Army Research Laboratory

EPM 2482 Power Cycling Evaluation Summary

by Mark R. Morgenstern

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14. ABSTRACT
The Power Components Branch of the U.S. Army Research Laboratory's Sensors and Electron Devices Directorate has evaluated the use of NuSil's EPM 2482 as an electrical insulator in power convertor modules. There is a need for a material that electrically insulates well and does not distort in form when heated. Distorting potting material can induce mechanical stress on and break wire bond connections in packaging. During the test described in this report, the EPM 2482 compound proved to have both the electrical and thermal-mechanical properties that were needed.

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1. Introduction

The U.S. Army Research Laboratory has been developing high power electronics for a variety of Army applications. Selecting the right materials for custom components plays an integral role in high power electronics development. A NuSil EPM 2482 potting material was evaluated for possible use in a high power convertor module as a metal-oxide semiconductor field-effect transistor (MOSFET) package electrical insulating material. There was some concern that the potting material would distort in form when subjected to many heating and cooling cycles. This kind of distortion would cause mechanical pulling and torquing of wire bonds that would result in opening the electrical connections to the source or gate of the MOSFET. To mitigate the concerns associated with using a new potting material, a practical power cycling evaluation of this material was performed in view of a thermal imaging camera.

2. Test Preparation

In order to evaluate the NuSil EPM 2482 potting material, we needed to isolate any changes in the material itself and account for the potting material obstructing the camera view of the die temperature. To do this, we compared the thermal response of the potted MOSFET with a unpotted MOSFET (figure 1). A comparison of otherwise identical potted and unpotted MOSFETs accounts for the thermal camera's obstructed view of the potted MOSFET, provided two conditions were met.

Figure 1. Unpotted MOSFET in a TO-256 package (left) and a similar but potted version (right).

The first condition was to make some basic assumptions about the thermal path from the MOSFET packages to the heat sink because other thermal paths could contribute to the loss of heat from the package. The thermal paths other than those directly connected to the MOSFET's heat sink would have to be relatively insignificant for the unpotted device to be a credible reference. Thus, the unpotted MOSFET was placed under the thermal imaging camera and power cycled only a few times at the same level of power dissipation and cooling as the two evaluation devices. The observed die temperature of the unpotted MOSFET cycled between 105 and 165 ºC. If the blocked convection path is, in fact, of negligible significance, then for all intents and purposes, the thermal responses of the potted and unpotted packages should be nearly identical, provided all other external and packaging variables are the same.

The relevant materials in this experiment and their thermal conductivities are as follows:

- Air (surrounds rest of package): < 0.03 W/mK at 20 ºC
- Arctic Silver (thermal heat sink paste): 8.6 W/mK
- Aluminum (in part package and heat sink): 235 W/mK
- Gold (in part package and heat sink): 300 W/mK
- Copper (in heat sink): 400 W/mK

Figure 2 shows the setup of the device.

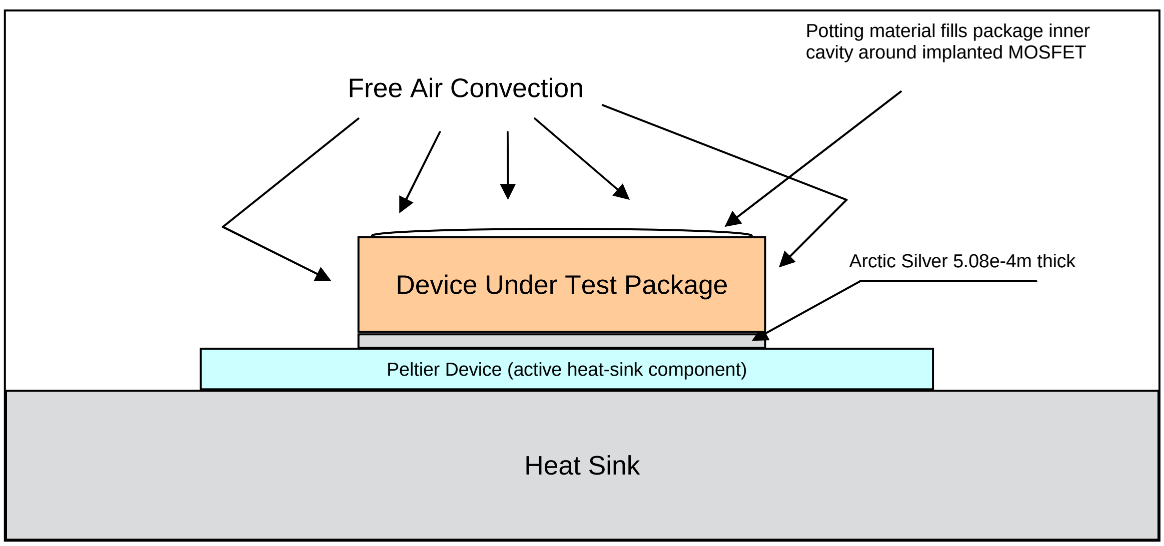

Figure 2. Setup of the device.

Two main paths of thermal power dissipation exist (apart from the radiation component) from the component being tested. According to the thermal conductivity values listed previously and the diagram in figure 2, the main bottleneck of heat transfer is through the Arctic Silver.

The heat flux through the Arctic Silver is calculated as follows:

$$Qac = \frac{k\Delta K}{x} = \frac{8.6*(70\text{K})}{5.08*10^{-4}m} = \frac{1.19MW}{m^2} \tag{1}$$

where k = thermal conductivity, W/mK, Q = thermal flux, W/m^2, and x = distance in meters through material.

Assuming 50% voiding would give us 595 kW/m^2. The free convection air flux is around 0.5 kW/m^2.

Even when considering that the surface area of convection is roughly three times larger than the conduction area, the contribution of convection losses are three orders of magnitude less than the conduction losses.

There is also a radiation component but it is also negligible. The power dissipated by the part package (radiation) can be estimated using the Stefan-Boltzmann Law:

$$\mathbf{Wnet = A\varepsilon\sigma}(K^4 - K_0^4) \tag{2}$$

where

A = area in m^2

ε = emissivity = 0.98 (part package coated with borium nitrite)

σ = Stefan-Boltzmann constant = $5.67 * 10^{-8} Wm^{-2}K^{-4}$

Wpackage = (6e-4m^2)(0.98)(5.67x10^{-8}Wm^{-2}K^{-4})((70)K^4) = 2.3 nW (negligible)

The conduction heat loss component, being far larger than the convection and radiation components, was found to be identical between the potted and unpotted parts. Thus, we conclude that the thermal camera image of the unpotted MOSFET, showing a die temperature of approximately 105 to 165 ºC, is a reasonably accurate prediction of the potted MOSFET die temperature.

With the expectation of the potted and unpotted packages thermally behaving in a nearly identical manner, only the possible difference in the electrical power dissipation between the MOSFETs remains to be resolved before the unpotted MOSFET can be used as a valid reference to predict the surface die temperature of the potted MOSFET. The MOSFET is the sole heat source in each package and the surface area and volume of the MOSFETs are identical: about 11 cm^2 and 1.6 cm^3, respectively. The packaging and heat-sinking are also identical. Thus, when a reasonable similarity between electrical characteristics is determined or compensated for, the power density and die temperature are assumed to be the nearly the same.

The parts according to the on-state characteristic curves (figures 3–6) are electrically similar but not the same. The power dissipation between the three parts evaluated was maintained at a constant 30 W by making small adjustments in the drain voltage.

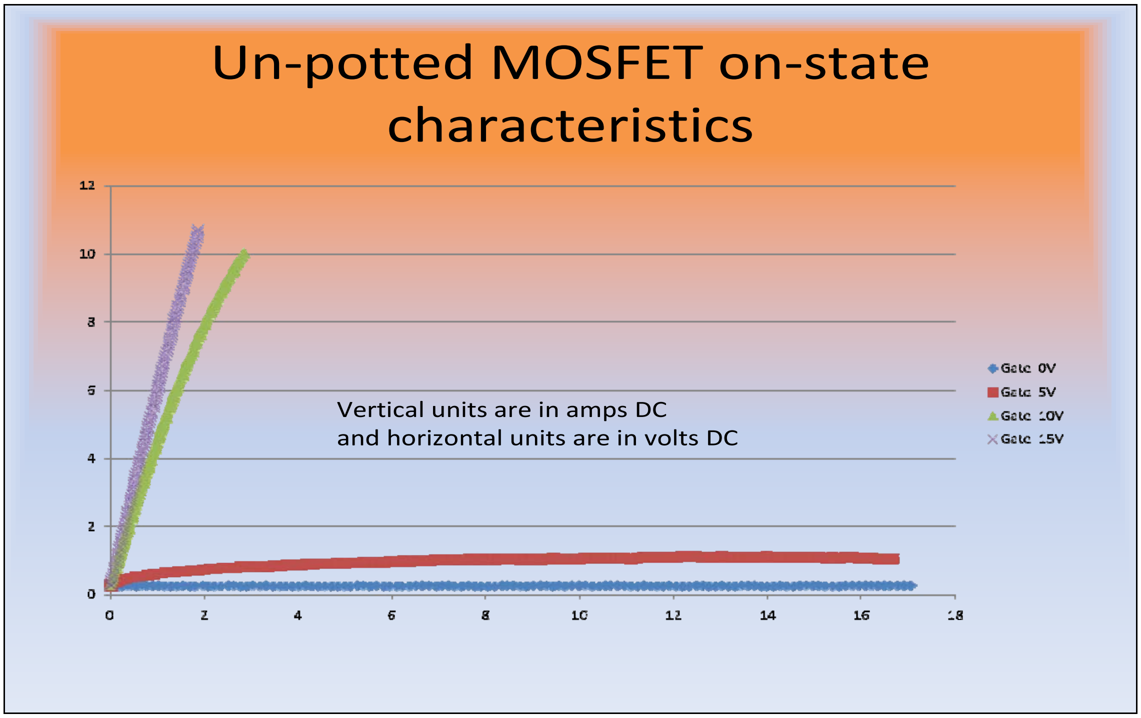

Figure 3. Unpotted MOSFET initial conducting state current as a function of voltage characteristics.

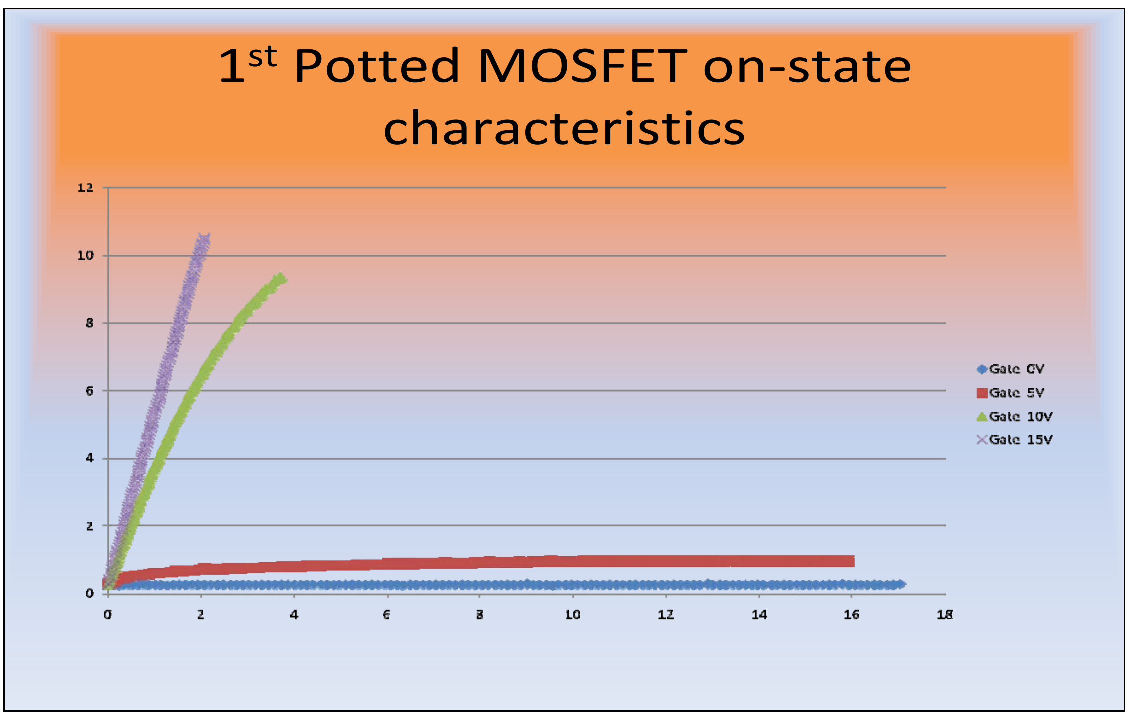

Figure 4. First potted MOSFET initial conducting state current as a function of voltage characteristics.

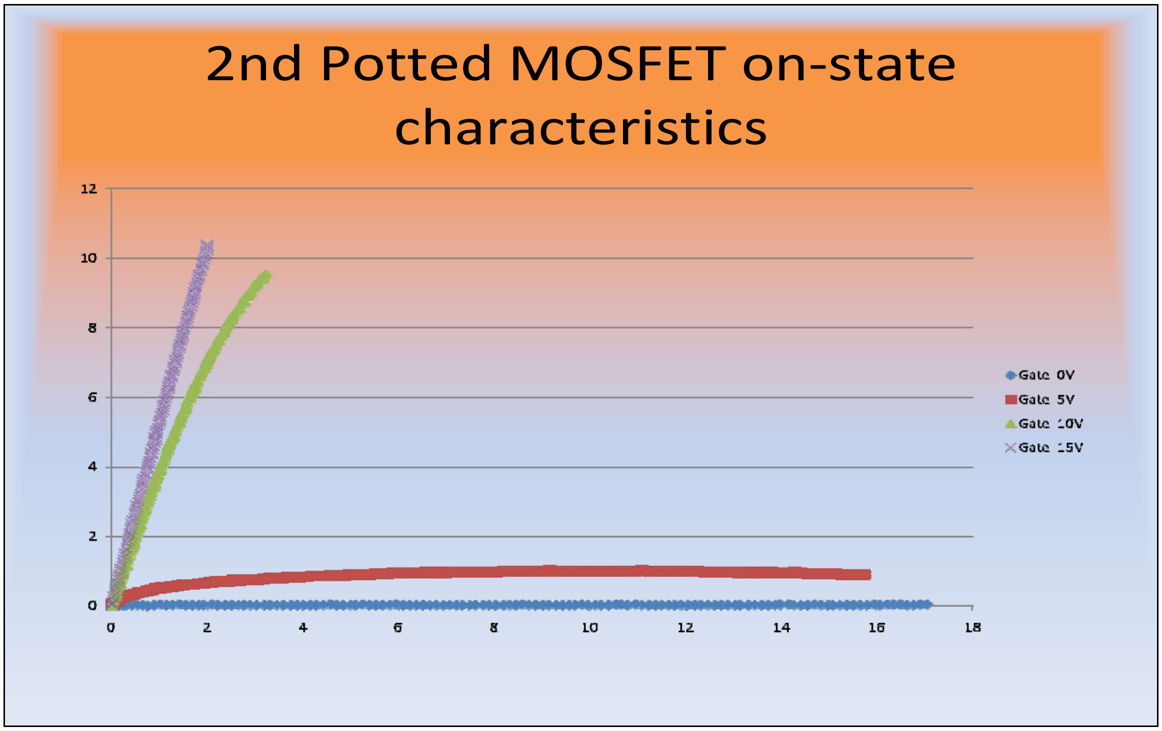

Figure 5. Second potted MOSFET initial conducting state current as a function of voltage characteristics.

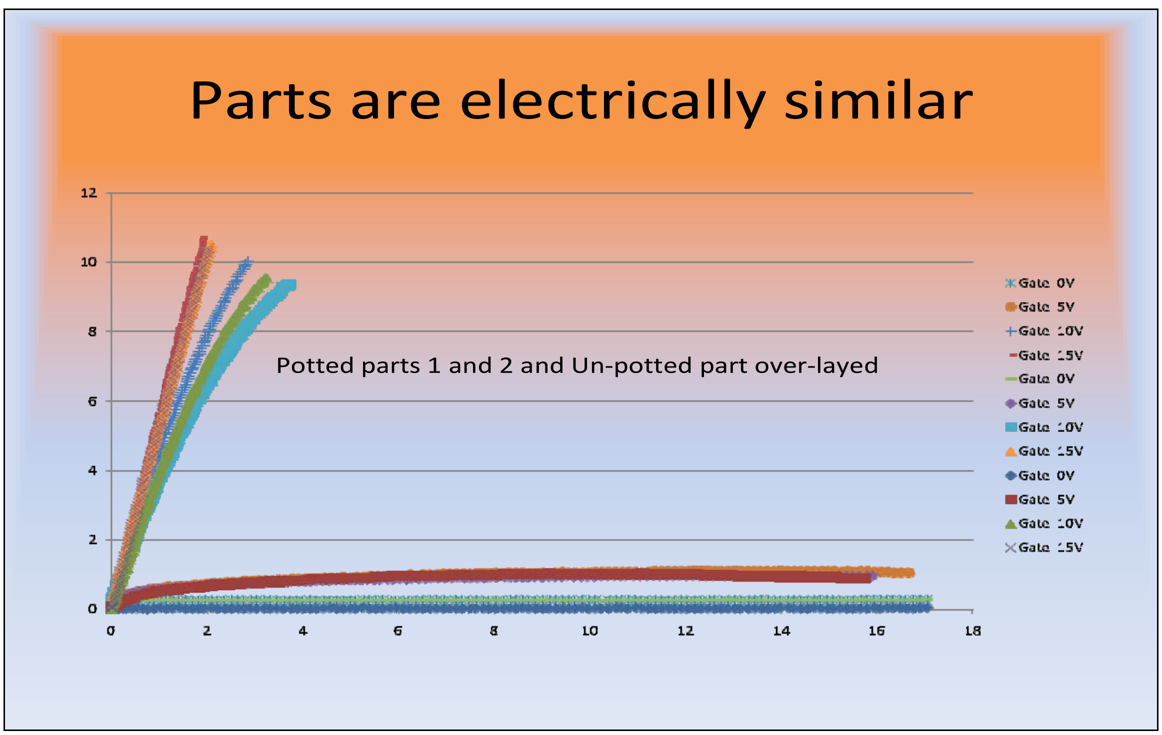

Figure 6. Overlay of initial conducting state current as a function of voltage characteristics.

3. Power Cycling Evaluation

The actions outlined previously allow us to account for the un-seeable die temperature underneath the potting material. Our goal was to power cycle the MOSFET so any part of the potting material would be subject to a maximum ΔT of 60–70 ºC for 2000 cycles.

In order to perform the actual evaluation, we used the following procedure:

1. We packaged three similar MOSFETs in a similar way.
2. We potted two parts.
3. We coated all three parts with borium nitrite to provide a uniform emissivity of close to 1.
4. We characterized the pre-stress electrical response curves.
5. We provided an active heat-sink for a controlled and elevated ambient temperature. A peltier device was installed in between the heat sink and package to force an additional temperature swing.
6. The unpotted part was evaluated briefly (cycled a few times under thermal imaging observation) in order to observe the die and wire bond temperatures under identical power dissipation and heat-sinking conditions. Convection blocking by the potting compound was not considered to be significant enough effect to spoil the evaluation. We knew that the die temperature of the potted parts would be close to the same temperature.
7. The first and second potted parts were cycled at the same power level (30 W) for 10 s on and 10 s off for 2000 cycles at a ΔT of 60–70 ºC at the die. The drain voltage was slightly adjusted throughout testing to offset drift in the electrical response curves in order to keep the power dissipation level (30 W) consistent.
8. We took post stress electrical response curves.
9. We made visual observations of the potting material.

The test bed for the device is shown in figure 7.

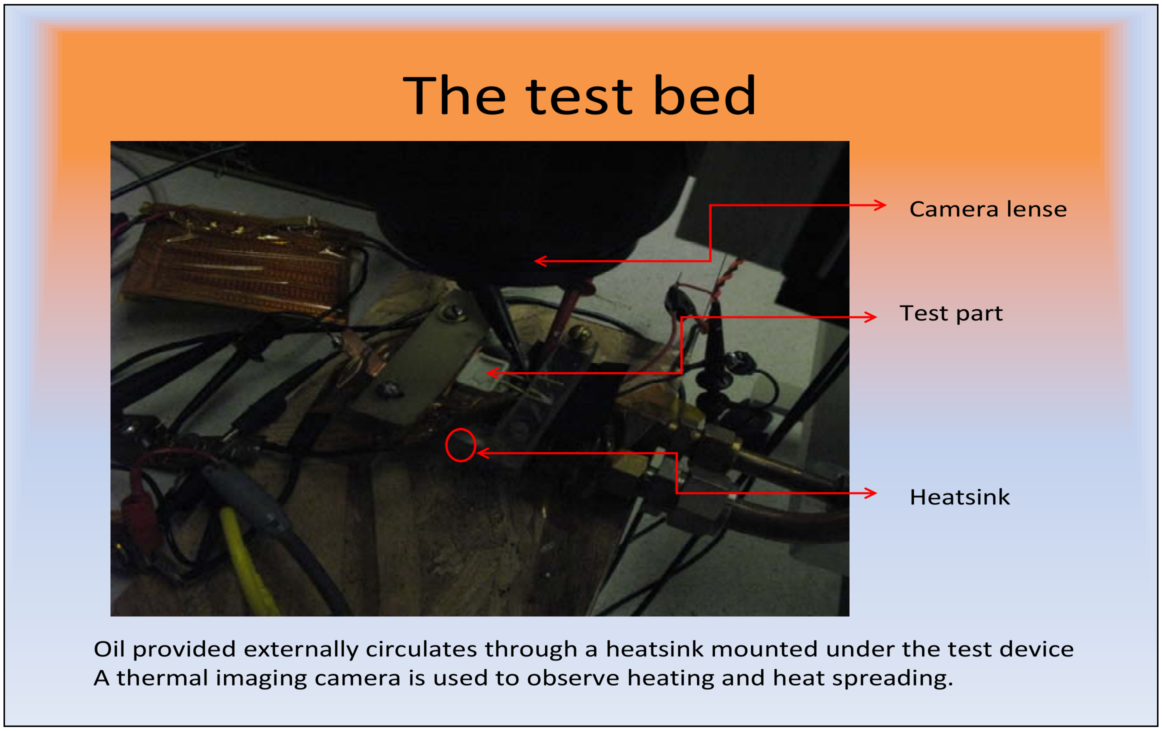

Figure 7. Device under test mounted to a heat sink and placed under the lens of a thermal imaging camera.

4. Conclusions

The potting material evaluation resulted in the following conclusions:

1. No visible change of the potting material was observed during or after testing.
2. Taking scaling into consideration, the heat spreading patterns (figure 8) look the same between the potted and unpotted parts. This result implies that convection losses do not play a significant role in die temperature.

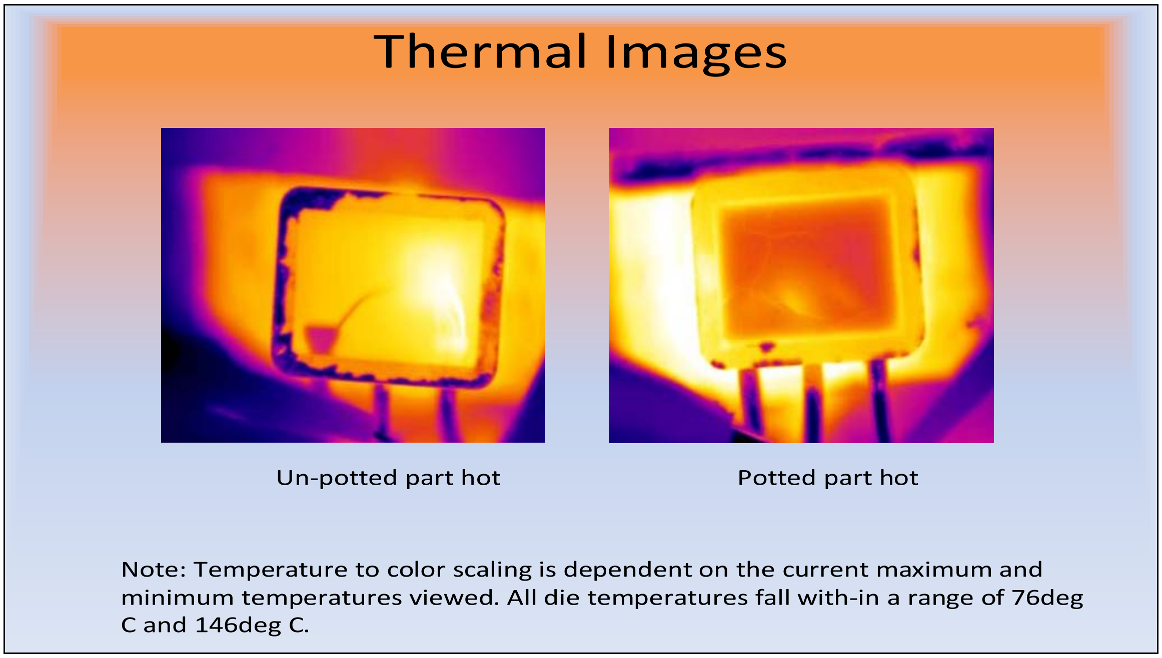

Figure 8. A thermal imaging comparison of the potted and unpotted MOSFETs at a peak (external to the package) temperature of 146 ºC.

3. Spot measurements placed near the die did not vary in minimum or maximum temperature throughout testing for each part as forward conduction drift was compensated for by holding the drain-to-source power constant (figure 9).

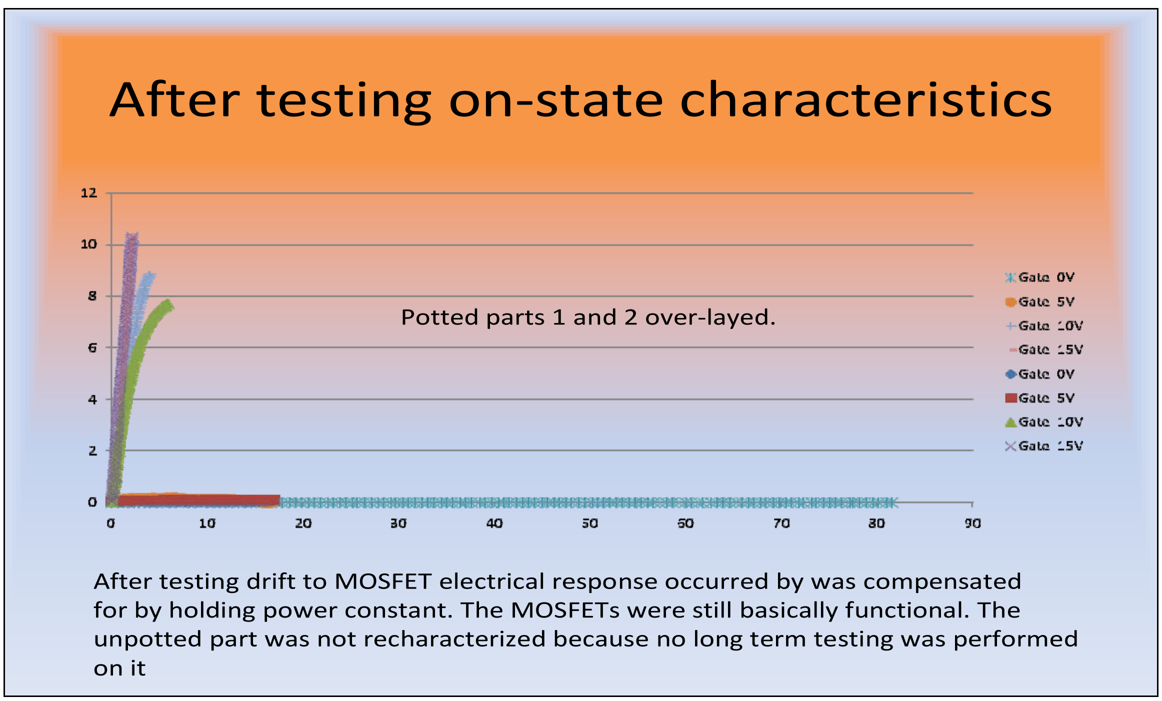

Figure 9. Overlay of the post-stress conducting state current as a function of the voltage characteristics of potted parts 1 and 2.

4. Because the potting material did not dislocate the wire bonds, the MOSFETs were basically operational after stress testing.

5. Reverse (up to 750 V) blocking (figure 10) was not compromised.

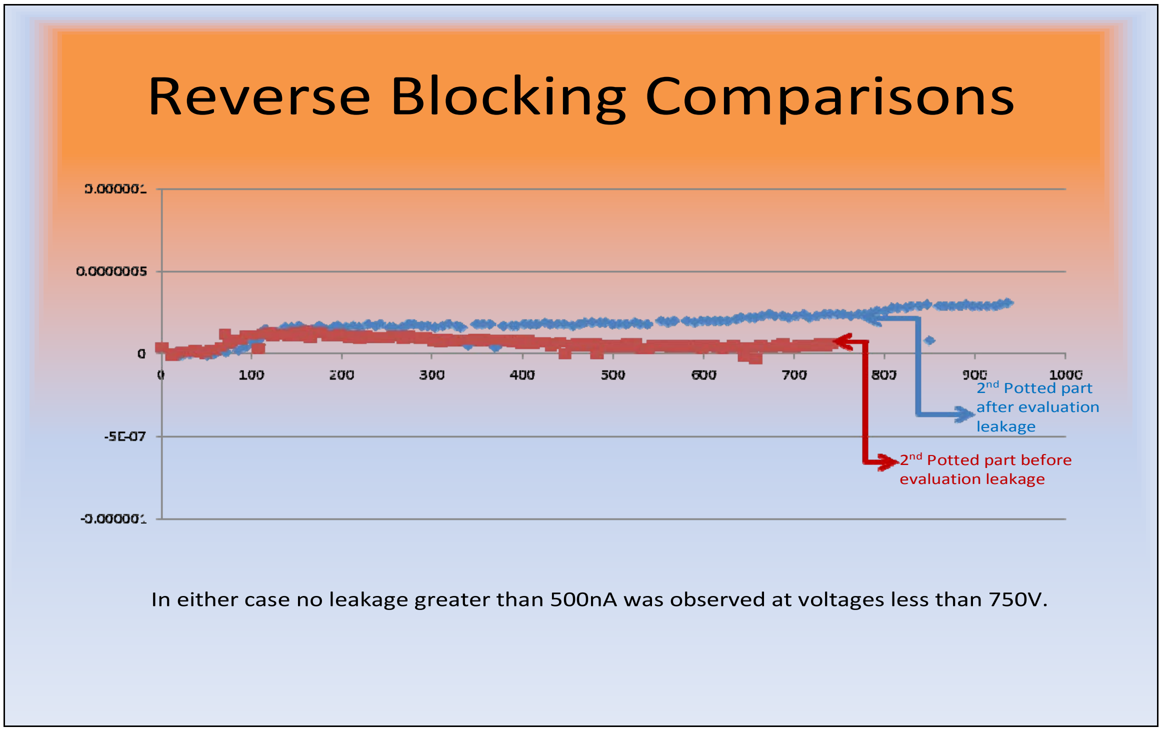

Figure 10. Overlay of pre and post stress blocking state current as a function of voltage for potted part 2.

Overall, we conclude that this potting compound, under the conditions to which it was exposed during the power cycling evaluation, did not significantly distort either chemically or physically in a way that would harm or hinder the basic functionality of the MOSFET devices being insulated. Furthermore, the potting material did not provide any real changes in thermal heating effects.

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