Breakthrough for Test Cost Reduction on Micro-LED Device with Electric-Luminescence and Electrical Test Embedded Solution

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ABSTRACT

To launch up Micro-LED display, the biggest challenge is cost reduction, With the urgent needs to reduce test costs, most critical issues is parallelizing electroluminescence (EL) test. In this paper, we propose super cost-effective test methods (PEMP^{TM}) embedding EL and electrical test and report its effectiveness and application results.

1 Introduction

1.1 Micro-LED overview

The Micro-LED is next generation display technology after OLED, which has panel with less than 100um pixel LED chip.

There are many technical advantages exists on Micro-LED which are, High luminance, Color rendering quality, Long life cycle, Power consumption, Response time etc.

Therefore, especially for signage TV, luxury TV, AR/VR and automotive segment will be good fit for this Micro-LED base display technology. But in any application model, the biggest dis-advantage is the manufacturing cost, and it is gating factor to be main, core technology of the display.

1.2 Key issues to be mass production

The production cost of Micro-LEDs, which has been a bottleneck, has also improved in recent years due to advances in Mass Transfer and color conversion technologies and improvements in system speed. The next important factor in this trend is test cost.

Although it is essential to conduct appropriate tests in appropriate processes to ensure the quality of the final display product, a realistic test method that can withstand the coming mass production has not yet been found.

How to optimize the cost of this testing process will determine the success of mass production in the future.

1.3 Typical Test Strategy

There are several approaches to testing to ensure the quality of the final product, but they can be summarized into the following two major categories. First, there are two ways to ensure final product quality: (1) to tolerate defective elements at the wafer level and repair them at the final product level, and (2) to identify and eliminate defective elements at the wafer level so that the final product is composed of only good LEDs.

In the former case, the repair cost is higher, and it is only feasible when the manufacturing process is sufficiently stable and there is almost no mixture of defects. As the number of pixels increases, it becomes necessary to further reduce the number of defects, which poses many challenges.

In the latter case, several methods are commonly used, each with its own challenges. (Fig. 1)

1.4 Photoluminescence Test (PL Test)

Photoluminescence Test evaluates the physical properties of LEDs using a test method that utilizes only optics.

Although it is an effective measurement method to identify trends in optical characteristics across Wafer, it cannot identify electrical or optical defects caused by electrical characteristics, and EL and Diode characteristic tests are required after the PL test.

1.5 Electroluminescence Test (EL test)

Electroluminescence Test which forces current, measure optical output from LED. It is the most suitable measurement technique for evaluating LEDs.

One of issue on test is the EL optical test performance. Typically, it is using integrating sphere and test the LED one by one. Some Spectroradiometer offer to test multiple LED at once but if LED goes small, it cannot be tested in parallel due to light leaking. When it is tried to test many LED in parallel, each LED’s lighting is merging and cannot isolate each LED luminance level to detect Failure. (Fig. 2)

Also, the EL testing system has CCD camera which required the data capture, imaging process and post process. It takes a time to figure out final Luminance level.

1.6 Diode Vf, Ir electrical test

Electrical Diode Vf, Ir test also required during mass production due to electrical specific defect exists.

Depends on the requirement, several measurement point on IV curve, Thyristor type of AC performance test are required.

These electrical tests are on multiple LED testing condition, but it is about few to 48 LED at once. It is not good enough parallelism for the pass production volume execution.

Currently most of setup has two separate setups with EL and electrical test.

1.7 Necessary Test Method for mass production

Each, PL Test, EL Test and Diode electrical Test has pros and cons. And not having perfect fit solution for upcoming mass production.

If these test requirements will be combined into single test cell with Massive parallel condition, it goes game changer test methodology.

2 New Test Method of PEMP™ Test

In this paper, we offer brand new approach of the Micro-LED wafer testing especially best fit for upcoming Mass Production phase.

This new PEMP™ Test approach has both electrical and optical test embedded as single setup, massive parallel test of electrical/optical test with excellent throughput. Also, this approach could use for matrix/unit testing.

2.1 Core method to test LED on PEMP™

When a forward voltage or current is applied to the device, the holes and electrons move toward the p-n junction, where they combine and disappear. At this time, the electrons move from a high energy state to a low energy state, and the excess energy is emitted to the outside as light.

But also LED act as Photo Diode when the LED receive the lighting energy from outside. The current flows and Voltage generated when light hits it without the need for an external voltage.

These two behavior of LED luminance and Electrical output by forcing light has relation and correlated with specific condition.

Therefore, the PEMP™ test method uses light energy as input and measuring electrical output from LED. To realize this test method, it is necessary to have tuned up specific light source and measurement scheme.

2.2 Benefits on PEMP™ Test approach

(1) Massive Parallel

When external lighting goes into LED, each LED could detect these external lighting level individually, therefore no light leaking issue exists on PEMP™ Test and able to realize massive parallel test.

(2) Test Speed

The PEMP™ Test has faster measurement time because of it is not required any image analysis and further conversion post processes to figure out luminance level.

(3) Embedded Testing

Since PEMP™ Test Setup has electrical test resources, the same Test Setup can be covered both optical and electrical test. It is another factor to realize effective test flow. It is important factor to test Optical Test and Electrical Test in same test condition.

2.3 Example of Test result

There is one of test result example on Fig. 3. In this wafer, there were defect area (with 12 LEDs) and some failure LED exists. 8 LED (LED #1 #2 #4 #5 #7 #8 #10 #11) in this failure area has just electrical failure and could be rejected by traditional electrical test as well. But another 4LEDs on right corner (LED #3 #6 #9 #12) is not failing on electrical test, but only optical test can be detected as FAIL.

The graph in Fig. 3 is the PEMP™ Test result. When it is tested by PEMP™ Test Cell, optical defected 4 LEDs has weak output of PEMP™ Test result.

To have accurate test result, it is used specific optical setup and test algorithm libraries for PEMP™ Test.

2.4 Traditional EL Test and PEMP™ Test result comparison

To make sure new PEMP™ test result has correlated between traditional EL test, we had measured with both solutions. (Fig. 4, Fig. 5) It is using our 2nd version of system setup which has test accuracy improvement.

From this result, the intensity level is well correlated between these two different test methods.

2.5 Use ATE as electrical test source

Instead of using instruments base setup, use Automated Test Equipment for this test, the setup, test programing, test resulting, reporting and analysis are all packaged and assisting the operation speed of data collection. Ease of setup meant to less risk of trouble and effective for stable test result as well.

3 Conclusions

We reached Mass Production capable solution with Optical/Electrical embedded with excellent performance

The PEMP™ solution is meeting expectation of performance for upcoming Micro-LED mass production. It should be capable for mini-LED as well.

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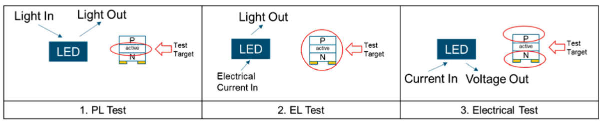

Fig. 1 Each Test methods

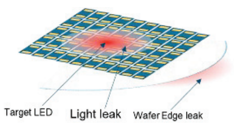

Fig. 2 Light leaking

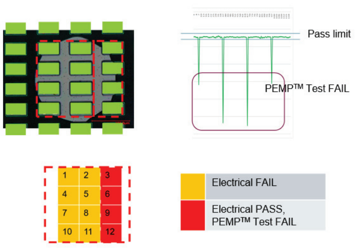

Fig. 3 Fail detect example

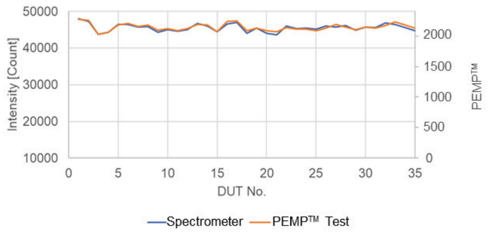

Fig. 4 Correlation result between Spectrometer and PEMP™ Test 1

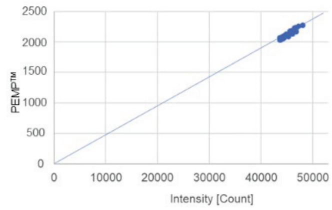

Fig. 5 Correlation result between Spectrometer and PEMP™ Test 2