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Conductive Anodic Filament Failures in Fine-Pitch Through-Via Interconnections in Organic Package Substrates

KOUSHIK RAMACHANDRAN,[1,2,3] FUHAN LIU,[1] P. MARKONDEYA RAJ,[1] VENKY SUNDARAM,[1] and RAO TUMMALA[1]

1.—3D Systems Packaging Research Center, Georgia Institute of Technology, 813 Ferst Drive, Atlanta, GA 30332-0250, USA. 2.—School of Materials Science and Engineering, Georgia Institute of Technology, 771 Ferst Drive, Atlanta, GA 30332-0245, USA. 3.—e-mail: koushik@gatech.edu

Failures due to conductive anodic filament (CAF) formation in copper-plated through-vias have been a concern in printed wiring boards since the 1970s. With the continuous reduction in through-via pitch to meet high circuit density demands in organic packages, the magnitude of CAF failures is expected to be significantly higher. In this study, an accelerated test condition [130°C, 85% relative humidity (RH), and 100 V direct current (DC)] was used to investigate CAF in two organic package substrates: (1) cyclo-olefin polymer–glass fiber composite (XR3) and (2) epoxy–glass fiber composite (FR4). Test coupons with through-via spacing of 100 μm and 200 μm were investigated in this study. CAF failures were not observed in either substrate type with spacing of 200 μm. With spacing of 100 μm, insulation failures were observed in FR4, while XR3 exhibited stable insulation resistance during the test. The substrates were characterized using gravimetric measurement, and XR3 was found to exhibit significantly lower moisture absorption compared with FR4. The CAF failures in FR4 were characterized using scanning electron microscopy and energy-dispersive x-ray spectroscopy. The results suggest a strong effect of moisture sorption of organic resins on CAF failure at smaller through-via spacing in package substrates.

Key words: Conductive anodic filament, organic package substrates, fine-pitch through-vias, electrochemical migration

INTRODUCTION

The trend towards miniaturized electronic systems demands higher density of integrated circuit (IC)–package–printed wiring board (PWB) interconnections, fine copper wiring on the surface of the substrates, and fine-pitch copper-plated through-via interconnections in thin organic substrates. The minimum through-via spacing for state-of-the-art flip-chip package substrates is 200 μm based on the International Technology Roadmap for Semiconductors.[1] Copper-plated through-vias in PWBs are known to fail by electrochemical migration processes by a phenomenon referred to as conductive anodic filament (CAF). CAF-related failures were initially discovered by Bell Labs when an unpredictable loss of resistance was observed in conductors held at a potential difference.[2,3] CAF failures are significant, especially in package substrates, since the through-via spacing is expected to be 50 μm to 100 μm as opposed to greater than 250 μm in PWBs.[4,5] Since the discovery of CAF, numerous studies have been carried out on investigating CAF formation in PWBs.[6–19]

A two-step model was first proposed by Lando to describe the CAF mechanism in epoxy–glass composites.[3] The first step is interface degradation or path formation for copper migration, which has been reported to be the rate-limiting step in CAF failure.[13] Interface degradation can occur through mechanical degradation from drilling processes, thermal stresses due to difference in coefficient of thermal expansion (CTE) between the polymer resin and glass fibers,

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