Proper long-term IC storage: Better plan carefully

By Edwin Slipher

The mismatch between rapid civilian technology obsolescence and the typical 10-plus year military program often forces system integrators and program offices to procure lifetime buys of ICs and store them for future use. For Diminishing Manufacturing Sources (DMS) devices, long-term storage presents problems – practical, mechanical, and financial, and counterfeit products. But is it possible to successfully store ICs for the long term?

The simple answer is “yes,” if proper conditions are met. Long-term storage of integrated circuits at the die/wafer level, in plastic packages, or in hermetic (airtight seal) packages can be accomplished, and in many cases some times exceeding 20 years. The process is not as easy as it sounds, but anything is possible, given enough time and money. So, what do we mean by long-term storage? This is a highly variable subject depending on the industry segment.

For standard commercial plastic ICs, many market segments want materials less than a year old and refuse to purchase older materials. Unfortunately, for military systems users, the commercial markets only need up to two years of storage, thus processes and methodologies aren’t designed to support long-term storage in the ranges of 5, 10, and 20 years. For instance, Sharp North America has a Technical Bulletin[1] titled “Long-term IC Storage,” which recommends “… that the customer perform their own reliability and manufacturability analyses on any product that is older than two years…”

Successful storage methodologies encompass special bagging materials and environmental controls. There are effective long-term methods for IC preservation including storage at the die/wafer level, as Plastic Encapsulated Microcircuits (PEMs), or in hermetic packages. (Table 1 shows a comparison of storage options.)

Storing ICs in die/wafer form

There is extensive long-term storage experience among military integrated circuits manufacturers, as most have used “die banking” for products no longer supported by their “commercial” divisions. Companies like TRW, Raytheon, Fairchild, National Semiconductor, Siliconix/Vishay, Signetics, and Philips have all had products based on long-term die banking at the die or wafer level. All of the “aftermarket” suppliers similarly base significant numbers of products on “banked” wafers and die.

Die/wafer storage can exceed 20 years and routinely exceeds 10 without product degradation when stored properly and under controlled, benign conditions. Proper storage requires either controlled atmosphere “dry boxes” (dry nitrogen purged storage) or storage in “dry bagged/vacuum storage.” In addition, there are oxygen barrier bags available that are designed specifically for this type of long-term storage.

It is obvious that storage at the die/wafer state requires care, cleanliness (both in particulates and gases), and benign temperatures. Since the same storage conditions are required both for long-term and short-term storage, Integrated Device Manufacturers (IDMs) have proper facilities available. The same is not true for most end users, as the long-term storage facility is not a side benefit of other day-to-day activity. However, there are businesses that offer appropriate storage of die/wafers as a service.

There are significant benefits to storage of DMS materials at the die/wafer level. The materials are compact, making the capital infrastructure investment and long-term storage costs economical. The product cost is lower than for packaged products.

Storage options: Lifetime comparisons

<table>
<thead>
<tr>
<th></th>
<th>Die/Wafer</th>
<th>Plastic</th>
<th>Hermetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Form Factor Flexibility</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Stability/Lifetime</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Storage Space</td>
<td>Small</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td>Storage Infrastructure</td>
<td>Moderate</td>
<td>Difficult</td>
<td>Easy</td>
</tr>
</tbody>
</table>

Table 1
As an example, in Figure 1, a single 6-inch wafer storage container is shown. This container holds nine wafers with nearly 64,000 gross die. Notice the relative size comparison to a standard data CD. The canister shown has been in active storage for 10 years. A recent build of one of the wafers had the same good yield performance as 10 years previous.

A key benefit of this strategy is that the end user has not committed to the final form factor. Often, the use rate during 10 to 20 years is not predictable relative to package type. With the die/wafer storage model, the final package selection can wait until just before use, ensuring that the critical "last units in the world" are available in the needed package type, not one selected by a guess 20 years earlier.

Storing ICs in hermetic packaging

Hermetic packages include the metal TO "can," and the ceramic and side-brazed packages (DIP, LCC, flat pack, and PGA) are designed to minimize moisture ingress. Storing hermetic packages for 10 to 20 years is routine. Additionally, based on several product analyses with which the author has been involved, storage for more than 10 years prior to use is not unusual for several major defense systems suppliers. In one case, the IC involved had been in storage 17 years. Solderability was marginal in several instances because the packages had not been stored in dry, uncontaminated environments, likely because the long-term storage was incidental rather than planned.

With reasonable care – keeping hermetic ICs dry in environments low in sulfur, chlorine, and hydrocarbons – long-term storage should result in the same performance the IC would have provided as the day it was completed by the original device manufacturer.

Storing ICs in plastic packaging

PEMs have much more variation in raw materials that create challenges for successful long-term storage. Unlike hermetic devices, plastic products are hygroscopic (the ability of a material to attract water molecules from the surrounding environment). In general, PEMs come to equilibrium with their environment in about 4 to 28 days, depending on package design and molding compound. Normal room environments are what would be considered "wet" for plastic integrated circuits, which leads to storage of moisture-sensitive parts in "dry bags" or <10 percent RH environment (see Figure 2).

Many plastic devices are “rated” as non-moisture sensitive, but this is related to resistance to solder heat/delamination/popcorning, not for long-term storage. The author recommends dry bagging all PEMs for long-term storage, since the storage medium not only keeps the parts dry but prevents contamination from other sources.

The common misunderstanding is that moisture is only a problem when a device is exposed to the heat of solder reflow. In reality, moisture is a problem when combined with long-term leaching of materials in the mold compound, harmful gases, or materials contaminating the exterior of the plastic package, which can result in degradation of product lifetime.

Unlike hermetic packages, there is a variety of PEM packaging materials. The specific PEM resin used, the type of filler, the size(s) of that filler, and the type of flame retardants used have dramatic effects on the success of long-term storage.
Considering storage materials

The quality of the storage material (for example, bagging materials, desiccants, moisture monitors, trays, and tubes), its permeability over time, and the external environment to which the storage material is exposed can all lead to early failure of the material, exposing the plastic ICs inside to external conditions earlier than predicted. Because of these issues, most manufacturers of products packed in Moisture Barrier Bags (MBBs) recommend periodic checks of the integrity of the partial vacuum or partial pressure applied to the bag/devices during sealing as well as the condition of the moisture-sensing card to ensure that the bag has not failed.

The expectation is that materials would be dry baked and repackaged periodically, potentially, every five years.

Challenges of ICs in storage

Storage for 5 to 20 years should have planned, periodic monitors with dry baking and repackaging upon failure. Periodic inspection and repackaging can be problematic for some packing schemes, like tape and reel, where the devices have to be demounted from the tape and reel to be re-baked and then remounted on new tape. Devices that have coplanarity requirements are easily damaged during any handling related to dry baking or repackaging, so lead inspection and lead stacking must be planned into their long-term storage requirements.

While the hermetic devices in long-term storage are primarily subject to changes in interconnect solderability, plastic products are subject to a number of additional failure mechanisms (Table 2).

Interestingly, several studies of long-term PEM use basically state that PEMs are appropriate for long-term storage, “especially when the continuous improvements in materials are considered.”[2] They assume that the only motivating market force is continuously improving quality.

Recent regulatory pressures have resulted in changes in lead finish (removal of Pb), changes in flame retardants (elimination of antimony- and bromine- based compounds), and market-driven reductions in plastic package form factors. Unfortunately, this has not increased product reliability relative to long-term storage (see sidebar “An unintended consequence”).

Associated risks

Long-term storage of integrated circuits in any form (plastic, hermetic, and/or die/wafers) is feasible, but each carries risk. These risks must be mitigated by thoughtful, preplanned, formalized methodologies and require long-term commitments from the organization stockpiling these valuable and often irreplaceable products.

Long-term storage of PEMs requires attention to detail, initial capital investment in the finished product, a physical storage facility, and periodic verification that the storage conditions remain as designed. PEM storage is similar to storing die/wafers, except that the physical size grows exponentially (a single 6-inch wafer may contain more than 7,000 good die, yet 7,000 14-pin plastic dip packages could require space approximating a full file drawer). As another example, two standard shipping boxes contain about 20,000 good packaged products. All are in sealed bags but will require annual checks of approximately 40 bags versus checking one wafer canister bag for nearly three times the storage quantity (Figure 3).

There is one last impediment that leads to increased risk. In many cases, procurement of 10 or 20 years’ worth of products is prohibited by regulation (FAR), which often limits procurement to one or two years. Systems manufacturers have rarely funded this long-term procurement on their “own dollar.”

So, in the “real world,” the long-term storage often occurs in “broker” storage, for example, in unqualified and uncontrolled environments as material changes hands many times over a 10- to 20-year “storage” time frame. Because of this, there has been rife opportunity for unscrupulous brokers to supply improperly stored parts or, worse, counterfeit products.

In the author’s opinion, often what is meant by “long-term storage” is really not that, but justification for trying to use undocumented, nontraceable materials because the programs involved could not by either resource or regulation (often both) put in place long-term support for their semiconductor requirements.

---

Table 2

<table>
<thead>
<tr>
<th>Failure Mechanism</th>
<th>Die/Wafer</th>
<th>Hermetic</th>
<th>PEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion</td>
<td>Bond pads</td>
<td>Leads may corrode when not properly stored</td>
<td>Same as Hermetic, Internal – die, lead frame, die attach</td>
</tr>
<tr>
<td>Cracking</td>
<td>Mishandling, scratch</td>
<td>Mishandling</td>
<td>Mishandling, passivation, dielectric</td>
</tr>
<tr>
<td>Delamination</td>
<td>None</td>
<td>None</td>
<td>Moisture induced and temp cycle related</td>
</tr>
<tr>
<td>Outgassing</td>
<td>None</td>
<td>None</td>
<td>Molding agents, die attach materials</td>
</tr>
<tr>
<td>Solderability</td>
<td>N/A</td>
<td>Improper storage leads to failure</td>
<td>Copper intermetallic diffusion (temp accelerates); chlorine, sulfur, hydrocarbons, oxidation</td>
</tr>
<tr>
<td>Metallic</td>
<td>N/A</td>
<td>None</td>
<td>Gold/Aluminum intermetallic diffusion</td>
</tr>
<tr>
<td>Tin Whiskers</td>
<td>N/A</td>
<td>Exempt from RoHS, not pure tin</td>
<td>Pure tin plating – lead (Pb) free</td>
</tr>
</tbody>
</table>

Making the case for die/wafer storage
Because mil/aero production lifetimes far exceed those of commercial products, creating a proper long-term IC storage strategy is necessary. There is a long list of storage requirements for PEMs, for instance, which differs from the storage challenges associated with the more ruggedized hermetic ICs. Die/wafer storage, while similar in methodology to PEMs, is simpler and actually offers some advantages: The needed physical storage space is smaller, the capital outlay is less, and there’s the flexibility of changing physical packages at time of use. Wouldn’t this be the better long-term storage methodology?

Edwin Slipher is chief technologist and director of engineering at QP Semiconductor. During his more than 28 years in the mil/aero industry, he has published technical papers on military ICs, co-designed a ceramic TO-5 package, discovered a new failure mechanism (embrittlement of hybrid solder joints), and designed ESD networks for 10K MECL, improving ESD performance from 900 V to 2,500 V. Edwin attended Arizona State University.

QP Semiconductor
2945 Oakmead Village Ct.
Santa Clara, CA 95051
408-737-0992
eslipher@qpsemi.com
www.qpsemi.com

References:
1. ©2007 by SHARP Corporation Reference Code SMA06024

An unintended consequence:
Case example

In the late 1990s and early 2000s, many major IC manufacturers including Fujitsu, Fairchild, Cirrus Logic, and Amkor were involved in litigation with Sumitomo over the introduction and use of a molding compound that used red phosphorus as a significant component. The change in Sumitomo’s molding compound was motivated by increasing regulatory restrictions in materials, to meet more stringent environmental regulations.

While early qualification results by many manufacturers approved use of this mold compound, virtually every company found that long-term reliability was compromised as indicated by high field failure rates.

The first symptoms were intermittent failures, which were difficult to identify. Variations in different lots of molding compound increased variability of the latent period prior to failure. Detection was difficult and slow in coming, resulting in millions if not billions of plastic ICs being manufactured with this built-in failure mechanism.

The problem described impacted virtually every IC manufacturer to some degree. Depending on the marketplace, sensitivity to the problem could take as little as a few months to manifest if conditions were ideal, to several years in more benign (drier) environments.

This is an example of a raw material supplier reacting to regulatory pressure to provide a more environmentally friendly product that has more reliability challenges than the preceding technology. The common perception that “things always get better over time” isn’t necessarily true when faced with external pressures to address environmental concerns.

Unfortunately, many components with red phosphorus mold compound are still available in the broker market today.

1Failures in Semiconductor Device Encapsulated with Red Phosphorus Flame Retardant - Yuliang Deng and Michael Pecht, CALCE Electronic Products & Systems Center, University of Maryland, November 2005
2The Japan Science and Technology Agency, Failure Knowledge Database, “Fujitsu HDD Defect,” July 2002