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Introduction to Liquid Crystal Thermography

By

Kaveh Azar, Ph.D.

Advanced Thermal Solutions, Inc.

Overview

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- Liquid Crystal Thermography in a Nutshell
- Define Terms
- Why Measure Temperature in Electronics Systems
- Options for Temperature Measurement
- Liquid Crystal Thermography— an In-depth Look

Liquid Crystal Thermography (LCT) in a Nutshell

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***Nutshell*— LCT correlates the color response of a heat surface treated with Thermochromic Liquid Crystal (TLC) to temperature.**

What are Thermochromic Liquid Crystals-

Thermochromic Liquid Crystals (TLC) are materials that change their reflected color as a function of temperature when illuminated by white light. Hence, reflect visible light at a different wavelengths.

Thermochromic → **Thermo- Temperature**

Thermochromic → **Chromic- Color**

Liquid Crystal Thermography (LCT) in a Nutshell

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Simplest Implementation— household temperature indicator

Process:

- A heated surface
- A liquid crystal with a known color-to-temperature response

Example

Fish-tank thermometers, Mood rings, Color sensitive coffee cup, etc.!

Advance Implementation—Research quality thermograph

- A heated surface
- Calibration facility for temperature/color response
- Image acquisition and software for image analysis

Example

thermVIEW™ system, a high resolution thermography system.

Terms Defined

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Electronics Packaging Hierarchy

Term	Description	Industry
System Enclosure Chassis Bay/Frame	A box housing the electronic circuitry. It can be made of plastic, metals and alloys, depending upon its application.	General Computer, consumer electronics Computer and consumer Telecomm
Board Circuit Board PCB Circuit Card Circuit Pack	The board that houses the electronic components (modules). This is where the functionality takes place.	General General General—most commonly used across the industry Computer--Telecomm
Back Plane Mother Board	The board where the PCBs attach.	Telecomm Computer
Component Module Chip Device	The package that contains the chip… location that the first level of operations take place.	General Computer General – a misnomer General
Die Chip Silicon	The package (typically silicon) that houses the parts. The hottest area on the die is typically referred to as the "junction."	General
Parts	Electrical and semiconductor components such as resistors, capacitors, transistors, etc. that provide the electrical functionality. In reality, the temperature of a hottest part is the true "junction" temperature.	General

Why Measure Temperature in Electronic Systems?

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Temperature and reliability are synonymous—

- Cooler devices imply better electrical operation and a longer expected life.

Electrical Operation —

- Semiconductor device operation experiences degradation at higher temperatures.

Reliability —

- Hard failures (fuse like breakage) occur at high temperature
- Material migration at the chip and component levels occurs at higher temperature which can cause shorts and substrate cracking.
- Activation energy (associated with the rate of failure) is exponentially dependent on temperature.

Monetary—

- According to AMD – a 1°C temperature reduction corresponds to $224 of savings (1988 dollars)

Where Should We Measure Temperature?

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Element	Location	Why Measure
System	On the boundaries	Safety Material selection for coating Thermal design – boundary condition
Board	On the glass-epoxy, typically in the vicinity of the hot or critical component.	Thermal analysis— Junction temperature calculation. Determination of thermal coupling between components on the board.
Component	On the component top surface, leads and at the location where the lead is attached to the board.	Thermal analysis— Junction temperature calculation Thermal characterization— Determination of thermal resistance (junction-to-case or case-to-board).
Chip	On the surface of the die and the surrounding area on the chip carrier.	Junction temperature determination—for evaluating reliability and operational integrity.

Sensors for Temperature Measurement

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Transducer or Probe	Temperature Sensitive Parameter	Contact Method	Remarks
Resistor	Electrical resistance or voltage at constant current	Direct contact	Useful as a "point" sensor.
Thermocouple	Open circuit voltage	Direct contact	Useful as a "point" sensor.
Diode or transistor	Voltage, usually with constant forward bias current	Direct contact	Usually employed to measure an active device or IC temperature.
Infrared or radiation	Detector voltage	Line-of-site or optical contact	Yields a temperature map or image but not strictly qualitative unless sample emittance (emissivity) is known at all image points.
Fluorescent detector	Detector voltage	Direct contact (proximity)	Approximate point detector, contact resistance a problem.
Liquid crystal	Color	Direct contact	Yields a temperature map, semi-quantitative unless a detailed calibration is performed.
Temperature sensitive paint	Color	Direct contact	Yields event temperature.

Sensor Application in Electronics Temperature Measurement

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Location	Resistor	Thermo-couple	Diode/ Transistor	Infrared	Fluore-scent	Liquid Crystal	Paint
System	Spot only, (useful for gas and solid).	Spot only (useful for gas and solids).	Transistor	Full system	N/A	Most desirable for spot. Can be used for full system (not practical).	Spot only
Board	Spot only	Spot only	N/A	Full board, must know emissivity, thus treat surface with an agent.	N/A... Possible spot measurement	Full board, paint board with black ink and LC	N/A
Component	Spot only	Spot only	N/A	Full component, must know emissivity,	Can be used for spot meas.. Though not a practical approach.	Full component. paint it with black ink and LC	For event temp. Not useful for dynamic tests.
Chip/Part	Maybe.. Die attachment an issue as well as the size and mechanical contact.	Maybe.. Die attachment is an issue	Yields spot measurement.Useful only when embedded	Can be used for chip/part measurement. The constraints are on spatial resolution.	Used for die temperature measurement, mechanical contact is an issue	Ideal for die and part meas.	For event temp. Not useful for dynamic tests.

Comparison of LCT and IR Systems

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Sophistication Level of Measurement	Infrared (IR)	Liquid Crystal (LC)	IR vs LC (n = IR/LC)
System-- Cursory	Full system	Most desirable for spot. Can be used for full system (not practical).	n = 3, can be used readily for temperature mapping. Useful for hotspot information, unless surface emissivity is known.
Board -- Evaluation	Full board, must know emissivity, thus treat surface with an agent (black paint or powder)	Full board, must paint the board with black ink and liquid crystal.	n = 1.5, can used readily for temperature mapping. Useful for hotspot information, unless surface emissivity is known.
Component -- Evaluation and analysis	Full component, must know emissivity, thus treat surface with an agent (black paint or powder)	Full component. must paint the board with black ink and liquid crystal.	n = 1, both systems are capable of this measurement. However, LC can provide a more accurate number, but IR time-to-measurement is shorter.
Chip/part -- Research quality	Can be used for chip/part measurement. The constraints are on emissivity, spatial resolution (max is 5 micron) and temperature averaging in the field of view.	Ideal for die and part measurements. Must treat the surface with paint and LC. Capable of measuring down to 1 micron.	n = 0.1, this is a sophisticated measurement. IR tends to be inaccurate or very costly in this domain. LC provides a clear advantage, while yielding more accurate results.

Liquid Crystal Thermography

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1- How Does LCT Work?

2- Liquid Crystals

3- Why Do You Need a System

4- *thermVIEW*™ System Components

5- Measurement Process

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How Does LCT work?

The following steps are taken when measuring surface temperature with an LCT system

a. Select the optics suitable for the spatial resolution required.
b. Select the appropriate liquid crystal and calibrate it.
c. Coat the test specimen with black paint.
d. Spray the test specimen with liquid crystal.
e. Apply power to the test specimen and start the measurement.

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What are thermochromic liquid crystals (TLC)?

- Thermochromic Liquid Crystals (TLC) are materials that change their reflected color as a function of temperature when illuminated by white light.

How are they Designated?

- Two color/temperature are used for specifying a given LC.

Example:

- R40C5W , implies, activation (red color) temperature at 40°C, a 5W implies start of Blue at 5°C above Red.
- 5W can be a crude estimate of bandwidth of the liquid crystal-- i.e., a 40 to 45°C compound. Beyond the rated range the material will not exhibit any colors to the naked eye.

What is a narrow-band LC

- When the LC formulation is below 2°C.

Example:

- 25C2W: implies a 25 to 27 °C compound, with red starting at 25 °C and blue starting at 27 °C.

Liquid Crystal Thermography

Liquid Crystal Types-

- *Encapsulated* — the liquid crystal material is encapsulated in a 5-10 micron sphere suspended in a water based binder material-- provides excellent protection.
- *Unencapsulated* — the material is in its native form-- susceptible to contamination, however, once applied, produces brilliant colors.

Temperature Range

- LCs are available from -30 ^{o}C to 120 ^{o}C, and bandwidths from 0.1 ^{o}C to 30 ^{o}C. With a LCT system, the range is expanded to 180 ^{o}C.

Why Need a System?

- Cursory measurement can be done by visual observations.
- Scientific measurement requires the Color/Temperature relationship.
- To measure with LC, one must know the relationship between temperature and color response (calibration).

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Temperature color relationship

T(C)	Red	Green	Blue	Hue	Saturation	Intensity
39.9	107.881	115.662	93.13	81.92725	30.02203	105.5577
40.2	97.013	194.411	73.189	137.7078	101.4411	121.5377
40.3	82.043	195.849	82.042	138.7264	80.62878	119.9767
40.4	77.524	183.403	103.029	129.9105	92.05212	121.3187
40.5	76.838	167.748	126.139	118.8215	96.44293	123.575
40.6	77.547	152.984	149.791	108.3637	99.01782	126.774
40.7	78.146	143.139	161.472	101.3901	98.81294	127.585
40.8	79.067	132.841	175.107	94.09571	98.71083	129.005
40.9	80.288	119.712	188.993	84.796	97.10431	129.664

A temperature, 39.9 ºC, is recognized by a system with RGB values as 107.9, 115.7 and 93.1. Hence, for qualitative measurement, a system is required to translate the RGB values into actual temperature.

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Measurement Process

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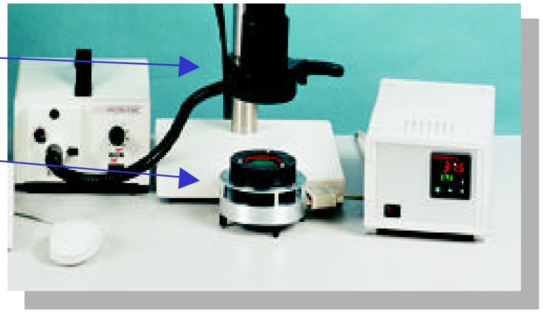
Calibration

- Apply the TLC to a clean surface.
- Subject the treated surface to known temperature levels.
- Measure and record the color response of the TLC.

Requirement

- Uniform light source on the specimen
- Isothermal calibration surface



Note:

This step is analogous to calibrating the voltage-temperature response of a thermocouple.

Liquid Crystal Thermography

Measurement Process

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Specimen preparation

- To ensure good measurement, the goal is to have a smooth and contaminant free calibration and the test specimen surfaces.
- Results are brilliant colors and accurate measurement.

Preparation Process

- Clean calibration and the test specimen surfaces (if possible) with alcohol and ensure that surfaces are dry.
- Apply a “thin and uniform” coat of black paint to the test specimen and the calibration surface (place them side by side).
- Dry the surfaces with a hot air gun at a mild temperature.
- Spray or apply the desired TLC material to both surfaces simultaneously.

Liquid Crystal Thermography

Measurement Process

Lighting and Light Source

- A bright and stable white light source is required to obtain accurate and reliable reflected light intensity from a TLC coated surface.
- The light source must be void of infrared (IR) and ultra-violet (UV) radiation.
- Any IR energy present in the incident light will cause radiant heating of the test surface.
- Extended exposure to UV radiation can cause rapid deterioration of the TLC surface. This causes the surface to produce unreliable color-temperature response performance.
- Consistent light source settings and lighting-viewing arrangements between calibration and actual testing are essential to minimize color-temperature interpretation errors.

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Measurement Process

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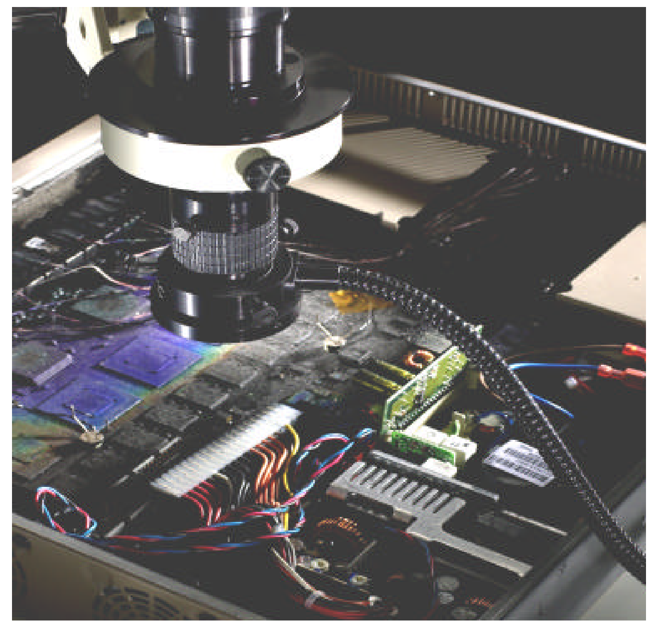
thermVIEW™ System

3 CCD digital camera

High resolution optics



IR free light source

Calibration system, *thermCAL*

TEC controller

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Measurement Process

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System Features

thermVIEW™ is designed to be an accurate and easy to use temperature measurement system for scientific and engineering applications.

Some of the system's features include:

- Transient and steady state temperature measurement capabilities
- Can be used for part (transistor) to board (PCB) level measurements
- Spatial resolution to 1 Micron
- Temperature accuracy to +/- 0.1°C
- A completely optical system based on visible light-- independent of surface emissivity
- Fast response liquid crystal for temperature measurement and data processing
- Uses *thermCAL*™ for precision color-temperature calibration of TLC materials
- Flexible and versatile 3D traversing camera support

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Measurement Process

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System Features, cont'ed

- Includes a precision 2D traversing test table for accurate positioning of the test specimen
- Fiber optic lighting for high intensity uniform illumination of the test specimen
- Polarized optics to enhance image viewing and measurement accuracy
- NTSC and PAL based video inputs
- Micro and macroscopic optics
- A state-of-the-art windows based user-friendly *thermSOFT™* (v1.1) software for data acquisition and image processing. *thermSOFT™* contains state of the art tools for image manipulation and data acquisition.

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Why Use LCT as a Temperature Measurement Tool?

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Advantages

- Flexibility of use in virtually any temperature measurement application from micron sized electronic circuits to large scale gas turbine blades.
- Ultra high (<1 micron) spatial resolution and non-destructive application for the device under test.
- Ability to easily use common color video cameras and recorders as input devices to the system.
- Customized and cost effective solution for many demanding applications. Two or three multiples less expensive than IR systems that offer poorer spatial resolution.
- Enables live tests by allowing to see temperature distribution through clear plastics (Lexan™).

Deficiencies

- Not a quick tool for measurement since the test specimen needs to be treated by LC; unless one uses plastic films treated with LCs
- Not a suitable tool for very large surfaces, i.e., system level tool.

LC and IR Thermography Systems Compared

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	IR	LC	Remarks
Test specimen surface treatment	Yes	Yes	required for both systems
Steady state measurement	Yes	Yes	
Transient measurement	Yes	Yes	
Non-evasive measurement	Yes	No	Must know emissivity for IR system
Ease of use	Yes	Yes	
Video imagery	No	Yes	
Compactness and transportability	Yes	No	
Surface emissivity	Yes (must)	No	LC is in the visible wavelength
Ability to see through plastics and glass	No	Yes	
Resolution			
Temperature	+/- 2°C	+/- 0.1°C	
Spatial	5 micron	1 micron or less	5 micron is the physical limit of IR
Price			
Base system	40k-70k	34k	
Microscopic (part level)	180k+	45k	

Liquid Crystal Thermography

Summary

- LCT has been used since 1950s and been present in the electronics industry since mid-eighties.
- Liquid crystals are a proven material for temperature measurement.
- LCT is a tool with points of weakness and strength. Thus, it is best suited for device and board levels temperature measurements.
- The ability to see and measure temperature gradients through transparent plastics (e.g., Lexan™) is a unique and powerful asset of LCT.
- Liquid crystals can be used for both qualitative and quantitative measurements. The qualitative measurements do require a complete system for accurate data.
- Like any other measurement system, LC calibration is of paramount importance in the accuracy of the measurement.