A Rochester Electronics White Paper

The Effects of Long-Term Storage on Mechanical Integrity and Electrical Performance of Semiconductor Components

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Abstract

In today's semiconductor industry of limited capacity, many Original Component Manufacturers (OCMs) are moving to shorter product lifecycles. However, multiple industries require equipment to be operational and maintained for many decades. Therefore, ongoing component supply is critical to sustaining these applications throughout their useful lifecycle.

Storing semiconductor components for extended periods of time after final production is one widely practiced solution. Since 1981 Rochester Electronics has been successfully practicing prolonged component storage to bridge supply chain disruptions for long-life applications.

When long-term component storage is used, it is important for end-users to have confidence that the components are reliable in the field. In a previous white paper, Rochester's Quality and Reliability teams investigated the effects of long-term storage on the solderability of semiconductor components where no defects were found [1]. The solderability testing, compliant with IPC/JEDEC J-STD-002E and performed by an independent 3rd party, confirmed no negative effects due to component aging, even after extended periods of storage. These results indicate that date codes do not pose a restriction on the useful life of semiconductor components.

This paper examines the long-term storage effects on *mechanical integrity and electrical performance*. A random sample of components, spanning a variety of package styles and stored for periods up to 17 years, were inspected and analyzed to determine the effects of aging. Extensive testing based on optical, X-ray, and SEM imaging, decapsulation, cross-sectional inspection, and electrical testing indicated no negative results or failures.

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1. Introduction

As discussed in our initial white paper [1], Original Component Manufacturers (OCMs) and traditional authorized distributors typically store components for a few years before turning over the inventory. However, since 1981, Rochester Electronics has been successfully storing components for extended periods of time to bridge supply chain disruptions for long-life applications. Fully authorized distributors, such as Rochester Electronics, identify themselves as compliant with the SAE Aerospace Standard, AS6496.

Within the AS6496 standard, the traceability requirements establish the documentation needs for military parts and commercial/industrial parts. Military parts require both the manufacturer's and the distributor's certificate of conformance, while only the distributor's certificate of conformance is required for commercial parts. There is also a provision that specifies the contents of the authorized distributor's certificate of conformance.

The JEDEC Solid State Technology Association has issued best practices for long-term storage of semiconductor wafers, dice, and devices in the document JEP 160. However, this document was first published in 2011. Many distributors, including Rochester Electronics, have been storing components for much longer periods, so complete adherence to these guidelines is not always realistic, particularly for older components.

Several technical white papers published by Texas Instruments [2], [3] have investigated the reliability of components after long-term storage. The initial paper highlighted that semiconductor products properly stored in a controlled environment have a shelf life exceeding 15 years, while a subsequent paper Texas Instruments authored highlighted that no failure mechanisms were found on components stored for up to 21 years. It is worth noting that these studies are based upon components that have been stored in controlled environments.

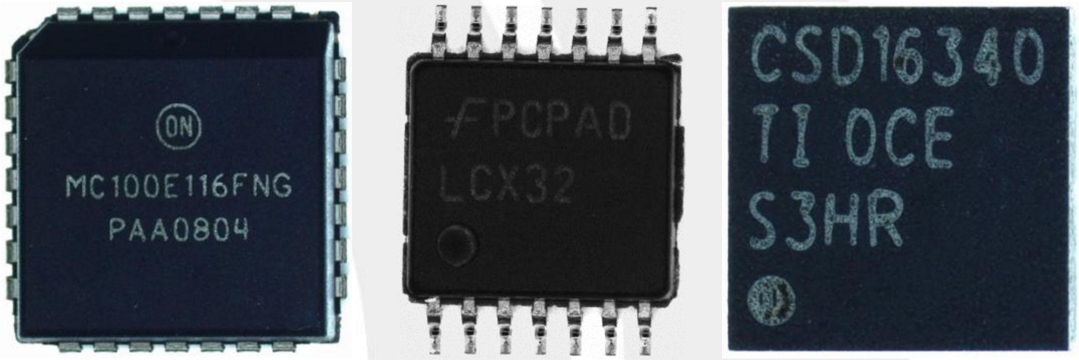
Rochester's investigations utilize a random sample of components that have been stored in a variety of environments for up to 17 years, some but not all, of which have been controlled. A selection of 8 different products was evaluated, composed of 3 separate lead finish types from a total of 5 different suppliers. In addition, our analysis includes an industry-standard board mount and solder paste reflow manufacturing process. An independent 3rd party electronic manufacturing company, experienced in PCB assembly, conducted the assembly process. The contract assembly house is fully ISO-9001 certified and has over 17 years of industry experience.

The Quality and Reliability teams at Rochester have performed analyses of package internal integrity, component-PCB solder joint quality, and electrical test results, to validate that semiconductor devices do not degrade after long-term storage. Analysis methods include X-ray imaging, laser, acid decapsulation, cross-sectioning, scanning electron microscopy (SEM), and both functional and timing electrical tests.

Three packages, a 28-lead plastic leaded chip carrier (PLCC), a 14-lead thin shrink small-outline package (TSSOP), and an 8-pad very thin small outline non-leaded package (VSON) package, of various date codes, was randomly selected for detailed analysis. Results of visual, mechanical, and electrical assessment are detailed herein. Electrical characterizations were obtained using three plastic dual in-line packages (PDIPs) due to available test solutions.

2. Samples

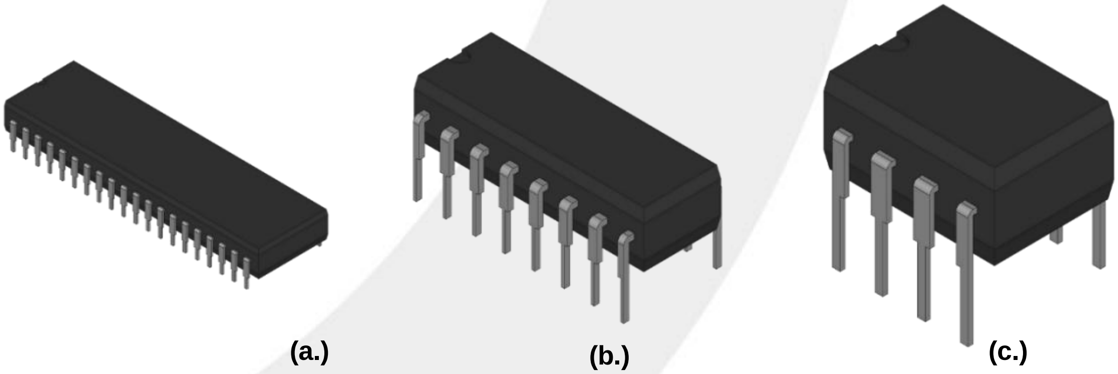
A random sample was conducted by selecting three packages of different types with varying date codes of devices available for testing. The three package types are a 28-lead plastic leaded chip carrier (PLCC), a 14-lead thin shrink small-outline package (TSSOP), and an 8-pad very thin small-outline non-leaded package (VSON), is shown in Figure 1 below.



(a.) **(b.)** **(c.)**

(Figure 1. *External images of* ***(a)*** *28 PLCC,* ***(b)*** *14 TSSOP, and* ***(c)*** *8 VSON packages were used in this investigation. Some date codes used slight variations of product die but shared identical packages.)*

Another random sample was selected from devices with test solutions available, yielding the three different plastic dual in-line packages (PDIPs) in Figure 2 for electrical testing.



(a.) **(b.)** **(c.)**

(Figure 2. *Schematic images of devices subjected to electrical testing:* ***(a)*** *9513APC (40 PDIP),* ***(b)*** *27S21PC (16 PDIP), and* ***(c)*** *UC3835N (8 PDIP). The 9513APC and 27S21PC are digital devices, whereas the UC3835N is analog.*

Product	Years of Storage	Lead Finish	Package Type
MC100E116	14	Matte Sn	PLCC
MC100E111	10	Matte Sn	PLCC
MC100E101	4	Matte Sn	PLCC
LCX02MTCX	13	NiPdAu	TSSOP
LCX32MTCX	9	NiPdAu	TSSOP
LCX02MTCX	6	NiPdAu	TSSOP
CSD16411	12	Matte Sn	VSON
CSD16340	11	Matte Sn	VSON
CSD25401	7	Matte Sn	VSON
9513APC	11	Matte Sn	PDIP
9513APC	3	Matte Sn	PDIP
27S21PC	9	SnPb	PDIP
27S21PC	6	SnPb	PDIP
UC3835N	17	NiPdAu	PDIP
UC3835N	9	NiPdAu	PDIP

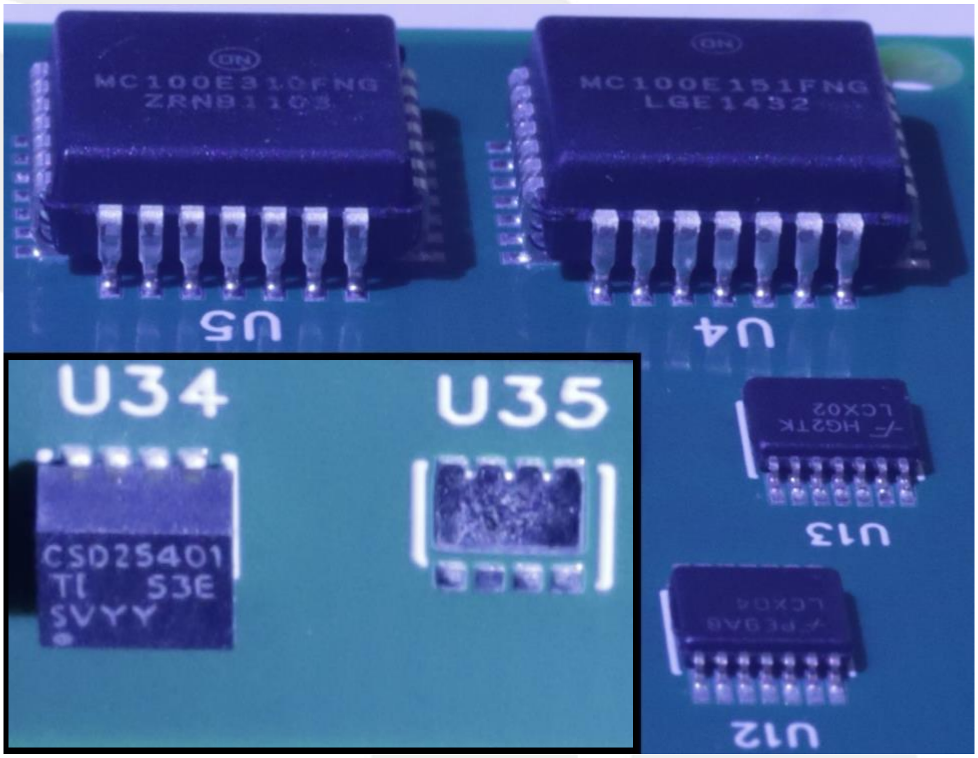
Table 1. *Sampled devices and key characteristics.*

3. Procedure

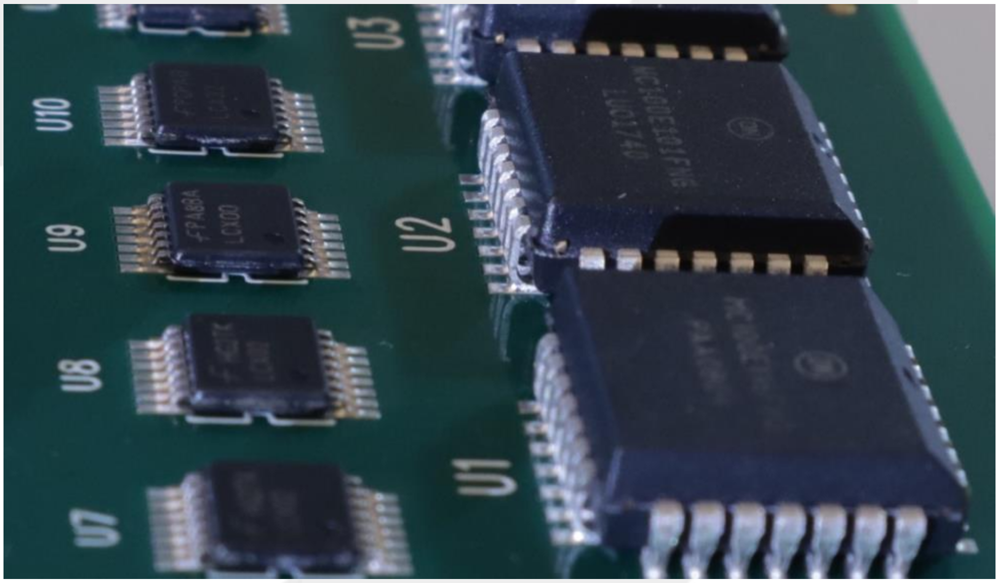
Laser decapsulation was performed on the selected devices to expose the die and examine for defects. No corrosion, cratering, or bond pad cracking was found. Rochester partnered with industry experts for the design, manufacture, and use of printed circuit boards to mount various surface-mount devices of differing package types and date codes. All devices successfully completed reflow at the independent PCB assembler. Rochester verified these results via optical and X-ray inspection of solder joints, cross-sectioning along the length of soldered leads, and SEM imaging of cross-sectioned solder joints. Optical images from external inspection, X-ray images from individual devices and mounted assembly inspection, and SEM images from cross-sectioning and decapsulation are presented below.

4. Optical Imaging of PCB Assembly

Fifty-seven plastic surface-mount devices of 12 different outlines, packaged as early as 2006, were mounted on both sides of each PCB. All pads were inspected, and no failures were found, confirming successful PCB assembly. Images of the solder fillets of devices featured in this investigation are shown in Figures 3 and 4.



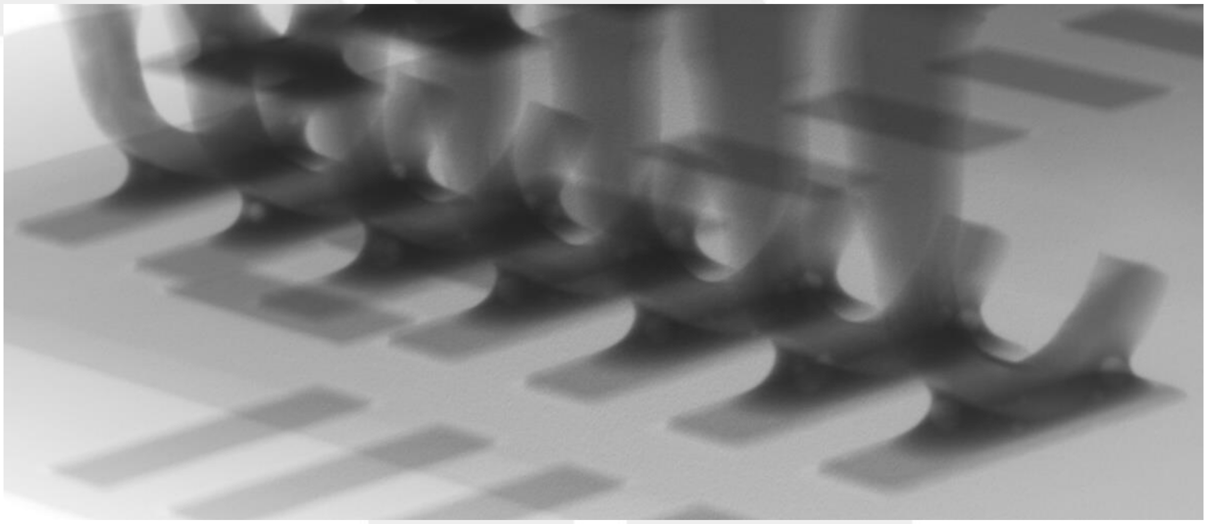
*(**Figure 3.** Optical image of two mounted 28 PLCC devices (upper) and 14 TSSOP devices (lower right). An image of a mounted 8 VSON device and its underlying pad pattern is inset in the lower left. The exposed pattern is due to a missing sample; solder paste was deposited without an available device to mount.)*



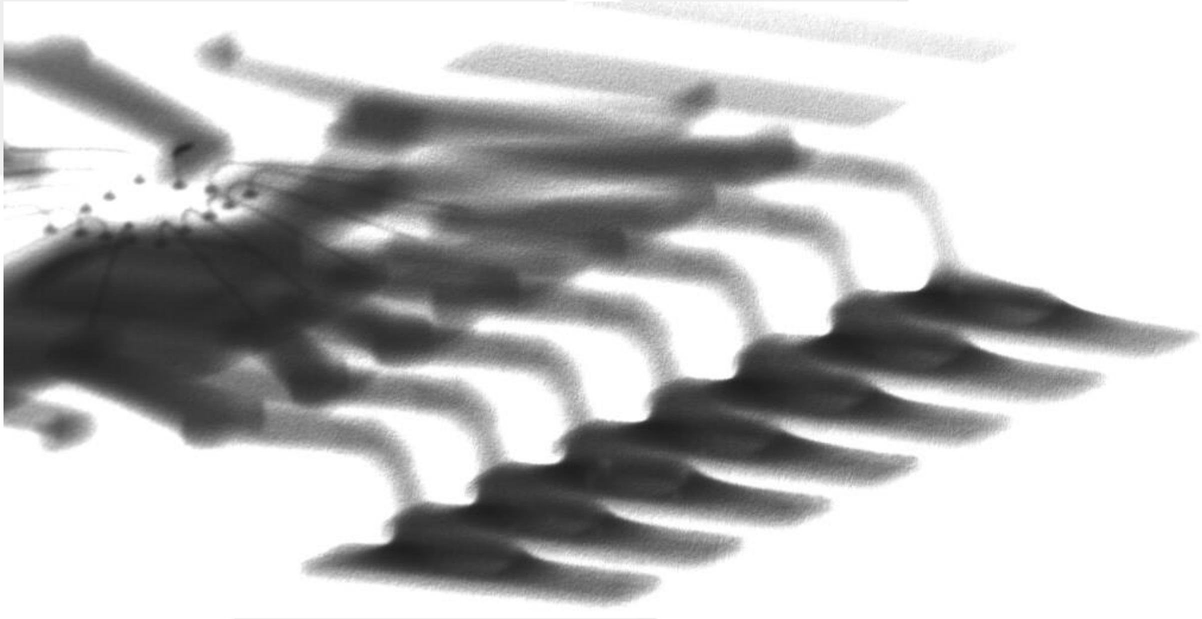
*(**Figure 4.** Optical image showing solder fillets of mounted PLCC and TSSOP devices in profile.)*

5. X-ray and SEM Imaging of PCB Assembly and Solder Joint Cross-Sections

To gain further insight into otherwise obscured solder fillets, PCB assemblies were imaged by X-ray at an oblique view. Imaging of the VSON package did not resolve any additional detail due to the length scale and density of solder coverage. Representative images of the PLCC and TSSOP packages are presented in Figures 5 and 6 below.

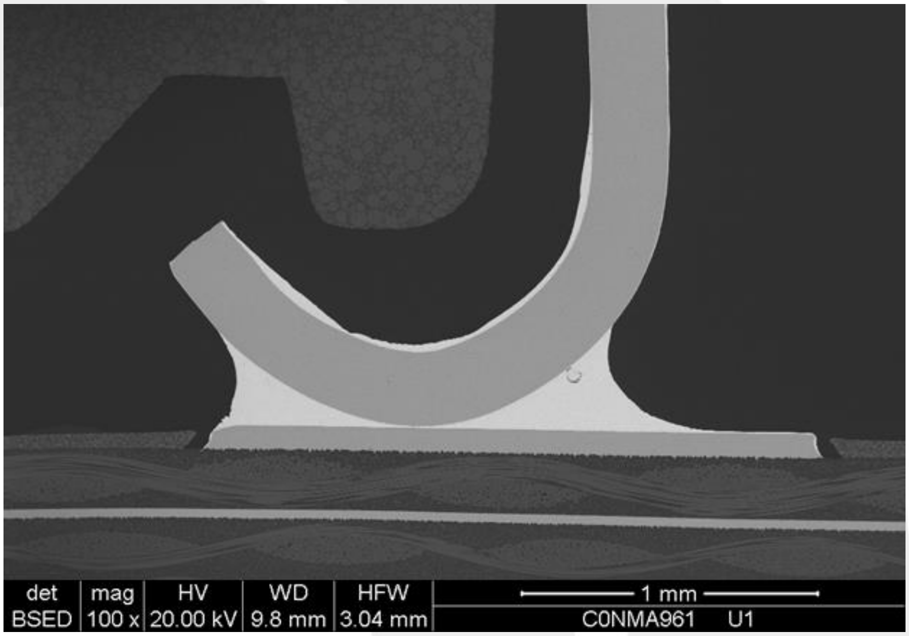


***(Figure 5.** X-ray image of 28 PLCC devices mounted to PCB. Note: duplicate pads are due to the unused underside of the double-sided PCB.)*

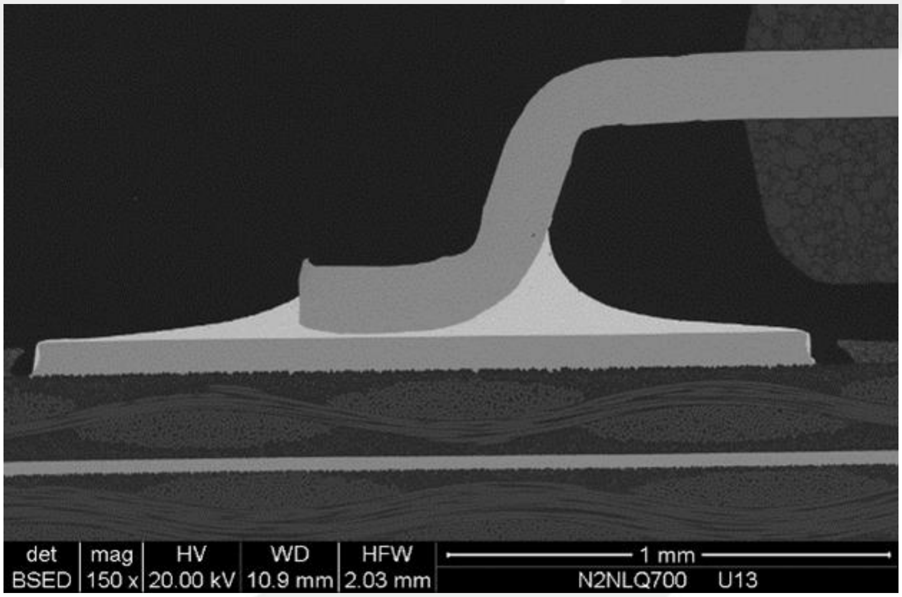


***(Figure 6.** X-ray image of 14 TSSOP devices mounted to PCB, with wire bonding visible.)*

Additionally, SEM images were captured after cross-sectioning through leads, revealing the precise profile and internal structure of solder fillets, shown in Figures 7 and 8. Internal structures of solder fillets were found to be robust, matching external inspections and further validating successful PCB assembly.



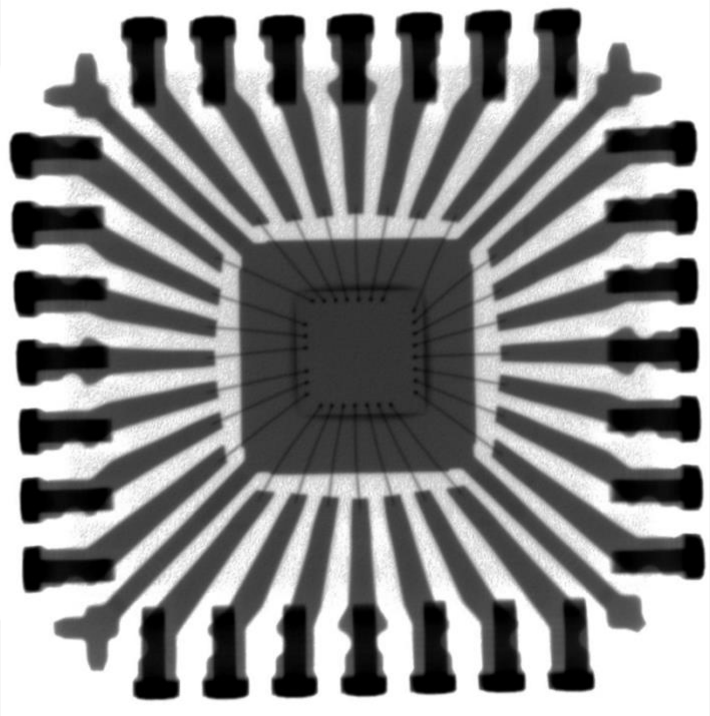
(Figure 7. *SEM image of a cross-sectional plane through the center of a lead on a PLCC device, capturing the PCB pad – solder – lead interface.)*



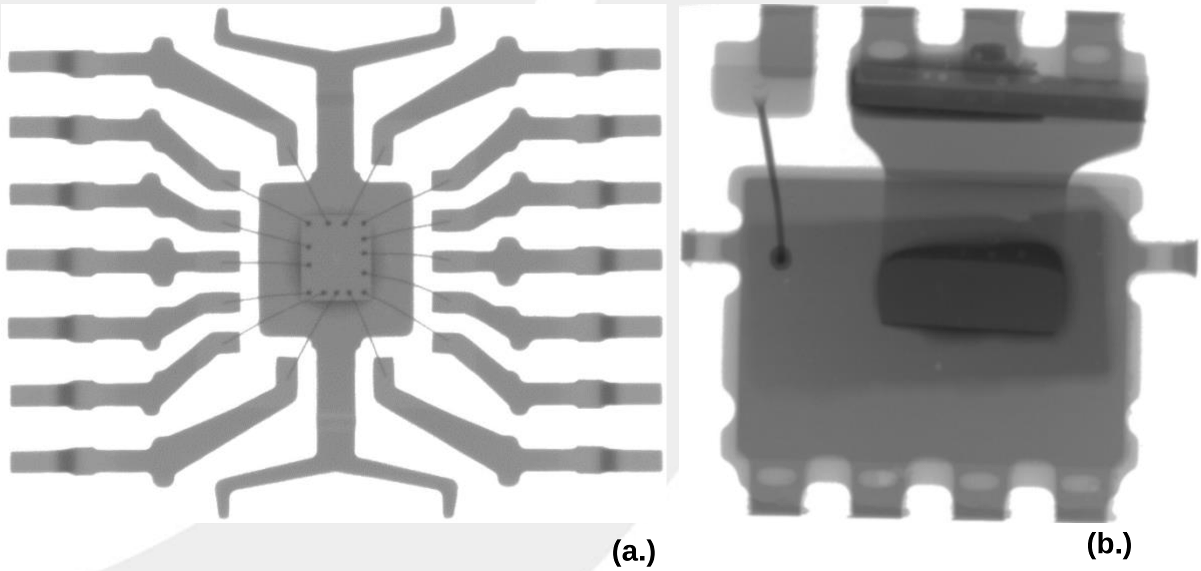
(Figure 8. *SEM image of a cross-sectional plane capturing the same interface on a TSSOP device.)*

6. X-ray and SEM Imaging of Package Internal Cross-Sections

The same imaging techniques were also used to validate the integrity of encapsulated material and inspect internal device features for defects. No defects were observed; characteristic images are provided below for each package type.

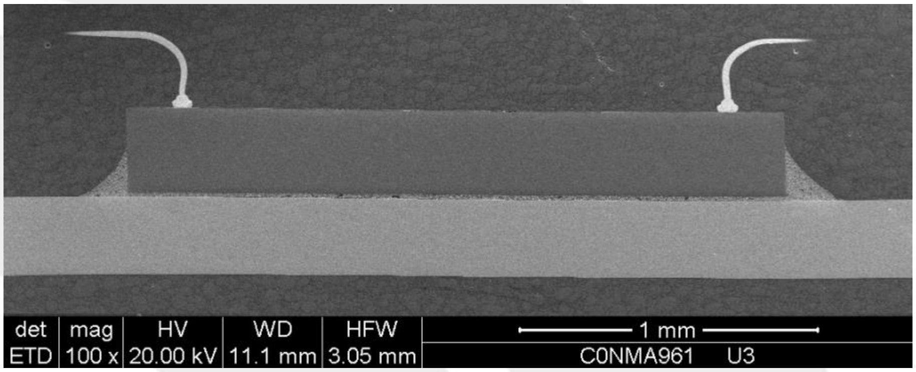


(**Figure 9.** *X-ray image of entire 28 PLCC device.)*

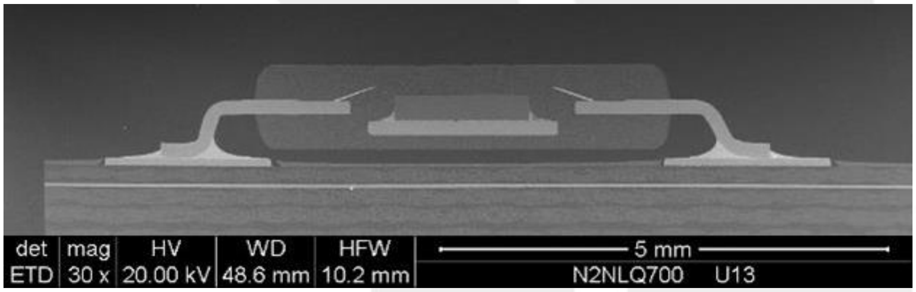


(a.) **(b.)**

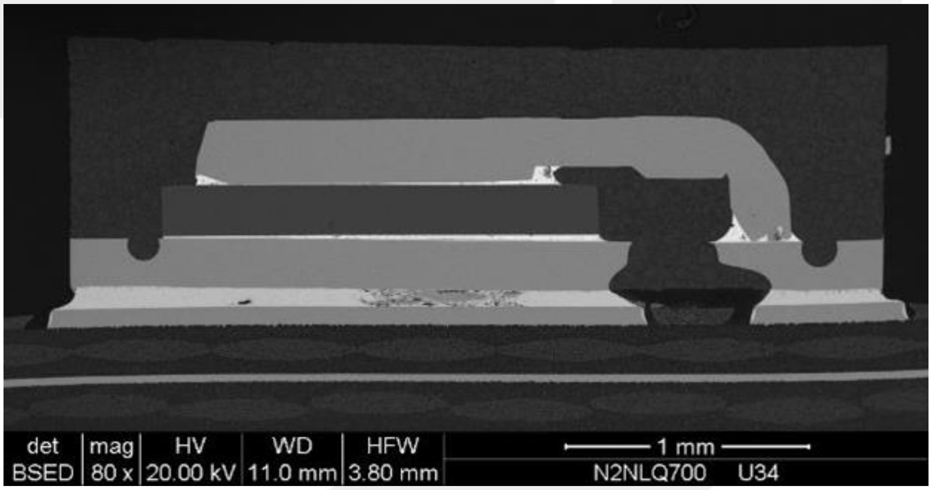
*(**Figure 10.** X-ray images of entire **(a)** 14 TSSOP and **(b)** 8 VSON devices.)*



(Figure 11. *SEM image of a cross-sectional plane through a PLCC device, displaying plastic encapsulant, ball bonds, and bond wires, die, die attach adhesive (note the fillets), die attach paddle, and encapsulant, from top to bottom.)*



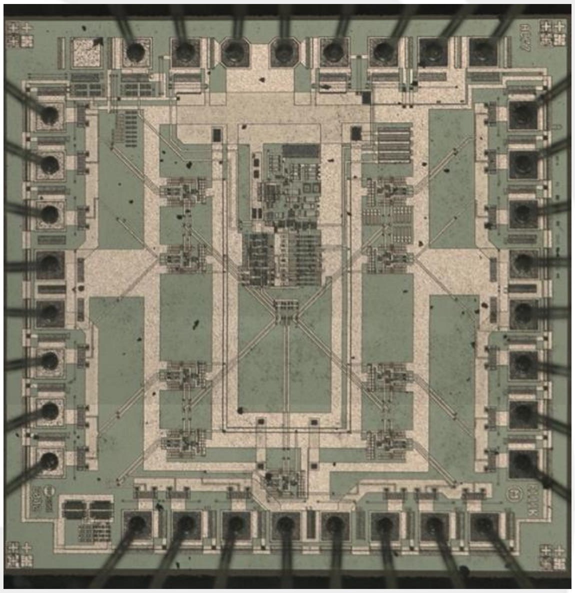
(Figure 12. *SEM image of the cross-sectional plane through a TSSOP device. Note that the TSSOP package is much smaller, with a lower standoff height than the PLCC, enabling the capture of the entire device profile. The same features are shown here, except the ball bonds now out of the sectioning plane, with the addition of package leads and solder fillets previously beyond the field of view.)*



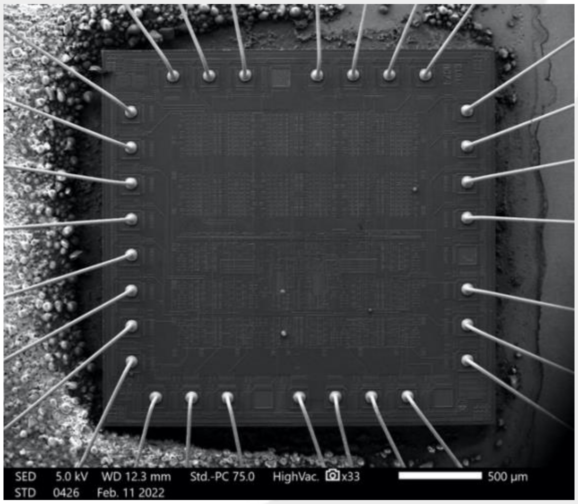
(Figure 13. *SEM image of the cross-sectional plane through a VSON device. The single bond wire (See Fig. 10b) is on an outer pad, beyond the central area of interest probed by the sectioning plane. The beginning of a void is visible. This segment of the cross-section was examined at higher magnification and found to exhibit a thin but uninterrupted layer of solder along with both the upper (device pad) and lower (PCB pad) interfaces of the solder joint. This complete solder coverage at both faces indicates that no dewetting has occurred and that the void is inherent to solder paste reflow due to the unique thermal demand of this large solder pad.)*

7. Post-Decapsulation Die and Wire Bonding Inspection

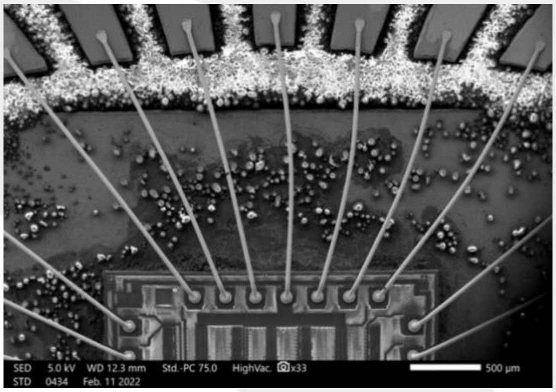
All devices were laser decapsulated and finished with a short acid etch. No damage consistent with environmental stresses or proposed mechanisms of degradation after long-term storage was observed. All devices were found to be free of cracking, delamination, and bond wire defects. Representative images highlighting critical features are presented in Figures 14 through 22.



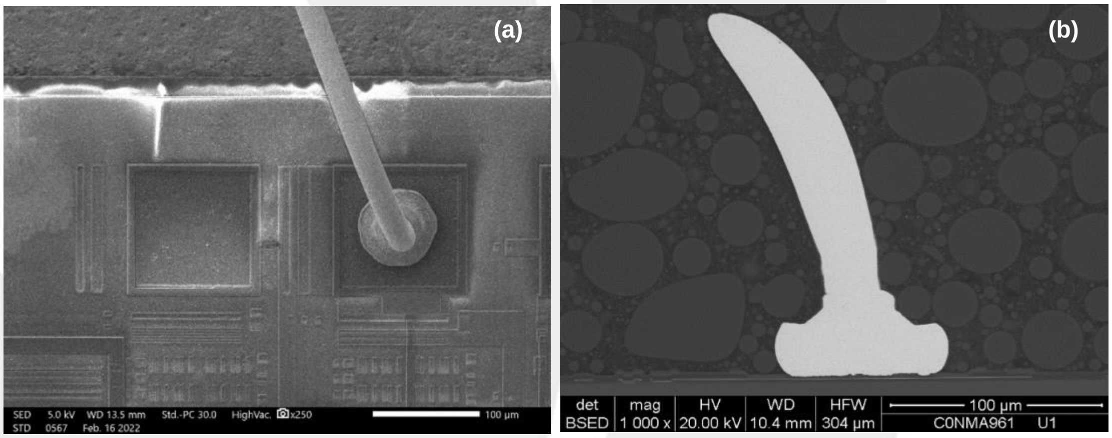
***(Figure 14.** Optical image of die surface after laser and acid decapsulation. Speckling on the surface is due to acid contact during the etching process. Digitally stitched to capture the entire area of interest.)*



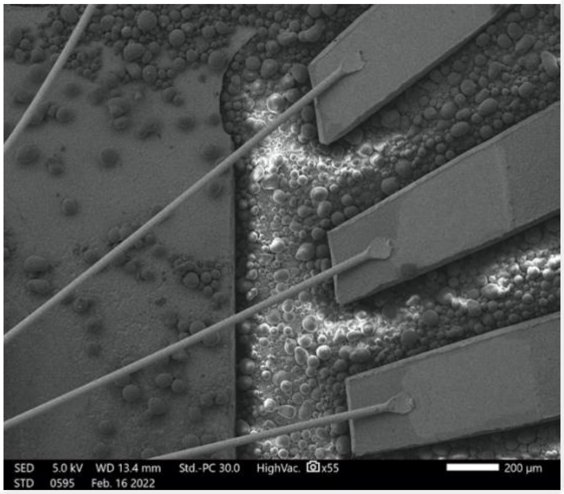
(Figure 15. SEM image of PLCC die top surface and wire bonds on die pads after decapsulation.)



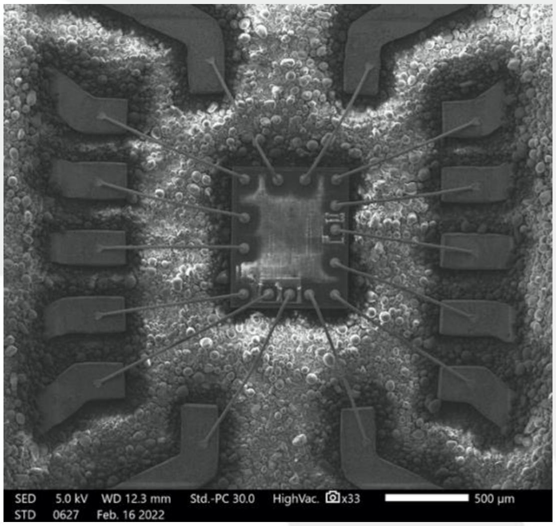
(Figure 16. *SEM image of PLCC wedge bonds, bond wires, and ball bonds after decapsulation.)*



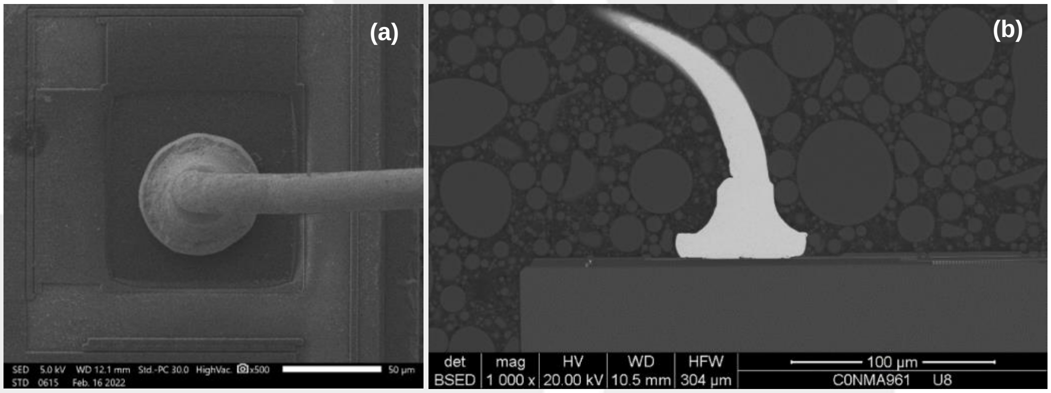
(Figure 17. *Side by side comparison: (a) SEM image of decapsulated PLCC ball bond and both bonded and unbonded pads; (b) SEM image of cross-sectioning through ball bond and bond wire.)*



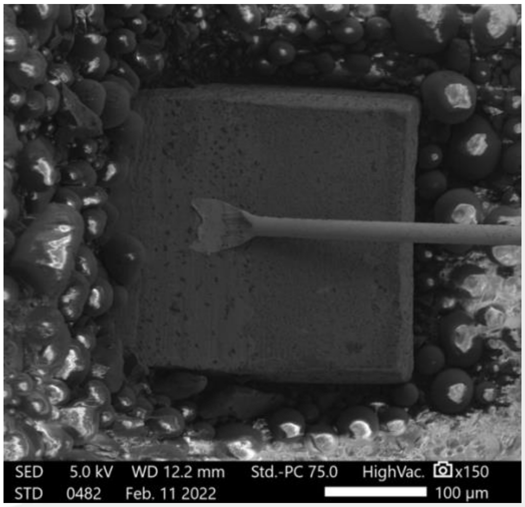
(Figure 18. *SEM image of wedge bond detail on PLCC leadfingers after decapsulation.)*



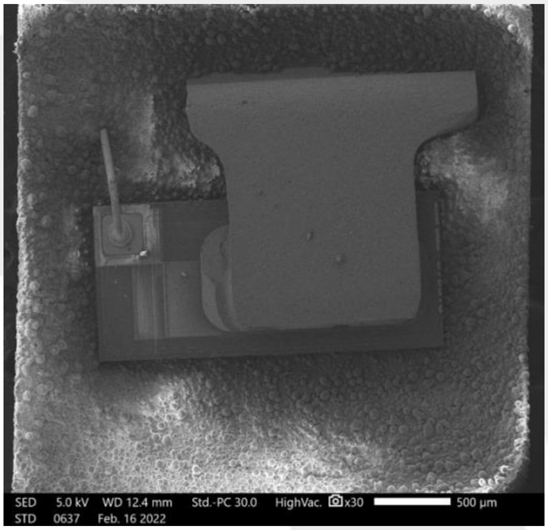
***(Figure 19.** SEM image of TSSOP die top surface, wedge bonds, bond wires, and ball bonds after decapsulation.)*



***(Figure 20.** Side by side comparison: (a) SEM image of decapsulated TSSOP ball bond and underlying pad; (b) SEM image of cross-sectioning through ball bond and bond wire.)*



***(Figure 21.** SEM image of wedge bond detail on a TSSOP leadfinger after decapsulation.)*



(Figure 22. *SEM image of single VSON bond after decapsulation. The die is obscured by the heat sink.)*

8. Electrical Test Results

Three products of two different date codes were tested to their respective datasheet requirements. The tested devices span nearly 15 years; the results are shown in Table 2. Twenty 9513APC devices, twenty-five 27S21PC devices, and fifty UC3835N devices of each date code were tested. All devices met their respective datasheet specification limits and exhibited no significant or consistent shifts in data distributions across date codes.

Product	Years of Storage	Lead Finish	Electrical Test Yield
9513APC	11	Matte Sn	100%
9513APC	3	Matte Sn	100%
27S21PC	9	SnPb	100%
27S21PC	6	SnPb	100%
UC3835N	17	NiPdAu	100%
UC3835N	9	NiPdAu	100%

Table 2. *Electrical test performance of sampled devices.*

9. Conclusion

The data presented in this paper indicates that devices maintain internal and external integrity, including robust soldering to printed circuit boards, beyond a decade of storage. Devices exhibited no evidence of corrosion, cracks, or delamination. The tested devices passed all applicable functional and timing tests.

This highlights that long-term storage represents a viable solution to maintaining a continuous supply of semiconductor components in long lifecycle applications such as automotive, medical, industrial, aerospace, and defense.

References:

[1] The Effects of Long-Term Storage on Solderability of Semiconductor Components, Rochester Electronics, Semiconductor Packaging News, Dec 6th, 2021

[2] *Component Reliability After Long Term Storage, Texas Instruments, May 2008*

[3] *Long Term Storage Evaluation of Semiconductor Devices, Texas Instruments, September 2021*