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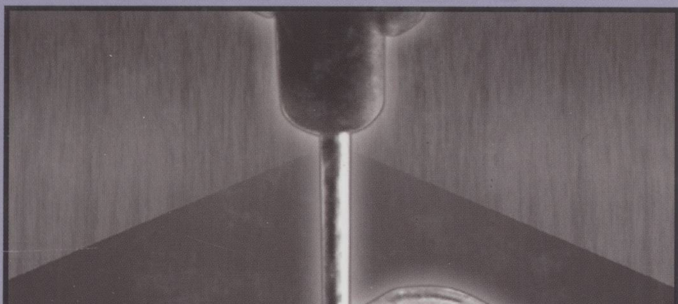
Encapsulation Technologies for Electronic Applications



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Materials and Processes for Electronic Applications Series

ENCAPSULATION TECHNOLOGIES FOR ELECTRONIC APPLICATIONS

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Preface

The use of electronics has become intimately intertwined with human lives. From laptops and mobile phones to medical instruments and aircraft control units, electronic devices are used in most products today and in increasingly varying environments. The dominant trend is toward smaller, lighter, and faster electronic devices. Electronic packaging and plastic encapsulation play a significant role in this trend. With advances in electronic packaging including three-dimensional packaging (or die-stacking), wafer-level packaging, environmentally friendly or "green" encapsulant materials, and extreme high- and low-temperature electronics, a book on encapsulation technologies used in electronic applications has become essential.

This book describes the fundamentals of plastic encapsulation, discusses advances in encapsulation materials and technologies, and explores the intersection of emerging technologies such as nanotechnology and biotechnology with encapsulant materials. The main emphasis of this book is on the encapsulation of microelectronics; however, the encapsulation of connectors and transformers is also addressed.

The book is organized into eight chapters. Chapter 1 presents an overview of electronic packaging and encapsulation. Various types of plastic-encapsulated microelectronics including 2D and 3D packages are discussed. Chapter 2 is devoted to plastic encapsulant materials, which are categorized according to encapsulation technology. A separate section is devoted to environmentally friendly or "green" encapsulant materials. Chapter 3 is focused on encapsulation process technologies including molding, glob-topping, potting, underfilling, and printing encapsulation. In this chapter, the encapsulation of wafer-level and 3D packages is also discussed. Chapter 4 discusses the characterization of encapsulant properties including manufacturing, hygro-thermo-mechanical, electrical, and thermal properties. Chapter 5 describes encapsulation defects and failures, while Chapter 6 presents defect and failure analysis techniques including both non-destructive and destructive tests. Chapter 7 is focused on qualification and quality assurance of encapsulated microelectronics. Both virtual and product qualification processes are discussed and accelerated tests and industry practices are presented.

The final chapter, Chapter 8, explores trends in and challenges for electronics, packaging, and plastic encapsulation. Moore's law and "More than Moore" are presented. Evolution from integrated circuits to system-in-package and system-on-package is discussed. Extreme high- and low-temperature electronics are described. Furthermore, plastic encapsulation associated with microelectromechanical systems, nano-electronics and nanotechnology, bioelectronics and biosensors, and organic light emitting diodes and photovoltaics is discussed.

This book is most suitable for the professional engineer and material scientist interested in electronic packaging and plastic encapsulation. Entrepreneurs in the electronics industry can also benefit from this book. Additionally, this book can be used as a textbook in an elective course for senior undergraduates or first-year graduate students with a background in material science or electronics.

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Contents

1 Introduction

Electronics are used in a wide range of applications including computing, communications, biomedical, automotive, military, and aerospace. They must operate in varying temperature and humidity environments ranging from indoor controlled conditions to outdoor climate changes. Exposure to moisture, ionic contaminants, heat, radiation, and mechanical stresses can be highly detrimental to electronic devices and may lead to device failures. Therefore, it is essential that the electronic devices be packaged for protection from their intended environment, as well as to provide handling, assembly, and electrical and thermal considerations.

Electronic packaging may involve either hermetic (ceramic or metallic) packaging or non-hermetic (plastic) encapsulation. Currently, more than 99% of microelectronic devices are plastic encapsulated. Improvements in encapsulant materials and cost incentives have stretched the application boundaries for plastic electronic packages. Many electronic applications that traditionally used hermetic packages such as military are now using commercial off-the-shelf (COTS) plastic packages. Plastic encapsulation has the advantages of low cost, availability, and manufacturability.

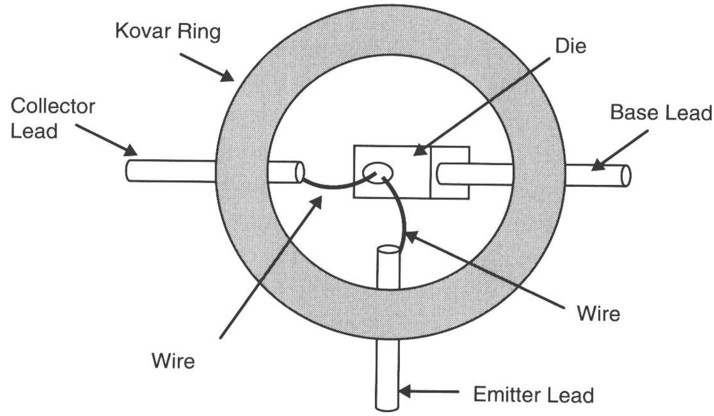
Much of the focus is aimed at the research and development of new and improved encapsulants. With recent trends in environmental awareness, new environmentally friendly or "green" encapsulant materials (i.e., without brominated additives) have emerged. Plastic packages are also being considered for use in extreme high and low temperature electronics. 3D packaging and wafer-level packaging require unique encapsulation techniques. Encapsulants also play a role in emerging technologies. Modified existing or newly developed encapsulant materials are being developed for microelectromechanical systems (MEMS), bio-MEMS, bioelectronics, nanoelectronics, solar modules, and organic light-emitting diodes. Nanocomposite encapsulants with improved material properties are also being explored.

In this chapter, a historical overview of encapsulation is provided. Electronic packaging including package levels, encapsulated microelectronic devices, hermetic packages, and encapsulation methods and materials are discussed. Microelectronic packages including both 2D and 3D packages are described. Finally, a comparison of hermetic versus plastic packages is presented.

1.1 Historical Overview

Electronic devices have been packaged in a variety of ways. Among the first package types was a preformed package made of Kovar (an alloy of nickel, cobalt, manganese, and iron). Kovar, a trade name of Westinghouse Electric and Manufacturing Company, and invented by Howard Scott in 1936 [1], has the advantage of a coefficient of thermal expansion (CTE) similar to that of glass. It is a suitable choice for sealing to glass because of lower CTE mismatch stresses.

One of the early transistor packages is shown in Fig. 1.1 [2]. In this package, the emitter, collector, and base connector leads were inserted



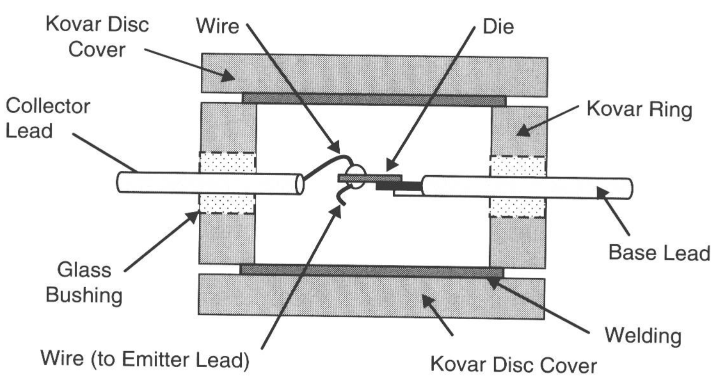


Figure 1.1 Kovar transistor package: (a) top view; (b) side view [2].

through a glass bushing positioned in a Kovar ring or cylindrical housing. The bushing was made of a suitable electrical insulating and moisture impervious (hermetic) glass material. The transistor device was then bonded to the base lead and interconnected to the emitter and collector leads using wires. The Kovar disc covers were later hermetically sealed by welding. Ceramic packages, similar in construction to the Kovar casing, appeared later as less expensive alternatives.

The first plastic-encapsulated packages appeared on the market in the early 1950s. By the early 1960s, plastic encapsulation emerged as an inexpensive, simple alternative to both ceramic and metal encasings, and during the 1970s, virtually all high-volume integrated circuits (ICs) were encapsulated in plastic. By 1993, plastic-encapsulated microelectronics accounted for over 97% of the worldwide microcircuit production.

Most early microelectronic devices were compression molded where the molding compound is heated and compressed inside the mold. Potting soon emerged as a suitable alternative. Potting involved positioning the electrical circuit in a container and pouring the liquid encapsulant into the cavity. Figure 1.2 shows a typical transistor encapsulated using the "can and header" method [3]. The transistor chip was soldered to a carrier which was then attached to the header assembly. The header assembly consisted of three parallel conductive lead-posts sealed into a button-like header made of pre-molded plastic encapsulant material such as a phenolic. The header served as a support for maintaining the relative positioning of the

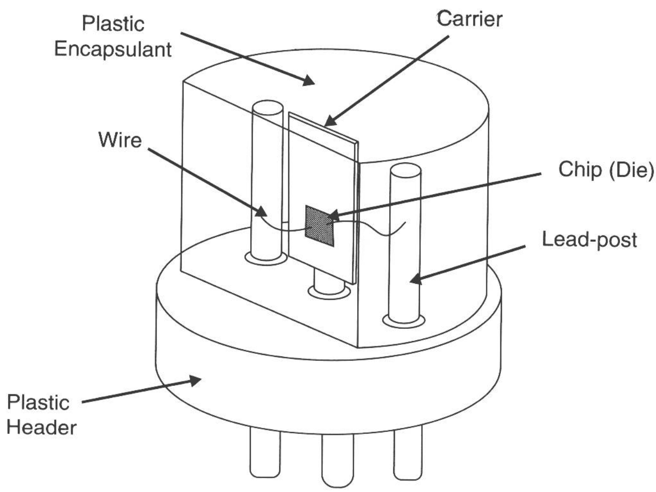


Figure 1.2 "Can and header" transistor package [3].