

1.0 INTRODUCTION

In today's sophisticated electronics workplace, reliability/quality, availability and cost are important considerations in the selection of components for products intended for the telecommunications, computer, automotive and military markets. The selection of hermetic or plastic encapsulated semiconductor packaging, which is still an important factor which must be assessed, can have a significant effect on the aforementioned considerations. The differences in these packaging approaches are illustrated in Figure 1.0-1. The significant amount of data and information that is provided and discussed in this report will assist your evaluation of the reliability and quality of plastic encapsulated microcircuits (PEMs).

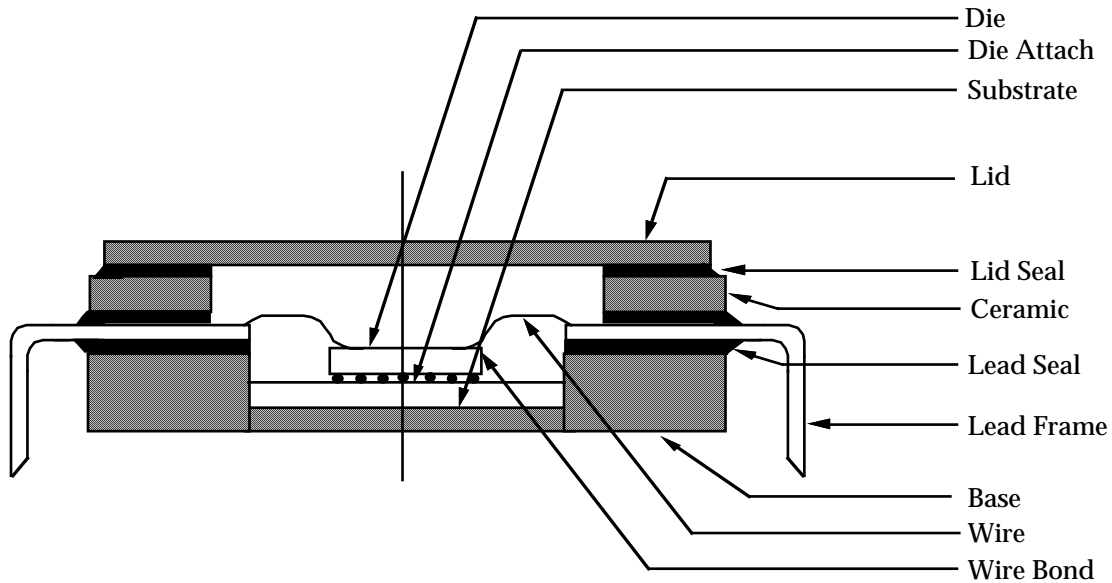
A PEM uses organic packaging material, either transfer molded or coated, for environmental protection. This material is in direct contact with the semiconductor element or an inorganic barrier layer. This is in contrast to metal or ceramic packaging, which has a hermetically sealed cavity and no active element or organic barrier interface with the packaging material. The vast majority of PEM usage has been in commercial, telecommunication, automotive and industrial applications. Military usage has been generally limited to high shock (munitions) and Nondevelopmental Items (NDI) or Commercial Off-The-Shelf (COTS) applications.

The major advantages that can be gained from the use of PEMs:

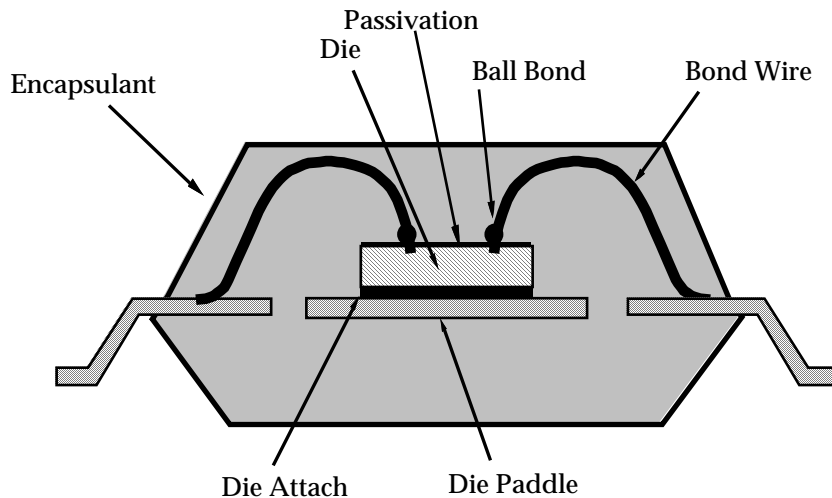
- Greater availability (especially surface mount packaging)
- Lighter weight
- Lower cost (high volume procurement)

Concerns associated with increased PEM usage, especially in military applications, include:

- Uncertainty regarding their long term reliability in harsh environments
- Lack of industry standard reliability/quality assurance procedures
- Insufficient military environment reliability data (operating and storage)
- Existing military Original Equipment Manufacturer (OEM) procurement expertise

CERAMICS:

- Single Base and Lid material
- Single Lid Seal material
- Single Substrate
- Single Lead Frame
- Single Die Attach material
- Single Wire material (Al)
- Mono metallic interface (Al to Al)
- Die Final passivation scratch; Ionic protection
- Single External lead finish
- Hermetic Cavity

PEMS:

- Multiple Encapsulants (Formulations)
(High, Low: Stress; Ionic; Particle size; TCE
Flame retardants; Glass transition, etc.)
- Multiple Lead frame materials (Cu, Alloy 42)
- Multiple Die Attach materials (Formulations)
- Multiple wire materials (Mostly Au; Al, Cu)
- Bi metallic interface (Al to Au)
- Die Final Passivation scratch, Ionic, Corrosion
protection, Interface matching required
- Single External lead finish
- Non Hermetic Bulk (Interfaces important)

FIGURE 1.0-1: THE DIFFERENCES BETWEEN HERMETIC (CERAMIC) AND PLASTIC PACKAGING

The concern over the lack of industry standard R&QA procedures is diminishing because of the following specification activity:

- Automotive Electronics Council (Chrysler, Delco, Ford) CDF-AEC-Q100-Rev. A, "Stress Test Qualification for Automotive Grade Integrated Circuits" (19 May 1995)
- MIL-PRF-38535 "Integrated Circuits (Microcircuits) Manufacturing, General Specification For", which includes provisions for PEMs
- JEDEC Standard 26 "Plastic Packages for Use in Rugged Applications" (being prepared)

Usage of early PEM's (1970's) was discouraged because of high failure rates. Table 1.0-1 summarizes predominant failure mechanisms and causes experienced in those devices. However, major improvements have been made in the fabrication of PEMs. The following lists some of the processes/materials/testing procedures that have been improved.

- Materials - increased epoxy molding compound (e.g., resin) purity
- Material attributes - enhanced CTE, glass transition temperature, fracture toughness, moisture desorption, adhesion, viscosity, mold release, appearance
- Lead frame design
- Die coatings - high quality device passivation (i.e., silicon nitride)
- Die design (i.e., metal layout)
- Material characteristics - reduced ionic contaminants such as chloride and other halides, flame retardant stability, and ion scavengers
- Fabrication equipment
- Testing procedures - Highly Accelerated Stress Testing (HAST), autoclave, moisture absorbance, C-Mode Scanning Acoustic Microscopy (C-SAM) and dye penetration testing

TABLE 1.0-1: PEM FAILURE MODE/MECHANISMS (CIRCA 1970's)

Failure	Cause
Wire bond intermittency/lifting	Coefficient of thermal expansion (CTE) differences
Wire/metallization corrosion	Moisture/contamination
Voiding/poor adhesion	Processing/materials
Data/soft errors	Alpha particles (filler material)

Recent data show that the failure rate of plastic packages has decreased from about 100 failures per million device hours in the 70's to those shown in Table 1.0-2.

TABLE 1.0-2: AVERAGE EARLY LIFE FAILURE RATES OF PEMS

Application	Failure/10 ⁶ Hours
Computer/Test Equipment	0.0007
Commercial Aircraft	0.04 - .07
Automotive	0.1 - 0.7

Today the most popular molding compound is based on epoxy novolac resin. The basic composition contains, by weight, 15-30% epoxy resin and hardeners; 60-80% fillers; 1-7% pigment, mold release, coupling agent and stress absorbers; 1-5% flame retardant; and 1-2% catalyst. Reduction of chloride and other halides in the basic epoxy composition, stable flame retardants and ion scavengers have essentially eliminated aluminum wire and chip metallization corrosion problems. Single bit loss and soft errors have been reduced through reduction of alpha emitting elements and by barrier coating of the integrated circuit (IC) die.

Delamination or "popcorning" associated with surface mount technology (SMT) using various soldering techniques is understood and can be controlled. Techniques used include baking the finished part and sealing it within an airtight plastic bag with a desiccant to reduce moisture levels. A second method that has proven successful is controlling temperature ramp change rates during soldering. At the device level, delamination effects can be reduced by perforating leadframes, decreasing filler particle size, and stamping lead frames to eliminate burr formation sites that contribute to stress concentration.

PEMs are currently being used in harsh environments, such as automotive under-hood applications and commercial avionics systems. The mechanical ruggedness of plastic packaged devices makes them attractive in high shock and vibration applications that can damage ceramic packages.

To ensure PEM reliability, it is important to carefully review each potential vendor's manufacturing process and reliability test results. Additionally, while PEM's are typically available and guaranteed by the vendor to perform over the commercial temperature range of 0-70°C, to vendor electrical parameters, the industry has had success with the use of these devices at greater temperature extremes. However, to ensure performance it is necessary for each OEM to not only certify each vendor, but also to verify that each device will satisfy its intended application. For example, temperature can affect device parameter limits (e.g., speed) or reliability (e.g., excessive current density).

Some items that have been proven to enhance reliability that can be used in evaluating the integrity of a supplier of plastic parts include, but are not limited to:

- reduced phosphorus levels in passivation
- dual layer passivation to ensure passivation integrity
- perforated lead frames
- benign (non-ionic) cleaning of lead frames after molding
- use of copper lead frames
- reduced stress trim and form
- corrosion resistant mold compounds
- nitride passivation
- control/elimination of ionic contamination
- comprehensive reliability program

Today there is general acknowledgment that there have been significant improvements in plastic encapsulated devices. Although their failure mechanisms have not been totally eliminated, they have been reduced by orders of magnitude.

Interest in the use of PEMs in commercial and industrial products for industrial and military applications is rising. The Army's advocacy has resulted in the proposed use of PEMs in several Army systems, which complements their current use in munitions. Both Army and Navy organizations have sponsored workshops to solicit active discussion of PEMs in all environments. The Army released MIL-HDBK-179 (ER) "Microcircuit Application Guide Book", dated 25 October 1993, to provide guidance for the use of PEMs. The A version of this document, dated 20 July 1995, is now approved for use by all departments and agencies of the DoD for guidance. The Air Force is actively involved in evaluating PEMs and developing test and procurement procedures to ensure their quality and reliability when procured in accordance with "best commercial practices." These subjects, as well as other relevant topics, are addressed in this report.

"Best commercial practice" is an ambiguous phrase that is used to describe the procurement of components, including PEMs. Each semiconductor company has in place an established procedure to supply and warranty PEMs that operate over the temperature range of 0 - 70°C to their specified performance levels. In addition, users have established procedures to complement "best commercial practice", such as vendor assessment and selection, testing/reliability monitoring and device design. This is not a criticism of vendor procedures, but indicates that the commercial/industrial use of PEMs includes supplier audits, data analysis, device robustness assessment and testing in addition to suppliers' standard processing to establish a baseline. However, when a relationship like this exists (i.e., user/vendor alliance demonstrates acceptable quality levels), features such as ship to stock, and on-line reliability monitoring of vendor testing/processing are becoming common.

On 29 June 1994, Secretary of Defense William Perry signed a memorandum dealing with Military Specifications and Standards labeled "A New Way of Doing Business". Basically, the memo directs the Department of Defense (DoD) to increase its use of "best commercial practices" and products. This would be accomplished by (1) requiring the use of performance specifications and Non-Government Standards (NGS) instead of military unique specifications and standards; (2) requiring waivers to justify the use of military specifications and standards for DoD acquisition programs; (3) emphasizing the use of process controls in lieu of government oversight and testing requirements; and (4) restricting excessive document tiering and referencing. This memorandum was an outgrowth of the Report of the Process Action Team on Military Specifications and Standards, April 1994, led by Ms. Colleen Preston, Office of the Undersecretary of Defense for Acquisition & Technology. In general, the intent of this new direction in DoD acquisition is to meet future needs by increased access to commercial state-of-the-art technology and adoption of business process characteristics indicative of a world class supplier. In addition, integration of commercial and military development and manufacturing facilities are endorsed, thus leading to an expanded industrial base capable of meeting defense needs at lower cost. This goal can only be accomplished by eliminating or modifying the military unique acquisition requirements.

Included in this new approach to military system procurement is the use of commercial parts including PEMs and the use of commercial manufacturing facilities and processes. The guidance within this report is intended to assist the implementation of PEMs into military systems/equipment.

The theme of a previous Reliability Analysis Center (RAC) report "Plastic Microcircuit Packages: A Technology Review", was to indicate that measurable improvements in their quality and reliability were becoming evident, and that significant user interest, whether they be automotive, commercial, industrial or military customers, had been documented. Also, the report provided information to help answer the question "Why does the military limit the use of plastic packaged devices?" At that time, answers to this question included:

- a lack of usage data from severe/harsh and storage environments
- no definitive test/procurement procedures
- the lack of a industry/government working relationship similar to that which exists for hermetic packaging

Since the publication of the RAC document in 1992, numerous programs, workshops, meetings and journals have provided additional information that should provide confidence in the wider utilization of PEMs. To further assist this wider utilization, the RAC implemented the Information Management Program on Advanced Component Technologies (IMPACT) program to enhance its data collection effort specifically for plastic packaged devices. Information was solicited on plastic packaged monolithic, GaAs and hybrid microcircuits and multichip modules, including failure rates and failure modes/mechanisms. Special emphasis was placed on:

- Air Force, Army, and Navy R&D organizations (i.e., Rome Laboratory, Naval Surface Warfare Center and Army Research Laboratory) who are in the forefront of new technology and their application in military systems.
- Component manufacturers/test houses to collect results of burn-in and life testing on the latest technologies. Device test data has been found to be an important data source due to the time delay of fielding equipment, non-existent or undependable data tracking and the prohibitive cost of collecting, evaluating and summarizing data.
- Component users, to collect system data from all environments (i.e., automotive, telecommunications, computer, military and commercial OEMs). This typically results in 1 year warranty data.
- Technical Interchanges - RAC participates in many forums (i.e., RwoH Programs, SHARP and microelectronic quality workshops, IRPS) which are major educational exchanges for component technologies and systems.

All new information and data collected from the IMPACT initiative is housed in existing RAC databases. Quantitative data has become part of the RAC component databases that

presently include failure rate, time-to-failure, failure mode/mechanism and electrostatic discharge susceptibility data. Qualitative information has become part of RAC's bibliographic database.

This program has led to the collection of a significant amount of data from various environments/sources. Table 1.0-3 lists the sources and the type of data that was collected in the IMPACT effort. While the companies listed in this table submitted data to RAC as part of the IMPACT data collection initiative, there already existed a significant amount of PEM data in the RAC database. All data analysis and modeling efforts were based on all available RAC data which includes but was not limited to data from the listed organizations.

The results of the IMPACT data collection effort includes information on device reliability and burn-in/life testing from vendors, test houses and government test activities. Many variations of data from commercial airplane and automotive environments; specification and test method activities and device test and evaluation programs from both commercial and government activities are discussed.

Due to the success of this study in collecting empirical data from a variety of sources it was now possible to quantify the reliability of PEMs under a variety of test and field usage. As a result, major emphasis was placed on developing a PEM reliability assessment model. Collected data was summarized and analyzed to determine its significance and impact on PEM reliability. The model form is based on the contribution of defects and identified failure modes/mechanisms. Model application is flexible, allowing the use of user/vendor existing data, or the default values derived from the RAC database.

TABLE 1.0-3: DATA SOURCES

Company	Type Of Data
AT&T - Component Evaluation Technology Center (CETC)	Component Test and Evaluation
Delco	Automotive User
PAR	Commercial User(Point of Sales Equipment)
Honeywell	Commercial User (Commercial Avionics)
TI	Semiconductor Vendor
Signetics	Semiconductor Vendor
Intel	Semiconductor Vendor
TriQuint	Semiconductor Vendor (GaAs)
Alliant Tech Systems	Military OEM (Munitions, Fuzes)
Hewlett Packard	Commercial OEM
Beckman Industrial	Hybrid Microcircuit Vendor
Catalyst Semiconductor	Semiconductor Vendor
Bofors Missiles	Military OEM
Eldec Corp.	Commercial/Military OEM
Ericsson Telecom	Telecommunications
Hughes Aircraft	Military OEM
Group Technology Corp.	Military OEM
National Semiconductor	Semiconductor Vendor
Dow Corning	Materials Vendor
Unitrode	Semiconductor Vendor
RelTech	Government
General Dynamics	Military OEM
Naval Surface Warfare Center Crane (NSWC)	Government
US Army Research Labs	Government
Rome Laboratory	Government

Additionally, responses from solicited CRTA PEM subscribers indicated the need for a destructive physical analysis (DPA) procedure and a recommended plastic decapsulation procedure, both of which have been included as part of this report.