THERMAL MANAGEMENT SOLUTIONS FOR THE LED MARKET

K. Andrew Kintz
LORD Corporation, 110 Lord Drive, Cary, NC 27511
Andrew.Kintz@lord.com

Sara N. Paisner
LORD Corporation, 110 Lord Drive, Cary, NC 27511
Sara.Paisner@lord.com

M. Shane Thompson
LORD Corporation, 110 Lord Drive, Cary, NC 27511
Shane.Thompson@lord.com

ABSTRACT

High-brightness light emitting diodes (LEDs) are challenged with thermal management issues due to increased power and reduced surface area. This has led to the need for new materials with higher thermal conductivity that can quickly remove the heat from the active layer. LORD Corporation has developed two new thermal management materials, a “no pump-out” thermal grease and a low modulus die attach adhesive, as solutions to the heat dissipation problems facing LED manufacturers. These innovative technologies will help engineers solve complex fundamental thermal management problems.

A new 4 W/mK silicone thermal grease has been developed with significant resistance to in-package bleed-out or pump-out eliminating the reliability problem most commonly encountered with traditional thermal greases. A new 10-20 W/mK thermal epoxy adhesive has also been developed creating a new class of flexible adhesives with high adhesion. This combination allows the new LORD die attach adhesive to not only effectively transfer heat out of the package, but also to dissipate the stress caused by thermal expansion and contraction during thermal cycling thereby affording improved package reliability.

KEY WORDS: LED, thermal management, TIMs, thermal grease, thermally conductive adhesive, low thermal resistance, low modulus adhesives, die attach adhesive.

INTRODUCTION

The industry trend towards increased power and reduced overall area creates higher thermal loads for new packages.[1] The method for removing heat from a package usually involves the use of heat spreaders or heat sinks attached to the die, or both. Due to the surface roughness of the mating surfaces, thermal interface materials (TIMs) are necessary to reduce the thermal resistance at the interface. The new generation of larger, high-power LED packages has underscored the need for new TIMs with high thermal conductivity and low overall thermal resistance.[2] Thermal adhesives and greases can be used to aid in the removal of the heat from the LED package. Common application points for these materials can be seen in the Figure 1. While heat removal is the key design feature, these materials must function in a demanding environment and meet other design specifications. LORD Corporation has commercialized two new products, TC- 501 thermal grease and MT-815 thermal adhesive, which offer unique solutions to the thermal management problems associated with modern LED packages.

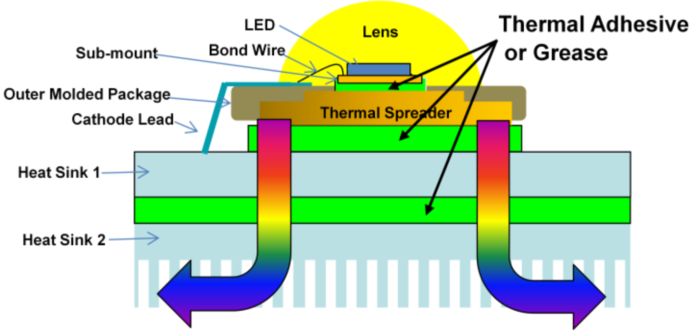

Figure 1.

Requirements for die attach adhesives are rigorous. Thermally conductive adhesives must accommodate the thermal stresses created in the package during thermal cycling due to the differences in the coefficient of thermal expansion (CTE) between the mating surfaces. Thermal adhesives are usually both very flexible with low thermal conductivity and low adhesion (i.e. silicone-based materials) or very rigid with high thermal conductivity and high adhesion (i.e. epoxy-based materials). As a result, conventional thermal adhesives' range of utility can be limiting for LED packages. To address this problem, a new 10-20 W/mK thermal adhesive has been developed creating a new class of flexible adhesives with high adhesion. This combination allows the material to effectively transfer heat out of the package and still dissipate the stress caused by thermal expansion during thermal cycling for improved package reliability.

High-performance thermal interface greases, gels, and adhesives significantly improve the transmission of heat out of electronic packages. Thermal greases generally have higher thermal conductivity than gels or adhesives, with similar fillers, due to the ability of greases to wet the surface both initially and during repeated heating and cooling cycles experienced by packages during use.[3,4] In other words, thermal greases are able to achieve very low interfacial resistances due to better surface wetting both initially and over time. Pump-out leads to increased bulk thermal resistance and increased interfacial resistance. For high-end applications, such a change in both the bulk and interfacial resistance is unacceptable due to the resulting dramatic reduction in performance. In order to overcome this reliability problem associated with traditional thermal greases, a new 4 W/mK silicone thermal grease has been developed.

RESULTS

New technology developments have resulted in the development of new silicone thermal grease (LORD TC-501) with properties that dramatically exceed traditional thermal greases while not pumping-out. TC-501 has typical thermal conductivity values of 4 W/mK (although in optimized packages even higher values have been measured). The optimal preparation method for each application is dependent upon individual LED package types and set-up. However, even with sub-optimal preparation, which resulted in lower thermal conductivity values, no pump-out was observed.

A new thermal adhesive (LORD MT-815) has also been developed to bridge the gap between traditional silicone- and epoxy-based adhesives, creating a new class of moderately flexible adhesives with high thermal conductivity and high adhesion. The high thermal conductivity combined with low modulus allows this material to absorb the stress caused by thermal expansion during thermal cycling, and thus effectively transfer heat out of the package or substrate. MT-815 provides a solution for applications where exceptional thermal performance and low stress are essential.

To test reliability of the TC-501 and the MT-815, the materials were tested individually as well as by comparison to a well-known commercial grease and a conventional, high modulus epoxy adhesive. Typical properties of the new materials are listed in Table 1. The reliability testing for thermal properties completed on TC-501 was 1,000 hours at 85ºC/85% relative humidity (RH), 1,000 hours at 150ºC high-temperature soak, and 1,000 thermal cycles from 0°C to 100°C with one-hour cycles. The testing was done with an internally designed thermal fixture using a NETZSCH *NanoFlash*® tester.[5] The 'sandwich' test samples, Figure 2, used for all reliability measurements in the *NanoFlash* tester were prepared with a previously described method.[6] The fixtures allowed for constant pressure on the grease sandwich samples. The samples were prepared using seven steps:

(1) TIM dispensed onto Ni/Cu substrate
(2) Second substrate placed using die bonder
(3) Sandwich structure placed into grease fixture
(4) Fixture placed into *NanoFlash* equipment
(5) Thermal conductivity (TC) measured in *NanoFlash*
(6) Reliability test conducted
(7) TC re-measured at end of test

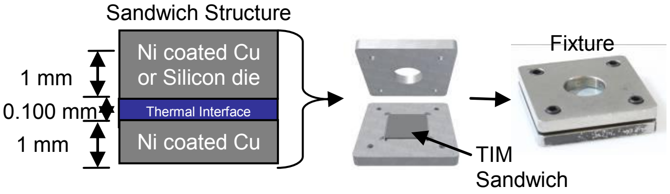

Figure 2. Thermal interface material 'sandwich' structure was used for testing *in situ* thermal conductivity (TC) and thermal resistance (TR) of developmental thermal materials.

Typical Properties	**TC-501**	**MT-815**
Appearance	Black Paste	Gray Paste
Viscosity (Pa.s)	85	70
Density (g/mL)	3.1	3.8
Work Life, hr@25C	N/A	24
Thermal conductivity (W/mK)	4.0	10-20
Volume Resistivity (Ohm-cm)	N/A	.00006
Glass Transition (C.)	N/A	11
Die Shear, PSI	N/A	6000
Flexural Modulus, MPa @ 25C.	N/A	500

TABLE 1.

These coated sandwich fixtures were used to test reliability using three different conditions. The first condition was to dispense TC-501 at room temperature (25°C) and then immediately place the test fixture into the reliability chamber. This would mimic the parts being used immediately after dispense, such that the structure-forming process is happening during use of the parts by the customer. The second preparation method was to take the test samples and place them into a 65°C oven four times for 10 minutes each. This would mimic the heating/cooling observed due to transit or a short burn-in process. The third condition was to place the parts into an 85°C oven for five hours to mimic a slow structuring process that might be experienced by parts during transit or due to more extensive burn-in tests. This condition accelerates the structure-forming process relative to room temperature, though it still remains slow.

TC-501 and a competitive grease were both tested in a fixture similar to the one shown for the thermal testing, but with a quartz die (due to its transparency) over the thermal material (instead of a silicon die used in thermal testing) to allow for visualization of the pumping-out and material separation normally observed in thermal greases.

With time, most greases pump-out. However, TC-501, which undergoes an internal structure forming process, exhibits no pump-out. Regardless of preparation method, the results are the same, as evidenced in Figure 3. This material is robust and survives all reliability testing conditions with no increase in thermal resistance. For thermal cycling, the thermal resistance actually decreases after the first set of cycles due to the improved interfacial wetting that occurs at higher temperatures. (For thermal cycling, the reduced initial thermal resistance seen in Method 2 is due to a lower bondline thickness (75 µm) of the samples used in that test. All other samples had a bond line thickness of approximately 100 µm.)

The internal structure that develops over time acts as a force to hold the filler and matrix together despite the stresses imposed by the CTE mismatch and flexing experienced by chip packages during heating and cooling cycles (such as during reliability testing). This eliminates the reliability problems most commonly encountered with traditional thermal greases, namely pump-out, cracking, and separation. This difference is most clearly demonstrated by comparing TC-501 to traditional greases in standard reliability testing methods.

Comparing how TC-501 and the competitive grease appear after thermal cycling (-40°C to 125°C for 1000 cycles) shows the difference in reliability. Thermal cycling is the most severe way to cause expansion and contraction in materials; despite the wide temperature range tested, TC-501 shows no visible change, while the competitive grease shows extensive separation and voiding. Both via thermal measurements and visual observation, TC-501 does not exhibit in-package bleed or separation during reliability testing and retains its low interfacial thermal resistance (Figure 4).

In addition to the thermal data collected during reliability testing, the post-reliability sandwich samples were also studied under C-mode scanning acoustic microscopy (CSAM). A sandwich sample that was subjected to 1,000 hours of 85°C/85% RH show no voiding or visible cracking, which suggests that no pump-out occurred.

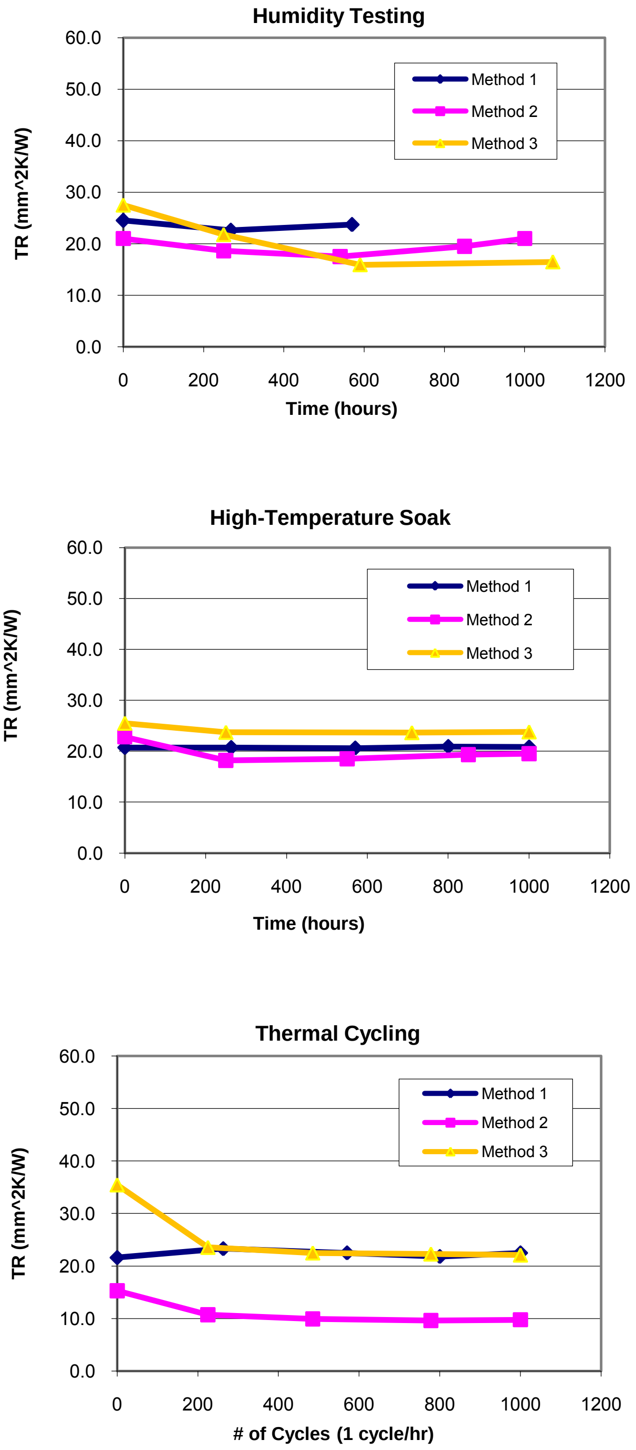

Figure 3. Reliability testing of TC-501 shows excellent results for 150°C high-temperature soak, 85°C/85% RH, and 0°C-to-100°C thermal cycling.

TC-501
647 cycles

Competitive grease
164 cycles

Figure 4. No voiding or separation in TC-501 compared to a Traditional Grease. Conditions: 1,000 thermal cycles from 0°C to 100°C for 1 hour; sandwich structure is Ni/Cu-TIM-quartz glass.

In use, the thermal adhesive must maintain thermal performance after exposure to a variety of stresses. To evaluate the reliability of the MT-815, sandwich structures were used to characterize the thermal resistance of the thermal adhesive after exposure to 1000 hours at 150°C and 1000 cycles of thermal cycling from -40°C to 125°C at 1 hour/cycle as shown in Figures 5. The data show the low resistance after cure as well as a drop in resistance after additional thermal aging. The key information gained from this study is that thermal resistance does not increase after exposure to such conditions.

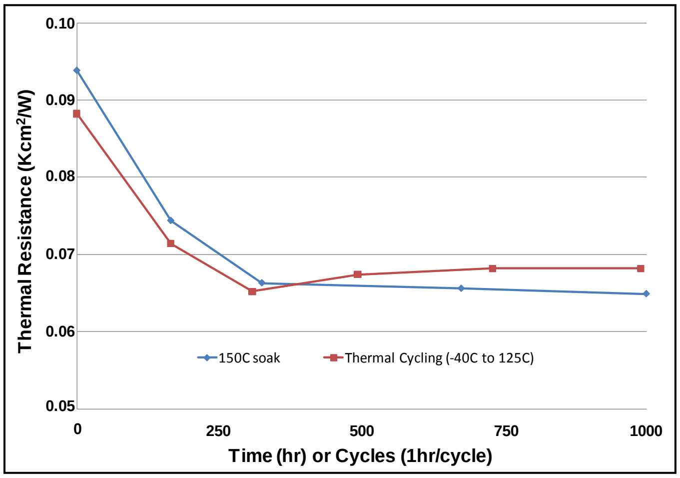

Figure 5. Reliability testing of MT-815 shows excellent results for 150°C high-temperature soak and 40°C to 125°C thermal cycling.

A comparison of the die shear strength of a conventional, high modulus epoxy adhesive versus the low modulus MT-815 adhesive is shown in Figure 6. Die shear adhesion tests were performed on Au-coated Al_2O_3 die (80 x 80 mil and 520 x 200 mil) bonded to Ni-coated aluminum after 120 cycles of -40°C to 85°C at 1 hr/cycle. The conventional high modulus epoxy adhesive displays a dramatic drop in die shear adhesion, especially for the larger die size, while the low modulus adhesive retains the majority of its adhesive strength. Figure 7 shows that the low modulus adhesive also maintains its adhesive strength after exposure to 150°C high temperature soak.

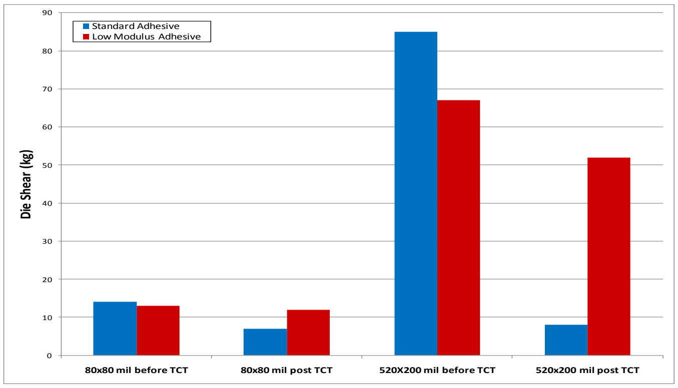

Figure 6. The low modulus adhesive shows superior retention of die shear strength after thermal cycling at -40°C to 85°C at 1 hr/cycle on large and small die.

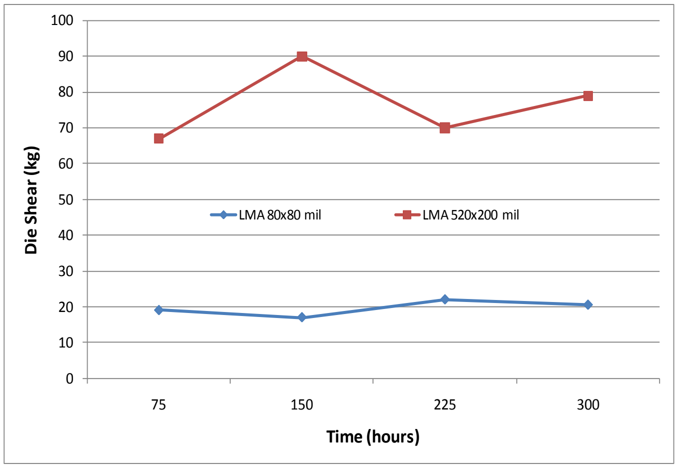

Figure 7. The low modulus adhesive shows excellent retention of die shear strength after 300 hours of 150°C high temperature soak.

CONCLUSIONS

Thermal greases have the ability to deliver high thermal conductivity, but their propensity to pump out has limited their use, especially in demanding applications. The development of a no pump-out grease with high conductivity can potentially expand the use of greases in LED applications. Similarly, low modulus die attach adhesives have been developed, creating a new class of flexible products with high adhesion and outstanding thermal performance (10-20 W/mK). The high thermal conductivity combined with a low modulus allows the material to dissipate the stress caused by thermal expansion during thermal cycling, and thus effectively making them excellent for applications in high-power LED packages and light engines.

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[1] Saums, Dave; Jarrett, Bob; Mackie, Andy C.; Ross, Jordan, "Thermal management materials choices for power semiconductors," *Advancing Microelectronics* Volume 36, Issue 4, pp 8-16, 2009

[2] "Synthesis of thermal interface material with high thermal conductivity for high efficiency of LED," Han, C. J.; Yu, S. H.; Hong, S. J.; Kim, Y. S.; Han, J. I., *Clean Technology Conference & Expo 2009,* pp 337-339, 2009

[3] "'Dry-to-the-touch' thermal grease," Khatri, Prakash; Ziemski, John, "Proceedings - International Symposium on Advanced Packaging Materials: Processes, Properties and Interfaces, Braselton, GA, United States," pp 236-240, 2001

[4] "Chip package with grease heat sink and method of making," Akram, Salman; US patent 2002052105 A1, Oct 6, 2005

[5] Robert C. Campbell, Stephen E. Smith and Raymond L. Dietz, "Measurement of adhesive bondline effective thermal conductivity and thermal resistance using the laser flash method," *15th IEEE SEMI-THERM Symposium*, San Diego, CA, pp 83-97, 1999.

[6] Gowda, A; Esler, D; Paisner, S.N.; Tonapi, S.; Nagarkar, K; Srihari, K "Reliability Testing of Silicone-based Thermal Greases," *21st IEEE SEMI-THERM* 2005 Symposium Book.