Testing of thermal interface materials engineering essay

Engineering

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Introduction

Thermal Interface Materials (TIM’s) are used in electronics to minimise contact thermal resistance in between microchips e. g. central processing chips (CPUs) and graphical processing units (GPUs), and a heat sink. With the continuing increases in power densities and device downscaling in electronics, 1, 2 there has been a need to more efficiently manage thermal transfer. Currently cooling systems are required to dissipate large amounts of heat, the current generation of CPUs will generally require; 13W3-55W4 for mobile processors e. g. laptops, and for desktop processors 35W5-150W6, of power for the cooling systems to dissipate. Graphics processors on the other hand require a greater amount of cooling, with chips producing between 29W7 to 250W8 for a top of the range GPU. Due to the density of this power production, much specialised heat dissipation techniques are required. These range from heat sinks and fans to illustrious liquid cooling systems. But all of these cooling systems are a slave to the surface contact the heat sink can make with the processor. Without a good surface to surface contact, heat transfer between the two surfaces is reduced significantly. TIM’s are designed to fill the gaps between the surfaces and aim to produce perfect heat conduction between the two surfaces. 9

The Problem

The problem encountered with heat dissipation from microprocessors is that of surfaces. Nominally flat surfaces are not flat at all. As two apparently flat surfaces are pressed together one would assume that they would produce a perfect 100% surface to surface contact. But what is observed is quite the contrary. In fact they are an intricate chaos of microscopic peaks, ravines, cracks and crevices (Figure 1). These micro-roughnesses are super-imposed on a macroscopic scale, in the form of a concave, convex or wavy surface. Resulting in as much as 99% of the surfaces not making contact at all and being separated by air filled gaps. 9 This is problematic as air is an effective insulator, with a thermal conductivity (k) of 0. 027W/mK10 at room temperature. Since the thermal conductivities of metals are much higher than that of air, when the heat flows through the interface between the processor and heat sink, the heat flow lines converge at the microscopic contact points. These in turn require higher driving potentials i. e. temperature difference to maintain the heat flow. Therefore the converging of heat flow lines causes a resistance, known as the constriction resistance. The constriction resistance along with the resistance from the air forms the contact resistance. This resistance is much larger than the resistance offered to heat flow by metals when the heat flow is uniform. 11 Thus it is greatly favourable to remove the air from the surface-surface interface. Now it is possible to flatten the surfaces using great pressure and produce better thermal conductivity12, but due to the frailty of microprocessors this isn’t practical without destroying the processor. It is much more practical to replace the air gap with a TIM. Figure Image representing the contact between two metal surfaces (a) and metal surfaces connected with an ideal TIM (b). 9Although replacing the gaps between surfaces sounds simple enough, doing this in practice is quite difficult. As this requires a TIM which is easily deformed by small contact pressure to contact all uneven areas including surface pores. In reality the TIM will create smaller pockets of air between itself and the surfaces (Figure 2). This creates another form of resistance between the surfaces and the TIM and that is contact resistance (Rcontact). Figure Image showing actual contact made by TIM between two metal surfaces. 9The ideal TIM would have the following characteristics: High Thermal conductivity. Easily deformed by small contact pressure to contact all uneven areas of both contacting surfaces. This would eliminate Rcontact. Minimal thickness. Would not leak out of the interface onto the sensitive electronics. Would maintain performance indefinitely. Non-Toxic, so as to be easy to handle. Easy to apply and remove from the interface so as to be manufacturer friendly. BackgroundMeasuring thermal conductivity and resistanceThe thermal performance of a material is generally characterised in terms of its thermal conductivity. For a one dimensional homogeneous material Fourier’s law states that the rate of heat flow through a material is proportional to the temperature gradient and the area perpendicular to that gradient: 13(1)Where q is heat flow [W], k is thermal conductivity [W/mK], A is the surface area of the electronic component of which heat transfer occurs [m2], ΔT is the temperature difference across the interface [K] and L is distance[m]. The higher the thermal conductivity, the better the TIM will work. Understanding this, maximising the area of contact between two surfaces with highly thermally conducting materials will maximise the heat flow between surfaces. This would require the replacement of air between the surfaces with TIM. There is also another way of measuring a Tim’s efficiency at transferring heat. And that is its thermal resistance:(2)Where, Rint is the thermal interface resistance [K/W]. When the absolute thermal resistance reaches zero, the TIM would reach perfect heat transfer, maintaining an isothermal environment between the microprocessor and heat sink.(3)Where, Rcontact1 is the contact resistance between the CPU surface and the TIM. RTIM is the conduction resistance across the thickness of the TIM and Rcontact2 is the contact resistance between the TIM and the heat sink surface. Referring back to Figure 2 we can see the thermal resistance encountered from a non-ideal TIM. Also we can calculate RTIM using the following equation:(4)Where kTIM is the TIM bulk thermal conductivity and L is the thickness of the TIM. From equation (3) and (4) and knowing that the total contact resistance Rcontact is the sum of Rcontact1 and Rcontact2, The total contact resistance can be calculated by measuring thermal resistances of a range of thicknesses of TIMs and plotting Rint vs. L. The Rint vs. L data exhibits the following linear relationship:(5)It is found that the slope is the inverse of the product of the conductivity of the TIM, kTIM, and the area A. The intercept of the Rint axis is equal to the total contact resistance, Rcontact. 10

Solving the Problem

Thermal conductivityTo first make an efficient TIM, it is required to use materials with a high thermal conductance. But this isn’t the only factor to take into account. Whether the material is electrically conducting or not is one factor. As when using the TIMs on electronic circuits having an electrically conducting TIM can produce the risk of short circuiting. Another factor is the ease of handling of the materials. If the material is toxic or has a low melting point this could cause complications in the production and application stage. Metals generally have high thermal conductivity. But this thermal conductivity comes at the price of the metals being equally as electrical conducting. This idea is embodied in the Wiedemann-Franz law, 14 this states that the electronic conductivity , σ, and electronic thermal conductivity , ke, in a metal or semiconductor are related by the following equation:(6)Where T is the absolute temperature and L is the Lorenz number, , where , kb, is the Boltzmann constant and , e, the charge of an electron. Although despite the electrical conductivity of metals, it is still possible to create a manageable TIM using them, as a stable medium can be used that will keep the material at a useable and controllable viscosity. MaterialThermal conductivity(W/m K)Carbon nanotubeSingle layer GrapheneGraphene nano platesDiamondBoron Nitride (cubic)3000-66003080-5150151500-3000151000-26001300Silver406. 0Copper385. 0GoldBeOSiCGraphite314300200-47080-230Brass109. 0AluminiumAluminium NitrideZinc Oxide205. 070-21060-100IronMgO79. 560SteelAluminium Oxide50. 24016LeadBoron Nitride34. 720-33Mercury8. 3IceSiO21. 61. 6Glass, ordinary0. 8Concrete0. 8Water0. 6Fiberglass0. 04Polystyrene (styrofoam)0. 033Polyurethane0. 02Air0. 027Figure Table showing thermal conductivities of different compounds at room temperature. 17A collection of thermal conductivities of various materials have been catalogued in Figure 3. Generally the metals show good thermal conductivity. But there are non-metals that show equal, if not greater, thermal conductivity e. g. diamonds and Boron Nitride, than the metals. These materials rely on acoustic phonons to transfer their thermal energy. Where a phonon is a quantum mechanical description of an elementary vibrational motion in which a lattice of atoms or molecules uniformly oscillates at a single frequency. As opposed to metals which transfer heat by their free electrons. 18Recently research has been conducted into the thermal conductivities of different forms of carbon. Namely Graphene19 and carbon nano tubes15. These, due to their uniform nature can transmit phonons extremely efficiently. Alternatively, an ever increasing attention is being given to the use of exfoliated graphene-nanoplates (GNPs) in polymers to produce thermally conductive nano composites, this is down to the difficulty of producing graphene and nano tubes for large scale use, as graphite, which is available in large quantities and is cheap, doesn’t readily exfoliate to yield individual graphene sheets . 20, 21 Studies have shown that that by adding a small amount of GNPs into polymers could result in much greater enhancement of the effective thermal conductivity. 22, 23Currently the best TIMs contain a mix of various compounds with different thermal conductivities, particle sizes and particle shapes. The reasons for this are down to percolation and the transfer of heat through particles in a medium. Another factor to consider in the thermal conductivity of TIMs is the medium in which the filler particles are suspended in. The liquid, usually oils, that binds the TIMs together. S. Kanuparthi et al. 24 discovered that increasing the conductivity of the liquid from 0. 2 W/mK to 0. 3 W/mK would increase the thermal conductivity of an silver based TIM from 1. 7 W/mK to 2. 6 W/mK24. Where increasing the thermal conductivity of the filler, changing from alumina 40 W/mK to aluminium 205 W/mK (Figure 3), shows an increase from 1. 64 W/mK to 1. 87 W/mK24, this shows that increasing the thermal conductivity of the filler by an order of magnitude does not increase the bulk conductivity of the composite material. Whereas increasing the conductivity of the liquid even a fraction causes a large increase in the thermal conductivity of the TIM. Percolation" Percolation is the passage of an influence through an irregularly structured medium where the influence can pass through some regions more easily than the other and in some regions not at all." 25To understand the importance of percolation we first have to understand the heat flow between spheres. Looking at Figure 4 we see that there are three points of thermal resistance between each sphere to sphere interaction. Figure Diagram showing the resistances encountered between spheres of material in TIMs. 24Where K1 and K3 are the resistance from the centre of the sphere to the boundary and K2 is the resistance between the inter particle gap resistance. The heat transport between these two spherical filler particles is approximately confined to within a cylindrical zone with radius R. R can be calculated as follows:(7)Where, R1 and R2 are the radii of the filler particles which heat are transferred and γ is an estimate of the fraction of the reciprocal of the mean curvature. Making R the radius of the cylindrical zone (Fig. 5)Figure Diagram showing the cylindrical zone between two spheres. 24How well percolation works in a TIM has a great impact on the thermal conductivity of the material. As a TIM with a sub optimal amount of filler material will perform worse than a TIM with a more fitting amount of filler. And to understand what volume of filler is the optimal amount to have in a TIM it is best to look into the close packing of spheres. Spheres of equal size arrange in four different schemes; simple cubic, orthorhombic, double-nested and face centred cubic. Which pack to 53. 36, 60. 46, 69. 81, and 74. 05% by volume. 26But the likelihood of spheres arranging themselves in a

TIM like this is highly unlikely. So if we assume that the distribution of particles would be random close, which is equal to 63. 71%. This value can be interpreted from the fact that the packing percentage for randomly packaged spheres should be somewhere near the average of the maximum packing fraction for face centred cubic (74. 05%) and simple cubic (53. 36%). 25Higher packing densities are possible. For example, using a variety of different particle sizes it is possible to achieve 95. 1% of theoretical packing volume using quaternary packaging. This was formed by mixing spherical particles with diameter ratios of 1: 7: 38: 316 and volume compositions 6. 1: 10. 2: 23. 0: 60. 7% respectively. 26To increase the effective surface area need to consult percolation theory, close packing of spheres and wetting of surfaces.

Do composites next. Then perculation then wetting! Then summary and future research!

Spreading and Wetting and DetergencyComposite MaterialsPercolation Theory