# Failure mechanisms of the bonded interface between mold epoxy and metal substrate exposed to high temperature

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## Abstract

The fast development of electric vehicles promoted the development of next-generation power modules. Along with this trend, the encapsulation techniques are also transforming from previous gel encapsulation to epoxy encapsulation because epoxy encapsulation reduces the module size significantly. However, the dissimilar bonding between the epoxy and the metal substrate is a weak part of the entire module. In this study, a high-temperature storage test (HST) was performed at 200 °C until 1000 h for encapsulated packages. We found that the fracture happened inside the epoxy rather than the copper/epoxy interface. More importantly, we found that copper atoms diffused into the epoxy reaching approximately 100 nm. The diffused copper atoms and the long-time high-temperature heating promoted the epoxy pyrolysis, forming a 100 nm thick weak layer at the epoxy side, which is the key reason for the high-temperature failure.

## Background & Results

With the application of wide-band gap semiconductors, encapsulation techniques are also transforming. Previously widely used gel encapsulation, which requires fixing the substrate in a case mechanically and pouring liquid silicon gel on the substrate, is replaced by epoxy encapsulation because epoxy encapsulation reduces the volume size greatly. In addition, epoxy encapsulation showed good reliability during the thermal cycling test and the power cycling test. However, study on the failure mechanisms from the perspective of improving epoxy properties and reducing thermal stress was not enough. It is necessary to reveal the failure mechanisms from the perspective of the interfacial interaction especially under the required reliability test conditions for next-generation power modules.

This paper aims to reveal the failure mechanisms between the encapsulation epoxy and the copper substrate by investigating the change in the interfacial interaction. The high-temperature storage test (HST) conditions (200 °C lasting for 1000 h), meeting the requirements for next-generation SiC power modules, were used. Different from previous studies, which used simplified samples (cylinder-shaped epoxy bonded with copper plate), real packages used in electric industrials were used in this study. we revealed the failure mechanisms of the bonding between encapsulation epoxy and the copper substrate under HST with solid evidence. The nano-scale weak epoxy layer formed by the copper diffusion and long-time high-temperature heating was identified for the first time. Under a long-time high-temperature condition, the diffused copper promoted the pyrolysis of the epoxy and the pyrolysis of epoxy reduced its strength, forming a 100 nm thick weak layer. This weak layer is the key reason for the failure of the epoxy encapsulation under HST.

## Significance of the research and Future perspective

Our study provided a fresh understanding of the failure mechanisms of the bonding between encapsulation epoxy and the copper substrate under HST, which will contribute significantly to future power module design and material development. This result will contribute greatly to the future power module design and the development of new epoxy materials. In the future, we will investigate the copper's catalytic effect on the epoxy with density functional theory calculation in detail.

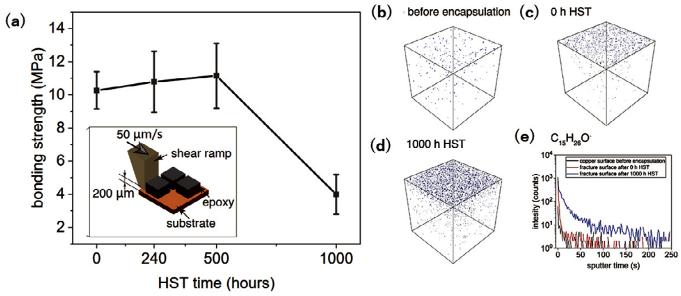


Fig. 1 (a) The bonding strength results for different lead frames under various reliability tests. (b) 3D render images of epoxy fragment $C_{15}H_{26}O^-$ for the copper surface before encapsulation and the fracture surface of the copper substrate after (c) 0 and (d) 1000 h HST; (e) depth profile of $C_{15}H_{26}O^-$ for the copper surface before encapsulation and the fracture surface of the copper substrate after 0 and 1000 h HST.

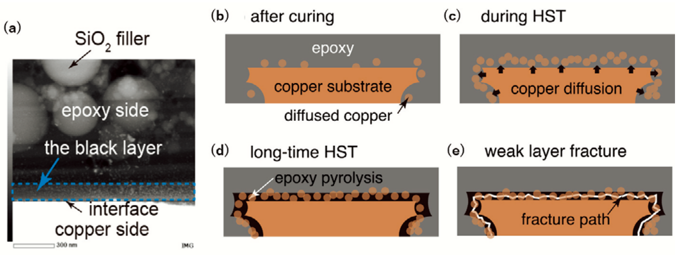


Fig. 2 (a)TEM HADDF image of the copper/epoxy interface after 1000 h HST, (b) minor copper diffusion happens after curing; (c) large extent copper diffusion happens during HST; (d) diffused copper promotes the epoxy pyrolysis resulting in a weak layer; (e) weak layer fracture under internal or external stress.

Patent

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