Fabrication of an advanced epoxy based molding compound with high thermal conductivity and outstanding mechanical properties

Authors
Nazila Dadvand[a], Mina Dadvand[b], and Georges Kipouros[c]

Affiliations
[a]Texas Instruments Incorporated, Dallas, USA
[b]Polytechnique de Montreal, Montreal, Quebec, Canada
[c]Dalhousie University, Mechanical Engineering Department, Halifax, Nova Scotia Canada

Abstract

A novel molding compound was fabricated through surface modification of aluminum particles followed by chemical grafting to an epoxy based resin. The fabricated material demonstrated high thermal conductivity and outstanding mechanical properties. A thin layer of alumina was formed on the surface of aluminum particles (spherical with average 30 μm in diameter) by ultrasonic treatment with hydrogen peroxide followed by functionalization with a hydroxylated long-chain organic acid. The fabricated composite was chemically bonded to epoxy skeleton. The chemical bond formation between the filler and organic matrix was responsible for high thermal conductivity as well as outstanding mechanical properties. As well, the loading capacity of epoxy matrix to surface modified fillers was remarkably higher than non-modified fillers.

Introduction

In electronic packaging, thermal management is a critical aspect of packaging design and it considers the issues associated with degradation of a device at high temperatures. Thermal management is becoming more critical with the continuous trends for compact and more highly integrated systems having smaller features and higher currents [1-3]. A good thermal management requires to provide heat flow paths with the highest possible heat resistance towards the heat sink locations. Therefore, there are great interests in fabricating of molding compounds with high thermal conductivity [1-3]. There are several publication related to the use of aluminum based ceramics such as aluminum nitride in fabricating of their composite materials with organic polymers[4-5].

The present manuscript describes a novel approach to enhance the thermal conductivity and wear resistance of epoxy based molding compounds through reinforcement of the surface modified aluminum particles within the epoxy based matrix and maintaining the required electrical resistivity of the molding compound.

Results and Discussion

In this research work, the surface of aluminum particles (approximately 30 μm in diameter) were hydroxylated by immersing into a solution containing hydrogen peroxide in an ultrasonic bath for approximately 2 hours at temperature of 50-60^{o}C. The hydroxylated particles were then washed with DI water and immersed into a solution containing a long chain organic acid (2-hyrdroxyoctadecanoic acid, D, L-2-hydroxystearic acid). Figure 1 shows a schematic diagram of the various steps of surface modification of aluminum particles. As it can be seen, the organic acid interacts with the hydroxylated layer on the surface of aluminum particles through carboxylate functional group [6]. The remaining hydroxide group on the organic acid interacts with a polar functional group of the epoxy resin matrix. As well, hydrophobic interactions are established between the long chain hydrocarbon of the organic acid and the hydrophobic portion of the epoxy matrix. Formation of hydroxylated layer as well as the interaction of long chain insulating organic acid on the aluminum particles ensure of maintaining the electrical resistivity of the fabricated molding compound.

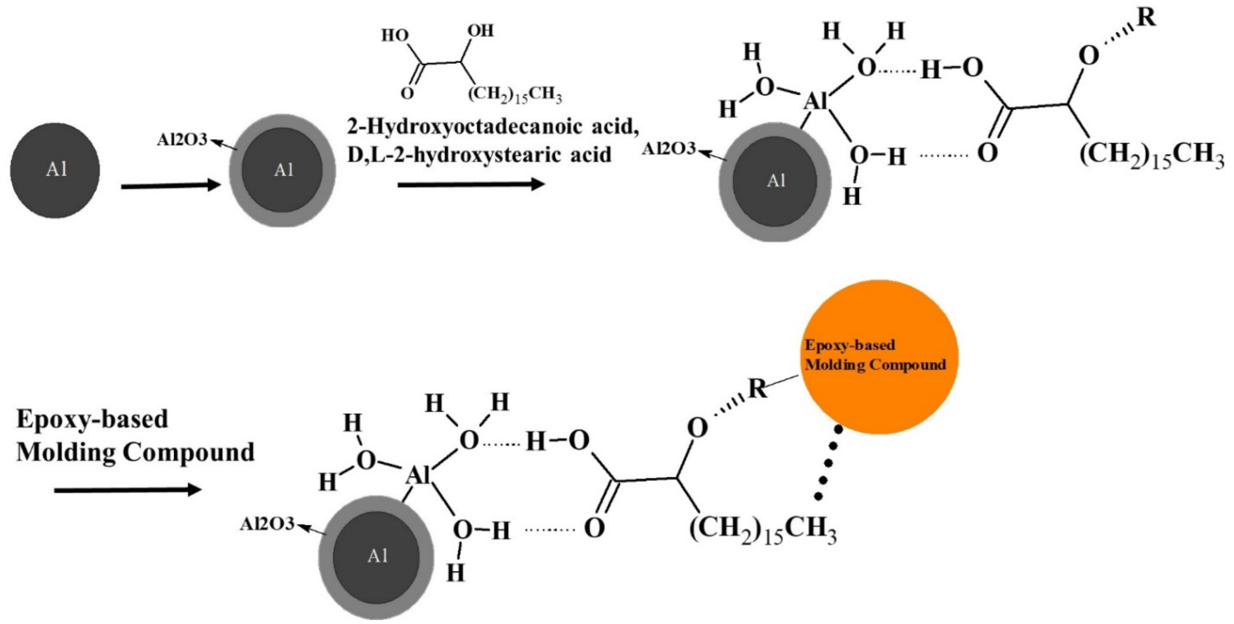


Figure 1. Schematic diagram displaying the various steps for surface modification of aluminum particles

Prior to applying of epoxy based molding compound on the package, the package was chemically treated in order to enhance the adhesion of the epoxy based molding compound on copper. Figure 2 demonstrates the process that was used for the treatment. As it can be seen, the package containing copper was immersed into a solution containing (3-mercaptopropyl-trimethoxysilane (MPTS)) in methanol followed by heat treatment at 50-60°C for 2-3 min. The mercaptane compound (MPTS) was interacted with copper through its sulfur containing functional group. The alkoxy groups (methoxy) on the other side of the MPTS were reacted with a poly functional group of molding compound.

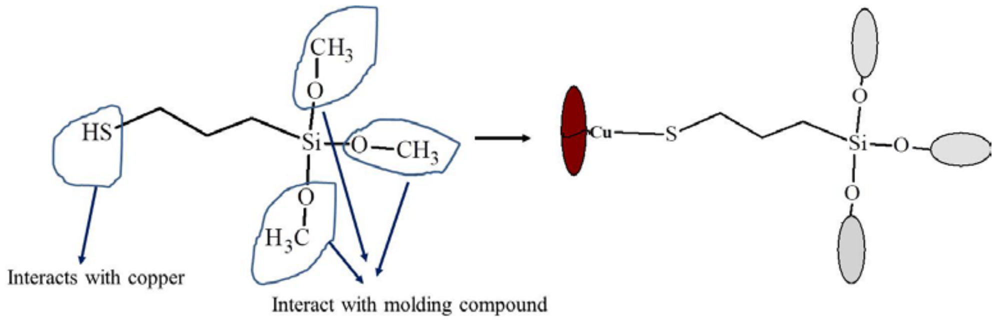


Figure 2. Adhesion promotion of copper with molding compound through surface treatment of copper prior to applying of molding compound.

Figure 3 shows a schematic diagram of a QFN type package after application of molding compound. The novel molding compound described in this article as well as the methodology for chemical treatment of copper surface can be used in fabrication of such packages displayed in Figure 3.

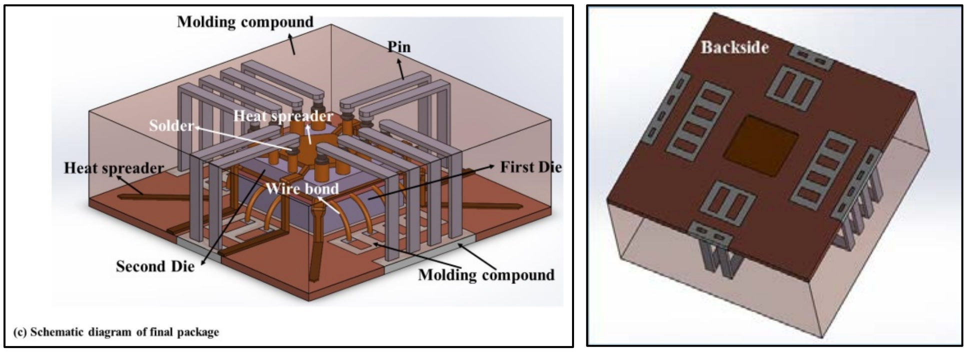


Figure 3. Schematic diagram of a QFN type package after application of molding compound.

Figure 4 summarizes the molecular structures of the chemicals described in this manuscript.

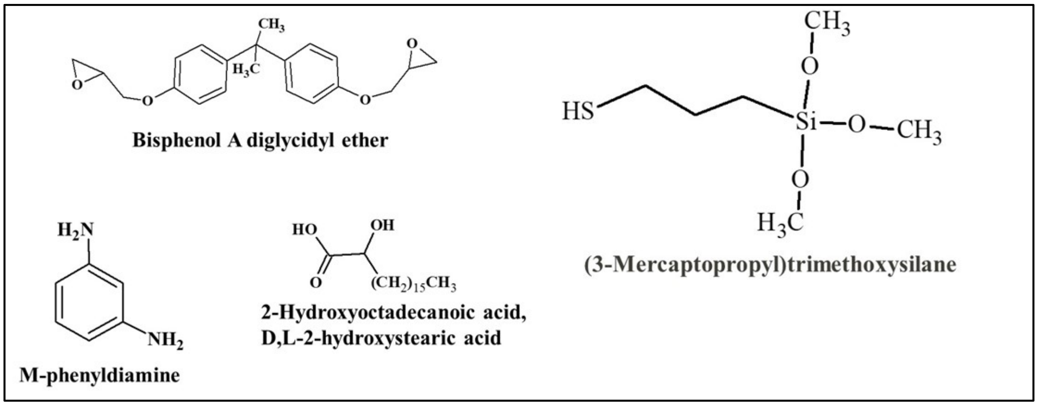


Figure 4. Schematic diagram of molecular structures

The epoxy based molding compound was prepared from diglycidyl ether of bisphenol A-based cured with m-phenylenediamine [7].

Microscratch tester (manufactured by CSM Instruments Inc.) was used in order to evaluate the scratch resistivity of the molding compound with and without incorporating of surface modified aluminum particles. Microscratch experiments were performed by using a spherical 90 degree (serial number: SF-A37) diamond nanoindenter. The radius of the indenter was 50 μm. The scratch normal loads were performed in progressive modes from 30 to 2000 mN (Figure 5) and from 30 to 7000 mN (Figure 6). As it can be seen from both Figures 5 and 6, the epoxy based molding compound containing 20 wt.% surface modified aluminum filler demonstrated higher scratch resistivity compare to the molding compound without filler.

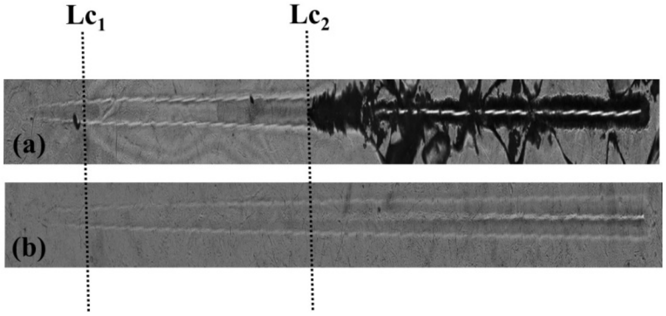


Figure 5. Optical photographs of microscratches induced by progressive applied normal load (30 to 7000 mN) in a length of 4mm track on epoxy based molding compound coated on copper substrate (a) Molding compound without any aluminum particles; (b) molding compound reinforced with 20 wt% surface modified aluminum particles. Lc_1 shows the critical load corresponding to initiation of stress deformation lines and Lc_2 demonstrates the critical load for initiating of coating failure.

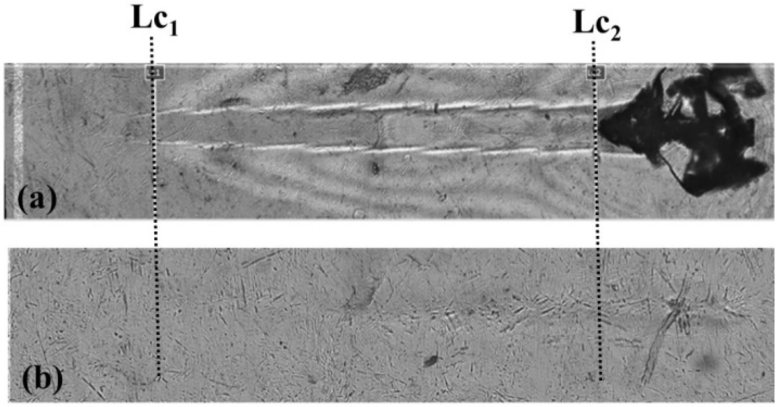
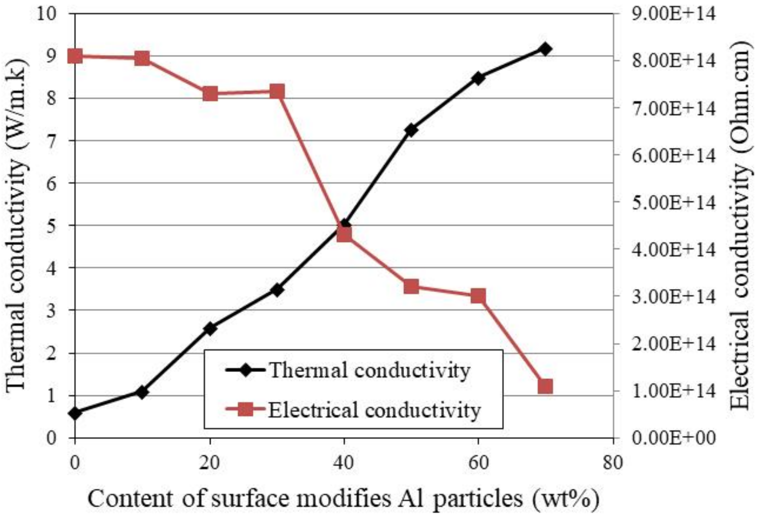


Figure 6. Optical photographs of microscratches induced by progressive applied normal load (30 to 2000 mN) in a length of 1mm track on epoxy based molding compound coated on copper substrate (a) Molding compound without any aluminum particles; (b) molding compound reinforced with 20 wt% surface modified aluminum particles. Lc_1 shows the critical load corresponding to initiation of stress deformation lines and Lc_2 demonstrates the critical load for initiating of coating failure.

Figure 7 shows the influence of filler (surface modified aluminum particles) and its content on thermal and electrical conductivities of the epoxy based molding compound.



As it can be seen from Figure 7, the incorporating of surface modified aluminum particles in epoxy based molding compound enhanced the thermal conductivity without having considerable influence on its electrical resistance. In fact, the electrical resistivity of the composite was maintained in acceptable ranges required for electronic packages application.

Conclusion

Surface modification of aluminum particles was performed by chemical grafting of long chain organic acid (2-hyrdroxyoctadecanoic acid, D, L-2-hydroxystearic acid) through initial formation of hydroxylated layer on the surface of aluminum particles. The incorporating of surface modified Al particles within an epoxy based molding compound enhance the thermal conductivity as well as scratch resistance of the composite. The electrical resistance of the composites was maintained within an acceptable ranged required for electronic packaging application. In order to enhance the adhesion strength of the composite with copper based metal, the surface of copper was chemically modified through chemical grafting of a meracaptoalkoxysilane based compound such as (3-mercaptopropyl- trimethoxysilane (MPTS)).

References

1. Y. Zhou, F. Liu, and H. Wang, Novel organic–inorganic composites with high thermal conductivity for electronic packaging applications: A key issue review, *Polymer Composites*, 38 (2017) 803-813.

2. P. Bujard, G**.** Kuhnlein, **S.** Ino. and T. Shiobara, Thermal conductivity of molding compounds for plastic packaging, *IEEE Transactions on components, packaging and manufacturing technology – Part A*, 17 (1994) 527-532.

3. P. Procter and J. Solc, Improved thermal conductivity in microelectronic encapsulants, *Proceedings 41st Electronic Components & Technology Conference*, May 11-15, 1991.

4. H. Cheg-Yu, and S. Chung, High thermal conductivity epoxy molding compound filled with a combustion synthesized AlN powder, *Journal of Applied Polymer Science*, 102 (2006) 4734-4740.

5. Potential thermally conductive alumina filled epoxy composite for thermal management of high power LEDs, *Journal of Materials Science: Materials in Electronics*, 28 (2017) 856-867.

6. L. Liang, K. Miru, L. Seungjun, K. Jongman, K. Hyunse, and L. Deugwoo, Study on surface modification of aluminum 6061 by multiple ultrasonic impact treatments, *International Journal of Advanced Manufacturing Technology*, 96 (2018) 1255-1264.

7. Thermal conductivity, specific heat, and dynamic mechanical behavior of diglycidyl ether of bisphenol A cured with m – phenylenediamine, *Journal of Applied Polymer Science*, 102 (1969) 2411-2425.