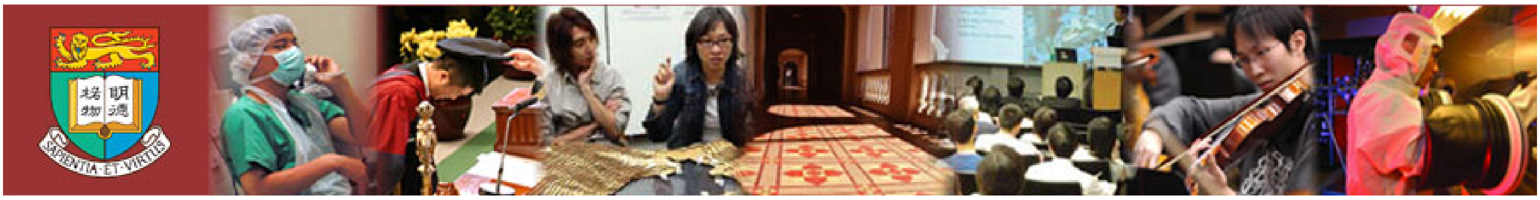

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OPTICAL CHARACTERISTICS OF GAN/SI MICRO-PIXEL LIGHT-EMITTING DIODE ARRAYS

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Two-dimensional arrays of emissive micro-light-emitting diodes (μ-LEDS) have been developed for a variety of applications such as high resolution micro-displays, maskless photo-lithography and multi-channel visible-light optical communications amongst others. μ-LEDs have traditionally been fabricated on InGaN LED wafers grown on transparent sapphire substrates, and have suffered from optical crosstalk issues. When a single pixel is addressed, adjacent pixels and regions appear illuminated simultaneously. Such problems could result in functional failure in high-density μ-LED applications, including reduced resolution of micro-display and decreased signal-to-noise ratio in optical communications. In this work, μ-LED devices have been fabricated on InGaN LED wafers grown on Si substrates which are opaque to visible light; their optical characteristics are compared with their counterparts on sapphire substrates.

Fig. 1 depicts the process flow of the μ-LED array on an LED structure MOCVD-grown on 6-inch (111) Si substrate with blue-light InGaN/GaN quantum wells. A semi-transparent current spreading layer consisting of a bi-layer of Ni/Au is deposited by e-beam evaporation. The array pattern consisting of 3×8 hexagonal pixels each with dimensions of ~60 μm is photo-lithographically defined and ICP-etched using Cl_2-based plasma down to the n-GaN surface. A thin SiO_2 film with thickness of 100 nm acting as an electrical-insulating layer is then e-beam evaporated. Finally the p- and n-contacts are e-beam deposited, followed by rapid thermal annealing (RTA). The resultant GaN-on-Si μ-LED array is schematically illustrated in Fig. 2(a) and (b). For comparison, identical GaN-on-sapphire μ-LEDs are fabricated for comparisons.

Figure 2(c) shows the current-voltage characteristics of the GaN/Si and GaN/sapphire devices. While both devices exhibit similar values of dynamic resistances of ~50 Ω, the leakage current of the GaN-Si devices is found to be slight larger than that of GaN-sapphire devices, which may be due to higher densities of threading dislocations due to large extents of lattice mismatch. However, the differences in optical cross-talk performances are evident from the CCD-captured images of the devices shown in Fig. 3(c) and (d) with a set of pixels illuminated. A strong blue background amongst the blue-light emitting pixels is clearly observed from the GaN-sapphire μ-LEDs, attributed to the presence of a transparent sapphire substrate which collects the downward emitted light from the pixels for re-emission at a different position after multiple total internal reflections as illustrated in Fig. 2(d). For the GaN-Si μ-LEDs, an unmistakably dark background amongst the emitting pixels is clearly observed, signifying effective suppression of optical cross-talk attributed to the light-absorption of the silicon substrate as shown in Fig 2(e). Confocal microscopy is employed to further investigate the intensity distribution across adjacent pixels on a single focus plane. As shown in Fig. 3(f) and (h), light emission intensity from the regions between pixels can be as high as 30% of the light intensity from the pixels themselves for the GaN-sapphire μ-LED. On the other hand, the signals from the in-between regions of the GaN-Si μ-LEDs are suppressed as shown in Fig 3(e) and (g). Coupled with higher thermal conductivities than sapphire, GaN-Si is an ideal platform for the development of μ-LEDs for high-contrast display applications.

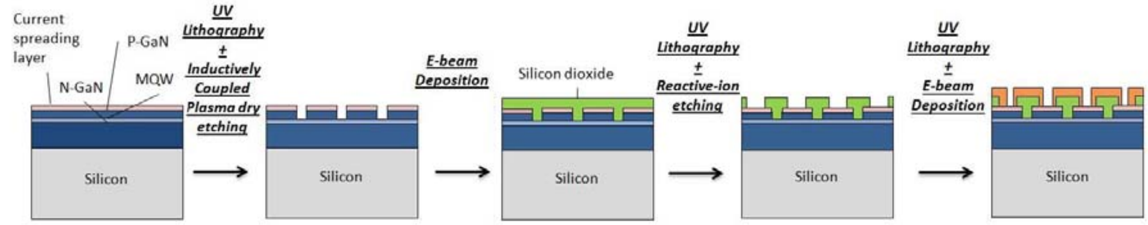

Figure 1 Schematic diagrams depicting fabrication flow of GaN-Si μ-LEDs.

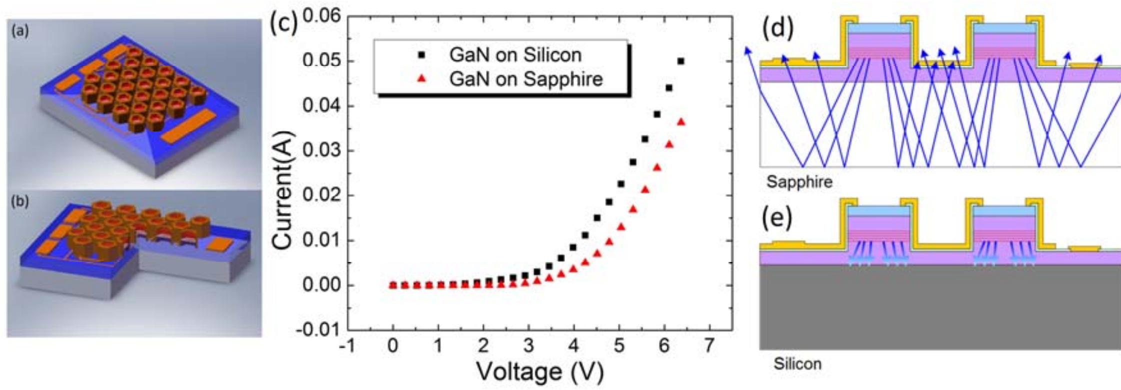

Figure 2 (a)-(b) Schematic diagram showing architecture of the μ-LED array. (c) Current-voltage (I-V) characteristics of devices. Light-ray pathways in (d) GaN-sapphire and (e) GaN-Si μ-LED devices.

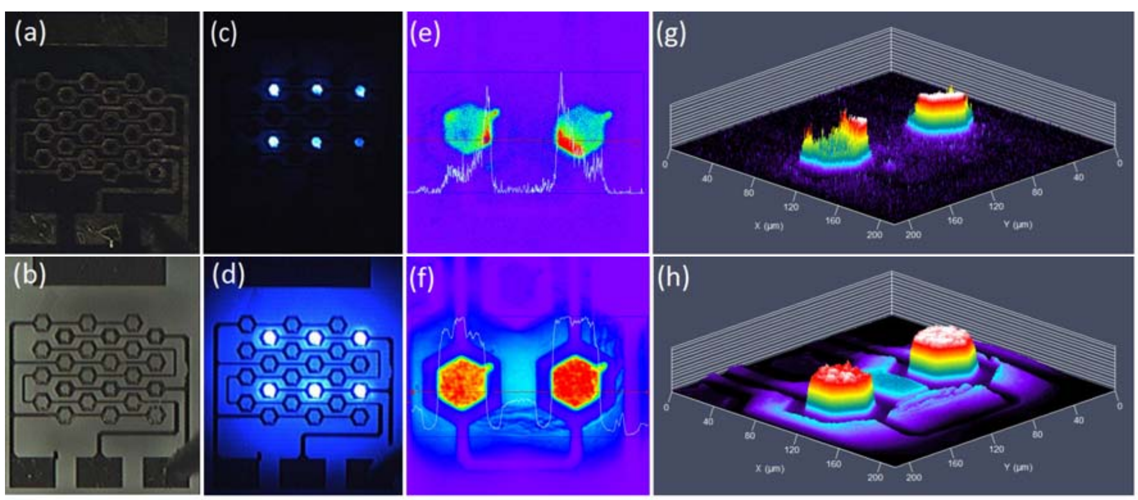

Figure 3 Planar views of fabricated (a) GaN-Si and (b)GaN-sapphire μ-LED devices. (c) and (d) show the GaN-Si and GaN-sapphire devices with a set of pixels illuminated. Planar confocal intensity maps of the (e)GaN-Si and (f)GaN-sapphire devices, and 3D confocal intensity maps of the (g)GaN-Si and (h)GaN-sapphire devices.