High-Durability Coating for Improved Thermal Management of Pluggable Optical Modules

R. Chesterfield[1], P. Goli[1], S. Querelle-Halverson[1], E. Sullivan[1], Z. Hoyt[1], K. Olson[1] M. Bren[1], A. Aranyosi[2], S. Doan[2], V. Le[2]
[1]Henkel Corporation, 18930 W. 78th Street, Chanhassen, MN 55317, USA
[2]Juniper Networks,1137 Innovation Way, Sunnyvale, CA 94089, USA
Reid.chesterfield@henkel.com, aaranyosi@juniper.net

Abstract: We introduce a new high-durability thermal interface coating designed to improve pluggable optical module to heat sink thermal transfer. Performance data and test methods for thermal resistance, durability, and long-term reliability are presented.
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1. Introduction

The remarkable growth in cloud computing is driving demand for 400 Gigabit Ethernet (GbE) which in turn creates challenges for temperature rise in pluggable optical transceiver modules (POMs) [1]. For example, in a common POM class, Quad Small Form-factor Pluggable (QSFP), power dissipation requirements have increased from 4-5W typical for QSFP-28 (100 GbE) to 15-20W for the latest generation (400 GbE) QSFP - Double Density (QSFP-DD) modules. To address the design complexity of multiple manufacturers and integrators, multisource agreements (MSAs) exist to coordinate specifications for the POM, connector, and cage systems [2]. Cages are sheet metal enclosures press mounted to a printed circuit board (PCB) and provide connector alignment and electromagnetic compatibility. Cost effective designs typically provide a spring-loaded riding heat sink (HS) mounted to the cage that contacts the inserted lid of the POM as shown in Fig. 1.

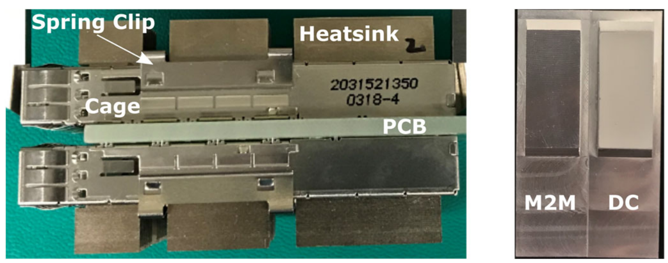

Fig. 1. Side view of QSFP-DD POM, cage, and spring clip assembly (left). Heat sinks with durable coating (DC) and without (M2M) (right).

Insertion and pull (I&P) of the POM forces the module lid metal across the HS surface under the spring clip vertical pressure (~10 psi). This scraping action can damage both metal surfaces and creates a challenge for achieving and maintaining low interface thermal resistance. Thermal interface materials (TIMs) such as liquid greases or thin soft pads are effective to reduce interfacial resistance by eliminating air at a metal-to-metal (M2M) interface [3]. However, commercially available TIMs are not designed to maintain shape and thermal function with repeated I&P of a POM [4]. The combination of high durability and thermal gap filling required a new material to enable a reliable solution.

This paper introduces a new durable coating (DC), developed by Henkel specifically for POM/HS application, and designed to improve efficiency of heat transfer between the POM and HS. We will describe the thermal resistance (TR) improvement and various aspects of the function and reliability of the new DC versus a control M2M interface.

2. Experimental Details

A Zygo® ZeGage™ optical profilometer with micrometer X-Y resolution was used to measure HS flatness, roughness, and DC thickness.

A simplified thermal test vehicle (s-TTV) setup was used to measure the TR at the POM-HS interface. A s-TTV-POM, QSFP-DD stacked cage, drilled HS and fan were combined in the s-TTV setup. The s-TTV-POM is an empty POM shell where the PCB and heat sources are replaced by an adhered tunable ceramic heater on the top inside surface. A hole for inserted thermocouple was drilled in the HS at a centered location above the heat source. The power applied to the ceramic heater is used to calculate the TR by the following:

$$TR\ (°\mathrm{C/W}) = \frac{T_{Heat\ Source}\ (°\mathrm{C}) - T_{Heat\ sink}\ (°\mathrm{C})}{Power\ (W)} \tag{1}$$

For pressure dependent measurements the spring clip was removed from the s-TTV setup and replaced by fixtured dead weights to control the static pressure between HS and POM. All manual I&Ps were completed with a separate cage, spring clip, and POM to avoid damaging the surface of the s-TTV-POM used to measure the TR.

Long term reliability in standard environmental chambers was measured every 250 hrs. up to 1,000 hrs. under 3 aging conditions: 85°C/85%RH, 125°C, and thermal cycling from -40°C to 125°C with a dwell time of 30 minutes and a ramp rate of 50°C/min.

3. DC Characterization and Discussion

The durable coating is a silicone thermoset-ceramic composite film and is optimized for both aluminum and copper HS metals. For this study, commercially available HS, cage, and clips were used (TE 2299940-3). HSs were compliant with MSA roughness and flatness requirements (50 µm and 0.8 µm, respectively). Optical profilometry reveals the concave nature of the mirror-like, fly-cut HS contact surface. There is a valley profile with high spots at the edges (Fig. 2 top right) and cutting tool grooves clearly visible. DC thickness was optimized for QSFP-DD at 23 ± 4 µm.

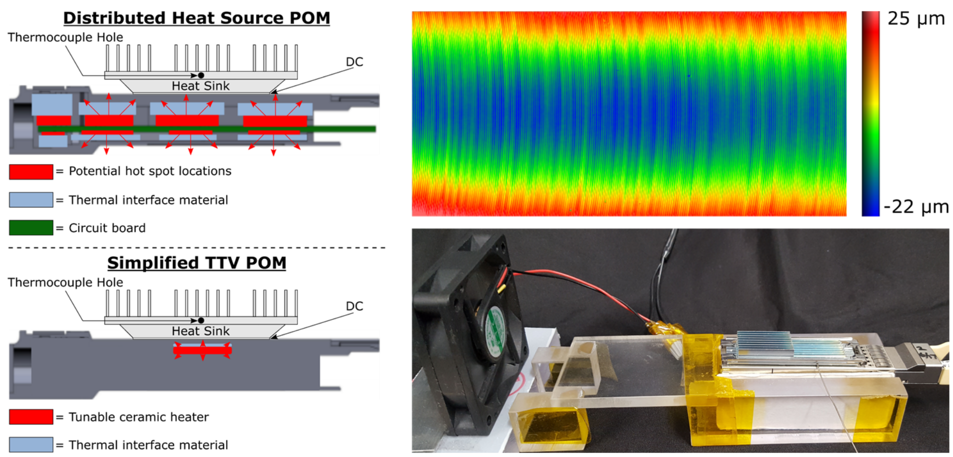

Fig. 2. Distributed heat source POM (top left), s-TTV-POM (bottom left); sample HS surface profile (top right) and s-TTV setup (bottom right).

Multilane Inc. makes passive loopback modules to simulate real 400 GbE POMs (Fig. 2 top left). These modules are well-suited to control the location and amount of power in a QSFP-DD for server or router design purposes. For improved precision, the s-TTV POM and setup were developed to concentrate the thermal pathway *between the POM lid and HS surface,* where a TIM in between has influence on the overall POM temperature.

Using the s-TTV, the DC showed a TR improvement of 0.33°C/W versus a M2M (Fig. 3 left). By extrapolation, a high-power density POM requiring 15W power dissipation, will be ~5°C cooler using a DC vs. M2M HS interface.

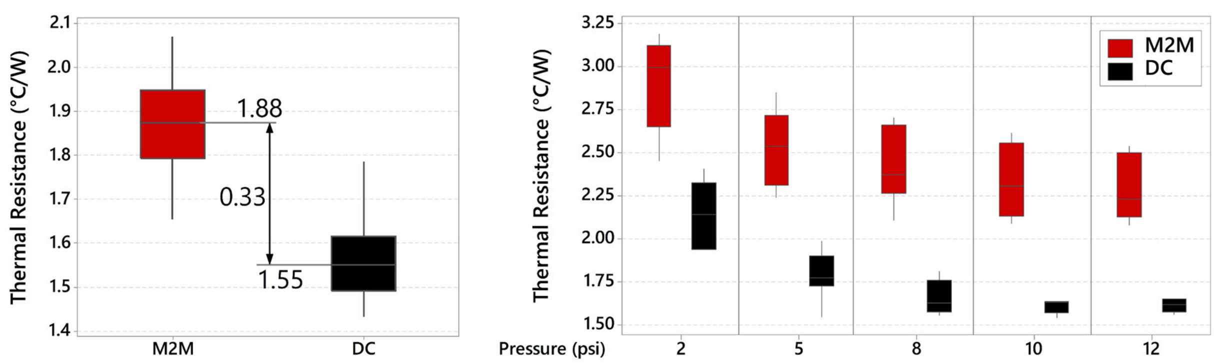

Fig. 3. Boxplot of TR using M2M (in red) and DC-POM (in black) interfaces measured for ~100 HS (left). Data boxplot for TRs at the M2M (in red) and DC-POM (in black) interfaces after 10 I&Ps with increasing contact pressure between the HS and s-TTV-POM (right).

Interfacial resistance models predict the TR to decrease with increasing spring clip pressure [3]. This was confirmed experimentally by measuring the TR while increasing the contact pressure on HSs that had 10 I&Ps of the POM (Fig. 3 right). From 2 to 12 psi, the DC shows better TR vs. M2M interface and the TR does not significantly change for pressures above 8 psi. The allowed spring clip pressure is limited by the 50N POM-cage maximum extraction force given in the QSFP-DD MSA [2]. While this is a limitation for M2M heat transfer, it is not with the DC because as little as 8 psi clip pressure is enough.

The current QSFP-DD MSA specification calls for a minimum of 50 I&P cycles for durability of the POM and 100 I&P cycles for the connector/cage [2]. The TR at the M2M and DC-POM interfaces were measured up to 500 I&P cycles. In as little as 10 cycles, the M2M TR degraded more than 0.75 °C/W, whereas, even after 500 cycles the DC is similar to initial TR (Fig. 4 left). It was also observed that the DC caused much less damage to the POM lid than the M2M HS. Optical profiles reveal grooves on both the POM and HS surfaces as deep as 40-80 µm after only 10 I&P cycles using a M2M interface, Figure 4 (center) shows an example image of 50 cycles of I&P for comparison.

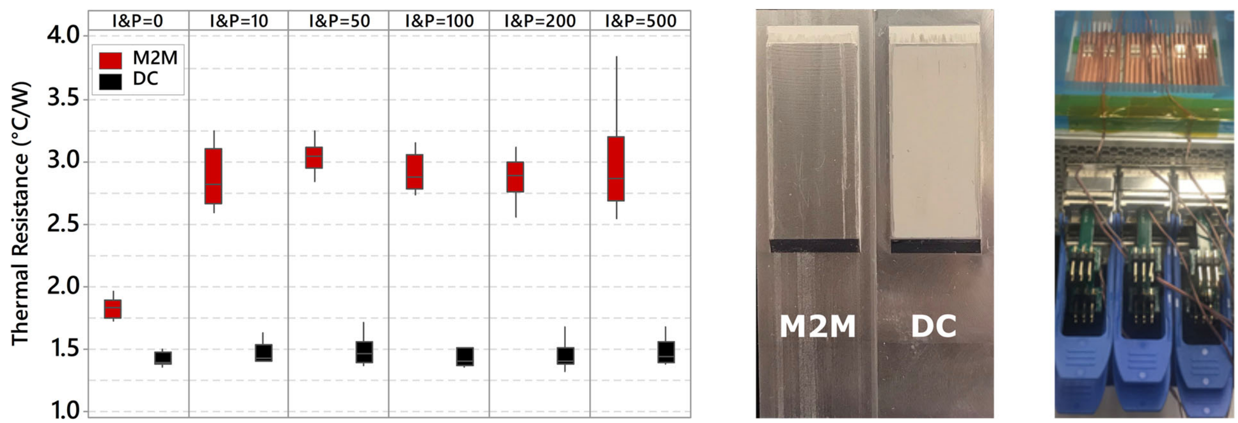

Fig. 4. Boxplot of TR on s-TTV for M2M (in red) and DC (in black) after 0 to 500 I&Ps (left). Example of 50 I&P damage on both HS surfaces (center). Setup / configuration for one of Juniper Networks performance verification tests (right).

A reliability study using the 3 aging conditions showed that the coating TR and durability do not degrade after 1,000 hrs. Additionally, after 1,000 hrs. of thermal cycling between -40°C and 125°C, the DC maintained an extraction force below 50N, this condition ensures the POM can be extracted from the cage throughout field life [2].

To confirm manufacturing scale-up of the DC, a pilot line was constructed by Henkel in Chanhassen, MN with a capacity of 40,000 HS per month. In one manufacturing trial, 1,200 coated HSs were made in 1.5 hrs. and full validation testing was done to provide data used in this paper. Additionally, the DC has been shown to withstand electroless nickel plating and high temperature solder processes which are frequently used in commercial HS assembly, and the DC shows no change in TR or durability in lab testing after these processes.

Comprehensive testing was conducted at Juniper Networks to verify the thermal performance of the DC. Tests were performed with a variety of heatsinks, mounting solutions and optics configurations, including belly-to-belly and stacked arrangements. Testing was done in actual systems under development with Multilane™ QSFP-DD passive feedback modules that were used to mimic the power dissipation maps of real POMs from different vendors. The total POM power ranged from 14W to 22W. The thermal performance was measured after every 10 I&Ps up to a total of 100 cycles. The measured performance showed negligible degradation after 100 cycles and 0.35-0.40 °C/W improvement over the TR achieved with dry, M2M riding HS. At 22W total module power this translates into 8-9 °C temperature reduction using the DC HS.

4. Conclusion

We have developed and confirmed the performance of a durable heat sink coating in both simplified TTV and actual system testing. While initially developed by Henkel for QSFP modules, the DC can be used for thermal management of other format POMs and in principle other applications requiring an abrasion durable TIM.

5. References

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