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A new LED structure for improved thermal management and increased efficiency

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A wing-type embedded electrode introduced into a lateral gallium nitride LED configuration eliminates the light-shading effect of conventional LEDs without adding the necessity of contact alignment.

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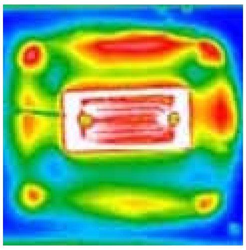

To satisfy the requirements of power-intensive solid-state lighting, LEDs are generally operated at high injection currents to generate high output power, which can lead to reduced efficiencies. To maximize the power output of LED devices, a structure is required that can enable greater heat dissipation, the elimination of light-shading (reduction of emitted light attributable to the position of the p-electrode), and simple fabrication.

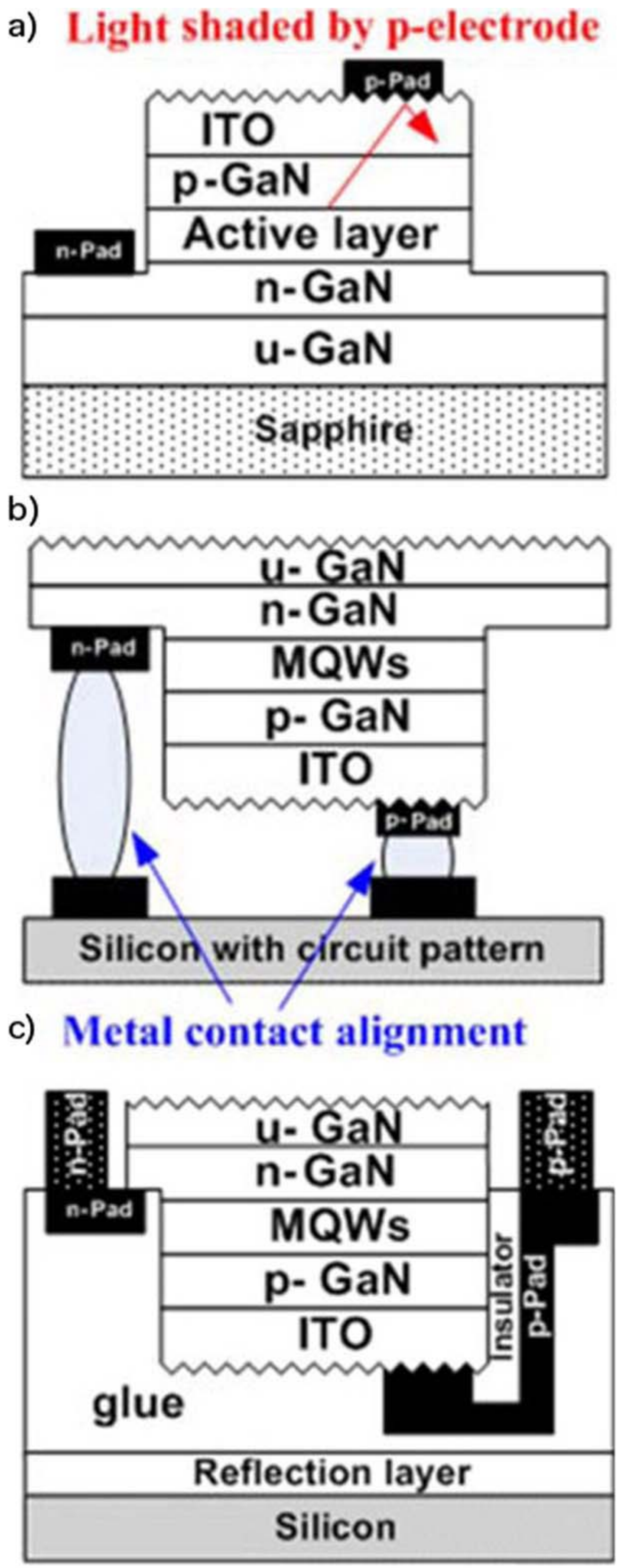

Figure 1. *The structures of three types of LEDs: (a) conventional sapphire-based LED (CSB-LED), (b) flip-chip LED (FC-LED), and (c) wing-type embedded electrode LED (WTIE-LED). ITO: Indium-tin oxide. GaN: Gallium nitride. MQW: Multiple quantum well.*

When LEDs are operated at high injection currents, a drop in emission efficiency ('efficiency droop') and a non-homogeneous distribution of current density ('current crowding') occur.[1] Current-crowding can be attributed to an unequal carrier mobility between holes and electrons in the LED structure, which confines the path of carrier flow to an area close to the electrode and results in non-uniformly emitted light. This thermally-induced phenomenon causes a reduction in carrier recombination at high temperatures, thereby degrading LED efficiency. For conventional sapphire-based LEDs (CSB-LEDs)—see Figure 1(a)—the lower thermal dissipation of sapphire substrates causes the efficiency droop to occur relatively early.[2] In addition to this, the issue of light-shading caused by the metal electrodes of the LED devices influences total LED output power.[3]

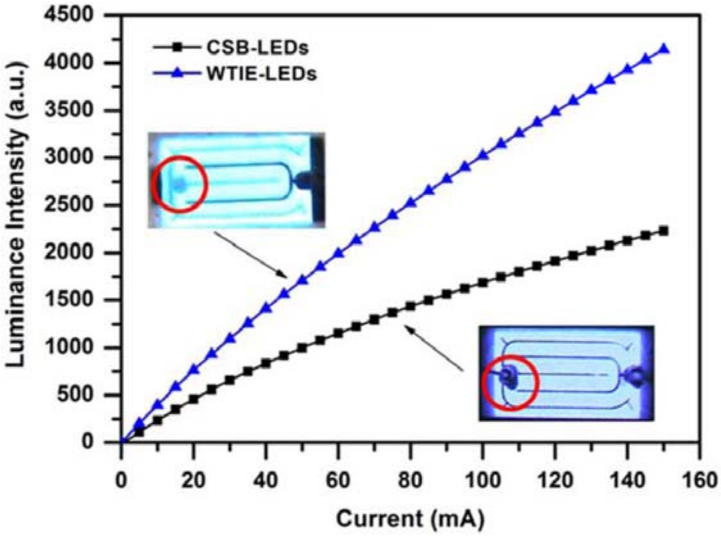

Figure 2. *Luminance intensity of both WTIE-LEDs and CSB-LEDs as a function of injection current. The p-electrode zone is indicated by a red circle. a.u.: Arbitrary units.*

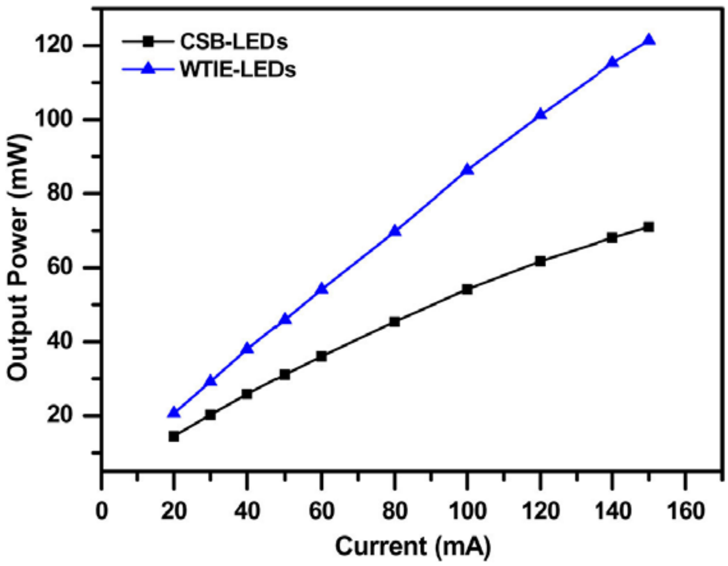

Figure 3. *Output power curves as a function of injection current for the WTIE-LED and CSB-LED.*

One approach to improving thermal management at high operating currents is to use a flip-chip LED (FC-LED) configuration: see Figure 1(b). Although the problem of light-shading is removed with this design, high precision is required in aligning the metal contacts when the chip is transferred to a silicon (Si) substrate with a circuit pattern layer.[4]

Here, we address these problems by demonstrating a high-power LED with a wing-type embedded electrode structure (WTIE-LED): see Figure 1(c). This design accommodates improved thermal management by positioning the highly thermally conductive Si substrate in the hottest region of the LED, at the multiple-quantum-well. Light output is also increased because of the elimination of light-shading and—because of the wing-type electrode design—it is unnecessary to align the metal electrodes of the LED with the Si substrate.

The fabrication procedure for WTIE-LEDs was divided into two steps. Firstly, we bonded an LED chip of $508\times965\mu m^2$ to a Si substrate using lowtemperature glue bonding and laser lift-off techniques.[5] Subsequently, a roughened surface of *n*-GaN (n-type gallium nitride) was added using photolithography and plasma etching processes using carbon tetrafluoride.

Figure 2 shows that the measured luminance intensity of the WTIE-LED and CSB-LED at an injection current of 100mA is 3021 and 1684 units, respectively. The higher luminance is attributed to the ability of the light above the *p*-electrode zone to directly emit toward the top of the WTIE-LED. The output power of the LEDs was determined to be 86.33mW for the WTIE-LED and 54.19mW for the CSB-LED, representing an output power enhancement of 59% for the WTIE-LED compared with the CSB-LED: see Figure 3. The surface temperature distribution of the two LEDs—see Figure 4—shows that the highest temperatures for the WTIE-LED and the CSB-LED are 58.1°C and 84.86°C, respectively, indicating that the WTIE-LED has good thermal dissipation with uniform temperature distribution.

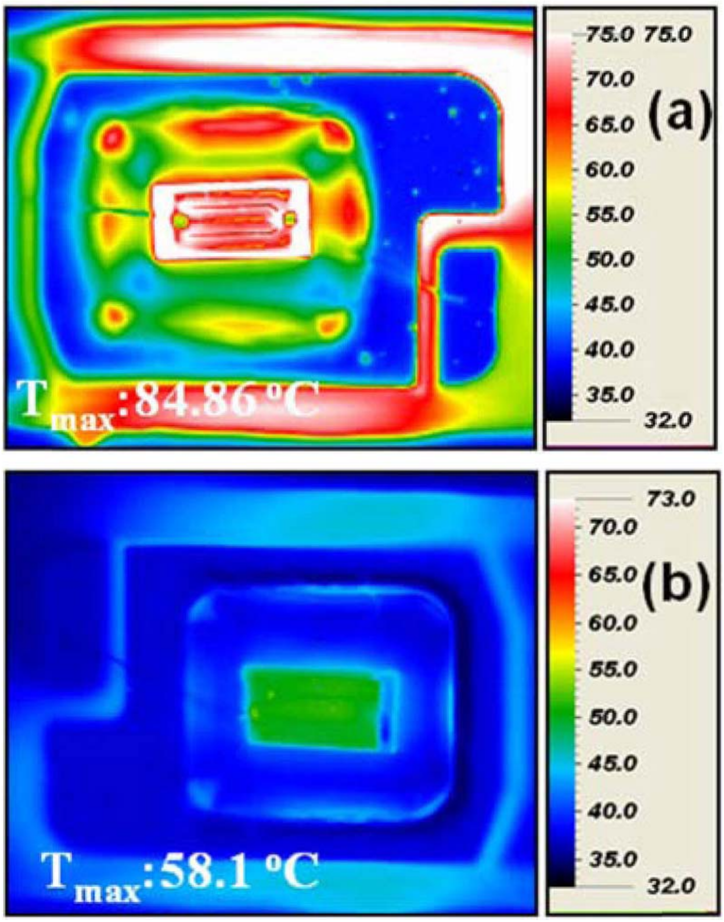

Figure 4. *Surface temperature distributions under driving currents of 100mA for LEDs embedded (a) without and (b) with a wing-type electrode.*

In summary, we have successfully demonstrated an LED with high output power using a wing-type embedded electrode structure. An output power increase of 59% was achieved with the WTIE-LED, compared with the CSB-LED. This significant enhancement was attributed to the improved thermal dissipation of the substrate and the reduction of light-shading issues via the incorporation of an embedded electrode. We are now developing a vertical LED configuration to further increase efficiency.

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