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Testing High Brightness LEDs Accurately and Cost-Effectively in a Production Environment

Dave Wyban and Jerry Janesch

Visible light emitting diodes (LEDs) combine high efficiency and long lifetimes. Today, they're used in a wide range of applications. Extensive R&D efforts by manufacturers have led to the creation of devices with higher luminous flux, longer lifetimes, greater chromaticity, and more lumens per watt. Accurate and cost-effective testing is critical to ensure device reliability and quality.

LED testing involves different types of test sequences at various stages of production, such as during design R&D, on-wafer measurements during production, and final tests of packaged parts. Although testing LEDs typically involves both electrical and optical measurements, this article focuses on electrical characterization, including light measurement techniques where appropriate. *Figure 1* illustrates the electrical I-V curve of a typical diode. A complete test could include a multitude of voltage values versus current operating points, but a limited sample of points is generally sufficient to probe for the figures of merit.

Many tests require sourcing a known current and measuring a voltage; others require sourcing a voltage and measuring the resulting current. Therefore, high speed test instrumentation with integrated, synchronized sourcing and measuring capabilities is ideal for these types of tests.

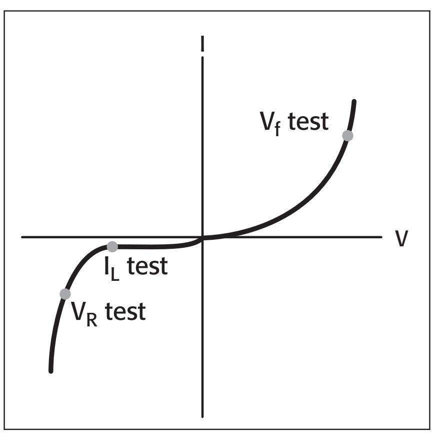

Figure 1. Typical LED DC I-V curve and test points (not to scale).

Forward Voltage Test

In an LED test sequence, the forward voltage (V_F) test verifies the forward operating voltage of the visible LED. When a forward current is applied to the diode, it begins to conduct. During the initial low current source values, the voltage drop across the diode increases rapidly, but the slope begins to level off as drive currents increase. The diode normally operates in this region of relatively constant voltage. It is also quite useful to test the diode under these operating conditions. The V_F test is performed by sourcing a known current and measuring the resulting voltage drop across the diode. Typical test currents range from tens of milliamps to amps, while the resulting voltage measurement is typically in the range of a few volts. Some manufacturers use the results of this test for binning purposes because the forward voltage is related to the chromaticity (the quality of color characterized by its dominant or complementary wavelength and purity taken together) of the LED.

Optical Tests

Forward current biasing is also used for optical tests because electrical current flow is closely related to the amount of light emitted. Optical power can be measured by placing a photodiode or integrating sphere close to the device under test to capture the emitted photons. This light is then converted to a current, which is measured using an ammeter or one channel of a source-and-measure instrument.

In many test applications, the voltage and light output of the diode can be measured simultaneously using a fixed source current value. In addition, details such as spectral output can be determined from the same drive current value by using a spectrometer.

Reverse Breakdown Voltage Test

Applying a negative bias current to the LED will allow probing for the reverse breakdown voltage (V_R). The test current should be set to a level where the measured voltage value no longer increases significantly when the current is increased slightly more. At levels higher than this voltage, large increases in reverse bias current result in insignificant changes in reverse voltage. The specification for this parameter is usually a minimum value. The V_R test is performed by sourcing a low-level reverse bias current for a specified time, then measuring the voltage drop across the LED. The measurement result is typically in the range of tens of volts.

Leakage Current Tests

Normally, moderate voltage levels (volts to tens of volts) are used to measure a leakage current (I_L). The leakage current test measures the low-level current that leaks across the LED when a reverse voltage less than breakdown is applied. It is a common practice for leakage measurements, and more generally for isolation measurements, to make sure only that a certain threshold is not exceeded in production. There are two reasons for this. First, low current measurements require longer settling times, so they take longer to complete. Second, environmental interference and electrical noise exert greater influence on low-level signals, so extra care in shielding is required. This extra shielding complicates the test fixture and may interfere with automated handlers.

Smart Instruments Increase LED Production Test Throughput

In the past, a PC often controlled all aspects of the test in many LED production test systems. In other words, in each element of a test sequence, the sources and instruments had to be configured for each test, perform the desired action, and then return the data to the controlling PC. The controlling PC then had to evaluate the pass/fail criteria and perform the appropriate action for binning the DUT. Each command sent and executed consumed precious test time and lowered throughput. Obviously, in this type of PC-centered test configuration, a large percentage of the test sequence time was consumed by communicating information to and from the PC.

In contrast, many of today's smart instruments, such as Series 2600A System SourceMeter® instruments, make it possible to increase the throughput of complicated test sequences dramatically by decreasing the amount of traffic over the communications bus. In these instruments, the majority of the test sequence is embedded in the instrument. A Test Script Processor (TSP®) is a full-featured test sequence engine that allows control of the test sequence, with internal pass/fail criteria, math, calculations, and control of digital I/O. The TSP can store a user-defined test sequence in memory and execute it on command. This limits the setup and configuration time for each step in the test sequence and increases throughput by minimizing communications to and from the instrument and PC. The process for programming an instrument of this type is relatively simple: 1) create the script; 2) download the script to the instrument; and 3) call the script to run. For Series 2600A instruments, scripts can be written and downloaded to the instrument using the Test Script Builder software provided with the instrument or downloaded to the instrument from custom applications written in languages such as Visual Basic or LabVIEW.

LED Test System for a Single Device

Figure 2 is a simplified block diagram of a system for testing a single LED. For automation purposes, a PC and a component handler—a probe station for on-wafer measurements—are typically included.

In this test configuration, the main purpose of the PC is to store measurement data in a database for documentation. A secondary purpose is to reconfigure the test sequence for different parts. Series 2600A instruments are unique in terms of their independence from the PC controller. The TSP embedded in each supports writing a complete test plan that operates on the instrument itself. In other words, it's possible to write a complete PASS/ FAIL test sequence script and run it from the instrument's front panel without instrument reprogramming.

A production test system is likely to incorporate a component handler to transport the individual LEDs to a test fixture, where they can be electrically contacted. The fixture is shielded from ambient light and houses a photodetector (PD) for light measurements. In the setup illustrated in ***Figure 2***, a single Model 2602A Dual-Channel System SourceMeter instrument is used for both connections. Here, Source-Measure Unit A (SMUA) supplies the test signal to the LED and measures its electrical response while SMUB monitors the photodiode during optical measurements.

The test sequence is programmed to begin using a digital line from the component handler that serves as a "start of test" (SOT) signal. After the SourceMeter instrument detects the SOT signal, the tests for characterization of the LED begin.

After all electrical and optical tests are completed, a digital line to flag "measurement complete" is set for the component handler. In addition, the instrument's built-in intelligence performs all pass/fail operations and sends a digital command through the digital I/O port on the instrument to the component handler to bin the LED based on the pass/fail criteria. Then, two actions can be programmed to take place simultaneously: data is transferred to the PC for statistical process control and a new DUT moves into the test fixture.

LED Test System for Multiple Devices/Arrays

In multiple device tests, such as those that involve burn-in, multiple parts are measured simultaneously over a specified period. A continuous current flow is usually mandatory to drive the DUTs, but multiple light detectors may be multiplexed to a current meter through a switching system. The appropriate choices for switching system and

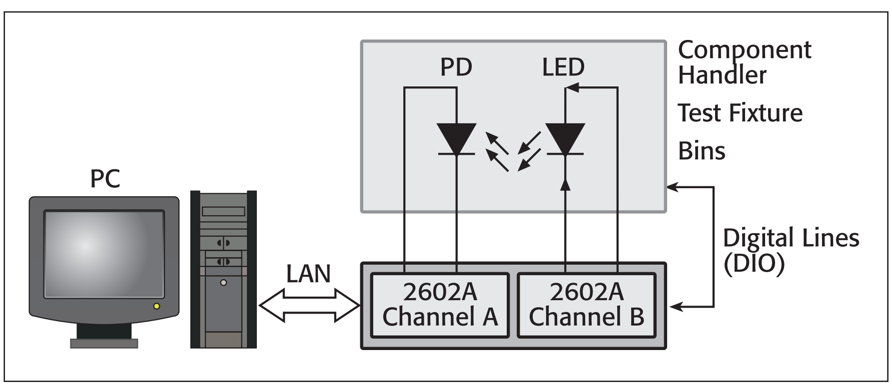

Figure 2. Block diagram of a SourceMeter-based single LED test system.

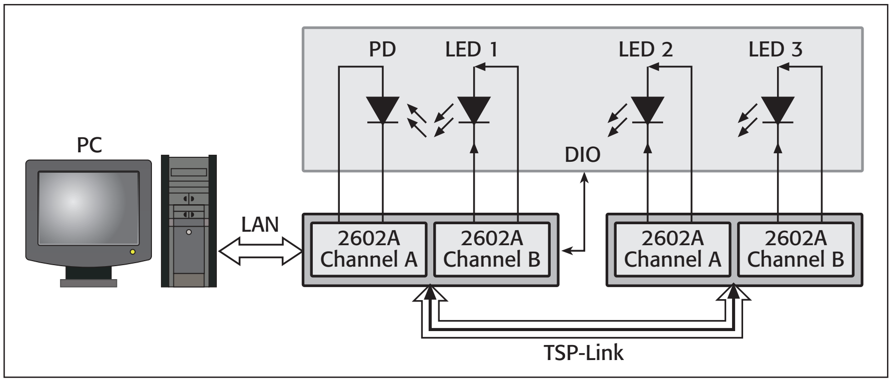

Figure 3. Block diagram with scalable Model 2602A SourceMeter channels for an LED array test system.

meter will be dictated by the dynamic range of the currents of interest.

Various switch options are applicable to testing multiple LEDs. For example, the Model 3706 System Switch/Multimeter has six switch module slots, so it can handle up to 576 multiplexed channels or 2688 matrix cross-points. Like Series 2600A instruments, it includes an on-board TSP and a TSP-Link® inter-unit communication/triggering bus, which allows integrating these instruments into a system quickly and easily. This integration allows tight synchronization of operations between the instruments and lets them operate from a single test script. ***Figure 3*** illustrates a three-LED device test system with one photodiode (PD) channel.

Minimizing LED Testing Error

Common sources of measurement error in LED production testing include lead resistance, leakage current, electrostatic interference, and light interference, but junction self-heating is one of the most significant error sources. The two tests susceptible to junction heating are the forward voltage and leakage current tests. As the junction heats, the voltage will drop or, more importantly, the leakage current will increase during the constant voltage test. Therefore, it is important to shorten the test time as much as possible without sacrificing measurement accuracy or stability.

Smart instruments with onboard test script engines simplify configuring the device soak time before the measurement, as well as the amount of time the input signal is acquired. The soak time allows any circuit capacitance to settle before the measurement begins. The measurement integration time is determined by the number of power line cycles (NPLC). If the input power were at 60Hz, a 1NPLC measurement would require 1/60th of a second or 16.667ms. The integration time defines how long the A-to-D converter acquires the input signal, and it represents a trade-off between speed and accuracy.

Typical soak times for the V_F test are from less than a few hundred microseconds to five milliseconds, and from five to 20 milliseconds for the IL test. By using these short test times, errors due to the junction heating are reduced. Also, the junction heating characteristics can be determined by performing a series of tests and only varying the test time.

To further reduce test time and junction self-heating, Series 2600A instruments are capable of pulsed operation. In this mode, they can source their outputs precisely for a specified period. Pulse width resolution of one microsecond gives precise control over how long power is applied to the device. Pulsed operation also allows these instruments to output current levels well beyond their DC capabilities. For example, the Model 2602A can output 3A DC at 6V. In pulsed mode, it can output 10A at 20V.

Conclusion

Additional information on new techniques for production testing of LEDs, including example test sequence script code, is available by downloading a free copy of Keithley's Application Note #2639, *High Speed Testing of High Brightness LEDs*. KEITHLEY

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