application brief AB20-6

replaces AN1149-6

Reliability Considerations for SuperFlux LEDs

LEDs provide solid-state lighting and are therefore extremely durable. If the recommended soldering and operating conditions are followed, SuperFlux LEDs will survive for the life of the vehicle.

SuperFlux LEDs have performed well in a number of durability, reliability, and accelerated life tests. Some of these tests are summarized in Lumileds' SuperFlux LED Reliability Data Sheet. A current revision can be obtained by contacting your local Field Sales Engineer or at the following URL: http://www.Lumileds.com

This section is dedicated to communicating: 1) the major tests included in the Reliability Data Sheet, 2) the appropriate testing of assemblies containing SuperFlux LEDs, and 3) providing information regarding the typical change in SuperFlux LED light-output over typical application lifetimes. Please note that the Reliability Data Sheet also includes the cumulative sample size and failure rate (if other than zero).

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Table 6.1

RELIABILITY, DURABILITY AND ACCELERATED LIFE TESTS

Mechanical Shock	MIL-STD-883 Method 2002 Condition B: 3 shocks each X-Y-Z axis, 3000g, 0.3 ms
Vibration Variable Frequency	MIL-STD-883 Method 2007 Condition A: 4 cycles, 4 minutes, each X-Y-Z axis, 20g minimum, 20 to 2000 Hz
Vibration	SAE 575 DEC88 Section 4.1: 10 to 55 Hz, 1 mm peak-to-peak, 2 minutes per cycle, 60 minutes total duration
Operating Life Tests:	*All tests of duration 1,000 hours*
Condition A: T_a = 100°C	I_f = 20 mA (AS)/30 mA (TS); T_j ~ 110°C
Condition B: T_a = 85°C	I_f = 45 mA (AS)/50 mA (TS); T_j ~ 110°C
Condition C: T_a = 55°C	I_f = 70 mA; T_j ~ 90°C
Condition D: T_a = 25°C	I_f = 70 mA; T_j ~ 60°C
Condition E: T_a = -40°C	I_f = 70 mA; T_j ~ -5°C
Weatherability	
Condition A: Forward	85°C, 85% RH, 45 mA, 1000 h
Condition B: Reverse	85°C, 85% RH, -5 V, 1000 h
Salt Atmosphere	MIL-STD-883 Method 1009: 35°C, 48 h
Corrosion	SAE 575 DEC88: 25°C, 2 times 24 h with one-hour dry
Temperature Cycle	MIL-STD-883 Method 1010:
Condition A: -55 to 100°C	15-minute dwell, 5-minute transfer, 300 cycles
Condition B: -40 to 120°C	15-minute dwell, 5-minute transfer, 300 cycles
Condition C: -40 to 100°C	15-minute dwell, < 10 s transfer, 300 cycles
Power & Temperature Cycle	-40°C to 85°C, 3°C per minute transfer rate, 2-hour cycle
Condition A: 70 mA	70 mA, 5-minute on/off, ~ 225°C/W thermal resistance (T_j ~ 120°C), 50 cycles
Condition B: 50 mA	50 mA, 5-minute on/off, ~ 225°C/W thermal resistance (T_j ~ 110°C), 50 cycles
Solder Heat Resistance Strife	Reference Figure 6.3

Durability, Reliability, & Accelerated Life Tests

Mechanical Shock

Lumileds SuperFlux LEDs are encapsulated in a solid plastic package. Therefore, they are extremely rugged and easily survive even extreme mechanical shock tests. As shown in Table 6.1, Lumileds used the test conditions specified in MIL-STD-883 Method 2002 Condition B to validate the SuperFlux LEDs mechanical shock performance. This test was conducted three times in each direction at 3000*g* for 0.3 milliseconds. All of the SuperFlux LEDs subjected to this test survived without damage.

Vibration

SuperFlux LEDs perform extremely well in typical vibration tests (up to 2 kHz). SuperFlux LEDs have survived MIL-STD-883 Method 2007 Condition A and SAE 577 vibration tests.

Ultrasonic welding is frequently used to secure the lamp housing to the lens and is occasionally used to secure the printed circuit assembly containing the LEDs to mounting posts in the lamp housing. Although ultrasonic welding of the lamp housing to the lens has not produced any known LED failures it has been identified as the root cause of some catastrophic failures of resistors and other leaded components. In addition, ultrasonic welding of mounting posts has been identified as the root cause of some catastrophic failures of LEDs. In these cases, the transfer of ultrasonic energy from the mounting posts resulted in a broken wire within the immediately adjacent LEDs. Although no failures of SuperFlux LEDs have been attributed to ultrasonic welding, the potential for this failure mode still exists. For this reason, heat-staking or a lower-frequency joining process such as vibration welding is preferred for securing the mounting posts of the lamp housing to the PCB. In cases where ultrasonic welding must be used, it is extremely important to build many evaluation units to prove the design's ability to withstand ultrasonic vibrations.

Operating Life

Because SuperFlux LEDs are solid-state devices, they survive thousands of hours of operation. As summarized in Table 6.1, Lumileds used several ambient temperatures to validate the operating life performance of the SuperFlux LEDs. These LEDs perform well over their operating temperature range of –40 °C to 100 °C.

Weatherability

SuperFlux LEDs also perform well in weatherability tests. As summarized in Table 6.1, Lumileds used both forward-biased and reverse-biased humidity tests to validate performance after exposure to humidity. These tests were performed with the LEDs mounted on a PCB. No housing was used for this test.

Corrosion Resistance

The metal leadframe used in SuperFlux LEDs is made from a copper alloy. The portion of the leadframe that is inside the plastic body is first plated with nickel and then silver. The portion of the leadframe that is outside the plastic body is coated in tin-lead solder. Therefore, SuperFlux LEDs perform well in corrosion resistance tests. The two tests listed in Table 6.1 were used to validate SuperFlux LED performance during corrosion testing. The MIL-STD-883 test was performed using individual LEDs, while the SAE 576 test was performed using LEDs mounted on a printed circuit board. No housing was used for either test.

Temperature Cycle

The semiconductor that emits the light in SuperFlux LEDs, the leadframe that it is mounted on, the bond wire that connects the anode of the chip to the anode of the leadframe, and the plastic that forms the LED's body all have different coefficients of thermal expansion. Therefore, thermal cycle test performance is an important measure of

SuperFlux LED durability. One of the two typical wear-out mechanisms in thermal cycle testing is separation between the plastic encapsulant and the sides of the reflector cup in the leadframe as shown in Figure 6.1. This type of separation lifts the semiconductor die off of the leadframe and causes an open circuit or intermittent-open circuit. The second typical failure mechanism is a necked-down wire break above the ball-bond (wire bond) as shown in Figure 6.2. In order to avoid these failure mechanisms, it is important that the maximum junction temperature listed in the SuperFlux LED Technical Data Sheet is not exceeded (refer to Application Brief AB20-4 *Thermal Management Considerations for SuperFlux LEDs*). Lumileds used the three temperature cycle tests listed in Table 6.1 to validate SuperFlux LED performance after thermal cycle testing.

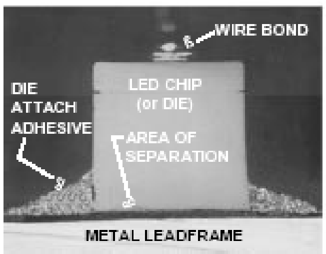


Figure 6.1 Example of LED die delamination.

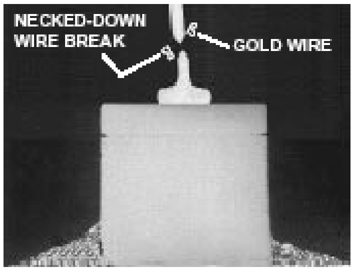


Figure 6.2 Example of neck-down wire break.

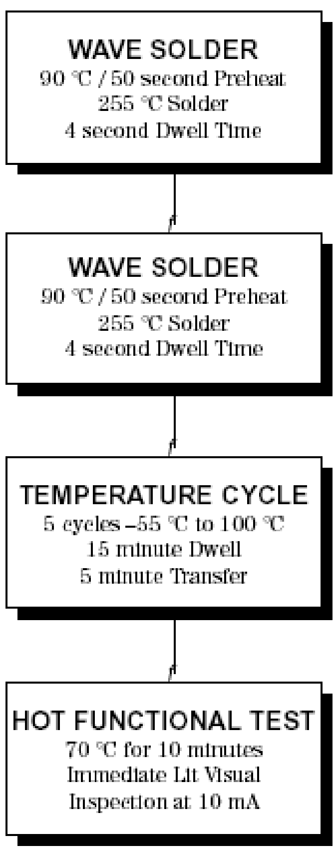
Simultaneous Power & Temperature Cycle

Simultaneously cycling both power and temperature can accelerate typical LED failure modes. Although these conditions are much more extreme than those seen in actual field use, this type of test is very helpful in comparing the performance of different designs. Performance under these conditions is benchmarked during initial LED product validation and then checked during subsequent validation tests for process or material changes. This test should also be used when validating assemblies containing SuperFlux LEDs to ensure that excessive self-heating will not result in premature failure of SuperFlux LEDs.

Although SAE J1889 describes a power temperature cycle test, Lumileds used more extreme power temperature cycle conditions to validate SuperFlux LED performance. SAE J1889 recommends powering the device while warming-and-hot and leaving it unlit when cooling-and-cold. Lumileds' tests, which are summarized in Table 6.1, are similar to SAE J1889, but the power is cycled by excessive solder heat, or improperly manufactured SuperFlux LEDs. Lumileds also extends the test from the 25 cycles recommended in SAE J1889 to a minimum of 50 cycles.

Solder Heat Resistance Strife Test

SuperFlux LEDs have been designed so that heat generated within the diode is quickly dissipated out through the copper leads. This thermally efficient design allows these LEDs to be driven at higher power levels relative to other LEDs, thus resulting in optimal optical performance. However, when the leads are immersed in solder, this design also allows heat to conduct from the leads up into the active area where the diode is located. Because SuperFlux LEDs transfer heat from solder-to-die much more quickly than other LEDs, it is extremely important that recommended solder profiles are followed during assembly to avoid thermal stressing of the LEDs. Lumileds' recommended soldering profiles are located in Application Note 1149-2 *Mechanical Design Considerations for SuperFlux LEDs*. Lumileds uses the solder heat-resistance strife test shown in Figure 6.3 to verify that SuperFlux LEDs can be soldered without damage. The temperature cycles and hot functional test ensure detection of latent damage or intermittent connections. This test sequence was used to validate SuperFlux LED performance. In addition, this test is repeated regularly to monitor the performance of SuperFlux LEDs.



Note: These conditions EXCEED Lumileds recommended soldering profiles.

Figure 6.3 Solder Heat Resistance Strife Test.

Table 6.2

Recommended Test	Test Parameters
Post-Soldering 30X Visual Inspection	Refer to Application Note 1149-2 *Mechanical Design Considerations for SuperFlux LEDs* for a description of the procedure and accept/reject criteria.
Room Temperature Operating Life	Ta = 25°C, 500 hours at nominal drive conditions
Temperature Cycle	-40°C to 85°C [1], dwell & transfer times selected based on thermal mass of the assembly, 50 cycles
Power Temperature Cycle	-40°C to 85°C [1], 3°C per *minute transfer rate*, 2-hour cycle, 5-minute on/off, 50 cycles at nominal drive conditions. Or, SAE J1889 OCT93: -40°C to 85°C [1], 0.6°C to 5°C per minute transfer rate, one-hour minimum dwell, powered at nominal drive conditions while warming and hot, no power while cooling and cold.

Table 6.2 Recommended Validation Testing.

Recommended LED Assembly Validation Tests

Lumileds recommends that customers use the tests listed in the Table 6.2 to validate the durability of assemblies containing SuperFlux LEDs. Other tests (such as vibration, or corrosion resistance) may be included to check the performance of other components, materials, or interconnections in the assembly. Please realize that Lumileds cannot guarantee LED performance during durability tests if the maximum operating or storage temperature ranges, or the maximum junction temperature listed in the SuperFlux LED Technical Data Sheet are exceeded. In some applications, such as high-mount stop lamps mounted in the headliner behind rear window glass, the local ambient temperature can reach temperatures in excess of 100°C. Lumileds recommends that Lighting System Suppliers work with vehicle manufacturers to perform temperature measurements on similar vehicles or mock-ups to determine the actual operating and storage conditions to which the LED assembly will be exposed. During these studies it is important for the Lighting System Suppliers to record both temperature and supply voltage measurements. Both of these parameters will be required when designing assemblies for 'worst case' conditions (reference Application Brief AB20-3 *Electrical Design Considerations for SuperFlux LEDs.*)

Verifying Root Causes of Power & Temperature Cycle Failures

The most common causes for SuperFlux LED failures during Power & Temperature Cycle testing are excessive heat during soldering, thermal shock, and exceeding the devices absolute maximum junction temperature.

Separation between the leadframe and the encapsulant is usually caused by excessive solder heat or thermal shock. If this type of failure is suspected, the root cause can be confirmed by measuring the wave solder station temperatures and the temperature gradients that the SuperFlux LEDs were exposed to during assembly. This is accomplished by attaching a thermocouple to the lead of an LED on the solder-side of the PCB and recording its temperature profile during each operation. This should include any preliminary operations such as surface mount glue cure, the soldering operation, any subsequent rework or touch-up operations, and any post-solder heating or cooling cycles such as conformal coating cure. (Reference Application Note 1149-2 *Mechanical Design Considerations for SuperFlux LEDs* for precautions required when attaching thermo-couples to the leads of LEDs.) The heating and cooling rates must not exceed ± 3°C per second, and the preheat and soldering temperatures should follow the recommendations provided in Application Note 1149-2 *Mechanical Design Considerations for SuperFlux LEDs.*

Exceeding the maximum junction temperature of the SuperFlux LEDs during Power & Temperature Cycle testing usually results in a necked-down wire break above the ball-bond on the LED chip (see Figure 6.2). To verify this root cause, the junction temperature during a typical Power & Temperature Cycle should be measured.

The maximum junction temperature can be determined by adding the temperature difference between the LED lead and the LED junction to the maximum lead temperature. The temperature difference between the LED lead and the LED junction is the product of the forward current flowing through the LED, the forward voltage of the LED (measured at this forward current), and the thermal resistance of the SuperFlux LED (listed in the Technical Data Sheet). This is expressed as the following equation:

$$T_j = T_p + R\,\theta_{jp} V_f\, I_f \qquad (6.1)$$

Where:

T_j = Junction temperature

T_p = Temperature of the LED pin (lead)

$R\,\theta_{jp}$ = Junction-to-pin (lead) thermal resistance

V_f = Forward voltage (at I_f)

I_f = Forward current

If the junction temperature from this evaluation exceeds the maximum junction temperature listed in the SuperFlux LED Technical Data Sheet, then it is unlikely that the assembly will consistently pass the Power & Temperature Cycle test.

The LED pin temperature can be measured by attaching a thermocouple to one of the cathode leads of the LED on the underside of the PCB on the solder pad; making sure that it has a good thermal contact to the metal lead. LEDs near the center of the assembly and near any heat sources (such as resistors or other driving circuitry) should be selected for monitoring.

After all thermocouples have been attached on the LED assembly, the LED assembly should be mounted inside the outer housing. Provisions must be made for the thermocouple leads to exit the assembly for attachment to a monitoring device. Place the device in the chamber in the way it would be placed during the Power & Temperature Cycle test.

Heat the chamber to the maximum ambient temperature to be used during the test, and power the LED assembly (or assemblies). Monitor and record the pin temperatures of the SuperFlux LED leads until the temperatures reach steady-state.

The junction temperature can be calculated using Equation 6.1. An estimate of the maximum junction temperature can also be obtained by performing this test on a test bench in normal ambient temperatures. Note that this test may not be able to duplicate the thermal conditions inside the test chamber such as airflow around the printed circuit assemblies and heating from adjacent boards. The ambient temperature of the room during the test should be noted. Using this approach, the maximum junction temperature is the sum of the measured pin temperature, the temperature rise between the pin and the junction calculated above, and the difference between the room ambient and the maximum ambient temperature to be used in the Power & Temperature Cycle chamber. This is expressed as the following formula:

$$T_j = T_p + \left(R\,\theta_{jp} V_f\, I_f\right) + \left(T_{amax} - T_{atest}\right) \qquad (6.2)$$

Where:

T_{amax}= Maximum ambient temperature from Power & Temperature Cycle test

T_{atest} = Ambient temperature of bench test

Changes in Light-Output During the Operating Life of AlInGap SuperFlux LEDs

The light-output of SuperFlux LEDs will gradually change during their lifetime. This change is usually a gradual reduction in light-output; however it is also possible to have a slight increase in light-output during early operation followed by a gradual reduction. This change in light-output is called light-output degradation. Typical amounts of light-output degradation for some popular automotive applications are summarized in Table 6.3. Light-output degradation occurs most quickly during the initial hours of operation and then slows with time as shown in Figure 6.4. There is some variation within a batch and between batches of SuperFlux LEDs. Figure 6.5 shows that the amount of light-output degradation is proportional to forward current. This figure also shows that some batches of SuperFlux LEDs get slightly brighter before starting the typical decline. Ambient temperature, humidity, and sunlight have minimal effect on light-output degradation as shown in Table 6.4, Table 6.5, and Figure 6.6. For SuperFlux LEDs, Lumileds is careful to select AlInGaP material with an average light-output degradation of less than 35% after 1000 hours of operation at 70 mA.

Table 6.3

LIFETIME CHANGE IN LIGHT-OUTPUT FOR SUPERFLUX LEDS IN AUTOMOTIVE SIGNALING APPLICATIONS

Lifetime Light-Output Change @ T_a = 25°C; I_f = 20 mA (Tail) and 60 mA (Stop and Turn)		
Function	Operating Life (h)	Typical LOP Change
Tail	1,500 to 3,000	-5 to 5%
Stop	750 to 2000	-30 to 5%
Turn	200 to 700	-20 to 5%

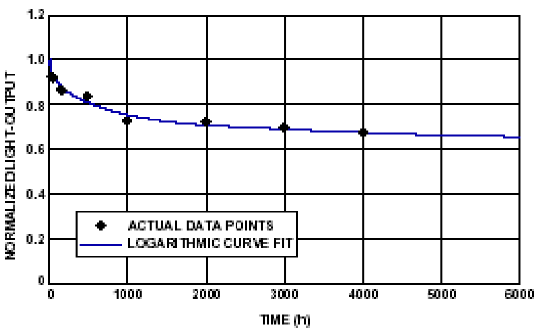


Figure 6.4 Operating life test results for HPWA-MHOO LEDs driven at 70mA, 55°C.

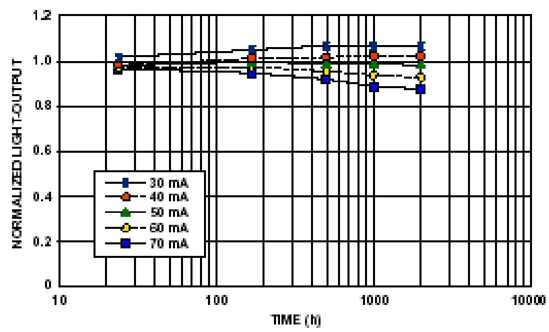


Figure 6.5 Change in light-output over time for HPWT-DHOO driven at multiple currents at 55°C.

Light output degradation for SuperFlux LEDs is a function of the current density in the LED semiconductor chip. The rate of change will be lower when SuperFlux LEDs are driven at lower currents. Figure 6.5 shows how the light-output varies over time for LEDs driven at several currents. Although this particular lot of LEDs became slightly brighter with time at the lower forward currents, their light-output peaked and then began the typical logarithmic decline. At high currents SuperFlux LED light-output will peak within a few hours. At lower currents they may continue to get brighter for several hundred hours before beginning the normal gradual reduction over time.

Ambient temperature has negligible effect on the light-output degradation of SuperFlux LEDs. During the initial product qualification, HP monitored the change in light-output during the operating and forward-biased weatherability tests listed in Table 6.1. The average changes for one of the TS AlInGaP wafers used for these tests are shown in Tables 6.4 and 6.5. The different stress temperatures and the presence of humidity had negligible effect on light-output degradation. In fact, the 100°C test had a lower light-output degradation than the tests run at cooler temperatures. This illustrates that drive current has a larger impact than ambient temperature on the rate of light-output degradation.

Figure 6.6 shows the light-output degradation of some samples mounted in the Arizona Desert. These samples were directly exposed to the harsh local weather conditions for over a year. Some of these samples were mounted on a vertically-oriented, south-facing printed circuit board. Other samples were mounted on a printed circuit board in a special apparatus that collects and concentrates sunlight by a factor of six. A picture of this sun concentrator is shown in Figure 6.7.

As shown in Figure 6.6, the concentrated sunlight had only a small effect on device performance.

The rate of change in light-output will vary within a batch and from one batch of LEDs to another. Within a lot, the individual standard deviation for results is approximately 5% after 1000 hours of operation. Lumileds Quality System is designed to prevent the use of AlInGaP semiconductor material that exhibits unacceptable light-output degradation in SuperFlux LEDs. Lumileds only uses batches of material with an average light-output change of less than 35% after 1000 hours of operation at 70 mA.

Table 6.4

Operating Life Test Results for HPWT-MHOO LEDs

Operating Life Tests	Average Change in Light-output (after 1.000 hours)
Condition A, HTOL, 100°C, 30 mA	-10%
Condition B, HTOL, 85°C, 50 mA	-21%
Condition C, HTOL, 55°C, 70 mA	-24%
Condition D, RTOL, 25°C, 70 mA	-24%
Condition E, LTOL, -40°C, 70 mA	-16%

Table 6.5

WEATHERABILITY TESTS

Weatherability Tests	Average Change in Light-output (after 1.000 hours)
Condition A, WHTOL, 85°C, 85% relative humidity, 50 mA	-19%

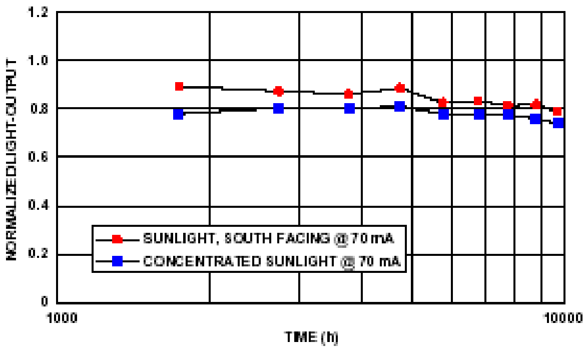


Figure 6.6 Change in light-output for HPWT-xHOO LEDs when operated in Arizona weathering tests, at 70mA and outdoor temperatures.

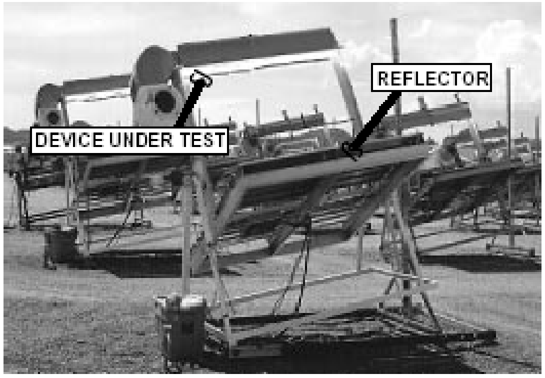


Figure 6.7 Photograph of apparatus used for Arizona accelerated sun exposure tests.

Company Information

Lumileds is a world-class supplier of Light Emitting Diodes (LEDs) producing billions of LEDs annually. Lumileds is a fully integrated supplier, producing core LED material in all three base colors (Red, Green, Blue) and White. Lumileds has R&D development centers in San Jose, California and Best, The Netherlands. Production capabilities in San Jose, California and Malaysia.

Lumileds is pioneering the high-flux LED technology and bridging the gap between solid state LED technology and the lighting world. Lumileds is absolutely dedicated to bringing the best and brightest LED technology to enable new applications and markets in the Lighting world.

LUMILEDS™
LIGHT FROM SILICON VALLEY

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