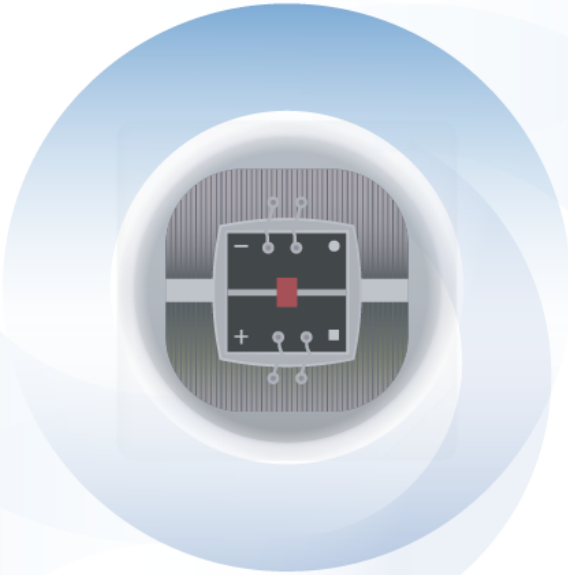
NPQD® R Series

Micro-LED chips for display



White-Paper

SAPHLUX

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I. Executive Summary

To realize market adoption of consumer 8k televisions of smaller sizes, augmented reality (AR) glasses and virtual reality (VR) headsets, there needs to be a Micro-LED light engine that provides a full color, high brightness, high contrast and consuming low power. Micro-LED technology is the only technology that facilitates the creation of extremely large displays as well as uniquely shaped modular displays. Current Micro-LED display solutions, typically use small dies from three different sources i.e., red, green and blue wafers resulting the manufacturing of Micro-LED display complex and costly. Advances and innovations in quantum dots (QD) have provided a unique QD incorporation process that allows seamless integration of Micro-LED displays and create never before possible products [1,2]. This white paper will demonstrate that the GaN-based blue LEDs, incorporating green and red color quantum dots in nanopores, pumped with blue LEDs is the technique for full-color Micro-LED display manufacturing addressing these challenges.

II. Challenge

Micro-LED is the display technology that will overcome deficits of OLED and LED-LCD technology and create never before possible solutions offering disruptive performance [3]. To get to the end-state where all displays driven by Micro-LED, key challenges need to be addressed i.e., red efficiency, mass transfer, and brightness performance at ambient conditions at a defined color space.

Red Problem

AlInGaP is widely adopted in lighting and display applications due to the advantages of low cost, high luminance, and reliability. However, the efficiency of AlInGaP-based Micro-LED is reduced by an order of magnitude when approaching micrometer scale, and as a result red efficiency is a key roadblock for the adoption of Micro-LED-based applications [4]. The smaller micrometer scale LEDs experience larger carrier loss due to nonradiative recombination at sidewall defects leading to lower efficiencies. Lower red performance has direct impact on the overall display brightness and power consumption.

Brightness at use-condition at defined color space

Vivid color and brightness are critical requirement of HDR displays. The human eye has a very wide dynamic range, covering an absolute specular highlight (10000 Nits) to an extreme dark state (0.005 Nits). As a Rec-2020 application target, Ultra HD Premium defined the HDR luminance range as 0.05~1000 Nits [5]. Rec-2020 color gamut is widest among the existing display specifications. Current best consumer displays can only cover around 60 to 80% of color gamut. Micro LED display as a technology can deliver the full potential of High Dynamic Range (HDR) with a peak brightness of 10,000 Nits and 100% of Rec-2020 gamut. However, with current AlInGaP red Micro-LED efficiency, it is very challenging to achieve 1000 Nits brightness at use-conditions due to high power consumption and low reliability.

III. Innovations

The NPQD® Technology

NPQD® stands for "Nano Pores Quantum Dot". Through electrochemical etching, a nano-porous layer is formed inside the GaN LED. The nanopores are filled with quantum dots (QDs) of choice to create R or G. Thus, the addressable R-G-B pixels inside a monolithic chip are achieved by exciting the QDs with blue light, which then can convert into red or green light.

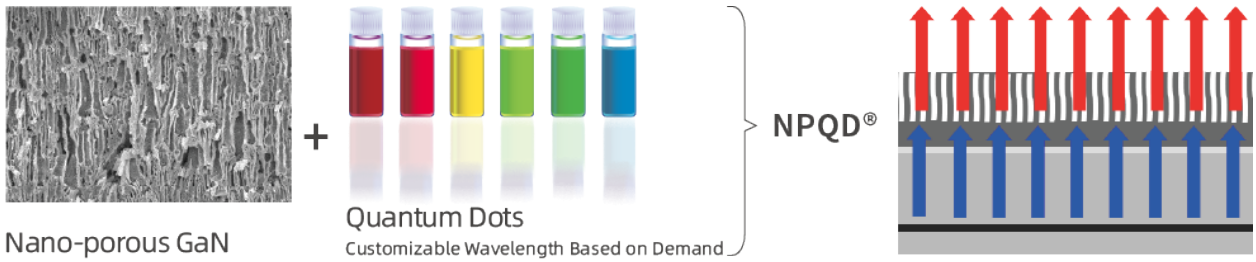

Figure 1. NPQD® Demonstration

Technical Features (Compared to other QD technologies)
Scattering effect: High Light Efficiency at a Few Microns of QD Layer Thickness

The strong blue light scattering effect of the nano-porous structure increases the total light bounces, leading to up to >99% of color purity and higher light conversion efficiency with just a few microns thickness of the QD layer.

Blue Radiometric Flux Re-distribution: Enhanced Quantum Dot Reliability

By dispersing the light among individual nanopores, the light-emitting surface area is increased by 40 times, resulting in an 8 times lower blue radiometric flux density on the QDs and thereby, significantly enhancing the reliability of the QDs.

Porous Gallium Nitride: Better Thermal Dissipation

Compared photolithography based QD color conversion where thermal conductivity (K) of photoresists are ~ 0.2W/m-K, the K value of nanopore GaN is more than 100W/m-K, making it a better heat dissipater for the QDs and significantly improving the thermal stability of the QDs.

Color Conversion: Reduced Manufacturing Costs

By combining nano-porous GaN and quantum dots, red or RGB Micro-LEDs can be converted from low-cost blue LEDs, thereby significantly reducing chip manufacturing and inventory costs.

Wavelength Consistency: Narrow Wavelength Distribution

The wavelength of NPQD® quantum dots can be precisely adjusted, allowing the spread of wavelength distribution within and between wafers to reach ±0.5nm.

The R Series Chips

- Chip Structure

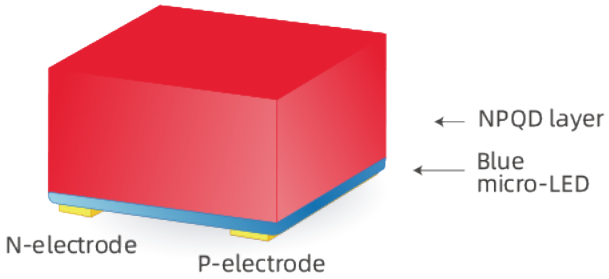

Figure 2. The internal structure of the R series chip

- Chip Dimensions

Chip Dimensions				
Product	R1-0305	R1-0406	R1-0307	R1-0408
Chip size	136×80 μm^2	150×100 μm^2	181×93.5 μm^2	200×100 μm^2
Chip thickness	80 μm	80 μm	80 μm	80 μm
P&N size	50×39 μm^2	62×41 μm^2	59.5×43.5 μm^2	70×47.5 μm^2

Figure 3. R Series chip dimensions

IV. Benefit

System Benefit :

AlInGaP is currently the widely used in red Micro-LED manufacturing. However, certain problems are still unsolved. The overall low EQE and WPE of AlInGaP Micro-LED Chips causes high system power consumptions. When the smaller Chip size are required, the EQE decreases more drastically due to native defects.[6] Under low current with relatively high duty cycle, the light output power of AlInGaP is limited. Additionally, at use temperature ~100 °C, AlInGaP experiences thermal decay up to 35%. NPQD® addresses the above AlInGaP issues.

	NPQD® 0406 Red	AlInGaP Chips as Common
EQE@1mA	29%	17%
EQE@100®μA	24%	13%
Power@100μA	33μW	7μW
Cold/hot factor@25 to 100	15%	35%
Color shift@1-10mA	2nm	5nm
Normalized System Cost	0.5	1

- R series chips used GaN material system to achieve the same driving voltage and RGB peak efficiency as blue and green chips.

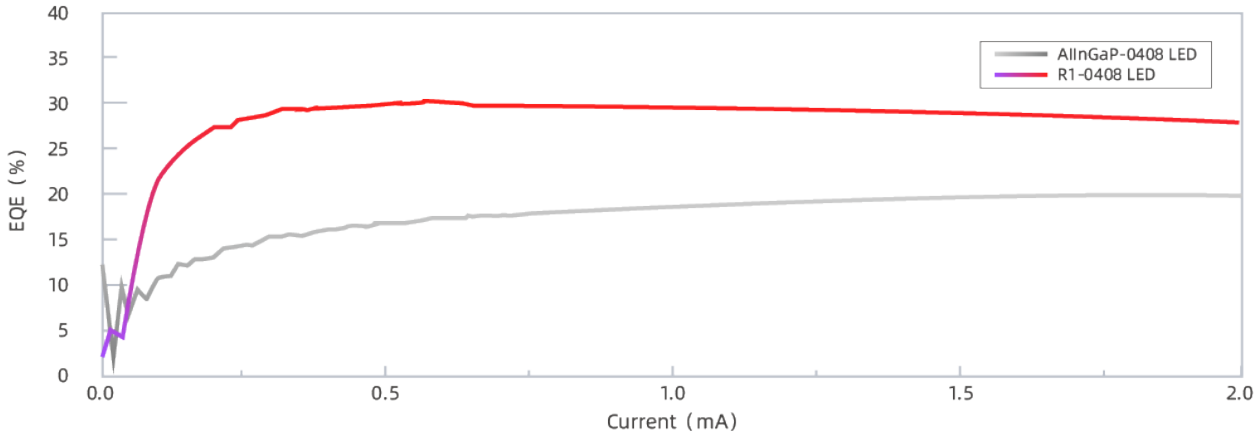

Figure 4. External quantum efficiency vs. Current

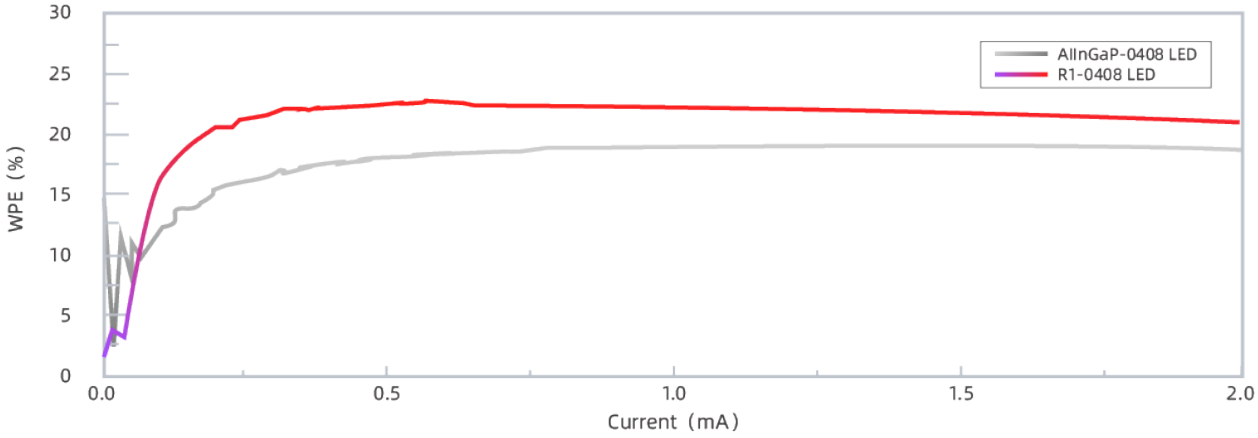

Figure 5. Wall plug efficiency vs. Current

- In GaN material system the blue light can reach peak efficiency at a very low current density, bringing in much higher light output power than red chips with AlInGaP material system at a low current.
- At 0.1mA (0.5A/cm2), NPQD® R Series LEDs can reach up to 10 times higher LOP than AlInGaP LEDs.

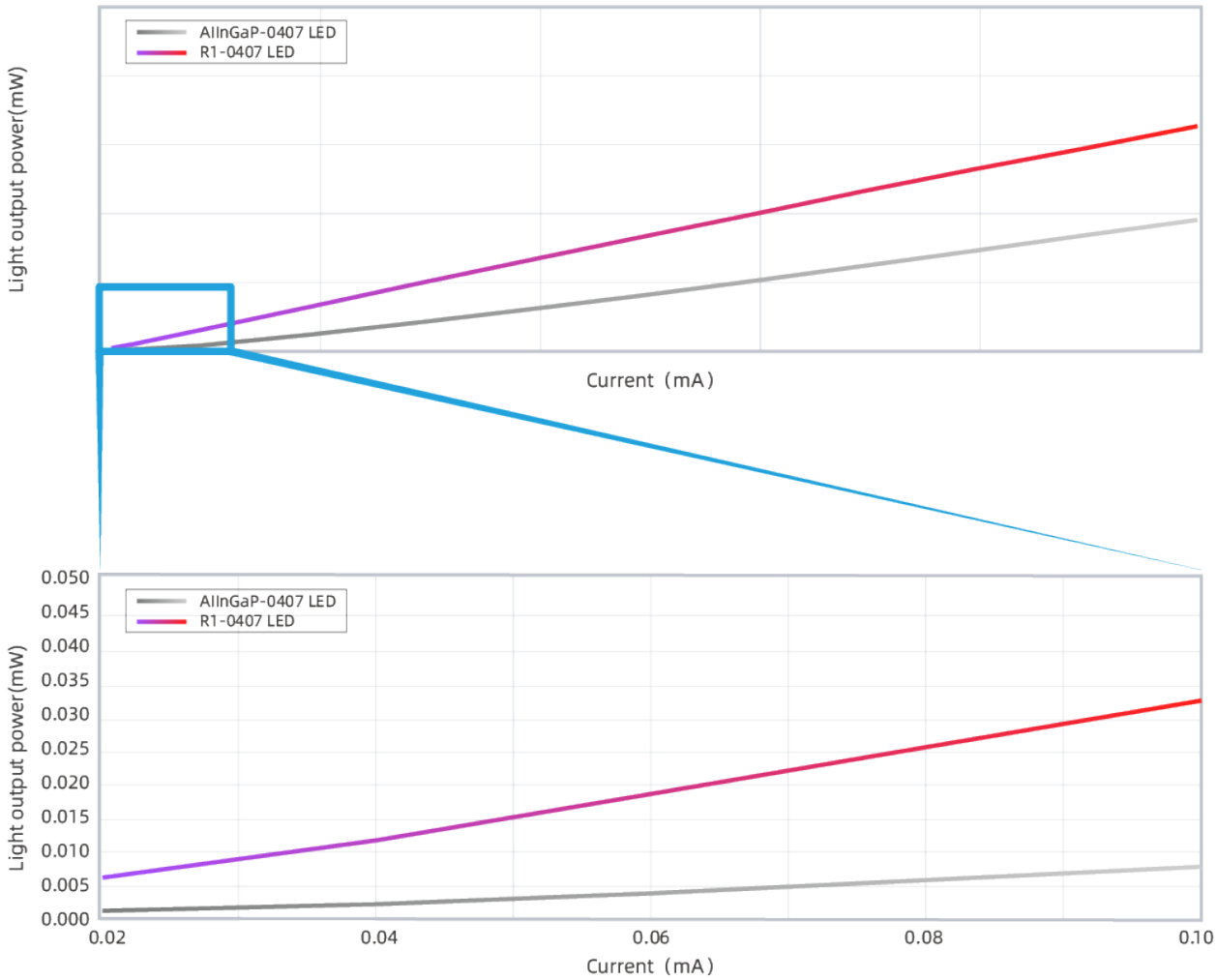

Figure 6. Light output power vs. Current

- Smaller FWHM drift: Under different usage scenarios, less half-peak width drift and thermal decay can bring in better color accuracy.

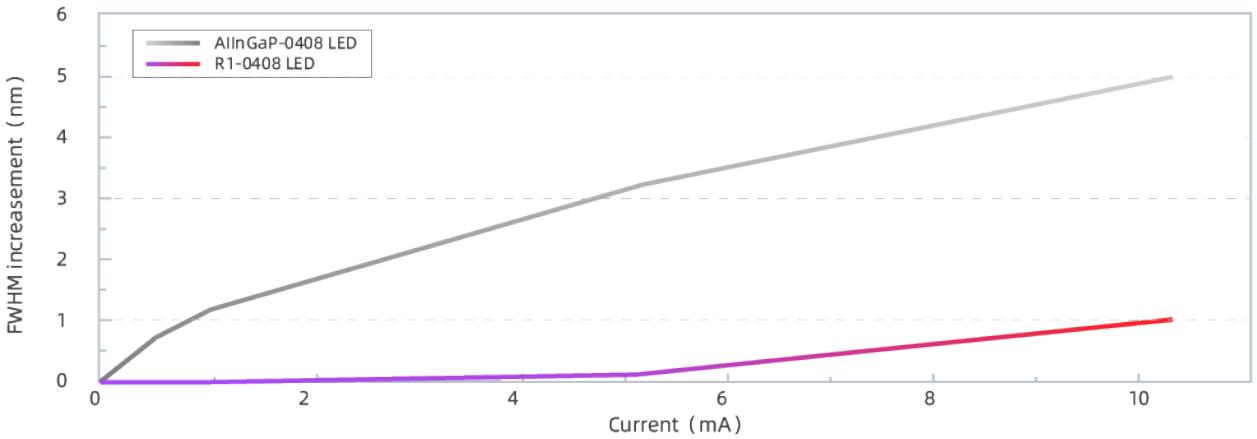

Figure 7. Full width at half maxima increasement vs. Current

- Less thermal decay

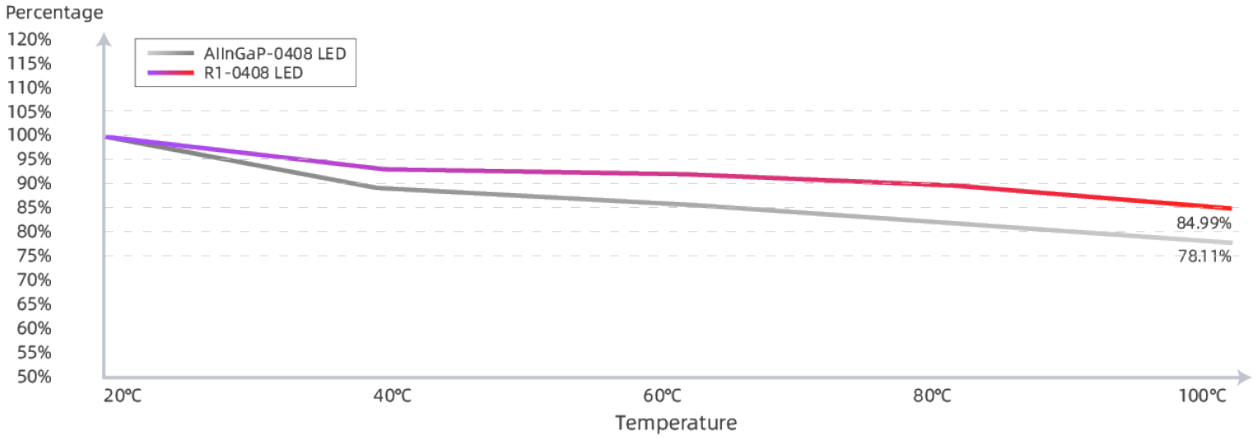

Figure 8. Percentage vs. Temperature

- Higher efficiency at small chip size

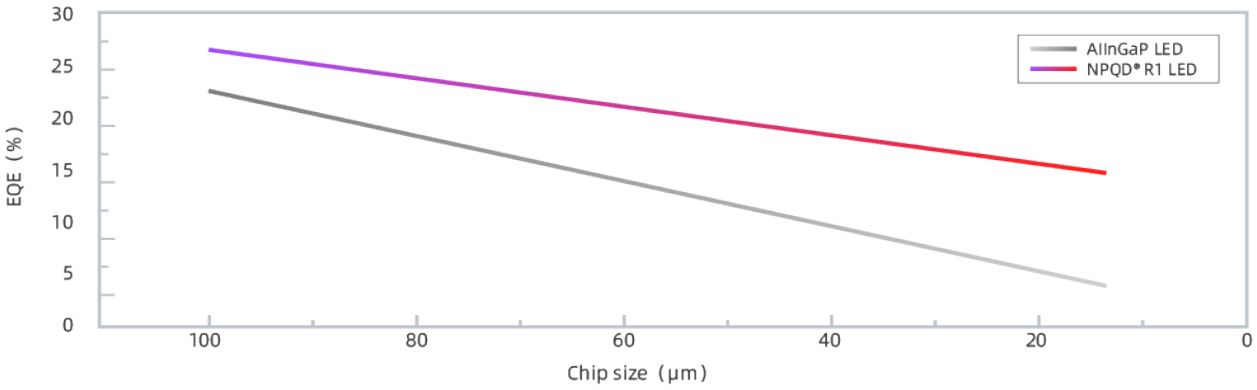

Figure 9. External quantum efficiency vs. Chip size

- Better WLD uniformity (WLD detection repeatability±0.5nm): NPQD® technology greatly improved the wavelength consistency of the R series chips, which can provide better color accuracy in display applications.

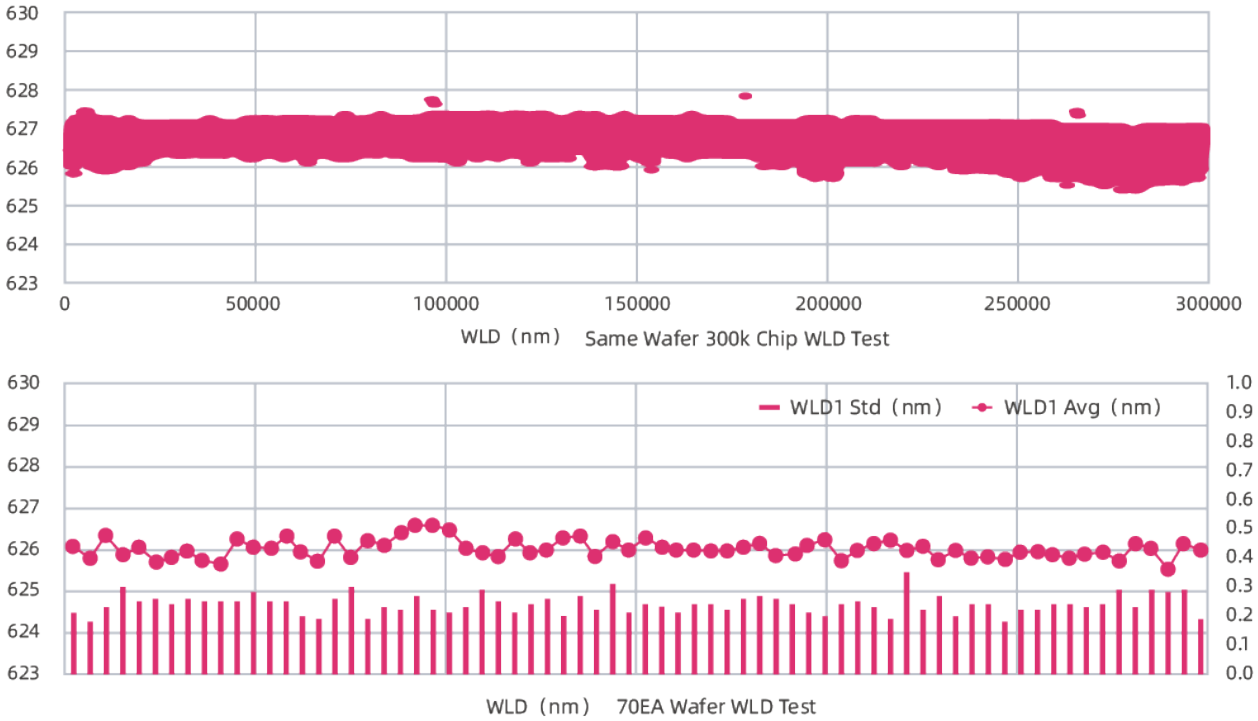

Figure 10. The WLD tests have proven the better WLD uniformity of the R series chips.

Operational Benefit:

Compared to AlInGaP red LEDs, the GaN-based R-series chips have significantly reduced fabrication costs and higher yield. The NPQD® wafer-level integration technology is compatible with existing LED fabrication process and production line.

- Color Uniformity: Implementing the NPQD® technology, the color shift is within 2nm, which meets most customers need. Due to lower yield loss, the production cost is lowered.

- In the conventional AlInGaP red LED manufacturing process, the intrinsic brittleness of AlInGaP contributes to an elevated risk of chip breakage during production, consequently impacting the overall yield of the chips. The adoption of NPQD® GaN as the material for red not only enhances the robustness of the chips but also significantly reduces the risk of breakage during the manufacturing process. As a result, our production efficiency and quality have been notably improved, leading to a more stable and reliable output.

- During the production process of AlInGaP red light LED chips, gallium arsenide is used and is highly toxic. The toxic material disposal leads to significant challenges in environmental assessments for manufacturing units, as well as complicates the production process itself. Consequently, these factors indirectly limit the increasing the production yields and reducing costs.

Applications/Customization：

Our current product line includes two sizes including 0406 and 0408 with standard red wavelength of 623nm~628nm. We can customize chip size and wavelength from 530nm~1000nm. The R-series can fulfill multiple applications. R-series offers greater viewing angle and better red light quality compared to AlInGaP Chips enabling display systems meeting Rec-2020 specifications.

	NPQD® R Series	AlInGaP Chips as Common
Viewing angle	150º	120º
Red Color Point	Rec-2020	DCI-P3
Wavelength Range	530nm~1000nm	N/A

- Brightness: Brightness Performance after being assembled on the display panel

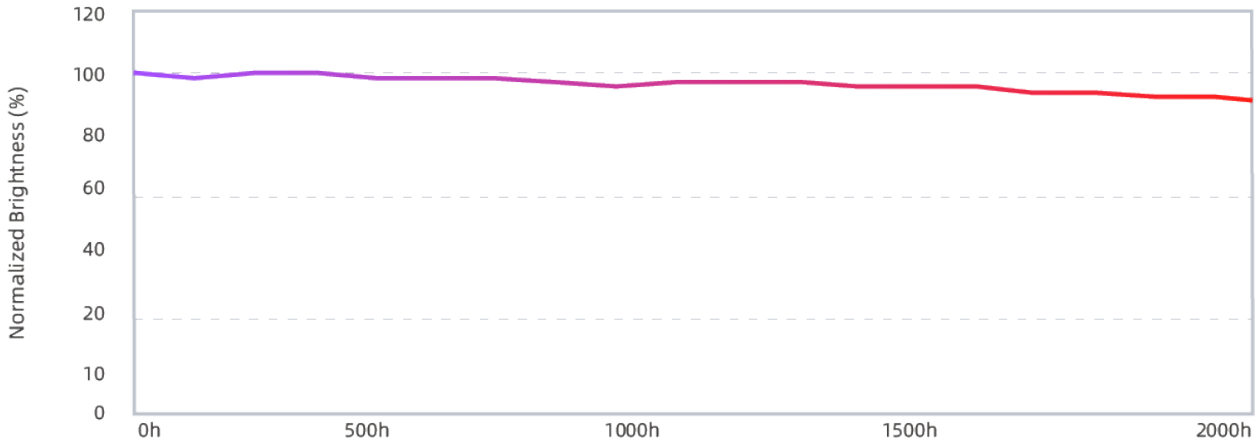

Figure 11. Normalized brightness of 94% over 2000hrs

- Red light storage reliability

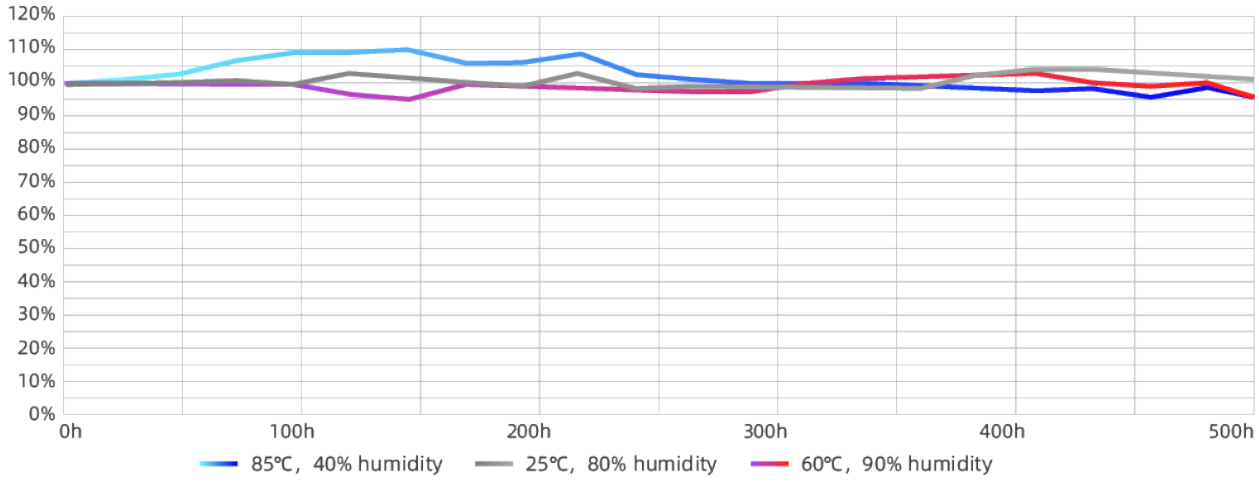

Figure 12. Actual test results by Saphlux: the red brightness is stable after 500-hour testing under 3 different environments of high temperature, high humidity and 60 ℃/RH90%

- Wider beam angle: The beam angle of R Series product is consistent with conventional blue and green LED. Wider beam angle solves the discrepancy of emitting angles between AlInGaP LED and NPQD® R Series Micro-LED, effectively improving color uniformity under different viewing angles.

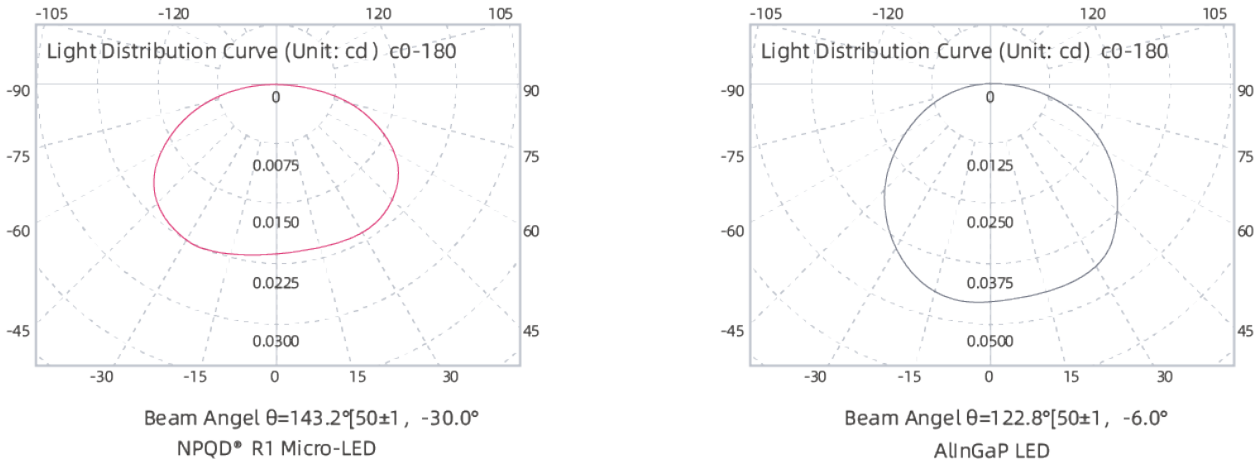

Figure 12. Left: Light distribution curve of NPQD® R Series Micro-LED. Right: Light distribution curve of AlInGaP LED

- Customizable Wavelength/Chip size

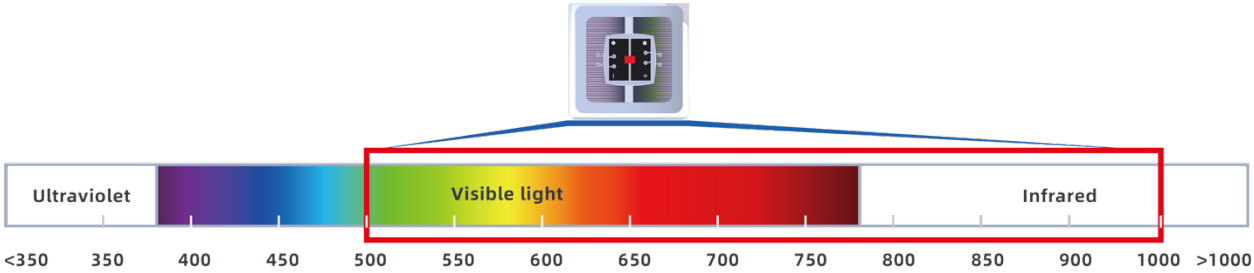

Figure 13. Range of wavelength can be achieved by using NPQD®

- Better color performance: Experiments have shown that the R series chips demonstrated excellent color gamut performance after standard potting.

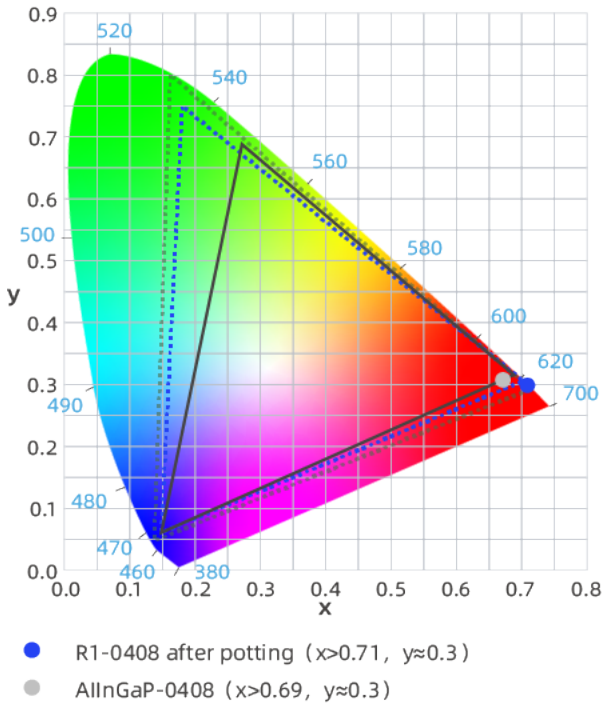

Figure 14. Color gamut comparison between R1-0408 and convention al AlInGaP-0408

Current Applications:

Future Applications:

Packaging Method	COB / MiP / COG	
Substrate	PCB / Glass	
Model	R1-0407/0408	R1 Series 15-50 micron chips
Applications	Large LED screen 	TV 
	All-in-one LED display 	Monitor 
	Digital signage 	Car display 
		Smart watch display 

Our R series of products is currently focused on providing solutions for building direct-emitting large screens. R1-0406 has been successful utilized to create a ground-breaking 162'' 4k direct-emitting screen. We are continuously expanding new chip sizes for large screens to cater to various needs. Our red LED chips offer significant advantages, including consistent viewing angles, minimal wavelength shift, high reliability, and cost-effectiveness.

As we venture into the future and explore diverse applications, our commitment to maintaining product quality and reputation remains steadfast. Adapting to evolving requirements presents challenges, especially with conventional red LED chips, as reducing chip size to achieve higher pixel-per-inch (ppi) demands can lead to yield and performance issues. The NPQD® technology enables us to continue producing smaller LED chips without compromising on critical factors such as mass transfer, light efficiency, and wavelength stability.

Looking ahead, the R series will find applications in various sectors, including but not limited to automotive displays and wearable devices, where superior display quality and reliability are imperative. By leveraging our NPQD® technology, we are well-prepared to meet the demands of these emerging markets and deliver exceptional LED solutions.

V. Conclusion

NPQD® technology based Micro-LEDs provide a manufacturable and cost-effective solution for variety of next generation high resolution displays. NPQD® delivers industry leading red performance and creates solutions where weight, appearance, user comfort and battery lifetime are critical factors for real world applications and user adoption. Thus, making it a disruptive alternate incumbent AlInGaP. In addition, benefit to the display manufacturers is a simplified and seamless process, reduced inventory of dies, and capital investment.

Basing on our unique NPQD® technology, we are constantly exploring new versions/colors/sizes of R-series Micro-LED chips to enable even more display applications.

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