some parts removed for clarity. A thermal image is visible on a large TLC (thermochromic liquid crystal) layer.

The T-camera specifications are presented in Table 1. Since the TLC response is purely thermal, there is no fundamental limitation on the wavelength range to 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 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.

Through the imaging of the illuminated TLC sheet onto the CCD camera one can obtain a transverse profile of the incoming radiation beam, see Figure 2.

RECENT DEVELOPMENTS

Lighting Fixture and Holder Design

Initial T-camera designs were negatively affected by the lighting scheme. The lighting fixture has been redesigned due to the blinding effect of the LED lighting ring being reflected off the acrylic cover of the TLC sensor into the CCD camera. The new lighting configuration includes positioning of the LED bars next to

the TLC sensor holder and feeding the light through the sides of the acrylic cover of the TLC sensor: the light gets trapped inside the water layer/acrylic cover due to the similar values of their refractive indices, and then, it gets scattered only by TLC, thus negating any blinding effects (Figure 1).

Enclosure Construction

One of the main objectives in T-camera development is user operability. To make the camera more user-friendly, the back panel has been re-designed to better meet specifications set by potential customers/beta-testers.

All power supplies for individual components (CCD, illumination fixture, water pump, cooler/heater) have been consolidated inside the camera enclosure for compactness, optimal power management and combined computer control. Extra care is taken to thermally isolate the TLC sensor element from the power supply. Our goal is to control the TLC temperature to within 0.1°C . Since one side of the active layer is exposed to water, and the other side to air, both must be controlled. The power supply and electronics have been thermally isolated from the active layer. Additionally, the external enclosure walls are thermally insulated to help maintain stable temperature.

Active stabilization of ambient air in the enclosure has proven to be unneeded because this air stabilizes to the temperature of the water reservoir. The entire detector with all its elements is incorporated onto a custom optical breadboard for compactness and future on-site testing.

Image Processing, DAQ and GUI

The GUI software acquisition speed was further increased. The MatLab modular executable was optimized

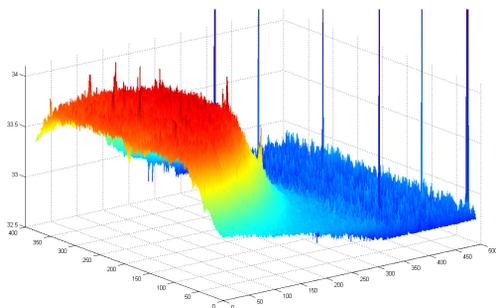
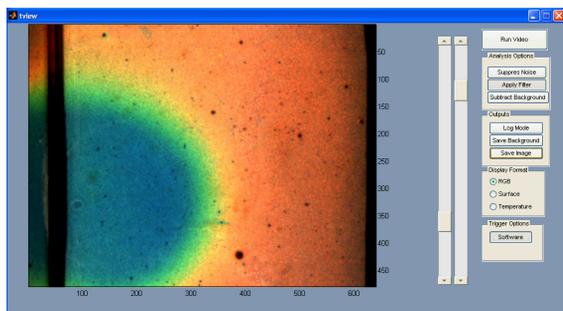


Figure 3: Screenshot of GUI developed for T-camera (top). 3D intensity plot from the Image acquisition software, part of GUI (bottom). The GUI controls both image processing as well as Temperature Feedback of the system. It also includes a calibration algorithm operable for different TLC targets.

to allow up to 80 frames per second (fps) image acquisition speed (currently limited by the firewire bus to 40 fps at full resolution). A real-time image processing speed (the GUI acquires, analyzes and displays temperature maps) at 640x480 resolution is currently limited to ~20 fps, due to computer CPU hardware limitations, see Figure 3. Considering that the TLC color-temperature relation currently uses a 10th order polynomial for accurate modeling, the obtained speed has proven acceptable. However, a spline interpolation model is being investigated to further enhance acquisition speed.

Remote control of the TLC temperature is now possible via a separate GUI. The GUI allows remote monitoring and setting of the TLC temperature (as noted above, this functionality is also available at the rear panel of the T-camera). Use of the T-camera in environments with differing temperature stability (a controlled lab versus near an air conditioner vent) requires different PID parameters to maximize stability and response to outside sources. Therefore, the temperature control GUI also allows the user to switch between pre-determined PID parameters to match their environment.

Future Testing

The T-camera beta-prototype is in its final stage of development and is almost ready to be shipped out for beta-testing after finalizing the TLC absorption layer. The potential users are Jefferson National Accelerator Facility

and UCSB FEL. After beta-testing is complete, the camera will be optimized according to the beta-testers' recommendations. We expect a number of issues to be clarified including temperature stability, sensitivity, user-friendliness and life expectancy. The enclosure will be optimized for durability and compactness (an approximate 50% reduction in volume).

CONCLUSION

The imaging device operating in sub-millimeter range (T-camera) is at its final stage of development and is almost ready to be beta-tested. A number of upgrades have been successfully implemented including both hardware (lighting and enclosure design) and software (data acquisition). T-cameratm will provide a diagnostic to FIR-THz community that is compact, inexpensive, has a large active area and sensitive.

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