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The Effect of the Epoxy Composites Constituents on Its Thermal Behavior as An Interface Material

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Abstract: *The importance of the electronic devices imposes a challenge of finding the ways heat squandering and then to create field of research for thermal handling. The thermal material which is used as an interface must show the demanded contribution in the dispersion of heat to improve the electronic devices. Among lots of different selective materials, epoxy resin has an excellent feature qualifies it to preside the proposed materials as thermal interface. The past literatures showed the incorporated fillers of conductive materials to raise the thermal conductivity of epoxy composites. Consequently the electronic devices acquire high thermal conductivity. This work discussed the topic of the thermal properties of the interface materials, and especially epoxy as thermal interface and the role of involved fillers with high thermal conductivity in its resin.*

Keywords: Thermal conductivity (TC), Thermal interface material (TIM), Epoxy resin, Filler material, Thermal properties, Thermo-gravimetric analysis (TGA).

Introduction

In electronic devices, it is very critical to manage thermal performance and reliability. The evolution of filler materials offers advanced technical applications pivot on thermal dissipation. The work in this field invoked popping up novel composite materials based on the polymer base that has a high thermal conductivity [1,2]. The importance of heat dissipation originated from the application of high power density in recent electronics and to protect them from the thermal failure produced by power consumption. The result of this fruitful effort produced, minimizing the size of the electronic devices to be more matching with the modern age [3]. The ridding of the waste heat of modern electronics is indispensable, for their exponentially depending on the temperature of the operating junction and in a consequence to gain the higher stability electronic devices [4-6]. The traditional electronics are hindered by a big obstacle of thermal dissipation. The problem was the conductive materials that made up the conducting path separates the heat sinks and electronics and the lack of excellent thermal contact [7]. This necessity demands using a suitable material of proper mechanical properties to ensure enough contact area to manage the consumed power in devices. The solution to the problem lies in filling the spaces of the air by using elastomer material that has high thermal conductivity to occupy the position in between the heat sink and the heated device. These materials, so-called thermal interface materials (TIMs) allow heat transfer to the heat sink readily by overcoming the thermal resistance which is caused by air gaps in the device.

Theoretical View for the Thermal Interface Material

The quality of the TIM depends on its ability to disperse the heat, which crosses that binding interface between the two coupled rigid surfaces. Gwinn et al [3] gave an obvious visualization about the case of the CPU-heat sink interface, the resistance of interface per unit area, R_{int} is expressed by the following:

$$R_{int} = \frac{T_{cpu} - T_{hs}}{Q} \qquad (1)$$

T_{cpu} is the temperature of the electronic packaging surface or the CPU surface. T_{hs} is the temperature of the sink base plate. Q is the power per unit area for the emitted heat of the component. In general the measurement unit of the interface resistance is K cm^2/W. The air gaps are established from the roughness of the surfaces of the interface that would never lead to ideal contact with the surfaces of the heat sink and CPU, this problem is solved by using TIM. Hence the question is to overcome the thermal barrier of air.

The total resistance of the interface, R_{int} is due to contact resistance, $R_{contact}$ which is composed of the conduction resistance at the points of the mating surfaces and/or the resistance of the radiation across the air gaps. The existence of the TIM of thickness t gives an additional resistance of the thermal conduction.

$$R_{int} = R_{contact1} + R_{cond} + R_{contact2} \quad (2)$$

And

$$R_{cond} = \frac{t}{k_{TIM}A} \quad (3)$$

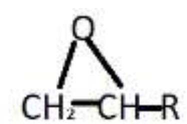
Where $R_{contact1}$ is the resistance of the TIM and CPU surface contact. $R_{contact2}$ is the resistance between the TIM and heat sink base plate and R_{cond} is the resistance of the conductor across the TIM thickness. k_{TIM} I the bulk thermal conductivity of TIM. A is the surface area of heat passing through it belongs to the component of the electronic appliance.

Reduction Methods for the Contact Resistance

The available methods for reducing the contact resistance of interface area by: firstly, increasing the contact point area through controlling the flatten peaks. This can be accomplished by applying suitable contact pressure to reduce any non-flatness of the surface micro roughness. The other possibility to reduce the surface roughness before forming the interface is by surfaces grinding. Secondly, utilizing high thermal conductivity TIM such that enable the imperfect surface properties of the coupled surface to be conformed [3].

The constraints of used load and cost make the treatments of applying high contact pressure and finishing the micro-roughness of the surfaces respectively inapplicable. Therefore, the clue is to employ TIM of elevated thermal conductivity. The full occupation of the inserted elastomer material without any air gaps and with thermal conductivity, superior than that of air is important to condition to dissipate the waste heat [3]. Among many proposed materials to play the role of TIP like thermal greases, phase change material, and many others materials which have high chemical and physical stability, epoxy resin has distinctive properties. Therefore, it has used extensively in the field of the electronic industries. One of its an important feature to be dealt is the low thermal conductivity (0.2 W/m k). Hence, raising the thermal conductivity of the epoxy resin is a beneficial mean for the novel electronic appliances. Epoxy can gain over this property through playing the matrix role of fillers with high thermal conductivity.

Epoxy resins are considering a low molecular weight of at least one epoxide group of form (pre-polymer).



This thermosetting polymers are cured by using different kinds of curing agents leads to curing chemical reaction. However, term of epoxy resin involves both the employed curing agents and the resin itself. Type of the resin and the used curing agents determine the properties of the epoxy resin. The variety of the properties create a wide spectrum of the epoxy applications [12].

2. Controlling thermal properties of epoxy composites by varying types of fillers

2.1 Filler's material role in the enhancement of thermal conductivity of epoxy resins

To explain the enhancement of heat transfer in composite materials, a few theories are originated [13, 14]. The added fillers into the epoxy resin might be in the form of particles or fibers. Whenever fibers are dispersed randomly in the matrix, then they would make the epoxy earns isotropic thermo-physical properties as to make as the fillers of particles. Otherwise, the regular arrangement of the fibers within the matrix produces anisotropic thermo-physical properties [15]. In addition, the size of fillers, doesn't matter whether it is being particles or fibers, can be of micro or nano order and that occurs a big difference in appearing the effect.

(i) Filler of metals

Different types of metals are used as fillers for the epoxy resin like nickel, copper, aluminium,…, etc. The produced increasing in the TC or electrical conductivity by adding that fillers were extremely effective in comparison with the physical properties of the matrix [16, 17,18].

(ii) Carbon based materials

This term refers to all materials constructed of carbon like graphite, graphene, carbon nanotube, diamond, carbon fiber, etc. [15, 18-24]. The characteristic property of such material is the high thermal conductivity, which causes an increase in the thermal conductivity of the composites by even small adding ratio.

(iii) Ceramic fillers

Ceramic fillers have a distinguishable thermal conductivity and electrical insulating, that make them of high usage into epoxy composites [25-28].

(iv) Hybrid fillers

The benefit of this kind of fillers is to rise the thermal conductivity of composites through mixing various sizes or types of fillers. This technique creates a network of thermal conductors, among fillers to maximize the packing density of fillers. Consequently, reducing the loading of fillers. This will contribute strongly in reducing the viscosity of the system and improving the thermal conductivity of the resin [4,6].

2.2 Epoxy thermal properties

The techniques of measurement for the thermal conductivity can be classified into two classes. The first is applicable to the material at the steady state and the second in the case of unstable temperature of material, during either cooling down or heating up [1,12].

2.2.1 Performing test of thermal conductivity of epoxy-metal composites

Different tests of thermal conductivity have been prepared in various powder volume fractions of several metals, for instance Ni, Cu, ZnO, BN, Al_2O_3,…, etc. [14,15]. One of the used methods is the laser flash, ITEM-1M instrument, Hot Disk TPS-2500 thermal constant analyser [16].

2.2.2 Testing carbon material role in rising thermal conductivity of the epoxy composite

Many of researchers focused on carbon materials as a nano-fillers for their importance in progressing the thermal conductivity of the epoxy composites and earn them exceptional properties.

2.2.3 Testing ceramic filler role in rising thermal conductivity of the epoxy composite

The characteristic usage of the ceramic fillers presents the possibility of improving the thermal conductivity of the epoxy composite as well as offering the ability of electrical insulation.

2.2.4 Testing implemented on epoxy-hybrid composite

As stated before the adding of different types of fillers with various shapes or/and sizes to the any matrix which can be the epoxy resin producing so-called hybrid composites. The latter composite has a distinct property of higher thermal conductivity than that of the conventional one.

Ahn et al. [4] have been raised the thermal conductivity by adding TiO_2 to the copper nanowire/epoxy composite. The thermal conductivity is measured by using the laser flash method.

Yuan et al. [6] have added different sizes of hybrid AlN particles in epoxy composite, furthermore graphene oxide, and graphite are used for the epoxy composite. Addition of graphene oxide of 8wt% of the epoxy composite showed enhancement of thermal conductivity with 6.42 times, while the addition of AlN of 5μm particles raised the thermal conductivity with 11.8 times.

3. Thermal Gravimetric Analysis (TGA)

TGA is the most popular method to experience both chemical and physical properties of materials especially that of polymer. In short, it is a measurement of mass loss as a function of the temperature. The temperature increases at a constant rate with the time. It is helpful to know the stability of the polymer within the range of its usage temperature. When the mass of polymer lasts at some temperature, then that refers to the thermal stability of that polymer. TGA limits the upper temperature can be polymer used within before starts to degrade.

The test is used by many researchers to know the influence of fillers in increasing the thermal stability of epoxy [17].

4. Conclusion

The review of the paper shows that the epoxy resin is better to use than other polymers as a thermal interface material. Epoxy composite has variable thermal properties according to the type of epoxy resin, curing agent, and curing conditions. The thermal conductivity of the epoxy composite affected positively with the adding ratio of loaded fillers. Furthermore, the increase of fillers in the epoxy composite makes the latter lower processability, mechanical properties and integrity, and higher cost. The fillers' shape, size, and orientation play an important role in changing the thermal properties of the composite. Epoxy composite is prepared by mixing filler and epoxy, curing conditions,…, etc. All these steps have a big influence on the thermal properties of the epoxy composite. Adding hybrid fillers leads to higher thermal conductivity at lower filler percent of loading. This kind of filler contributes to lowering the viscosity of epoxy composite and consequently improving its processability.

When the surfaces of fillers are treated with chemical agents, filler dispersion is improved and decreasing the viscosity and the thermal interfacial resistance.

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