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# An X-ray Radiography Study of the Effect of Thermal Cycling on Damage Evolution in Large-Area Sn-3.5Ag Solder Joints

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There is a need for next-generation, high-performance power electronic packages and systems utilizing wide-band-gap devices to operate at high temperatures in automotive and electricity transmission applications. Sn-3.5Ag solder is a candidate for use in such packages with potential maximum operating temperatures of about 200°C. However, there is a need to understand the thermal cycling reliability of Sn-3.5Ag solders subject to such high-temperature operating conditions. The results of a study on the damage evolution occurring in large-area Sn-3.5Ag solder joints between silicon dies and direct bonded copper substrates with Au/Ni-P metallization subject to thermal cycling between 200°C and 5°C are presented in this paper. Interface structure evolution and damage accumulation were followed using high-resolution X-ray radiography, cross-sectional optical and scanning electron microscopies, and X-ray microanalysis in these joints for up to 3000 thermal cycles. Optical and scanning electron microscopy results showed that the stresses introduced by the thermal cycling result in cracking and delamination at the copper–intermetallic compound interface. X-ray microanalysis showed that stresses due to thermal cycling resulted in physical cracking and breakdown of the Ni-P barrier layer, facilitating Cu-Sn interdiffusion. This interdiffusion resulted in the formation of Cu-Sn intermetallic compounds underneath the Ni-P layer, subsequently leading to delamination between the Ni-rich layer and Cu-Sn intermetallic compounds.

**Key words:** High-temperature packaging, power electronics, X-ray imaging, creep, fatigue, intermetallic compounds

## INTRODUCTION

Developing next-generation power devices, modules, and systems is critical for the advancement of hybrid electric vehicles and electric vehicles. Such systems should have the required electrical and thermal performance characteristics in addition to satisfying weight, volume, and cost requirements.[1] One strategy for achieving this reduction in weight and volume of the overall system is the reduction in the size and volume of accessories such as associated thermal management systems. In addition, operating power electronics at higher temperatures enables the achievement of optimum benefit from the use of SiC and other wideband-based devices in power electronic systems. Thus, there is a demand for higher temperature operation of power electronics packages and systems.

In a typical power package, the die (Si/SiC/GaN) is mounted onto a direct bonded copper (DBC) substrate through the use of a die-attach material. DBC substrates are composed of a ceramic substrate (commonly alumina, aluminum nitride, or silicon nitride) with a layer of copper bonded to the two broad surfaces of the substrate through a high-temperature oxidation process. Wire bonds are used to achieve other interconnections through the contacts on the top surface of the die. Increasing the

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