Fabrication of nano-patterned sapphire substrate by hybrid nano-imprint lithography in combination with nickel as etching mask

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GaN based light emitting diodes (LEDs) are widely applied in illumination area. The most commonly used substrate for growing GaN films is sapphire substrate. However, the light-extraction efficiency (LEE) of LEDs is limited due to the large lattice mismatch between sapphire substrate and GaN epitaxial layer, and the large difference of refractive index between GaN and the air. Patterned sapphire substrates (PSS) have been considered as one of the most effective approaches to improve this problem.[1] Nano-patterned sapphire substrates (NPSS) have distinct advantages over PSS at micro-scale because NPSS can significantly enhance the LEE and simplify the fabrication process. Among all nano-fabrication techniques, nanoimprint lithography (NIL) is a potential low cost, high throughput approach for fabrication of NPSS. However, the surface of sapphire substrate is not as flat as Si wafer, which makes it difficult to have a conformal contact with rigid NIL mold even under high imprint pressure.

Recently we developed a hybrid nanoimprint-soft lithography (HNSL), which combined the advantages of both a rigid NIL mold to achieve a high-resolution and a soft lithography stamp to enable conformal contact. Here, we used HNSL to fabricate NPSS through a UV-NIL process with double-layer resist system composed of a top UV-curable imprint layer and an underlying PMMA layer (Fig.1a). After UV-NIL, the residual layer of UV-resist and PMMA layer were removed by RIE. A 50 nm thick nickel film was deposited on the above patterned surface by e-beam evaporation and periodic nickel patterns were formed by a lift-off process. Due to its high etching resistance, nickel was used as etching mask to transfer nano-patterns into sapphire through chlorine based dry etching instead of depositing SiO_2 layer on sapphire by PECVD as etching mask. Fig.2a shows the NPSS of nano-cone structures with a pitch of 400 nm and height of 330 nm. A GaN LED structure for λ= 450.8 nm emission was grown on the fabricated NPSS by MOCVD. Compared with the flat sapphire substrate, the photoluminescence(PL) intensity of NPSS increased by 150%.

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[1] M.Yamada, T.Mitani, Y.Narukawa, S.Shioji, I.Niki, S.Sonobe, K.Deguchi, M.Sano and T.Mukai, Jpn.J.Appl.Phys.**41**,1431 (2002).

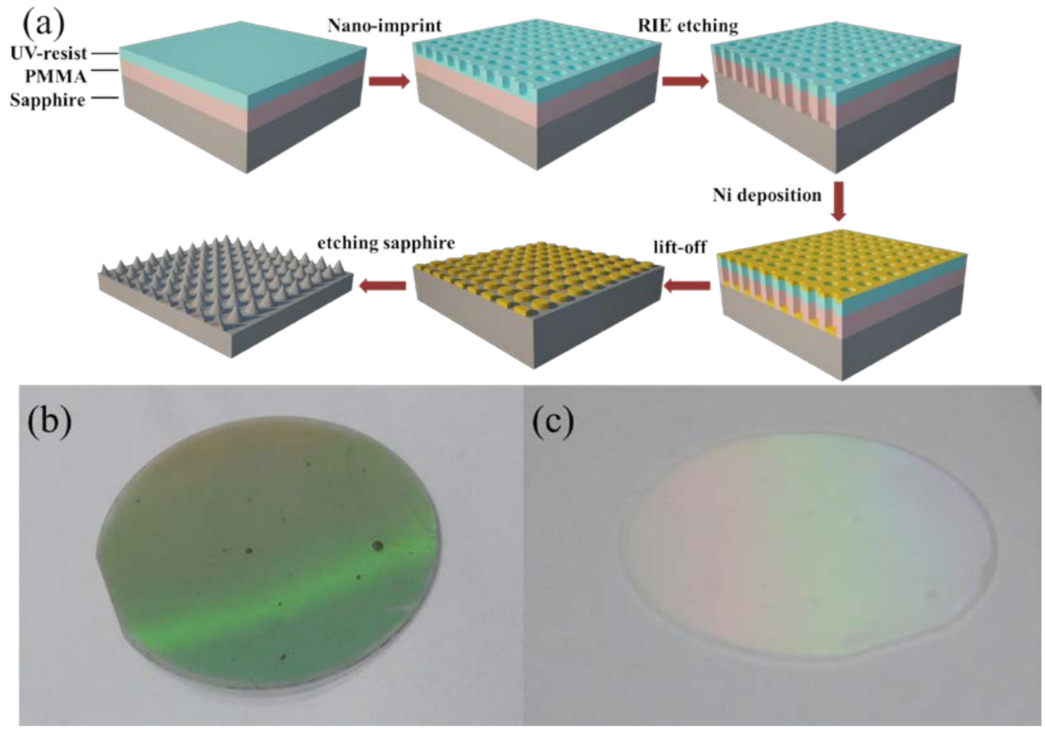
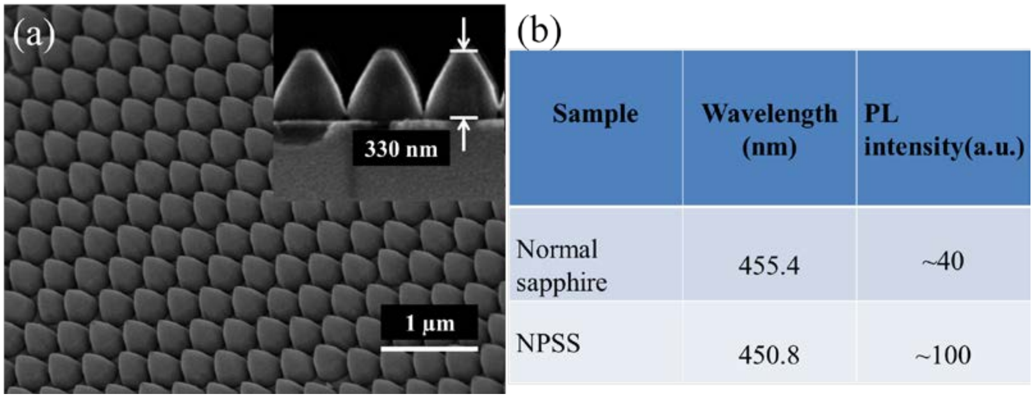


Figure 1: (a) Schematics of fabrication of nano-patterned sapphire substrate by hybrid nano-imprint lithography. (b) Photograph of 2-inch sapphire substrate with periodic Ni patterns after Ni deposition and lift-off process. (c) Photography of 2-inch sapphire substrate after sapphire ICP etching.



Sample	Wavelength (nm)	PL intensity(a.u.)
Normal sapphire	455.4	~40
NPSS	450.8	~100

Figure 2: (a) Tilted and cross-sectional view SEM images of NPSS of nano-cone structures with a pitch of 400 nm and height of 330nm. (b) Table of emission wavelength and PL intensity of normal sapphire substrate and NPSS LEDs. The "blue shift" of NPSS indicates that it reduced quantum-confined Stark effect (QCSE) so that had better epitaxial growth than normal sapphire substrate. The PL intensity of NPSS is 2.5 times larger than that of normal sapphire substrate.