Light enhancement of GaN LEDs by transfer from original substrate to reflective trench

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Gallium nitride (GaN)-based light-emitting diodes (LEDs) have drawn much attention in a variety of applications, in particular in the display, visible light communication and more.

High-performance LEDs are required for the aforementioned applications. In the GaN LEDs, the big difference of refractive index between GaN and the air can cause a large amount of light emitted from the active region trapped within the materials, resulting in low light extraction efficiency\(^1\). Therefore, proper light management is required to achieve high-performance devices to enable using these devices in different applications.

In this work, to advance the performance of transfer printed GaN-on-Si LEDs, first LEDs are released from original substrate using wet etch and the backside of the released LEDs are roughened using aqueous Tetramethylammonium hydroxide (TMAH) solution during the coupon preparation process for transfer printing. Measurements show that light output power collected into a numerical aperture of 0.5 from the roughened devices is enhanced by a factor of 2.14 when compared to the non-roughened LEDs, which is attributed to the effective light scattering from the roughened surfaces where a high density of pyramids is formed. The combination of roughening technique in conjunction with silver reflector improved the light output power by the factor of 4.2 when compared to the device on the initial substrate.

In order to further enhance the collected optical power by redirecting the emission the released µLEDs were printed into silver-coated reflecting trenches formed in Si creating a 3D structure. Results showed that, there is an approximately doubling (1.8x) of the collected power for roughened blue µLEDs in the trench in comparison with that of on the flat platform which is attributed to the redirection of light which means trench can effectively reduce the angular distribution of light, consequently converging higher optical power. It is shown that the light output collected for the roughened µLED in the trench is over 7 times that of the device on the initial Si substrate (before undercut). In addition, the potential of printed µLEDs for visible light communication was demonstrated. The µLEDs in the trenches exhibits higher signal-to-noise ratio and lower bit-error rate than those on the flat platform due to the higher collected optical power.

Acknowledgment:

This work is part-funded by SFI through IPIC and by the ECSEL Joint Undertaking MICROPRINCE under grant agreement No.434737.

References:

Figure 1: Schematic diagram of a) opening SiN, b) Si trench with coated silver C) Transfer printing of device into reflected trench d) metal interconnection after printing devices e,f) SEM image and optical image of printed roughened LED into trench with depth of 10 µm. g) comparison of light output power of printed LED onto flat platform and trench.