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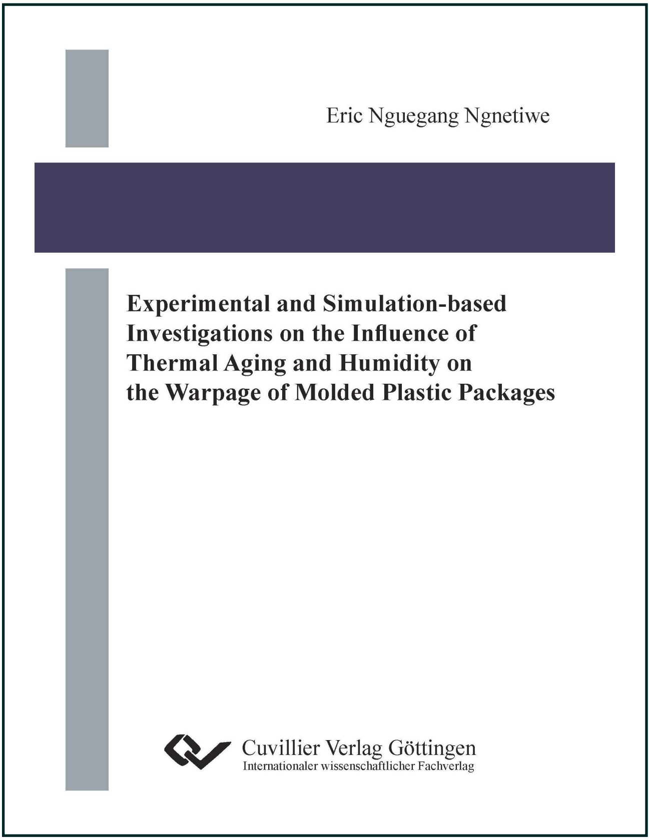
Experimental and Simulation-based Investigations on the Influence of Thermal Aging and Humidity on the Warpage of Molded Plastic Packages



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Chapter 1

Introduction

1.1. Motivation

Epoxy Molding Compound (EMC) is a composite material composed of silica fillers, epoxy resin, hardeners and other additives, like flame retardant and coupling agent [52]. This complex composition gives EMC very good properties like high adhesion strength, low shrinkage, excellent chemical resistance and heat resistance [35]. Compared to conventional encapsulating materials, like metal and ceramic, the use of EMC as an encapsulating material shows many advantages. The prominent advantages are low complexity and low cost. Due to all these excellent properties, the use of EMC in the semi-conductor industry has increased. In this field EMC is used to protect chips against environmental influence like shock, chemical loads, heat and water [35].

The increasing developments in the microelectronic and semiconductor technology have led to two big challenges in the development of Micro-Electro-Mechanical-Systems (MEMS). The first one is that MEMS are becoming smaller and more compact, while performance is increasing. The combination of small size and high performance induces that the encapsulated chips are becoming more sensitive to stress changes in the plastic package. The other challenge is that the requirements concerning robustness, reliability and long-term stability are increasing. The strong need of high reliable packages can be seen in the steady increase of severity of reliability tests during package qualification.

Many studies have been performed to understand the way assembly related processes lead to stress change in molded plastic packages [54, 22, 37, 45, 77]. These studies show the way assembly process-induced stress impacts the output signal of MEMS. Unlike the impact of assembly related processes, the impact of thermal aging of EMC on the reliability and long-term stability of molded plastic packages is scientifically hardly investigated.

In the product qualification, the interaction between chip and plastic package is investigated by subjecting the product to many tests. One of these tests is the high temperature storage, which is commonly used to check the impact of the aging of the plastic package on the product properties. Thereby, molded plastic packages are subjected to high temperature storage at a defined temperature and for a defined time. Both storage temperature and storage time are calculated on the basis of activation energies. The warpage of molded plastic packages typically changes during thermal aging leading to some stress change in plastic packages. Since the plastic package is composed of many different materials having different aging behaviors, the mechanism leading to warpage change during thermal aging is not yet fully understood. On the other hand, the mechanisms leading to warpage changes in molded plastic packages during thermal aging have to be understood in order to be able to improve the robustness, reliability and long-term stability of molded plastic packages.

A typical molded plastic package used in automobile electronics is composed of many different materials. These different materials are for instance copper-based or Land Grid

Array (LGA)-based leadframe, silicon die, adhesive, EMC and so on. Besides its many advantages, EMC has one important disadvantage. Namely, in a humid environment EMC absorbs moisture. In fact, when EMC is exposed to a humid environment, it absorbs moisture [69, 86]. The absorbed moisture leads to volumetric changes of the EMC and consequently to strain changes in EMC. The Coefficient of Hygroscopic Swelling (CHS) was defined to quantify the strain changes as a function of moisture concentration in polymeric materials [71]. Typically, the other materials in the package do not absorb moisture, or absorb less moisture than EMC. Consequently, the different materials in the package undergo different degrees of moisture expansion, resulting in some stress changes in the packages. Such stress within the packages caused by moisture absorption is called hygroscopic stress. Some of the damages resulting from stress changes in the plastic package due to moisture absorption are die cracking, EMC cracking and delamination. Often these damages impact the output signals of the MEMS and can even lead to the failure of the MEMS. On the other hand, the materials in the plastic packages typically have different coefficients of thermal expansion (CTE). Therefore, temperature changes lead to different thermal expansion, causing some stress changes in the package. This stress induced by temperature changes is called thermal stress. In some cases, both hygroscopic stress and thermal stress occur at the same time within the plastic packages. Consequently the induced stress is a combination of hygroscopic stress and thermal stress. A prominent example for such a case is the reflow soldering process. During the soldering process, the hygroscopic stress can be of the same order as, or larger than, the thermal stress [6].

Depending on the applied thermal loads or moisture loads, tensile stress or compression stress arise in the plastic package. This stress leads to warpage of molded plastic packages. The knowledge about the mechanisms of warpage changes of plastic packages under thermal loads and moisture loads is necessary to better understand the origins of stress changes in plastic packages. This can be used to improve the robustness, the reliability and the long-term stability of MEMS molded plastic packages.

1.2. Objectives Target

The goal of this study is to understand the mechanisms leading to stress changes within molded plastic packages subjected to thermal loads and moisture loads. For this purpose the warpage changes of plastic packages were investigated. The mechanisms leading to warpage changes within plastic package are complex. The complexity results from the fact that the plastic package is composed of different materials behaving in different way when subjected to thermal loads or moisture loads. In order to systematically perform the investigation, the main goal was divided into four objectives, as depicted in figure 1.1.

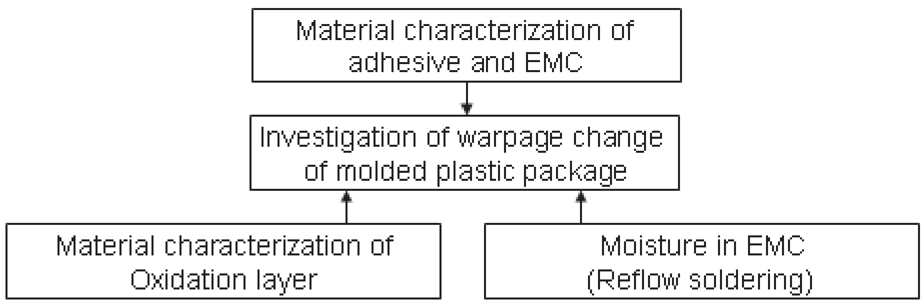

Figure 1.1: The four main objectives of this study.

The first objective of this study refers to the material characterization. Material characterizations will be performed in order to understand the way thermal loads impact the thermo-mechanical properties of adhesive material and EMC. The thermal loads taken into account in this study are post-mold cure (PMC), reflow soldering, temperature cycles (TC) and isothermal high temperature storage (HTS). The stress conditions used in this study are showed in Figure 1.2.

	Curing / Post-Mold Cure	Reflow Soldering	Temperature Cycle (Hold Time: 30 minutes)	High Temperature Storage
Adhesive	1h @150°C	from RT to 260°C	1000TC @-40°C/150°C	1000h @175°C
EMC	3h @175°C	from RT to 260°C	1000TC @-40°C/150°C	1000h @175°C

Figure 1.2: Stress conditions used in this study.

The focus of the material characterization will be put on three material properties. The three material properties are Young's modulus (E), the coefficient of thermal expansion (CTE) and glas transition temperature (Tg).

The second objective of this study will be the investigation of mechanisms leading to warpage changes of plastic packages subjected to thermal loads. The focus will be put on the relationship between the change of the thermo-mechanical properties and the warpage change. For this purpose, bi-material and tri-material systems will be investigated as test specimens. The warpage versus temperature curve of the test specimens will be measured. Based on the changes in the characteristics of these curves, the way the change of thermo-mechanical properties of adhesive materials and EMC can lead to warpage change of molded plastic packages will be demonstrated.

By subjecting EMC to thermal aging at high temperature, the surfaces of EMC acquire a brown color. The color change indicates some chemical changes within EMC. It was found that, in addition to the chemical changes, structural changes also take place within EMC during thermal aging. In this study the brown structure growing at the surfaces of EMC during thermal aging will be called oxidation layer. The third objective and one of the main objectives of this study refers to the characterization of the oxidation layer. New approaches will be developed to extract the thermo-mechanical properties of the oxidation layer. The way the structure change within EMC leads to warpage changes of multi-material systems will be investigated. Finally, the relationship between the formation of oxidation layer and mass change of EMC will be investigated.

The last objective of this study refers to the investigation of warpage changes of molded plastic packages when subjected simultaneously to thermal loads and moisture loads. The moisture absorption and moisture desorption in EMC will be characterized. Thereby, the impact of sample geometry on the investigation results will be analyzed. The characterization results of moisture absorption and moisture desorption will be used to determine the diffusion coefficients. The extracted material parameters will be used to investigate the impact of moisture on the warpage of test specimens during reflow soldering. A new approach will be used to characterize the coefficient of hygroscopic swelling (CHS) of the investigated EMC.