Chapter 1

Introduction

1.1 Background Information

Lead-based solder materials have been used for interconnections of electronic components on printed circuit boards (PCBs) for many decades. However, as public environmental awareness increases, the toxicity of lead has become increasingly important, and the pressure to eliminate or reduce the industrial use of lead is growing. Legislation and policies have been proposed in Europe to ban or limit the use of lead in solders, and the United States is very likely to follow this trend. Following this tendency, great efforts have been made in the industry to develop lead-free and environmentally friendly soldering materials to replace lead-based solders. One alternative to lead-bearing solders is lead-free, low melting temperature metals and metal alloys. Some applications have been found in this area. However, some limitations still exist in lead-free solder technology, including the relatively high cost or limited availability of some candidate metals, and the requirement for relatively high soldering temperature for some metal and metal alloys [1]. Moreover, compared with lead-bearing solders, joint embrittlement and fatigue are also serious concerns in lead-free solder applications as embrittlement of solder joints after reflow and fatigue cracks induced by temperature cycling are among the major causes of lead-free solder joint failure [2].

The other alternative for lead-bearing solders is electrically conductive adhesives (ECAs). ECAs consist of a polymer binder that provides mechanical strength, and conductive fillers, which offer electrical conduction. Electrically conductive adhesives provide an environmentally friendly solution for interconnections in electronic applications. Moreover, ECAs also offer several potential advantages over conventional solder interconnection technology including finer pitch printing, lower temperature processing, and more flexible and simpler processing [3,4]. In addition, compared with lead-free solders, conductive adhesive systems exhibit greater flexibility, creep resistance, and energy damping [5], which can reduce the possibility of failures that occur in lead-free solder interconnections. Therefore, electrically conductive adhesives are perceived as the next generation interconnection material for electronic packaging [6]. As a relatively new interconnection technology, however, conductive adhesive technology does have some limitations and drawbacks. Some reliability issues including limited impact resistance [7,8], increased contact resistance, and weakened mechanical strength in various climatic environmental conditions [8,9] are several major obstacles currently preventing ECAs from becoming a general replacement for solders in electronic applications. Therefore, fundamental studies are necessary to develop a better understanding of the mechanisms underlying these problems, and to improve the performance of conductive adhesives for electronic applications, before ECAs are widely used for solder replacement.

1.2 Objectives and Significance of This Study

This study aims at improving our understanding of mechanical and thermal properties of electrically conductive adhesives and their joints, and is conducted from three aspects as listed below and detailed in the following paragraphs.

1. Study the effect of environmental aging on thermal and mechanical properties of bulk electrically conductive adhesives.

2. Investigate the effect of environmental aging on the durability of the conductive adhesive joints.

3. Develop a test method for characterization of impact performance of electrically conductive adhesives.

The first objective of this study is to investigate changes of thermal and mechanical properties of electrically conductive adhesives upon exposure to a hot/wet environment. It has been shown in many polymeric systems that warm, moist environments can considerably alter the performance of the adhesives. Moisture absorbed in a polymer matrix may lead to both reversible and irreversible effects on the polymeric material [10]. As a polymeric material filled with conductive metallic fillers, electrically conductive adhesives would react to the environmental aging in a similar way as other polymeric systems. Numerous studies have shown that the reliability of conductive adhesive joints can degrade significantly upon exposure to hot/wet environments. However, there is a lack of literature discussing the mechanism of water adsorption into the ECAs and subsequent effects of water on the properties of bulk conductive adhesives. Through a comparative study of three model conductive adhesives, this study aims at improving our understanding of reactions of different conductive adhesives to water attack and exploring the possible mechanisms underlying the different responses to water attack.

The second objective of this study addresses environmental aging effects on the mechanical behavior of conductive adhesive joints exposed to elevated temperature and humidity conditions. Moisture may affect the behavior of the adhesive joints by attacking the adhesive/substrate interface, in addition to the bulk adhesive [10]. Several researchers have shown [11-13] that interfacial properties become increasingly critical when adhesive joints are subjected to hostile environmental conditions, due to the degradation of the interfacial region, which may cause failures of adhesive joints at the interface. Some research has suggested that the reliability of ECA joints depends on the properties of the conductive adhesives, as well as the substrate metallization [9,14]. Therefore, it is important to inspect the degradation mechanism of conductive adhesive joints with different adhesive/substrate metallization combinations. Numerous studies have been found in the literature to investigate *electrical* reliability aspects of conductive adhesives by conducting environmental tests such as temperature/humidity tests and thermal cycling tests on actual component and board assemblies. However, there is a lack of literature reporting thoroughly on the *mechanical* aspects of reliability of conductive adhesive joints upon exposure to environmental aging conditions. In the present study, a fracture mechanics-based approach was utilized to study the durability of the conductive adhesive joints and obtain a better understanding of the failure mechanisms of the adhesive systems being studied. With this study, we expect to contribute from the following aspects. First, the test method utilized in this study could be adopted as a useful tool in evaluating newly formulated conductive adhesives. Second, a comparative study on the failure mechanisms of different conductive adhesive and substrate metallization combinations could provide the electronics industry with some insights on the selection of electrically conductive adhesives and substrate metallizations for tougher and more durable conductive adhesive interconnections.

The third objective of this study is to characterize the impact resistance of conductive adhesives using an appropriate test technique, and investigate how the impact performance of ECAs can be improved. Limited impact resistance of adhesive interconnections is one of the major obstacles preventing ECAs from becoming a general replacement for metal solders in electronic applications. Current efforts to evaluate the impact resistance of lead attachments involve dropping mounted chip and board assemblies onto hard surfaces from a 60-inch height. Passing six drops is defined as a pre-requisite for the application of the conductive adhesive [8]. This drop test is easy to conduct. However, the results obtained from this technique can be very inaccurate as many factors such as inconsistent release, inconsistent drop angle, and possible multiple hits may introduce great errors in the results. Moreover, this technique can only qualitatively evaluate the impact resistance of conductive adhesives, and not much optimal information can be obtained from the drop results. It is desirable to develop a test technique that can quantitatively characterize the impact resistance of conductive adhesives at a material level and yield useful information in screening adhesives and helping to formulate new conductive adhesives with favorable impact performance. In the present study, a falling wedge test was adopted for the characterization of impact resistance of conductive adhesives. The results generated in this study could provide some useful information for conductive adhesive development.

1.3 Organization of This Dissertation

This study is divided into six chapters and each chapter is briefly described as follows.

Chapter 1 gives a brief description of background information related to this research and presents the objectives and significance of this study.

Chapter 2 deals with a literature review covering various topics related to this research work such as conductive adhesives, theories of adhesion, water adsorption and diffusion in polymer systems, fracture mechanics and double cantilever beam test, and a review of some high loading rate tests for adhesively bonded joints.

Chapters 3 through 5 are the core parts of this study. Each of the three chapters forms an independent study and is written in paper format for formal publication in several journals. As a result, a small part of information may be shared in different chapters, for the purpose of independent publication.

Chapter 3 is entitled “Environmental Aging Effects on Thermal and Mechanical Properties of Electrically Conductive Adhesives”. This was written for submission to the

Journal of Adhesion. This paper investigates environmental aging effects on thermal and mechanical properties of bulk electrically conductive adhesives (ECAs). A combination of several experimental techniques including thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), and stress-strain dogbone testing was utilized throughout this study. Both reversible and irreversible effects of water on the conductive adhesives were investigated.

Chapter 4 is entitled "Environmental Aging Effects on the Durability of Conductive Adhesive Joints". This is also a paper prepared for submission to the *International Journal of Adhesion and Adhesives*. This paper aims at studying effects of the environmental aging on the durability of the conductive adhesive joints, and investigating the failure mechanisms of the conductive adhesive joints. A fracture mechanics-based approach, in conjunction with the surface characterization techniques including scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS) was utilized in this study.

Chapter 5 is entitled "Determination of Impact Resistance of Electrically Conductive Adhesives Using a Falling Wedge Test", which will be submitted to the *IEEE Transactions on Components & Packaging Technologies* for publication. A falling wedge test was adopted to quantitatively characterize the impact performance of conductive adhesive joints. The impact behavior of three conductive adhesive joints was compared and factors that may affect the impact behavior of conductive adhesive joints were investigated.

As closure of this dissertation, Chapter 6 summarizes the important conclusions and findings of this research work, and also proposes some future work in this area.

Finally, several appendices are included. Appendix A-E give some supplemental information related to this research and some results that are not incorporated in the formal chapters of this dissertation.

Appendix F was the effort from the first year of work and covers the study of the mechanical performance and long-term durability of high performance polyimide adhesives and their joints.

1.4 Reference

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