ARMY RESEARCH LABORATORY

Infrared Imaging of Power Electronic Components

by Dimeji Ibitayo

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14. ABSTRACT

It is often advantageous to perform in-situ temperature measurements on operating devices to ensure that they do not exceed their maximum allowable junction temperature. A number of techniques are available to perform such measurements. This report focuses on the use of an infrared imaging technique to perform non-contact thermal characterization on one or more devices under test.

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1. Introduction

Thermal management of electronic devices and packaging is important when dealing with high-voltage high-power systems as excessive device heating can have a catastrophic affect on the performance of a system and can lead to premature device and system failure. Therefore, it is necessary to accurately assess and characterize the thermal performance of power electronic components. The U.S. Army Research Laboratory has been working to develop methods for making accurate temperature measurements for components operating in high voltage, high power and related applications. Several techniques are available for performing thermal characterization on power electronic components. Three common techniques include the use of temperature sensitive parameters, temperature sensors, and thermal imaging. Thermal imaging using an infrared camera provides a single measurement technique that would be broadly applicable to a variety of high power systems.

2. Fundamentals of Infrared

The use of thermal imaging equipment (infrared cameras) allows us to see beyond the visible into the invisible infrared. Our eyes are capable of detecting visible radiation but not infrared radiation.   Infrared radiation is a form of electromagnetic radiation as are: visible light, radio waves, ultraviolet, and X-rays. Infrared radiation is longer in wavelength than visible light and is classified in a different waveband. Although few objects emit in the visible waveband, in the infrared waveband all objects emit. It is only that it cannot be seen with the physical eye. An infrared camera, therefore, becomes the "infrared eyes" into the infrared world. Infrared radiation is absorbed and emitted by objects. Absorptivity is the measure of how well an object or material absorbs radiation. Emissivity is the factor that correlates to the ability of an object to radiate infrared energy. In the way that visible light reflects off a mirror, infrared radiation reflects off many objects. For example, infrared radiation reflects clearly off metals such as aluminum. The fact that metals are good reflectors makes them poor emitters. Metals reflect most of the infrared radiation of the environment and therefore in infrared they look and measure close to the environment temperature. The opposite is true for poor reflectors or good emitters. A good emitter, such as black tape, looks and measures close to its true temperature in infrared.   Also, similar to how visible light transmits through glass, infrared radiation is able to transmit through some materials. Such materials can be used to protect an infrared camera lens from potential hazard while thermal imaging is being performed. However, it is necessary to account for the fact that the camera is seeing through the transmissive material to the object being measured. One example of a transmissive material is germanium. Germanium is opaque to visible light, but is a good infrared transmitter.

3. Infrared Camera

A system being used at the Army Research Laboratory (ARL) is the FLIR ThermaCAM® SC 500 (shown in fig. 1). The ThermaCAM® SC 500 system utilizes 3rd generation uncooled microbolometer long wave detectors to sense IR radiation. It features real time 14-bit digital output, a 320 x 240 pixel detector, precision temperature measurement, internal data storage, and outstanding thermal sensitivity. Coupled with ThermaCAM® Researcher RT (shown in fig. 2), the SC 500 provides 5 Hz digital image acquisition for temperature measurement and statistical analysis. Sequences of images can be stored for later playback or converted to AVI files. For 60/50 Hz real-time digital recording and analysis of data and dynamic events, the SC 500 is also compatible with FLIR's PC-based ThermaCAM® Researcher HS Analysis System. The SC 500 provides a powerful, affordable solution for scientific thermal testing and general purpose non-contact temperature measurement.

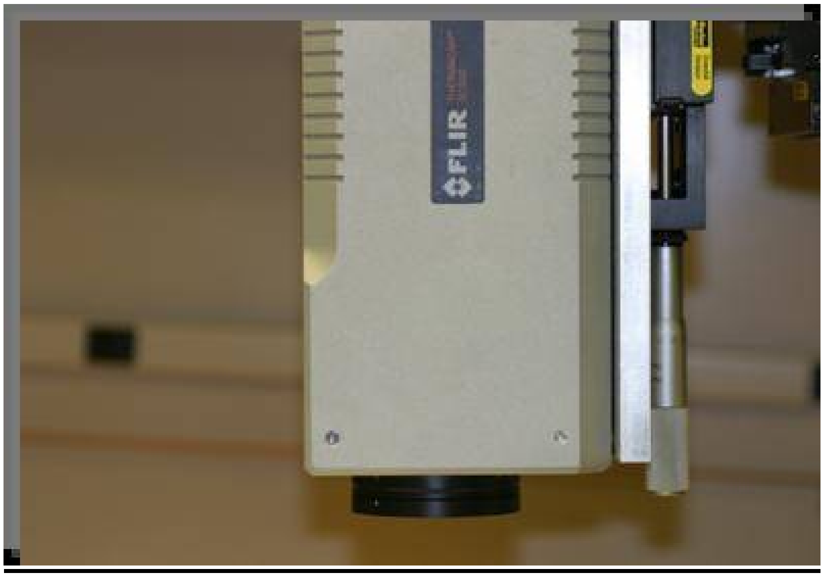

Figure 1. Photograph of the FLIR ThermaCAM® SC 500.

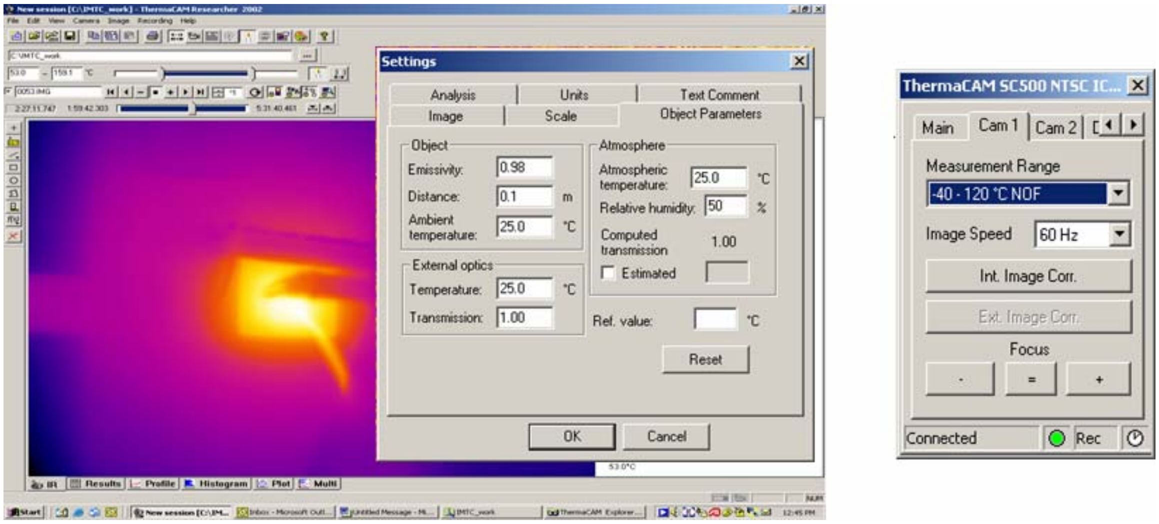

Figure 2. ThermaCAM® Researcher user interface displaying the thermal image of an operating device and Settings toolbar.

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4. Thermal Characterization

Thermal analysis was performed on the 10 kW half-bridge inverter board pictured in figure 3. The board consists of eight 2x2-mm SiC bipolar junction transistors (BJTs) and two 4-mm SiC junction barrier shottky (JBS) diodes packaged on metal pads on an AlN substrate. Thermal characterization was performed using the combination of a temperature sensor (direct-mount thermistor) and the infrared camera. This analysis was conducted in order to gain an understanding into the thermal performance of the device and package technology prior to running them in an actual system. The analysis was performed on a single phase of a 10 kW AC-DC half-bridge inverter board. The four BJTs on each side were packaged for parallel operation.

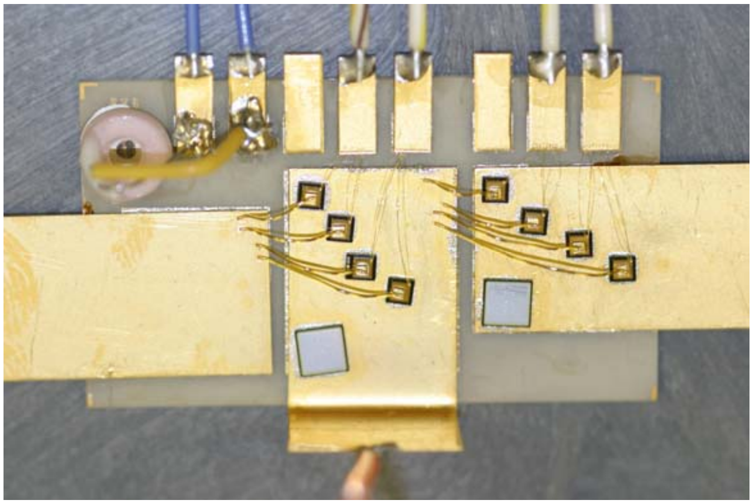

Figure 3. SiC half-bridge inverter board.

Figure 4 is an infrared camera image of the board in figure 3 under test. The SiC bipolar junction transistors are switched in parallel. It can be seen from the image that current is not being shared evenly among all devices. In particular, the circled device of the right side set of devices is running much other than the others. It can be seen that this device is carrying the greatest amount of the load. Thermography plays a crucial role here in the study of how well current is being distributed among all the devices.

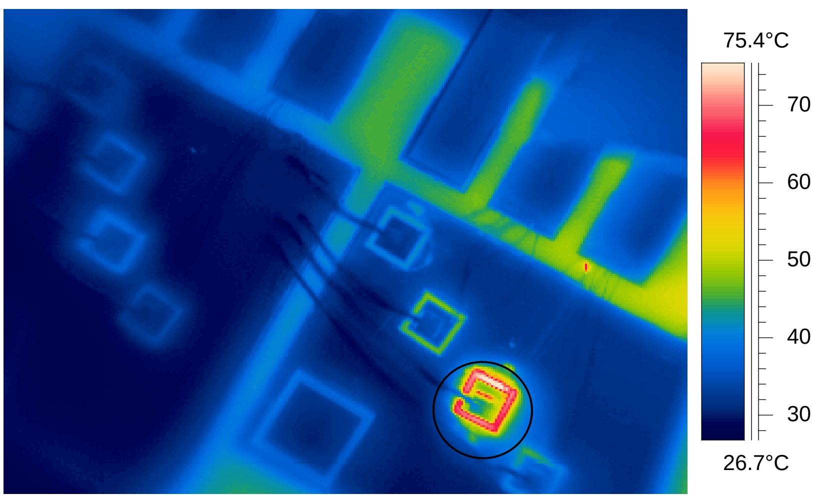

Figure 4. Infrared image of SiC half-bridge inverter board under test.

A better focus could have been achieved for the image pictured in figure 5. A poor focus can have a significant impact on the accuracy of temperature measurements. However, for this test the important factor was relative temperatures among devices and not exact temperatures. This image was the 7th image taken in a sequence (recording) of images at 2 s intervals as the voltage was ramped up quickly. This was also the last image taken before a failure occurred on the board. This image also depicts the matter of temperature range settings. The highest temperature on the board before failure occurred suddenly exceeded the upper temperature limit of the selected range which introduced error into the temperature measurements. The symbol “>” denotes that measurements were made out of range. Post-failure characterization of the devices using a curve tracer revealed that the circled device experienced a failure.

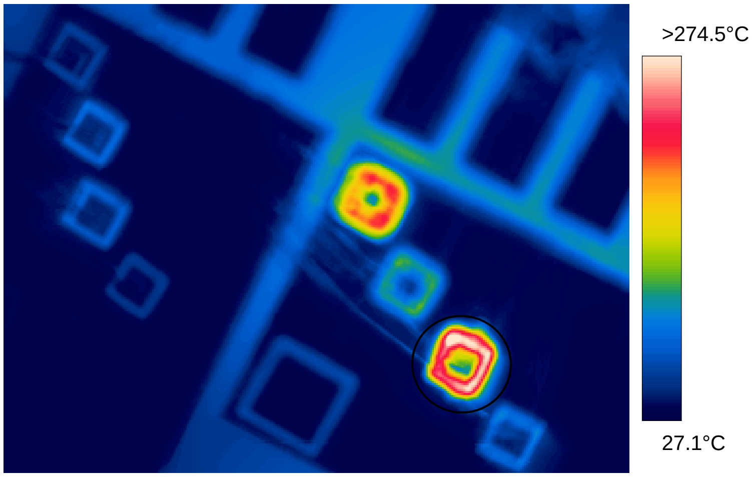

Figure 5. Infrared image of board prior to failure.

The FLIR camera system was purchased with an 18 µm (spot size) lens which allows for a close look at individual devices. Shown in figure 6 is one of the 2x2-mm SiC BJTs operating near 180°C.

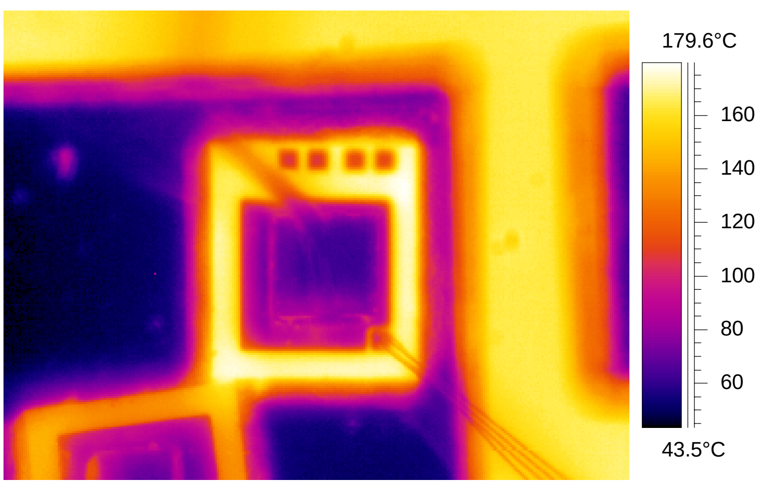

Figure 6. Thermal image of a 2x2-mm BJT using an 18 µm lens.

5. Calibration Methodologies

Surface emissivity is the most crucial parameter in infrared imaging. As defined previously, emissivity is a factor that correlates to the ability of an object to radiate infrared energy. Emissivity depends on several factors. In order of decreasing importance: type of material, surface material finish (polished or oxidized), and surface geometry. Low emissivity surfaces can be coated with high emissivity material to increase the ability to radiate. This also serves to equalize surface emissivity when multiple surface types are being measured. High temperature black spray paint and spray-on boron nitride have been investigated at the Army Research Laboratory (ARL) for calibration purposes to improve the accuracy of the infrared camera for temperature measurements. The two substances, pictured in figure 7, do not affect device operation. Boron nitride also has the advantage of being easily removed.

Figure 7. High temperature black spray paint (left) and spray on boron nitride (right).

The high voltage SiC diode module shown in figure 8 was used to evaluate the performance of high emissivity spray coatings. The module contains multiple surface types, including metal (wire bonds, kovar tabs, and device surface metallization), the AlN substrate, and the oxide at the outer edge of the SiC diodes. Emissivity for a given material ranges from 0 to 1. Metals (uncorroded and nonoxidized) have emissivities of ~0.1. Non-metals have emissivities close to 0.9, and the emissivity of ceramics ranges from 0.7 – 0.9.

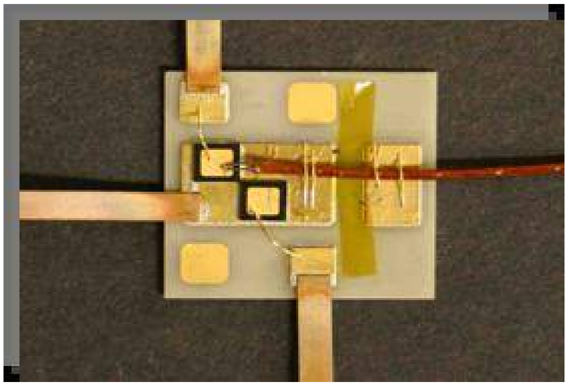

Figure 8. High voltage SiC diode module.

Figure 9 illustrates the problem of performing infrared imaging on surfaces with unequalized emissivities. The figure shows an infrared image of the SiC diode module without the use of a surface coating. The emissivity was set to approximately 0.8 when this image was captured. The inaccuracy in temperature measurements is evidenced most in the case of metal surfaces due to low emissivities. In figure 9, “hot” metal surfaces appear “cold”.

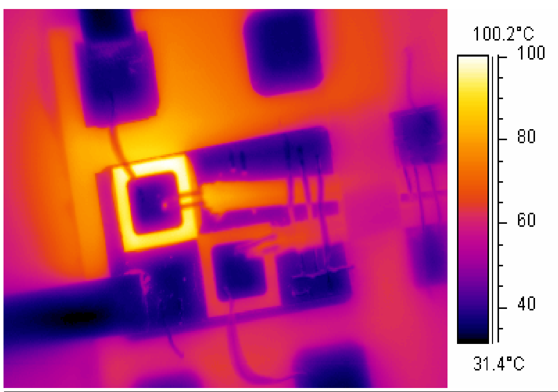

Figure 9. Infrared image of module under test and uncoated.

Figure 10 illustrates the benefit of coating the surface being measured with high emissivity material prior to infrared imaging. Several coats of spray-on boron nitride was applied to the module in figure 8. The result is an equalized, high surface emissivity which reveals the true temperature map of the module with the upper diode operating at near 100°C.

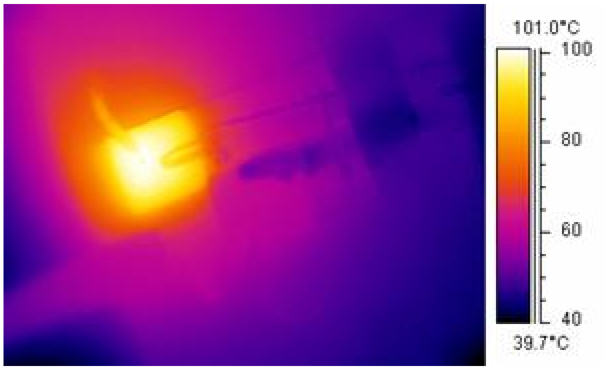

Figure 10. Infrared image of module under test and coated with BN spray.

6. De-Encapsulation Capabilities

Separate de-encapsulation techniques have been implemented at ARL allowing the analysis of commercial devices and packaging. The first technique involves the use of fuming nitric acid to remove plastic encapsulation of packaged devices. Figure 11 shows a Si MOSFET package which was de-encapsulated with the use of fuming nitric acid.

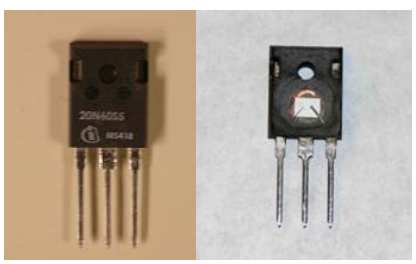

Figure 11. Encapsulated (left) and de-encapsulated (right) Si MOSFET package.

A second technique involves the use of heated Dynasolve 711 to completely remove silicone gel. This process was used to completely remove silicone gel inside a Powerex custom IGBT module with integrated heatsink prior to testing and infrared imaging. The module is shown in figure 12.

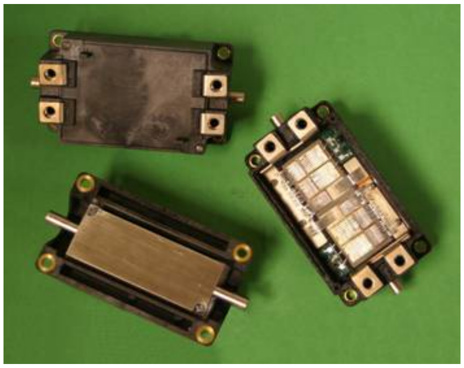

Figure 12. Different views of a custom Powerex IGBT module with integrated heatsink.

7. Summary

In summary, infrared imaging methodologies have been developed to perform accurate temperature measurements of power electronic components. In addition, de-encapsulation techniques have also been implemented to allow the analysis of commercial packages. This work is allowing the use of COTS devices in higher temperature environments. These COTS devices, when proven to operate at higher temperatures, will reduce size, weight, and cost of current Army systems.

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