Experimental Thermal and Fluid Science 35 (2011) 1250–1254

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

Characterization of a liquid–metal microdroplet thermal interface material

A. Hamdan, A. McLanahan, R. Richards, C. Richards *

School of Mechanical and Materials Engineering, Washington State University Pullman, WA 99164, USA

ARTICLE INFO

Article history:
Received 10 December 2010
Received in revised form 1 March 2011
Accepted 22 April 2011
Available online 30 April 2011

Keywords:
Contact resistance
Thermal interface material
Thermal interface resistance

ABSTRACT

This work presents the characterization of a thermal interface material consisting of an array of mercury microdroplets deposited on a silicon die. Three arrays were tested, a 40 × 40 array (1600 grid) and two 20 × 20 arrays (400 grid). All arrays were assembled on a 4 × 4 mm^2 silicon die. An experimental facility which measures the thermal resistance across the mercury array under steady state conditions is described. The thermal interface resistance of the arrays was characterized as a function of the applied load. A thermal interface resistance as low as 0.253 $mm^2\,K\,W^{-1}$ was measured. A model to predict the thermal resistance of a liquid–metal microdroplet array was developed and compared to the experimental results. The contact resistance of the mercury arrays was estimated based on the experimental and model data. An average contact resistance was estimated to be 0.14 $mm^2\,K\,W^{-1}$.

1. Introduction

Heat transfer between solid interfaces can be of great importance in many applications, where it is desired to have a minimal thermal resistance between the two surfaces in contact [1–3]. Although solid materials used in many applications have high thermal conductivity, solid–solid interfaces usually have relatively high thermal resistance. This is often due to the surface roughness of both surfaces which prevents perfect contact between the surfaces and which in turn leads to high contact resistance. For example, measurements on a thermal interface consisting of bare silicon to silicon contact yielded contact resistances on the order of 100 $mm^2\,K\,W^{-1}$ [4,5]. Thermal interface materials (TIMs) can be used to reduce the contact resistance between solid contacts. In general, a thermal interface material should have sufficient compliance to ensure great conformability to the solid surfaces, and it should have high thermal conductivity. Such thermal interface materials can significantly enhance the contact between solid surfaces and thus reduce the contact resistance.

Examples of thermal interface materials include: thermal fluids, thermal greases or pastes, phase change materials (PCM), solders, thermal pads, thermally conductive adhesives and vertically aligned carbon nanotubes [6,7]. Thermal greases can have thermal interface resistances ranging between 20 and 100 $mm^2\,K\,W^{-1}$ when filled with conductive powders, while it can be as low as 6 $mm^2\,K\,W^{-1}$ when filled with sodium silicate + boron nitride [7]. Polymer based gels can achieve values in the range of 40–80 $mm^2\,K\,W^{-1}$ [7]. Currently, research on thermal interface materials has focused on improved gels [6], the use of more advanced fillers such as graphite nanoplatelets [8], and the fabrication of thermal interface materials using carbon nanotube arrays (CNTs) [9–11]. A thermal interface resistance as low as 19.8 $mm^2\,K\,W^{-1}$ has been reported [10]. The thermal contact resistance can be reduced by coating the tips of the CNTs with metals [5], or by using thermocompression bonding of CNTs [12].

In previous work we have designed and fabricated MEMS thermal switches using liquid–metal microdroplets [13]. In this paper, liquid–metal microdroplets as a thermal interface material are studied. Three mercury microdroplet arrays were studied: one 40 × 40 array (1600 grid), and two 20 × 20 arrays (400 grid). The thermal resistance for the three arrays is measured as a function of the applied load. A model is then presented to validate the experimental results. The model predicts the thermal resistance of the array by relating the geometry of the deformed drop to the applied load, and using the geometry to estimate the thermal resistance of the array.

2. Approach

In this study, three mercury arrays were tested: a 40 × 40 array, and two 20 × 20 arrays. All arrays were assembled on a 4 × 4 mm^2 silicon die. The mercury arrays were fabricated by preferentially condensing mercury vapor on gold targets which were patterned on the silicon die. The radii of the resulting droplets comprising the arrays were 15 μm for the 40 × 40 array, 20 μm for the first 20 × 20 array and 22 μm for the second 20 × 20 array. A platinum resistance thermometer (PRT) and a heater were micromachined on the backside of the silicon die. The thermal resistance of the arrays was measured by bringing the array in contact with a bare

---

* Corresponding author. Tel.: +1 509 335 7753; fax: +1 509 335 4662.
E-mail address: cill@wsu.edu (C. Richards).

0894-1777/$ - see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.expthermflusci.2011.04.012