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Research Paper

Measurement of thermal interface conductance at variable clamping pressures using a steady state method

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HIGHLIGHTS

- Characterization of interface conductance with and without TIM.
- Designed and built a steady state characterization experiment.
- Measured the conductance of six commercial thermal interface materials.
- Investigated how interface conductance varies with clamping pressure.

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ABSTRACT

Thermal conductance of an interface, between aluminum surfaces, was measured at pressures ranging from 0.172 to 2.76 MPa. The conductance was measured for a bare interface as well as with several commercial thermal interface materials (TIMs) applied. A steady state TIM characterization device was developed in house. A total of six different TIMs were tested using this device: Tgrease 880, Tflex 720, Tmate 2905c, Tpcm HP105, Cho-Therm 1671, and Cho-Therm T500. The characterized TIMs showed a very strong dependence on clamping pressure. The conductance of samples at 2.76 MPa were shown to be between 135% and 515% greater than the conductance at 0.172 MPa. Many of the samples showed a near linear increase in conductance while others leveled off at higher pressures. The steady state characterization device was found to have high experimental uncertainty when characterizing high conductance TIM samples (specifically Tgrease 880). It was determined that this uncertainty was mainly the result of inadequate cooling.

1. Introduction

One of the major practical applications for thermal interface materials (TIMs) is in electrical component cooling, most notably computer processors. The computer industry strives for chips with increased processing power and smaller die sizes. With current technology this results in an increased heat dissipation and decreased heat transfer area, both contributing to increasing the heat flux required to cool components. As a result, the cooling of microchips has become a significant challenge to the development of smaller, faster microchip designs [1]. The optimization of the cooling circuit for electronic components will play an important role in the continued development of computer systems; TIMs play a large part in the overall design efficiency of cooling solutions for electronic components.

The primary goal of a TIM is to increase the thermal conductance across an interface. When two surfaces are pressed together, only a small portion of the total area is in direct contact due to surface features such as roughness and flatness. As a result, air is trapped between the two surfaces [2]. TIMs are deformable materials which can be placed into the interface to fill air pockets and improve the thermal conductance of that interface. Some TIMs are also designed with additional goals, for example, electrically insulating two surfaces [2].

TIM cannot be suitably characterized by a bulk thermal conductivity because their performance depends both on their inherent thermal properties and their ability to conform to the two sides of the interface. It is useful to think of a TIM in an interface in terms of a small thermal circuit containing three components: two contact resistances associated with the TIM contacting either side of the interface and a resistance associated with the bulk layer of TIM [3]. Some test methods are designed to separate the contact components from the conductance of the TIM layer itself while others focus on the total conductance of the interface [3]. The conductance of an interface with a TIM applied will vary with: the surface characteristics of the interface (roughness and flatness), the clamping pressure applied to the interface, the operating temperature, mechanical properties and the thermal properties of the TIM [3].

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There are two basic methods of characterizing TIMs described in the literature: steady state and transient. The steady state method is typified by ASTM D5470-12 “Standard Test Method for Thermal Transmission Properties of Thermally Conductive Electrical Insulation Materials” [4] and involves setting up a steady state, one dimensional heat transfer through the TIM sample. Interface conductance is then determined from the ratio of the heat flux through the interface to the temperature drop across the interface [4,5]. The standard steady state test procedure will determine the total conductance of the interface. There is a method, often referred to as the variable bond line thickness (BLT) method, which can be used to determine the contact component of the conductance. In a variable BLT test, the steady state test method is used to determine the conductance of several different thicknesses of TIM sample; result of which are used to extrapolate the conductance of the interface with zero BLT and this value is the contact component [2,3].

The transient characterization method involves placing the TIM sample between two thin plates and applying a transient pulse of heat to one side of the assembly and then recording the transient temperature response at the opposite side. Deconvolution algorithms are used to identify the resistive elements in the thermal circuit. A commonly cited transient test method is the laser flash diffusivity method [6–9]. This method inherently determines the contact component of the total interface conductance separately from the TIM thickness component.

Several authors have published on the merits of the different types of testing [2,3,10]. There is no consensus in the literature as to which test method is superior. The steady state method is well defined by ASTM D5470 and has been adopted by most TIM manufacturers. The calculations for the steady state method are simpler than for the transient method and the conditions during testing closely parallel the conditions of the intended application. However, due to the steady state nature of the testing, this method is quite slow which reduces the number of data points which can be realistically collected. The transient method on the other hand is quick and inherently provides more information than the steady state test method. The transient method is conceptually more complex and the test environment is very different from that of the intended TIM application. There are little published data which show a steady state apparatus and a transient apparatus concurrently being used to produce the same result.

Both the steady state and transient methods have been used extensively to evaluate different TIMs. Luo et al., from the University of New York at Buffalo, used the transient laser flash method to measure the conductance of six different formulations of thermal paste to investigate how their conductance deteriorated after thermal cycling. Samples were tested at a single clamping pressure (0.46 MPa) [11]. Researchers from the same laboratory have published three other papers where they used the transient laser flash method to study the conductance of other TIMs [12–14]. Xu et al. measured the conductance of a lithium doped polyethylene glycol TIM at 0.46 MPa [12]. In another paper Xu et al. measured the conductance of a sodium silicate based TIM over a pressure range of 0.23–1.15 MPa. The conductance values show no consistent trend with increasing pressure [13]. Liu and Chung found that the conductance of a boron nitride particle filled paraffin wax showed an upward trend over the pressure range of 0–0.43 MPa. This trend was non-linear, showing a tendency to level off at pressures above 0.3 MPa [14]. Khuu et al. used the transient laser flash method to analyze the degradation of different TIMs under temperature cycling as well as elevated temperature and humidity [15] but did not measure the clamping pressure during testing. Instead the percentage compression of the sample was controlled during loading. Liu et al. used a steady state method to analyze the effect of adding carbon nanotubes into a silicone elastomer TIM. Samples were measured at a clamping pressure of 3.0 MPa [16]. Carlberg et al. used a steady state method to analyze polymer–metal nano-composite films as TIMs. The samples were tested at clamping pressures ranging from 0.2 to 0.8 MPa and showed a linear increase in conductance over this range of clamping pressures [17]. Xu and Fisher used the steady state method to study the use of carbon nanotube (CNT) arrays as TIMs. Measurements were made at clamping pressures between 0.15 and 0.45 MPa. The measured conductance of the CNT arrays shows a linear increase. However, when the CNT arrays were combined with an indium sheet or a commercial phase change material (PCM) based TIM, the conductance leveled off around 0.35 MPa [18]. Roy et al. used the steady state method to characterize several low melting temperature alloys at pressures ranging from 0.034 to 0.34 MPa. It was found that the conductance of the low melting temperature alloy samples was nearly independent of pressure over the range tested [19]. Vass-Várnai et al. developed an in house testing apparatus which combines the transient method and the BLT method into a novel test methodology [20].

A related area of study is the modeling and prediction of thermal interface conductance. This work ranges from complex numerical studies to simpler analytical approaches. Kempers et al. used the finite element method to produce a sophisticated mechanical and thermal model of the deformation of microscale surface features with application to thermal interfaces. Yuan et al. and Some et al. both presented analytical models of thermal interface contact [21,22]. There is a need for a practical engineering tool for estimating the thermal conductance of an interface using three readily available factors: TIM properties, clamping pressure, and surface finish. It is important that there is an extensive and reliable database of experimental results to allow researchers to validate these models.

Many of the researchers who have published conductance data on TIMs have done so in the interest of characterizing a particular TIM, often one they have developed. The author is unaware of research devoted purely to the observation of how the thermal interface conductance varies with clamping pressure in different types of TIM. In this work the author used a steady state method, on an apparatus designed in-house, to measure the interface conductance of six commercially available TIM samples: Tgrease 880, Tflex 720, Tmate 2905c, Tpcm HP105, Cho-Therm 1671, and Cho-Therm T500. These TIM samples represent four different groups of TIM: particle filled silicone greases, particle filled gap fillers, phase change material TIMs, and elastomer gap pads. Samples were tested at clamping pressures ranging from 0.172 to 2.76 MPa. The primary focus of this study is the investigation of how total conductance varies with clamping pressure in different families of TIM. Ultimately, total conduction of the interface is of primary interest to practicing engineers, manufacturers and researchers working on modeling the total behavior of TIM.

2. Methodology

A steady state method was used to measure the contact conductance of TIM samples. This method closely approximates the actual operating conditions of most TIMs, *i.e.*, long-term heat transfer through a TIM sandwiched between two solid surfaces under a predefined clamping pressure. The rigidity of the meter bars and the design of the steady state press make it easy to ensure that the pressure is applied evenly over the sample area. Most TIM manufacturers have adopted this method.

The core of this characterization method is to approximate a steady state one dimensional heat transfer through the TIM sample. Under these conditions, the temperature gradient through the system will be linear and the interface conductance can be calculated using explicit heat transfer equations. The challenge is in approximating a steady state one dimensional system, and therefore, in the experimental design. The methodology used in this paper is essentially the same as that from ASTM D5470, except that only the total