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11. SUPPLEMENTARY NOTES

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13. ABSTRACT (Maximum 200 words)

During Phase I duration, we have further improved blue micro-size light emitter output power efficiencies by optimizing the material qualities as well as device structures. During Phase I optional phase duration, we learned how to achieve white light emission from InGaN/GaN QW micro-size emitters. We have employed three-color emitting (red-blue-green) phosphorus coating on near UV micro-size LEDs and conventional LEDs to obtain white light emission. Comparing with coating an yellow-emitting phosphor on blue LEDs, the three-color phosphors approach yielded improved white light color rendering. We have also further developed interconnected microdisk LED technology to enhance the extraction efficiency and improve the current spreading. Large-area LED chips have been successfully fabricated. An output power as high as 50 mW has been achieved in interconnected microdisk blue LEDs with a 3 x 3 mm^2 chip area size. Further works dealing with heat management and efficiency improvement are still needed. The technologies developed in the optional phase laid the groundwork for the development of solid-state white lighting, which is a technology with an enormous market interest worldwide for energy savings as well as for pollution reduction. The color down conversion technology developed in the optional phase can be equally applied to the development of full color microdisplays based on III-nitrides.

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Based on promising results obtained in the Phase I project, we have identified the following 3 potential products for the proposed Phase II research effort:

1) III-nitride full color microdisplays;
2) White LEDs with improved color rendering and efficiency with no cost penalty;
3) Possibly prototype functional III–nitride photonics integrated circuits (PICs).

1. White Light Emission from III-Nitride Micro-Size LEDs

We intend to lay the groundwork for the proposed Phase II work during the Phase I optional duration. Because light-emitting diodes (LEDs) based on III-nitrides emit blue light and blue light is at the high end of the visible light spectrum, it thus can be converted to longer wavelengths (e.g., green or blue). However, we must develop technologies for down converting UV/blue color to yellow-green-red colors as well as white color.

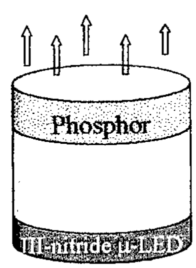


Fig 1 (a) Layer structure of white micro-LED

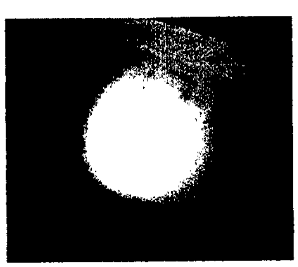


Fig. 1 (b) Optical microscope image of a micro-size white LED based on InGaN/GaN QWs under current injection.

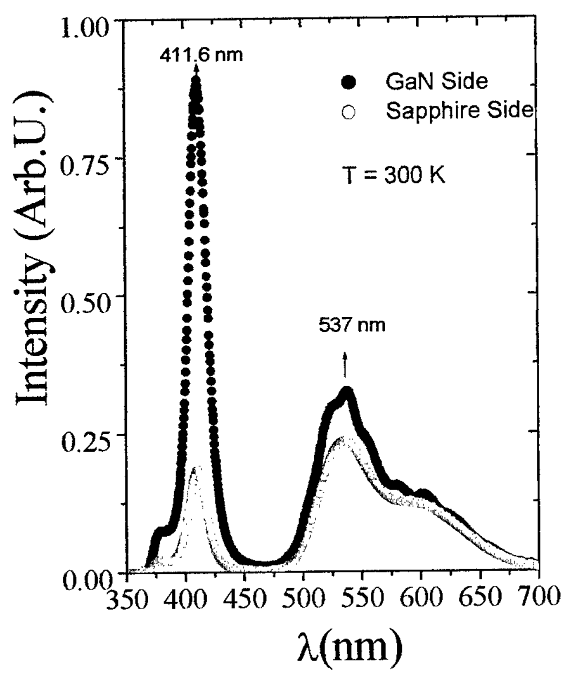


Fig. 1 (c) Electroluminescence spectra of a micro-size white LED (near UV emission pumping green phosphor) in operation with a forward bias of 5 mA.

We have already successfully obtained white light emission from our micro-size LEDs by coating yellow or green-emitting phosphor on blue micro-LEDs or by coating three color emitting phosphors (red-blue-green) on near UV or blue micro-LEDs. As shown in Figure 1, by coating the sapphire side of a micro-emitter by a yellow or green phosphor, we have obtained white emission. In anticipation of Phase II award, we are in the process of investigating three-color phosphor down conversion. We have obtained real white light emission from conventional LEDs by coating a blue (473 nm) LED with red (590 nm) - green (533 nm) - blue (484 nm) phosphors. This is illustrated in Fig. 2, where EL spectra of our blue LED and white LED are presented.

Shown in Fig. 2 is also a comparison between the EL spectra of our white LED and Nichia Chemical's commercial white LED, showing that our white LED covers even broad spectral range than Nichia's white LED. Furthermore, the emission intensity in the red wavelength region is much higher in our white LED than in Nichia's white LED. This means that our white LEDs have a better color rendering than those of Nichia's white LEDs.

Phosphor color down conversion and micro-LED technologies developed here can be further developed to produce white LEDs with improved efficiency and color purity at no cost penalty. If all household 100 W light bulbs were replaced by white LEDs, the total energy savings in US would approach $35 billions/year. The associated reduction in environmental pollution can also be enormous.

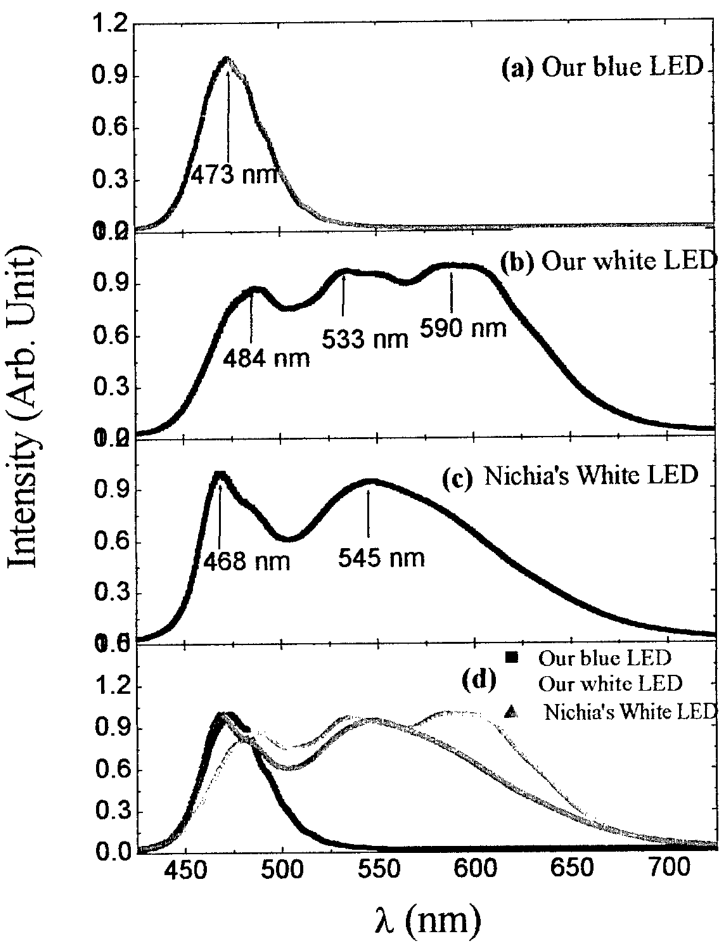


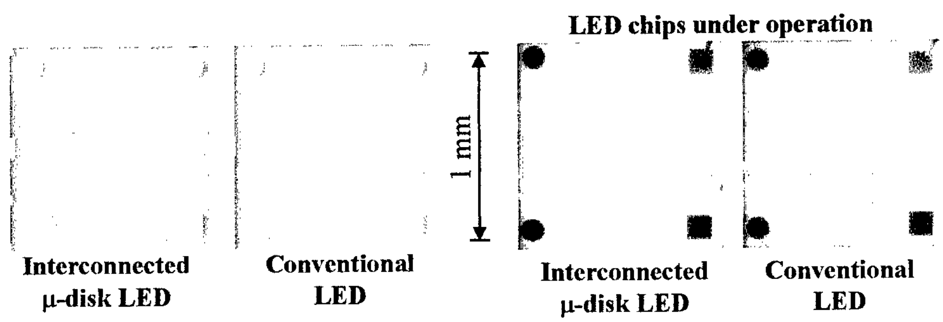
Fig. 2 Electroluminescence (EL) spectra of (a) our blue (473 nm) LED; (b) our white LED – blue LED pumping three-color phosphors; (c) Nichia Chemical's commercial white LED; (d) comparison between EL spectra of our white LED and Nichia's white LED. It can be seen that our white LED has a better color chromaticity than Nichia's white LED, particularly in the red region. The phosphor color down conversion technology involved here can be further developed for full color microdisplays.

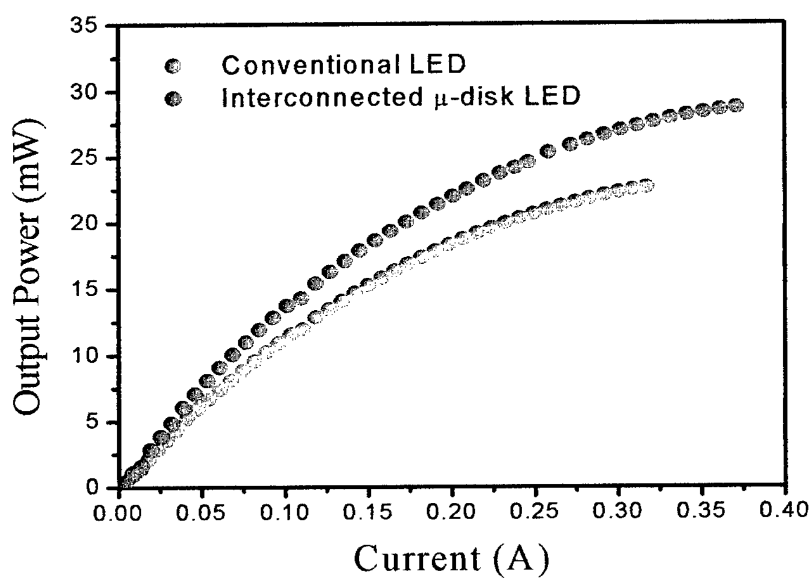
2. High Brightness III-Nitride Emitters Based on Micro-Size LEDs

In addition to the development of three-color (red-blue-green) phosphorus coating on near UV LEDs for improving white light color purity, we have also further developed interconnected microdisk LED technology to enhance the extraction efficiency and improve the current spreading.

We have further developed interconnected microdisk LED technology to fabricate large-area LED chips (up to 3 x 3 mm^2). Fig. 4 shows the optical microscope images and emission characteristics of our blue LEDs with conventional and interconnected microdisk LED architectures for a chip area size of 1 x 1 mm^2. It can be seen that the interconnected microdisk LEDs provide higher output power at all input currents. Fig. 4 illustrates the L-I characteristics of our LEDs with different chip area sizes up to 3 x 3 mm^2. It can be seen that these large-area LED chips are capable of delivering output power of 50 mW, while a conventional high quality III-nitride LED chip (0.3 x 0.3 mm^2) can only deliver an out power around 2 to 3 mW. The interconnected microdisk LED architecture improves both the extraction efficiency and current spreading. This work together with our phosphor color down conversion technology laid the groundwork for fabricating white LEDs with improved efficiency and color rendering at no cost penalty.

Fig. 3 Unpackaged Large-Area III-Nitride Blue LED Chip 1 x 1 mm^2





L-I characteristics of large-area (1 x 1 mm^2) III-nitride blue LEDs: conventional LED (°°°) vs. interconnected microdisk LED (°°°).

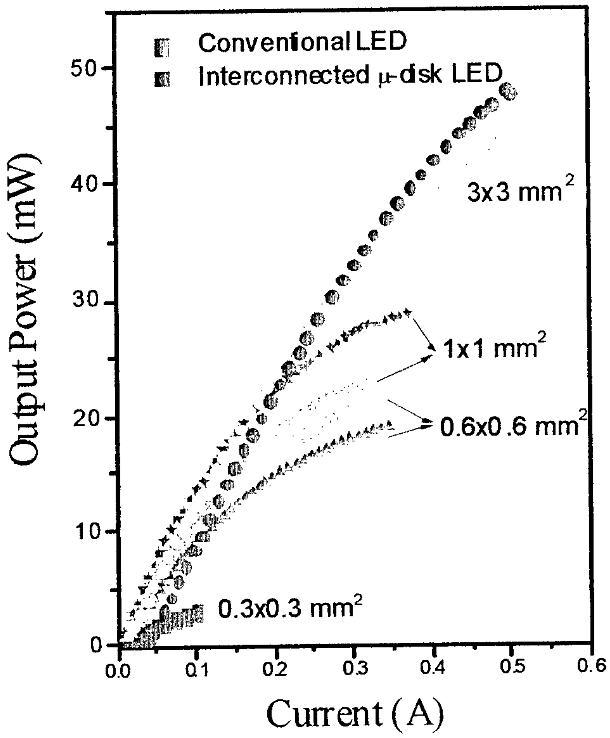


Fig. 4 L-I characteristics of III-nitride LEDs with different chip areas. The output power and the operating current range increase dramatically with chip area size. We have achieved a 50 mW output power from a 3 x 3 mm² LED chip using interconnected microdisk LED architecture.