Chapter 14
Popcorn Cracking

Rainer Dudek

14.1 Introduction

Interface delamination and popcorn cracking are among the most common reasons for mechanical damage in plastic packaging. Alpern et al. [1] formulate the popcorn mechanism as follows: When a plastic IC package is exposed to normal ambient air (temperature, humidity), moisture diffuses into the molding compound (MC) of the package. The absorbed moisture causes the degradation of adhesion strength of the package's various material interfaces. During printed circuit board (PCB) reflow soldering, an IC package is subjected to solder shock temperatures, typically between 220 and 240°C for conventional SnPb solder, but up to 260°C for lead-free solder. Thermal stresses caused by thermal mismatch between the package's constituent materials may cause delamination of the die-pad/MC interface. Absorbed moisture then diffuses into the delaminated gap resulting in a vapor pressure build-up and subsequently in the doming of the MC underpad layer. When the maximum stress caused by the doming exceeds the MC strength, package cracks occur ("popcorn effect"), see Fig. 14.1.

In general, one distinguishes between three types of popcorn failure modes in relation to the starting interface of the cracks. Mode I refers to cracks emanating from the die-pad backside/MC interface delamination, mode II from the die-attach/die-pad delamination and finally mode III from the chip surface/MC delamination. A polyimide chip coating is normally used to curtail mode III failure. Mode I is the most common failure mode in conventional plastic IC packages.

R. Dudek (✉)
Fraunhofer ENAS, Micro Materials Center Berlin and Chemnitz,
Technologie-Campus 3, 09126 Chemnitz, Germany
e-mail: Rainer.Dudek@enas.fraunhofer.de

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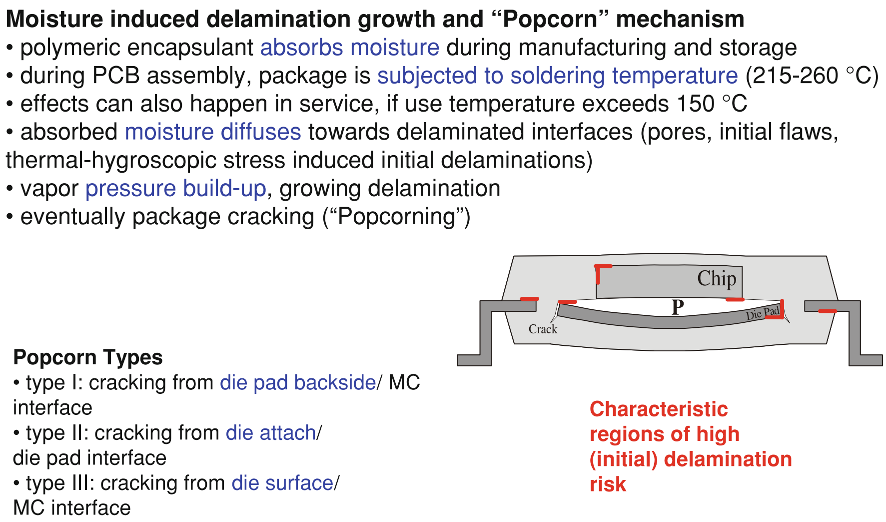

Fig. 14.1 Schematic of vapor pressure-induced delamination and "popcorn effect" in plastic packages

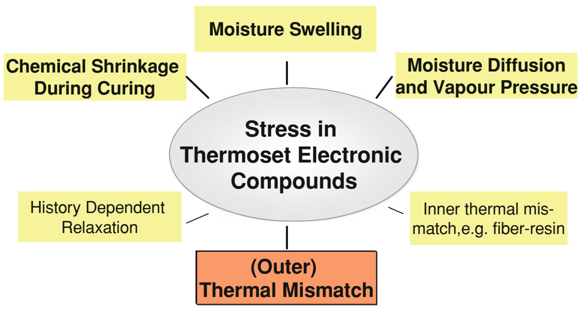

Fig. 14.2 Schematic of stress sources in plastic packages

14.2 Stress in Plastic Packages

Obviously, the phenomenons are related to stress build-up in plastic packages, which might depend on several sources, see Fig. 14.2, the most important one being thermal mismatch. Other sources of package stresses are linked to the action of moisture, as can be observed from Fig. 14.3. According to Koh et al. [2], three property characteristics of the polymers involved are to be considered for reducing the package failures: adhesion strength, moisture absorption, and stress relaxation. The last characteristic is dependent on the material mechanical properties such as the modulus of elasticity, flexural strength, fracture toughness, and the glass transition temperature.

Since package cracking is mainly caused by vapor pressure, moisture absorption and desorption properties of the molding compounds are studied by various authors [3, 4]. They pointed out that both the moisture content and the distribution

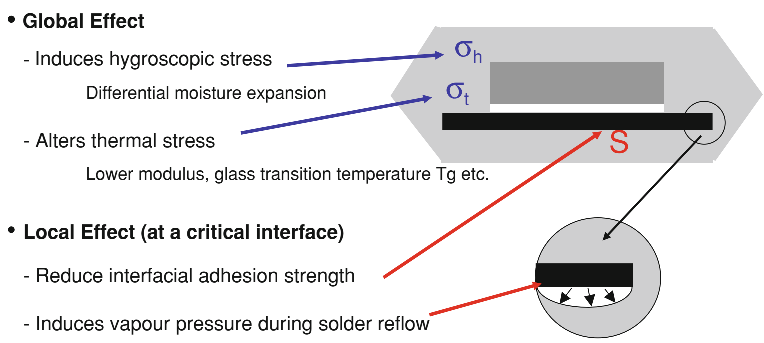

Fig. 14.3 Schematic of effects of moisture in plastic packages

of moisture in regard to the critical interface affect the popcorn resistivity of the packages. Moisture diffusion calculations based upon a one-dimensional simplified diffusion model were applied to calculate the moisture content near the die-pad.

For thin packages investigated, moisture saturation of the encapsulant material is reached fast and concentration gradients become meaningless. Additionally, the typical delamination mechanism at the lower die-pad/encapsulant interface, which is addressed by most of the popcorn models, was seldom observed for thin packages.

14.3 Experimental Observations

The popcorn phenomenon for PQFP packages can be studied by high-speed camera investigations. The already described effect of pressure build-up and popcorn cracking is illustrated in Fig. 14.4.

The effects of moisture preconditioning on package cracking were evaluated in a second experimental step [5]. The specimens were exposed to vapor at a 85°C/85% R.H. environment for 168 h according to JEDEC 112A, level 1. A second batch of samples was exposed to 30°C/60% R.H. for 192 h (level 3 conditions). Both the packages with absorbed moisture and dry packages were subjected to surface mount solder reflow conditions with different peak temperatures up to 215°C.

No package cracking was observed for the dry packages. Again, the unfailed packages were inspected by scanning acoustic microscopy. No inner damage could be detected.

The level 1 preconditioned samples failed in all cases by popcorning. In spite of the commonly expected failure mode with delamination at the lower die-pad/ encapsulant interface (type I), all packages exhibited delamination at the upper die-attach/die-pad interface and subsequent package cracking to the outside, see Fig. 14.5. In the case of level 3 preconditioned packages, about 30% of the

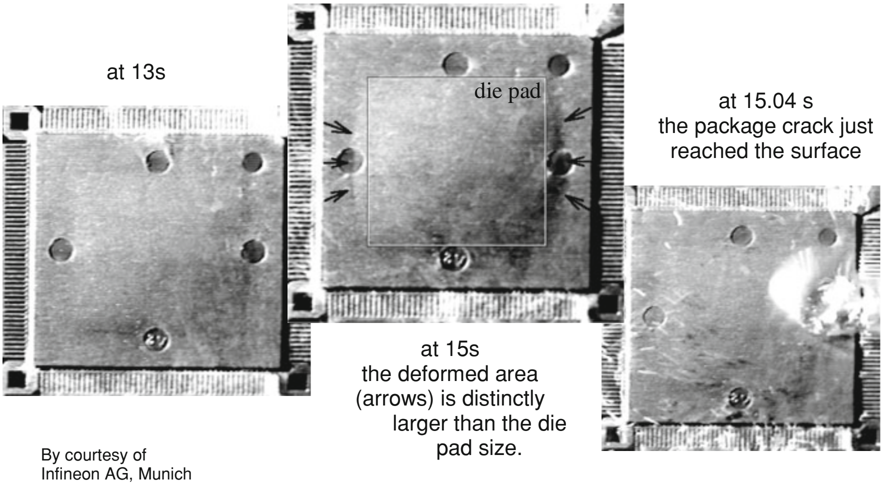

Fig. 14.4 Observation of the development of popcorn delamination growth and MC cracking

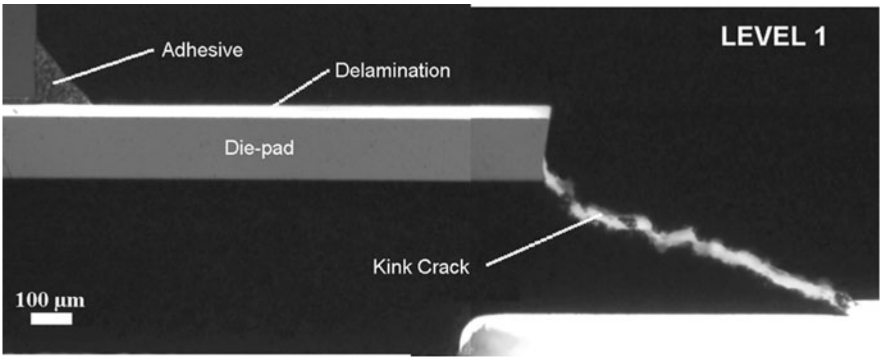

Fig. 14.5 Characteristic popcorn failure mode after level 1 preconditioning (type IV)

cracked samples have shown the same type of cracking, often referred to as type IV cracking, while 70% failed by delamination pad/encapsulant. A typical cross-section of a type I cracked sample is shown in Fig. 14.6. It is obvious from the figures that the kink angles of the package cracks differ for both types of cracking. Cross-sectioning of several samples has validated those cracking directions to be characteristic in connection with the different delaminations. Full delamination of the die-attach and package cracking initiating at the lower edge of the die-pad with crack growth in the characteristic direction shown in Fig. 14.5 is the dominant failure mode with the thin QFP packages at level 1 preconditioning. Thus, this failure mode was studied in further detail by finite element analysis.

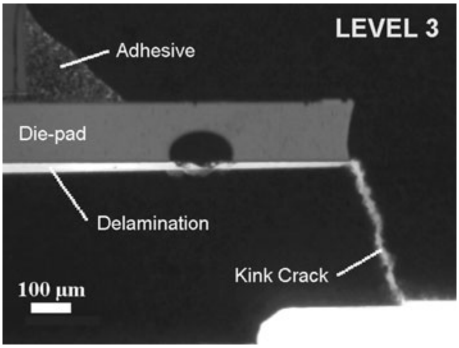

Fig. 14.6 Characteristic popcorn failure mode after level 3 preconditioning (type I)

14.3.1 Characteristics of Encapsulant Materials

It is obvious from the stress phenomena discussed so far that mainly two ways are open to improve package reliability:

- reduce intrinsic stress
- improve interface adhesion

Obviously, the first points become more significant for lead-free soldering, since higher peek temperatures are reached during the soldering process. IC package are subjected to solder shock temperatures, typically up to 260°C for lead-free solder.

To reduce stress, one opportunity in standard application is to use the so-called low-stress encapsulants. According to Koh et al. [2], low-stress encapsulants have commonly been interpreted as having a low CTE: value to be closer to that of the silicon chips. However, since thermal mismatch cannot be avoided, a truly low-stress material must therefore possess additional characteristics that resist crack initiation and moisture penetration. Because the shear stress is proportional to the modulus, lower modulus is desired. Higher flexural strengths, on the other hand, tend to retard crack initiation and propagation.

14.4 Theoretical Analyses

The stress state of the packages, when subjected to moisture, heat, and vapor pressure, can be studied by FE analysis. Different delamination-related types of analysis have to be performed to fully characterize the popcorn phenomenon: moisture diffusion, transient thermal history, and thermo-mechanical stress analyses. However, since a variety of materials data is required and these analyses require non-standard coupling, they are seldom performed in such a detail.

Most important input data is the materials data. It is well known that filled epoxies exhibit dependencies of the mechanical characteristics on moisture,

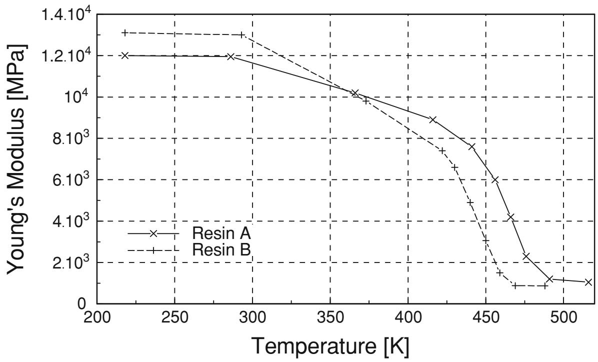

Fig. 14.7 Flexural modulus as a function of temperature

temperature, and time, see e.g. [2, 6, 7]. A drop in mechanical stiffness occurs in the range of the glass transition temperature T_g, while the coefficient of thermal expansion (CTE) usually increases. Additionally, the constitutive response of the filled polymers becomes time dependent, especially at this temperature level.

Characteristic examples for the dependence of the elastic modulus on temperature are shown in Fig. 14.7. The two multifunctional resins shown are the so-called low-stress, highly filled epoxy-based molding compounds with 80 wt% silica content. Both encapsulants reach their T_g at a temperature of about 170°C. Their moisture absorption is low, a value of 0.42 wt% is given by the materials supplier at 85°C/85% R.H. after 168 h. Similarly, the epoxy-based die-bonding adhesive exhibits low moisture content of 0.66 wt% at the same conditions.

Reduction in CTE is achieved through use of optimized filler particle sizes and distributions. The lower limit of approx. 10×10^{-6} mm/mmK has already been reached, and further reduction will be more difficult. Rather than continue to try lowering the CTE, package failures are tried to be reduced more effectively if other properties such as the flexural strength and moisture resistance are improved.

In numerical investigations by means of FEA, either strengths concepts or fracture mechanics concepts are commonly used for design optimizations using sensitivity analyses

In doing so, the most important points in simulation are

- the description of the constitutive behavior of all materials present in the model,
- the measurement and preparation of all relevant geometric and materials properties,
- the definition of all necessary boundary conditions, loading conditions as well as data or additional simulation steps required to define the stress-free state and residual stresses from manufacturing (this could also include special materials models describing the curing process of polymeric materials), and
- (after appropriate simulations) the evaluation of the possibly occurring failure modes.

A variety of investigations on the fracture mechanical treatment of interface mechanical issues has been published by Tay et al., see e.g. [8, 9]. A complex analysis considering all hygro-thermo-mechanical effects is published by Guojun and Tay [9]. The main objective of this paper is to investigate the effects of temperature, moisture diffusion, and vapor pressure on the likelihood of delamination of the interface between the lead frame pad and the encapsulant. In this paper, the entire thermal and moisture history of a plastic IC package is simulated from the start of level 1 moisture preconditioning (85°C/85%RH for 168 h) to subsequent exposure to a solder reflow process lasting about 5 min.

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