Liquid Crystals Detect Hot Defects

David Burgess - December 01, 1999


Usually when a failure on an integrated circuit or semiconductor device causes excessive current to flow, the failure shows up as a hot spot on the device. If you can locate a hot spot, you’re well on the way to analyzing why the device failed. A defect causing a failure often resides at or near the source of heat. In the early 1980s, failure analysts started using liquid-crystal materials to detect hot spots, but many test engineers remain unfamiliar with this technique. (See, “How Do Liquid Crystals Work?”)

For the most part, using liquid-crystal materials—I’ll call them just “liquid crystals”—provides a nondestructive way to locate semiconductor defects that draw excessive current. After locating a hot spot, or spots, you can simply wash off the liquid crystals and perform additional tests and analyses on the device. Liquid-crystal hot-spot analysis can easily detect a point source of 1 mW, and under optimum conditions you can locate a point that dissipates only 10 mW.

The lab setup diagrammed in Figure 1 shows the equipment needed for a typical liquid-crystal test. In most cases, you’ll use an analytical probe station that combines all of the elements in Figure 1 except the electronic test instruments. The station includes a metallurgical optical microscope set up with a polarizing light source and a polarizing filter in the microscope’s reflected light path.

A curve tracer provides the best source of power for the DUT because you can use it to accurately monitor current and voltage. You may need additional power supplies to set bias conditions that cause the DUT to draw excess current.

To locate defects dissipating power of 20 mW or less, the test station must heat the DUT by a few degrees. You need to heat the bulk of the device to just under the liquid crystal’s clearing point—the temperature at which it becomes transparent—so minute amounts of heat from the defect can “clear” the liquid crystals. A precisely controlled thermal chuck will do the job, and so will a Peltier device. The Peltier device offers an advantage because it can cool or heat a device. You could also build an inexpensive homemade heater using a variable power supply and a few resistors. Precise temperature control is necessary, but precise temperature measurement is not. Liquid crystals provide their own temperature indicator.

The setup in Figure 1 includes a switch between the collector supply of the curve tracer and the DUT. Switching the power on or off lets you alternately heat the device and let it cool (unpowered),
which can enhance hot-spot visibility. A high-side switch lets the DUT share a common ground with other power supplies or test equipment. You must choose the proper probes to drive the DUT.

Figure 1. A probing station comprising electrical probes, a thermal stage or chuck, and optical components provides a foundation for testing a semiconductor device using liquid crystals to detect hot spots. A curve tracer lets you set bias conditions so that defects generate heat but do not destroy themselves.

Although the test setup requires no other equipment, you might add a video or photographic camera to the microscope to document test results.

Bias Devices Properly
To use the test setup, all you need to know is how to bias the device undergoing testing so that it “operates” in the high-current state. The procedure is simplest when the leakage occurs between two pins such as I/O signals and ground, or between VDD and VSS, because you simply power the device and observe the point or area that produces heat. Some analyses may require more specific operating conditions. For example, a device might require a specific set of internal logic states or external pin stimuli to properly bias a device that failed a specific IDDQ test.

Unlike other failure-analysis techniques, such as emission microscopy, which detects radiation emitted only from junctions or gates, you can use liquid crystals regardless of the source of heat. Thus, heat generated by polysilicon-to-polysilicon shorts is easy to detect. Keep in mind, though, that radiation located by liquid crystals as well as by an emission microscope may not coincide with a defect. For example, a metal-to-metal short in a CMOS circuit may not produce detectable heat, but the short may bias an individual transistor that will produce heat, and thus help you determine what caused the failure.

In my work, I use a liquid-crystal material that has a 29°C (84°F) clearing temperature, but other liquid crystals work equally as well.

Add a Pinch of Liquid Crystals
Two techniques let you quickly apply a film of liquid crystals over a DUT. In the first technique, you apply the liquid crystals in an undiluted form, while in the second, you use a diluted liquid-crystal solution.

By using a syringe, you can place a drop of pure liquid crystal on a DUT. Then, by using a strip of filter paper, you spread the material across the surface of the DUT, and the paper absorbs any
excess liquid. Maintain a clean work area to avoid contaminating the liquid crystal with foreign materials such as dust, solder flux, and so on, which can alter the liquid-crystal properties.

You also can dilute liquid crystals in a solvent and apply the solution to a DUT using a pipette or a small brush. The solvent will evaporate quickly leaving a thin, uniform film of liquid crystals. This application technique provides better results than the application of concentrate liquid crystals. I achieved my best results by starting with one part liquid crystal dissolved in nine parts methylene chloride. Pentane, petroleum ether, trichloroethylene (TCE), or trichlorethane (TCA) also dissolve liquid crystals. Do not use methyl alcohol (methanol), because it does not dissolve liquid crystals.

I obtained the best results by applying the diluted liquid crystal with a small nylon art brush. The solution retained in the brush tip wets the surface and spreads across it quickly. Any missed spots are easy to touch up with the brush. Viewing the DUT under a microscope using cross-polarized lighting conditions lets you see when solvent evaporation and liquid-crystal coverage are complete. The net result is an even film of liquid crystals on the surface.

A pipette delivery also produces good results, but it’s easy to apply too much solution—drenching the DUT—and the use of a pipette can introduce particulate contaminants into the liquid crystals.

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**Figure 2.** A thin coat of liquid crystals shows a hot spot better than a thick coat. The thin coat holds the heat and the crystals in one place.

**Figure 3.** A hot spot on an integrated circuit coated with liquid crystals and biased properly shows up as a black area between the inner two bond pads.
Figure 4. A curve-tracer plot for a failed device shows when the current rises steeply. Set the supply voltage just below the break point to bias a device for hot-spot testing with liquid crystals.

**Thinner Is Better**

The thinner, cleaner, more uniform film produced by diluted liquid crystal overrides any minor contamination effects from such things as moisture absorption. A small amount of moisture will have a negligible effect compared to the enhanced action of a thin film. The transition from clear to dark at a hot spot shows up better in a thin film (Fig. 2), because the thin film requires less energy to heat, and the liquid-crystal molecules mix less with cooler adjacent liquid. Under nonpolarized light, the thin film appears practically invisible, so photos of the hot spot also include the structures and shapes of surrounding devices.

You also can use the diluted solution around wire bonds and probes because the less-concentrated liquid crystal solution won’t flow up those connections (Fig. 3) due to surface tension. A thick application of liquid crystals would cling to the wires, forming an uneven surface. That surface makes it impossible to properly photograph the hot spot shown in the figure. After testing a device covered with liquid crystals, just use a solvent such as acetone to remove the material so you can perform other tests.

**Performing the Test**

Now that you understand more about how liquid crystals can detect small temperature changes, how do you go about running a test? The steps below describe in abbreviated form how to go from initial electrical testing to failure detection.

1. Electrically characterize the failed device to establish proper bias conditions that you’ll apply to the device during testing. Use an I vs. V plot from a curve tracer (Fig. 4) to determine the maximum voltage you can apply without introducing excess current.

2. Apply a thin film of liquid-crystal solution to the DUT by touching the device’s surface with a small brush saturated with the diluted solution.

3. View the device under a microscope and a cross-polarized light path. The liquid-crystal material should appear mottled due to the optical properties of liquid crystal below its clearing temperature.

4. Slowly increase the voltage to the DUT up to the maximum amount determined in step 1. Slightly vary the voltage about its maximum as you view the device and look for any hot spots. If a hot spot does not appear, try slowly warming the entire device until you can detect a hot spot, or until the entire surface darkens. If the entire surface becomes dark, decrease the external heat until a mottled appearance returns. Warming the device to just under the clearing temperature makes the
liquid crystals more sensitive to small temperature changes.

5. When you find a hot spot, document its location. Here’s where a microscope with a photographic or video camera can help collect information.

If you locate one or more hot spots, the next step is to understand the nature of the failure. Often, electrical characterization and location of a hot spot provide sufficient evidence to support a conclusion about the nature of a failure. If you didn’t find a hot spot, consider possible reasons for a lack of heat generated at one location.

You Can’t Always Spot a Failure
To an experienced analyst, failure to isolate a hot spot does not mean that the liquid-crystal technique didn’t work. The test still provided knowledge about the failure. Specifically, if characterization (step 1) showed that a device consumed nearly 1 mW of power, a hot spot should show up if the device dissipates the power at a spot within a few microns of its surface.

Liquid-Crystal Sources
Liquid-crystal materials are available from the following suppliers:

**Accelerated Analysis**
Half Moon Bay, CA
Phone: 650-867-8443
Fax: 650-726-1833
[www.acceleratedanalysis.com](http://www.acceleratedanalysis.com)

**Allchem Industries**
Gainesville, FL
Phone: 352-378-9696
Fax: 352-338-0400
[www.allchem.com](http://www.allchem.com)

**Chemos, GmbH**
Regenstauf, Germany
Phone: +49-9402-933-610
Fax: +49-9402-933-613

**Hallcrest**
Glenview, IL
Phone: 847-998-8580
Fax: 847-998-6866
[www.hallcrest.com](http://www.hallcrest.com)

**Image Therm Engineering**
Waltham, MA
Phone: 781-893-7793
Fax: 781-893-7324
[www.imagetherm.com](http://www.imagetherm.com)

**Tempronic**
Newton, MA
Phone: 617-969-2501
Fax: 617-969-2475
[www.tempronic.com](http://www.tempronic.com)

Failure to detect a hot spot suggests that the device dissipates the power at several sites or deep in
the substrate. An area-leakage phenomena such as surface inversions may have too low a power density to create a hot spot. Surface inversion changes the electrical characteristics of a p-doped semiconductor area in a way that produces current flow over a large area.

Practically speaking, if power dissipation is less than 5 mW, it may prove difficult to detect a hot spot. Consider etching away most of the DUT’s passivation layer. Removing this layer places the liquid crystals closer to the heat source.

Using this technique, a researcher detected between 10 and 100mW on an IC. As an alternative to removing a layer from the DUT, investigate biasing the device differently to provide more power to the suspected defect. A probe station can apply voltage directly to a specific circuit.

If a low breakdown-voltage element in parallel with the suspected circuit limits the voltage you can apply, consider removing the offending element.

For example, a diode with a low breakdown voltage in parallel with a leaky capacitor can limit available power to the capacitor. Mechanically isolating the capacitor by using focused-ion beam (FIB), laser, chemical, or mechanical techniques lets you apply higher voltages to the capacitor.

On the other hand, too much power may overwhelm a sample and produce too much heat. In such a case, consider using a lower duty cycle on the power to curtail the “growth” of a hot spot using a low duty cycle is usually more advantageous than opting for a liquid crystal with a higher clearing temperature. T&MW

FOOTNOTES


David Burgess owns Accelerated Analysis, which he founded 10 years ago. Prior to starting his own company, he worked as a reliability physicist at Hewlett-Packard. He received a B.E.E. from Rensselaer Polytechnic Institute, and an M.S.E.E. from San Jose State University.
How Do Liquid Crystals Work?

Common chemicals have well-defined melting and boiling points, such as 0°C and 100°C, respectively, for water. On the other hand, chemicals that act as thermotropic liquid crystals have an intermediate temperature called the clearing point.

A test tube of this type of liquid crystal material appears milky white below its clearing point, but it becomes water-clear above that temperature. The optical transformation is instant. The optical change at the clearing-point temperature comes about due to the nature of the liquid-crystal chemical.

Below its clearing-point temperature, liquid crystal in its nematic phase twists light that passes through it. Above the clearing point, in its isotropic phase, liquid crystal loses its unique property of twisting light. This phenomena results from a loose alignment of long molecules, a cooler temperature, and the random alignment above the clearing point.

A discussion of how liquid crystals behave goes beyond the scope of this article, but you can find more in an online tutorial on the Web starting at: fy.chalmers.se/lc/.

The optical transition at the clearing point also occurs in a thin film of liquid crystals. You can observe this phenomenon using a metallurgical microscope equipped with a polarizing filter at the illumination source and another polarizing filter in the path of light reflected from the thin film into the microscope lens.

Recalling your basic physics, you would expect to view only a dark field through the microscope because of the cross polarization of the light.

Below its clearing point, a thin film of liquid crystal twists the light, thus defeating the cross-polarized blockage. The surface under the film appears bright and colorful. Above the clearing point, however, liquid crystal looses its “magic” and light reflected from the surface below is blocked, as expected, by the cross-polarized filter. Thus, the liquid crystal “identifies” hot spots by blocking light reflected from them. — David Burgess