Epoxy Sealing for Photonics Packages: Approaching Fine-Leak Performance After Thermal Shock or Humidity Stress

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0 Abstract.

Brilliance and RJR are co-developing a package for Brilliance's point-illuminator consisting of a SiN substrate and a Si cap. The cap is assembled onto the substrate using a B-stage epoxy formulated by RJR. Reliability testing following JEDEC standards has shown that the assembled package passes the hermetic fine-leak testing. It is a popular understanding that epoxy adhesives cannot pass fine-leak testing. Helium permeability is an inherent property of organic sealing materials. Consequently, epoxy-sealed packages are frequently viewed as incapable of achieving the leak performance associated with traditional hermetic packaging This paper reflects test results of using an epoxy to seal a photonics package that this CAN be done, provided the epoxy formulation, application and processing are fully optimized for the application.

The present work documents the seal-test methodology, relates the measured Helium leak rates to MIL-STD-883-1, METHOD 1014.19, 19 April 2024 and discusses the results after temperature shock, 168 hrs uHAST (unbiased) and 1000 hrs steady state humidity test. The results shown in the supplied data demonstrate that the epoxy-sealed silicon-cap construction retains a low measured fine-leak rate after the environmental stresses, approaching or meeting fine-leak performance..

Keywords: reliability, optics, photonics, PIC, packaging, air cavity package, JEDEC fine-leak testing

1 Introduction

In 2026, Brilliance RGB started to industrialize its Neptune family Point Illuminator [1]. Figure 1 shows a picture and a schematic drawing of the device. Within this effort, the focus was placed on product reliability as well as the development of a robust and scalable manufacturing process for high-volume production. As part of this effort, Brilliance initiated a collaboration with RJR to further develop a near hermetic design and related manufacturing assembly process, specifically the attachment of the Si-cap to the SiN substrate using an epoxy-based sealing material.

From Brilliance RGB's perspective, the primary objective of the sealing process was to ensure reliable device operation throughout the intended product lifetime by protecting the laser chip from environmental influences. Exposure to moisture, particulate contamination, and other external factors can negatively affect optical performance and long-term reliability. At the same time, the sealing approach needed to be compatible with high-volume manufacturing, requiring a robust and reproducible process with sufficient throughput and process control. The development therefore focused on the design of the package, the sealing process, the selection of an adhesive with high adhesion, excellent moisture resistance properties, and processability for high volume manufacturing using RJR Isothermal sealing system, which included: the complete seal as a packaging process: material formulation, B-staging, application geometry, cure profile, post-cure and control of the sealant volume, which all contributed to the success of approaching or passing the Helium fine leak test.

RJR introduced a proprietary B-stage epoxy that has been developed and optimized over the years as part of a family of sealants to assembly packages of different materials (ceramic, metal and plastics) reliably and cost-efficiently. The sealants and sealant processing are optimized in formulation to reduce outgassing and maximize adhesion. Pre-drying (B-stage) improves handling and further reduces outgassing. Processing (temperature profiles during curing, post-curing) and application (thickness, amount of material) are further optimized to eliminate leaks and blow-outs. The technology has been proven over the last 20 years in the application of RJR's epoxy sealants in LCP air-cavity RF power packages [2,3,4]. More than 50 million packages have been produced for RF applications without a single package-related failure in the field.

This process-oriented approach is important because an epoxy seal is not inherently equivalent to a conventional welded or brazed hermetic seal. The objective for the Brilliance package is a near-hermetic enclosure with sufficiently low leakage and moisture ingress for the intended operating environment. RJR's broader packaging experience shows that the relevant engineering question is therefore not whether epoxy is intrinsically permeable, but whether the complete seal system can be designed so that permeability, outgassing, adhesion and defect-driven leakage remain below the application limit.

In this paper we will show the design of Brilliance's Neptune family Point Illuminator product assembled with the RJR B-stage epoxy and the results of the leak tests after temperature shock (Temperature Cycling Test acc. to NEN-EN-IEC 60068-2-14 NA), 168 hrs uHAST testing (accelerated moisture resistance -unbiased HAST- according JESD22-A118. Condition B, 110°C/85% RH. In compliance with ISO/IEC 17025) and 1000 hrs steady state humidity test according to JEDEC and MIL-STD (1000h (+168/-24) Steady state temperature humidity test according JESD220A101, 85+-2C, 85+-5%R.H. in compliance with ISO/IEC 17025), see [5,6,7].

The results are interpreted below with particular attention to fine-leak testing. A distinction is made between the Helium tracer-gas fine-leak measurement and gross-leak bubble testing, because these are different parts of MIL-STD-883-1, method 1014.19 and should not be presented as the same test.

2 Package and sealing technology

The Brilliance construction consists of a silicon nitride (SiN) substrate carrying the optical/electronic functions and a silicon cap that forms the air cavity. The cap is attached around its perimeter with a thin B-stage epoxy seal (epoxy type RJ4MB-V2, BLACK 6104, thickness 71 ±7 µm). The approach is attractive for photonics because the cap and substrate can be matched mechanically and thermally while the adhesive provides a compliant interface that accommodates local dimensional variation and coefficient-of-thermal-expansion differences.

The seal performance is controlled by five coupled parameters. First, the epoxy formulation must limit volatile content and outgassing. Second, B-staging removes a substantial fraction of volatile components before final assembly and gives a controlled, reproducible pre-applied seal. Third, the amount and geometry of adhesive must be sufficient to create a continuous seal without producing excessive internal surface area. Fourth, the final cure and post-cure must establish the required cross-link density and adhesion without creating voids, cracks or local blow-outs, Fifth: the use of RJR's isothermal sealing system to obtain the best repeatable package sealing results in the industry. It is worth noticing that this isothermal sealing systems was not yet used in the assembly of the samples in this test. We expect therefor some room for improvement in the test results.

This is consistent with RJR's established packaging philosophy: the package, adhesive and sealing process are developed as one system. RJR's public technical material describes the company's air-cavity packages as near-hermetic solutions that combine specialty packaging materials, formulated epoxies and controlled sealing processes [2–4]. The same approach is used here, but with a silicon-cap/SiN construction rather than the LCP air-cavity package architecture used in RJR's RF and photonics applications. The test results further support RJR claims that they can achieve a "Near Hermetic solution" using its epoxies, designs and sealing solutions.

The package drawing in Figure 1 also illustrates why this construction is potentially attractive for future volume production. The cavity is defined by the cap rather than by a precision-machined metal or ceramic wall with a flat lid (as commonly used in traditional hermetic packaging), while the sealing process can be adapted to automated dispensing, pre-applied B-stage material and controlled thermal curing. For a photonics product moving from engineering quantities toward higher volume, this process integration can be as important as the intrinsic material properties of the sealant.

3 Reliability testing

3.1 Test Approach

A comprehensive test plan was developed to evaluate the integrity and reliability of the package sealing concept under environmental stress conditions. All samples were subjected to an initial visual inspection to assess assembly quality and identify any visible defects prior to testing. Baseline Helium fine-leak measurements were subsequently performed in accordance with MIL-STD-883 Method 1014.19 to establish the initial leak rate of each package.

Next, samples were exposed to a range of environmental stress tests representative of conditions that may be encountered during manufacturing, handling, and operation. These tests included temperature-shock and humidity-related exposures designed to induce thermo-mechanical and environmental stresses on the package structure and seal interface.

After completion of the environmental testing, Helium fine-leak measurements were repeated using the same test methodology. Comparison of the pre- and post-exposure leak rates enabled evaluation of the seal robustness and identification of any degradation in Helium leak rate performance resulting from the applied environmental stresses. Finally, visual inspection was performed to identify any signs of physical damage, cracking, delamination, corrosion, or other observable changes that could be associated with the environmental exposure.

All samples were divided into 3 sample groups, each group consisting of ten devices was only subjected to one test methodology. The objective of the testing was to assess the Helium leak rate sealing performance of the package design and assembly process. Due to the sample size, the test results are intended as an engineering evaluation and process verification rather than a formal product qualification. MIL-STD-883-1 Method 1014.19 was therefore used as a reference standard for performance assessment and acceptance criteria, while no claim of full qualification or statistical compliance with the standard is made based on this dataset alone.

The following sections provide a more detailed description of the test methods used, as shown in figure 2.

3.2 Fine-leak test method and MIL-STD-202 assessment

MIL-STD-883-1 Method 1014.19 distinguishes between gross-leak and fine-leak testing. Test conditions are labelled A through G and describe specific test using defined equipment and corresponding test procedures. Test Conditions B, C, D, E, and G are gross-leak methods, whereas Test Condition A employs Helium as a tracer gas in combination with a Hmass spectrometer to quantify fine leakage. Test condition A was used in this paper.

The Neptune Point Illuminator package has an internal cavity volume of approximately 0.003 cm^3, placing it within the ≤0.05 cm^3 category defined in MIL-STD-883-1 Method 1014.19. The test data reported in this study were obtained using Helium exposure at 75 psia for 1 hour, followed by a 30-minute dwell period prior to Helium leak-rate measurement. For this package volume, the corresponding Helium reject limit is 6.5×10^{-9} atm·cm^3/s He.

3.3 Test group 1: Temperature-shock test

Temperature shock testing was performed in accordance with IEC 60068-2-14, to evaluate the robustness of the package and seal structure under repeated thermal stress. The samples were subjected to 100 temperature cycles between −25°C and +100°C. At each temperature extreme, the samples were held for 15 minutes to allow thermal stabilization. Transitions between the low- and high-temperature conditions were completed within 30 seconds. This test induces thermo-mechanical stresses resulting from differences in the

coefficients of thermal expansion of the various package materials and interfaces. The objective was to assess the ability of the package assembly to maintain its structural integrity and Helium leak rate performance following repeated exposure to temperature fluctuations.

3.4 Test group 2: 168h Accelerated Moisture Resistance test (uHAST)

The moisture resistance of the package assembly was evaluated using an Unbiased Highly Accelerated Stress Test (uHAST) in accordance with JESD22-A118, Condition B. The test was performed at 110°C and 85% relative humidity (RH) for a duration of 168 hours. All samples were tested in an unpowered condition.

The objective of the uHAST exposure was to accelerate moisture-related degradation mechanisms, such as moisture ingress, material degradation, and interface deterioration, that may affect long-term package reliability.

3.5 Test group 3: 1000h Steady state humidity test

The long-term moisture resistance of the package assembly was evaluated using a steady-state temperature humidity test in accordance with JESD22-A101. Samples were exposed to an environment of 85 ± 2°C and 85 ± 5% relative humidity (RH) for 1000 hours (+168/−24 h). The test was performed on unpowered samples. In contrast to the 168h uHAST test, this test employs lower stress levels over a substantially longer duration and is intended to assess the durability of the package under prolonged exposure to humid environments. Potential degradation mechanisms are moisture ingress, material aging, corrosion, and interfacial degradation.

3.6 Test results

The test results are shown in figure 3. The pre-stressed points are shown in blue and the post-stressed points are shown in orange. The rejection limit is also shown in orange. A few pre-stressed points are slightly above the rejection limit in the temperature-shock test, but the majority is well below.

All post-stress points shown in the three plots are around or below the plotted acceptance line. The strongest observation is the absence of an upward drift in post-stress leakage between the 168 h and 1000 h humidity tests. The temperature-shock results are particularly useful because they show that the seal survives repeated thermal expansion/contraction without generating a persistent increase in leakage.

4 Discussion

The results of this study support the central hypothesis of this work: an epoxy-sealed air cavity can achieve sufficiently low leakage for a photonics application when the adhesive chemistry and sealing process are purposefully engineered. The experimental evidence is especially relevant because the seal is exposed to three different forms of environmental stress: thermal shock high-temperature/high-humidity pressure exposure and long-duration 85°C/85% humidity exposure.

The data also illustrates why the phrase 'epoxy cannot pass a fine-leak test' is too general. An adhesive is a material system, not a single leakage specification. Leakage through a package seal can arise from, poor package design, poor sealing process, epoxy permeability, volatile release, interfacial defects, voids, cracks, insufficient wetting, poor adhesion or mechanical opening of the interface during thermal shock. The RJR approach addresses these mechanisms simultaneously through formulation, B-staging, controlled application and cure.

From a product-development perspective, the most significant result is the combination of low measured leakage and a manufacturing-friendly seal process. Traditional hermetic packages often achieve their performance through rigid metal/ceramic structures and high-temperature joining processes. An optimized epoxy seal can instead provide a compliant, high units-per-hour (UPH) manufacturing process, lower-temperature joining process and die temperature exposure and can simplify assembly of dissimilar materials such as silicon, SiN and other package materials. This can be particularly valuable when the photonic device

is moving toward higher production volumes, UPH limitations and packaging cost becomes a significant fraction of the total module cost.

The results should nevertheless be presented with appropriate precision. 'Near-hermetic' is preferable to 'hermetic' unless the package is demonstrated to meet the applicable hermeticity definition. Similarly, 'passes fine leak testing' should be accompanied by the actual acceptance limit and test method. This avoids conflating a project-specific fine-leak screen with formal qualification to a military or JEDEC standard.

Based on the data currently available, the following claim is technically defensible: 'The RJR B-stage epoxy-sealed silicon-cap package demonstrated approaching or passing fine-leak rates below the project acceptance limit after 100 temperature-shock cycles, 168 h of 110°C/85% RH elevated-pressure exposure and 1000 h of 85°C/85% RH exposure. No systematic increase in leakage was observed after environmental stressing in the samples shown.

5 Conclusions

This study demonstrates that a carefully designed, formulated and processed B-stage epoxy can be used to seal a silicon-cap/SiN photonics air cavity while maintaining low Helium leakage after significant environmental stress. The temperature-shock, 168 h humidity/pressure and 1000 h 85°C/85% datasets supplied in the draft all show post-stress leakage close or below the plotted acceptance line, with no visible evidence of progressive seal degradation.

The results support the use of RJR's epoxy sealing technology as a high UPH, a low-cost, manufacturing-compatible alternative where a near-hermetic rather than fully hermetic package is sufficient. The approach is consistent with RJR's broader air-cavity packaging strategy, which combines engineered package designs, materials, assembly solution , formulated epoxies and controlled sealing processes to deliver high reliability at lower cost [2–4].

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6. U.S. Department of Defense, MIL-STD-883, Method 1014, “Seal,” current environmental test method; fine-leak acceptance limits depend on package internal free volume and device class.

7. JEDEC, JESD22-A101, “Highly Accelerated Temperature and Humidity Stress Test (HAST).”

Authors

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Anke Hasper is a process engineer at Brilliance RGB. She received her BSc and MSc in industrial design engineering from the University of Twente in the Netherlands in 2019 and 2022 respectively. Prior to joining Brilliance RGB, she gained experience in the semiconductor industry, working on high-tech equipment in an environment characterized by stringent quality, precision, and reliability requirements.

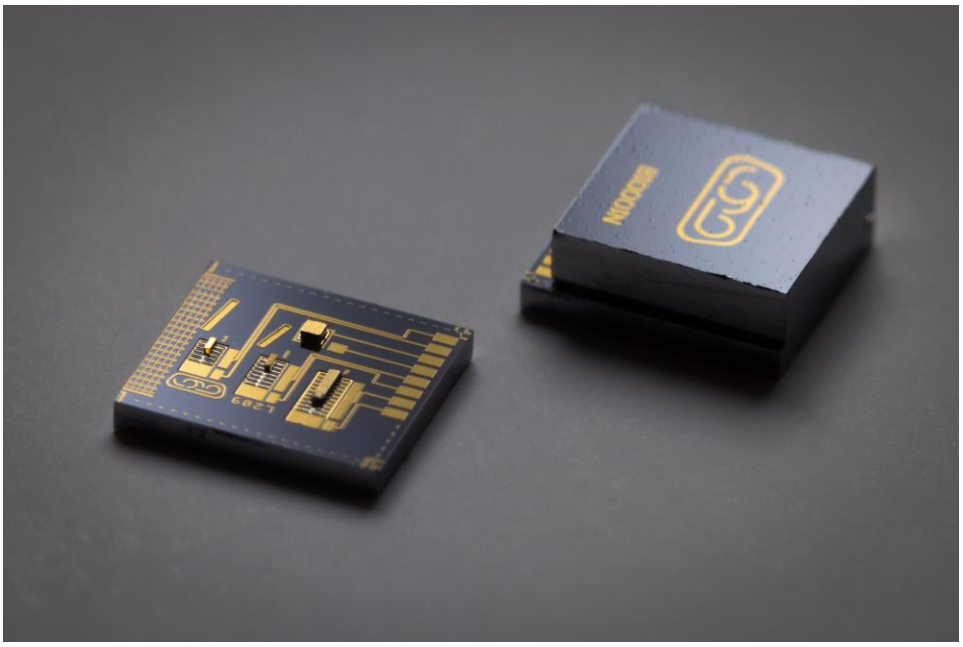


Raymond Bregante is the co-founder and Executive Chairman of RJR Technologies, Inc. He has been the technical lead for many of RJR’s advanced technologies, such as fully automatic sealing systems, high reliability air cavity QFN package, and air cavity plastic packages for oscillators, LiDAR and Photonics applications. In addition, Ray has been the patent holder for RJR’s key innovations that resulted in commercial success, such as US6511866B1 – “Use of diverse materials in air-cavity packaging of electronic devices”, amongst other.

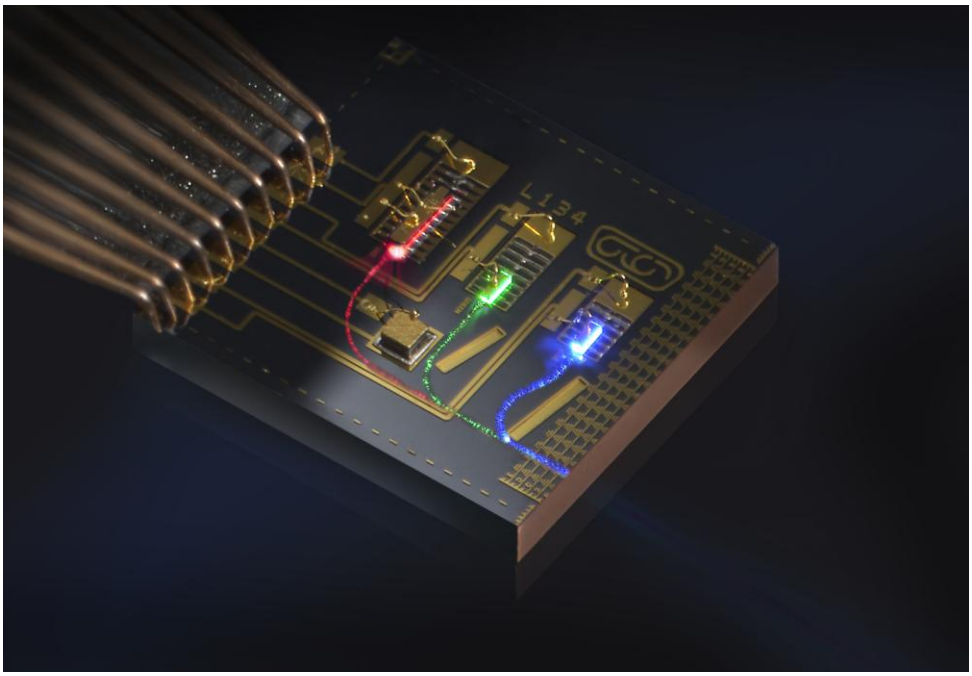
Figure 1. Brilliance Neptune V2 point-illuminator package

A and B show a picture and an artist impression of the product. C and D show dimensions. The dimensions and numbering shown in are reproduced from the supplied design data. The purpose is to establish the cavity and seal geometry relevant to the leak-test discussion; it is not intended as a manufacturing drawing.

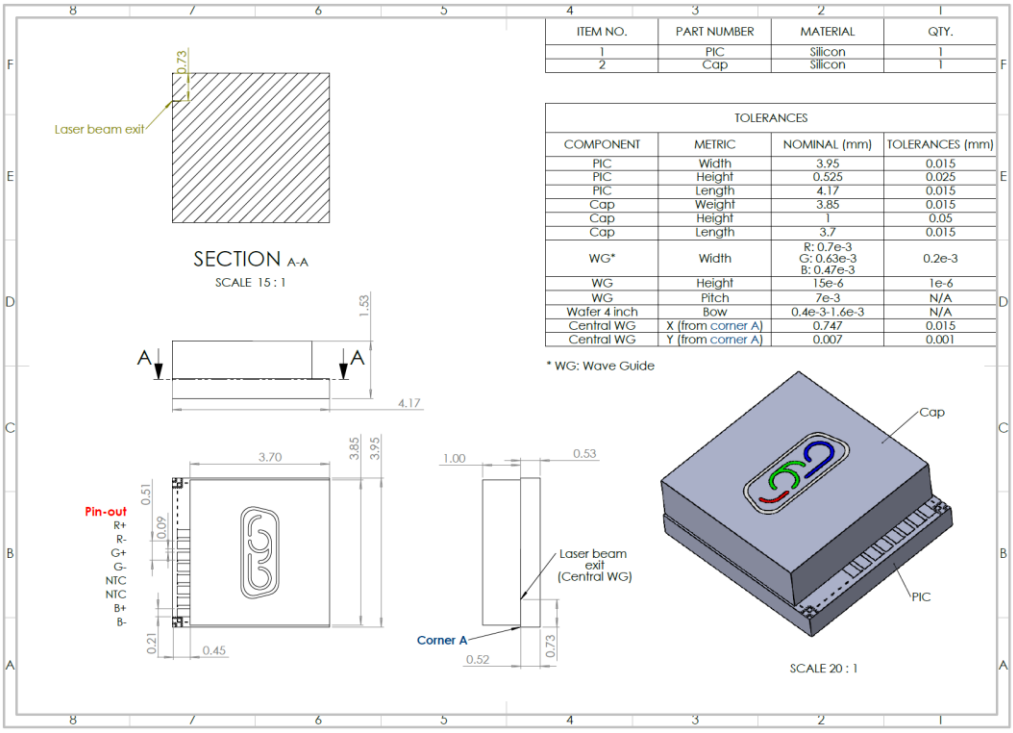
A



B



C



ITEM NO.	PART NUMBER	MATERIAL	QTY.
1	PIC	Silicon	1
2	Cap	Silicon	1

TOLERANCES			
COMPONENT	METRIC	NOMINAL (mm)	TOLERANCES (mm)
PIC	Width	3.95	0.015
PIC	Height	0.525	0.025
PIC	Length	4.17	0.015
Cap	Weight	3.85	0.015
Cap	Height	1	0.05
Cap	Length	3.7	0.015
WG*	Width	R: 0.7e-3 G: 0.63e-3 B: 0.47e-3	0.2e-3
WG	Height	15e-6	1e-6
WG	Pitch	7e-3	N/A
Wafer 4 inch	Bow	0.4e-3-1.6e-3	N/A
Central WG	X (from corner A)	0.747	0.015
Central WG	Y (from corner A)	0.007	0.001

* WG: Wave Guide

D

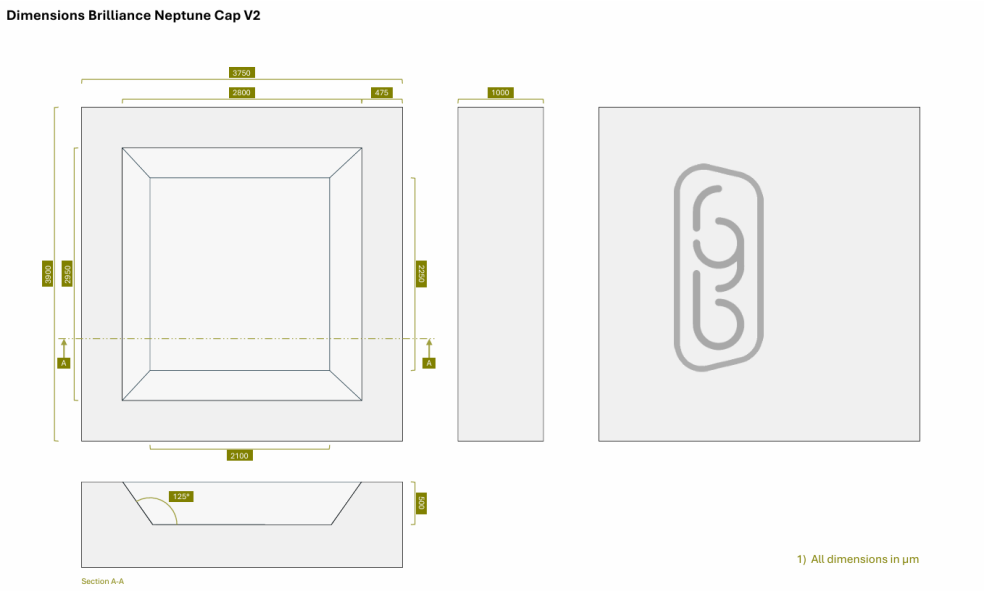


Figure 2. flow diagram of the test methods used

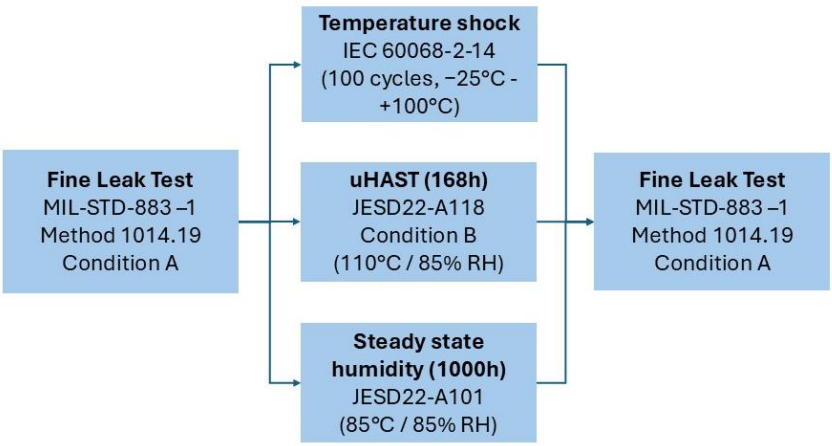


Figure 3. Fine-leak test results before and after environmental stress

Left: temperature shock; centre: 168 h uHAST; right: 1000 h steady state humidity. Blue/orange traces are the initial and post-stress Helium measurements, respectively; the horizontal red line is the acceptance limit plotted in the supplied test data.

