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IN SITU TESTING OF METAL MICRO-TEXTURED THERMAL INTERFACE MATERIALS IN TELECOMMUNICATIONS APPLICATIONS

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Abstract. A metal micro-textured thermal interface material (MMT-TIM) has been developed to address the shortcomings of conventional TIMs for Remote Radio Heat (RRH) applications. The performance of the MMT-TIM was characterized in-situ by monitoring the temperatures of the dominant heat generating devices in an RRH Power Amplifier for a fixed input power. Measurements show that the use of the MMT-TIM results in significantly lower devices temperatures than achieved with the conventionally used graphite pads with a maximum temperature drop of 14.9 °C observed. The effect of power cycling on the long term performance trends is also examined.

1. Introduction

The mitigation of thermal contact resistance is essential to the performance of conduction-based electronic thermal management solutions which are employed in numerous ICT applications. Typically the most feasible strategy to reduce thermal contact resistance is to insert a thermal interface material (TIM) of higher thermal conductivity between the mating surfaces to conform to the contacting surface asperities and displace any micro and macroscopic air voids, thereby providing an improved path for heat transfer between the two components.

To work effectively, TIMs must physically conform to the mating surfaces under reasonable assembly pressures and exhibit low contact resistance with adequate bulk thermal conductivity. The bond-line thickness values are kept as low as possible to help reduce bulk thermal resistance; however the thickness must be sufficiently large to enable the TIM to comply with surface irregularities and non-planarities.

Many different TIMs are commercially available that attempt to meet these requirements in different ways. These include a range of adhesives, greases, elastomeric pads, phase-change, carbon and nano-structured materials [1-3]. However, the main weakness of many commercially available TIMs remains their relatively poor

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thermal performance. Many of these technologies typically consist of a low-conductivity organic phase, such as silicone grease, interspersed with higher conductivity metal (e.g. silver, copper) or ceramic particles (e.g. aluminium oxide, zinc oxide or boron nitride) to enhance the bulk thermal conductivity of the material.

2. Metal Micro-Textured Thermal Interface Materials

To address the performance limitations of conventional thermal interface materials, particularly graphite pads used in RRH PA applications, a metal micro-textured thermal interface material (MMT-TIM) has been developed [10, 11]. The concept is illustrated in Fig. 1. These materials consist an array of small-scale (≈0.1 mm to 1 mm) raised features. When this structure is compressed between two mating surfaces, the features plastically deform and conform to the contacting bodies as illustrated in Fig. 1.

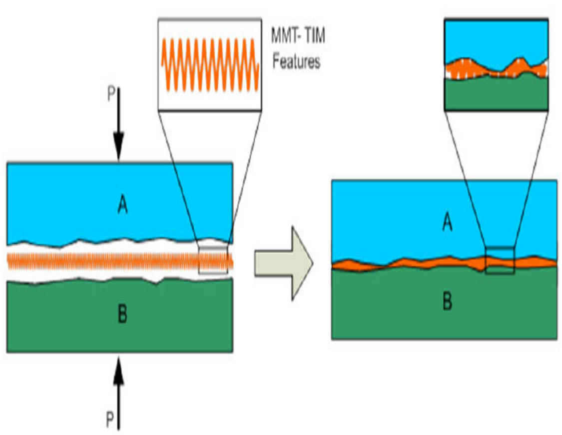

Fig. 1: Metal Micro-Textured Thermal Interface Material Concept

Plastic deformation of the features into the asperities of the contacting surfaces ensures intimate contact with the contacting bodies. The result is an array of conformable, yet continuous solid metal features of low thermal resistance (or high effective thermal conductivity) that are in intimate contact with the mating surfaces due to the plastic deformation of the raised features.

Given the nature of this concept, there is clearly a large design space within which the materials and geometries of the MMT-TIMs could be optimized to minimize thermal resistance and compressive pressure while maximizing mechanical compliance and effective thermal conductivity. Initial investigations into MMT-TIMs explored the effect of size and shape of the raised features on their thermal-mechanical response during compression [10, 11].

Complete thermal-mechanical models which simultaneously characterize the complex feature deformation and effective thermal resistance of MMT-TIMs have been developed to serve as design tools for these materials [12, 13].

The present embodiment of this technology is shown in Fig. 2. In this embodiment, the TIM geometry consists of continuously formed truncated domes approximately 0.5 mm in size extending in both directions from a mid-plane however. This geometry is desirable because it readily allows for buckling and compression when assembled between two components. The open “holes” in the tops and bottoms of the raised features reduce the stiffness of these structures and allow the compression and flow of metal as the entire structure is compressed. These MMT-TIMs were fabricated from flat, 25

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μm tin foil using a proprietary micro-stamping operation.

The objective of the present study is to characterize the thermal performance of a remote radio head (RRH) using the MMT-TIM shown in Fig. 2 installed in the critical interface between the power amplifier (PA) board and the main natural convection heat sink.

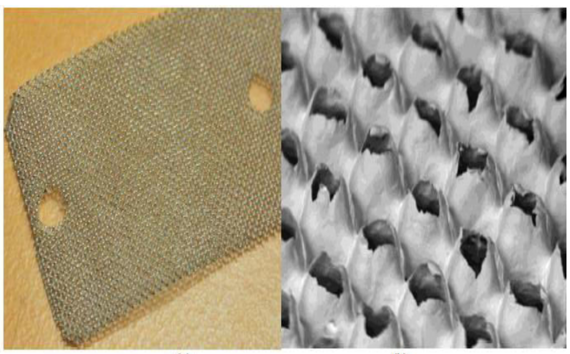

Fig. 2: a) Photograph and, b) SEM image of a MMT-TIM prior to compression

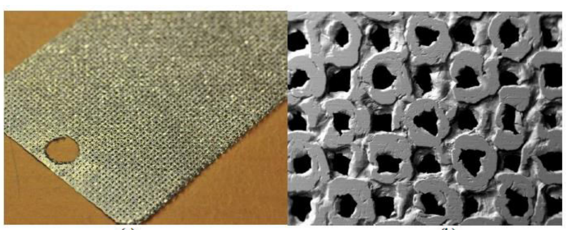

Fig. 3: a) Photograph and, b) SEM image of a MMT-TIM subsequent to compression

2. Experiment Characterization

A drawing of the RRH in-situ test setup employed in the present study is shown in Fig. 4. The upper part of the RRH consists of a PA heat sink on which the PA board is mounted. Here The PA transistors (shown in red) are the dominant heat-generating components on the PA board (blue). This PA is configured of two main and peak pairs (Doherty configuration). The PA transistors are soldered to a flush mounted copper coin embedded and flush mounted with the bottom of the PCB. These coins serve primary RF ground purpose but do afford some heat spreading. The TIM is between the PA board and the heat sink and an RF shield is mounted over the PA board. Forty M3 screws torqued to 1.0 N·m bolt the RF shield to the heat sink, sandwiching the PCB tightly against the heat sink. Standard screw fasteners and torque patterns were maintained.

The aluminum heat sink is approximately 500 mm tall and 270 mm wide and contains several heat pipes embedded in the base to improve heat spreading. The fins are optimized for natural convection.

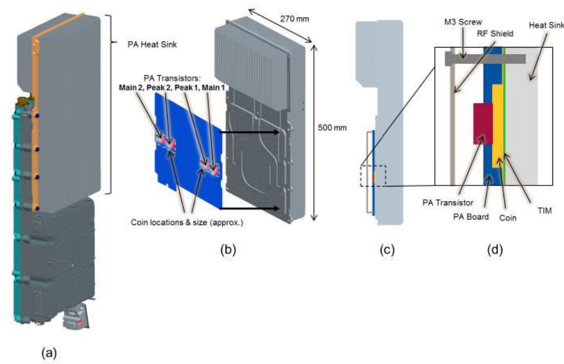

Fig. 4: Drawing of the RRH PA assembly used in the present work a) overall RRH with PA heat sink indicated, b) PA board (transistors in red) and PA contact interface with heat sink, c) side view of assembly showing d) cross-section of assembled component stack-up

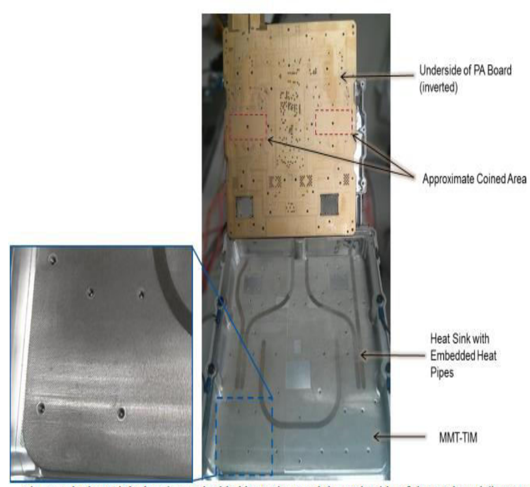

Fig. 5: The heat sink showing embedded heat pipes and the underside of the PA board (inverted relative to the heat sink) with a close up of the MMT-TIM prior to installation

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A photograph of the contact area of the heat sink and the underside of the PA board (inverted relative to the heat sink) is shown in Fig. 5. Here the approximate size and shape of the flush-mounted coins in the PA board are indicated. Also visible are the embedded heat pipes in the heat sink base and the MMT-TIM prior to installation.

The outer case of each PA transistor was instrumented with a T-type thermocouple using a high-temperature epoxy. An additional thermocouple was used to measure the ambient air temperature. The required heat load was generated by the transistors themselves by wiring them in a bias mode. Four TTi CPX4000DP DC power supplies provided the operating and bias voltages. The power dissipated by each device was controlled by varying the bias voltage of the circuit and measured by computing the product of the current draw and operating voltage. A fixed power of 81.5 W on the two main devices and 23.6 W on the two peak devices was used. This corresponds to the maximum thermal output of these devices in the field. Ambient temperature was approximately 20 °C.

3. Results & Discussion

Four different interface conditions were tested and compared: i) the PA assembled with no TIM, ii) using a flat, 25 tin foil, iii) the conventionally specified graphite pad , iv) the tin MMT-TIM presented in the previous section. The thermal resistance of this interface (and indeed the system) is difficult to characterize due to the presence of multiple heat sources with thermal communication between them. Consequently, results here are presented using the heat source temperatures rather than thermal resistance.

The steady-state temperature of each device above ambient is shown in Fig. 6 for each of the four interface conditions. As could be expected, using no TIM resulted in the highest observed device temperatures with outer case temperature of Main 1 at 88.5 °C. The conventionally used graphite pad lowered this temperature somewhat while the MMT-TIM resulted in significantly lower device temperatures across the board. For comparison, an un-textured flat Sn foil was also tested as thermal interface material however, only minimal temperature reductions were observed.

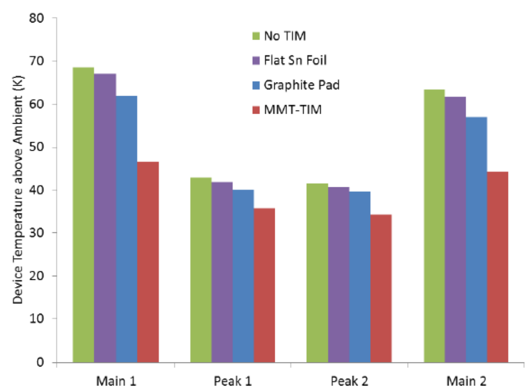

Fig. 6: Device operating temperatures for different TIMs

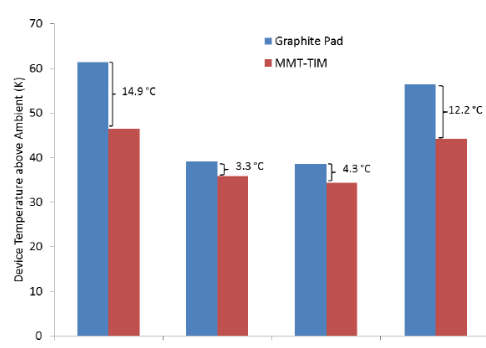

Fig. 7: Detailed comparison between conventional graphite pad and MMT-TIM in terms of resultant device temperatures

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The results further illustrate the thermal benefit from using a MMT-TIM in this assembly compared to a conventional graphite pad. This level of temperature reduction has significant implications on overall system design. For example, this level of temperature reduction can have significant positive implications upon device and system reliability. Alternatively, the decreased thermal resistance of this interface can be offset by employing a smaller and lighter heat sink in order to minimize the overall size and weight of the RRH.

The results presented so far characterize the MMT-TIM at shortly after installation at beginning of life. Another crucial aspect is how the TIM performs over time as the assembled interfaces heat up and cool down, expanding and contracting over time. Power cycling tests are recommended for assessing TIM reliability since these tests resemble most closely the actual use of the material [14].

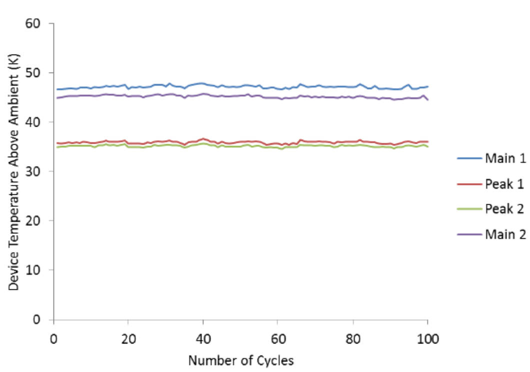

Fig. 8: PA transistor steady-state temperatures during power cycling

4. Conclusions

In-situ tests of a metal micro-textured textured thermal interface material (MMT-TIM) in an RRH PA application have demonstrated a significant reduction in system thermal resistance and therefore device operating temperatures. These temperature reductions will allow for improved system reliability or could be traded off against a smaller heat sink to decrease overall system size and weight.

System power cycling tests were employed to make an initial assessment into the reliability of MMT-TIMs in this application and it was shown that the device temperature remained constant over 100 cycles from zero to full power.

This experimental data will be combined with system-level numerical simulations in order to establish the fractional contribution played by MMT-TIM to the total thermal resistance of the RRH and evaluate possible reductions in heat sink size and weight as a result of lowering the interface resistance.

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