Electronic Supplementary Information for

UV Electroluminescence Emissions from High-Quality ZnO/ZnMgO Multiple Quantum Wells Active Layer Light-Emitting Diodes

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The thickness of $Zn_{1-x}Mg_xO$ barrier layer and ZnO well layer was determined by controlling deposition rate and time. Figure S1 shows the cross-sectional SEM image of a thick ZnO layer grown under the same epitaxial conditions. The thickness of the thick layer is 373 nm with the deposition time of 4 hours. The deposition time for $Zn_{1-x}Mg_xO$ barrier layer is 400 s and calculated thickness is about 10 nm. As for the ZnO well layers, the deposition time is varied by 80 s, 160 s, 240 s and 320 s. Thus, the corresponding thickness are 2 nm, 4 nm, 6 nm and 8 nm, respectively.

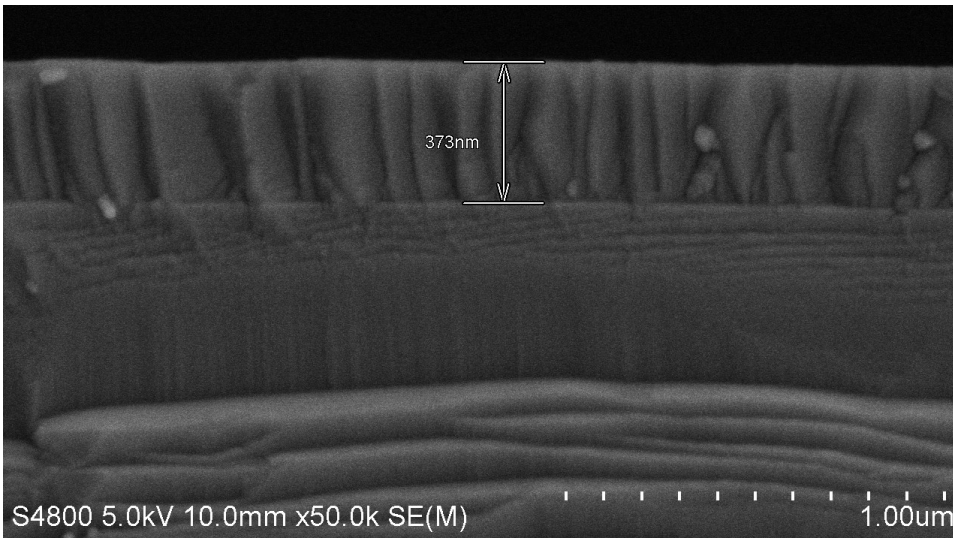


Figure S1 Cross-sectional SEM image of ZnO layer with the deposition time of 4 hours.

Table S1 The FWHM values of (002) and (102) X-ray rocking curves for GaN/Al_2O_3 template and $Zn_{1-x}Mg_xO$ films.

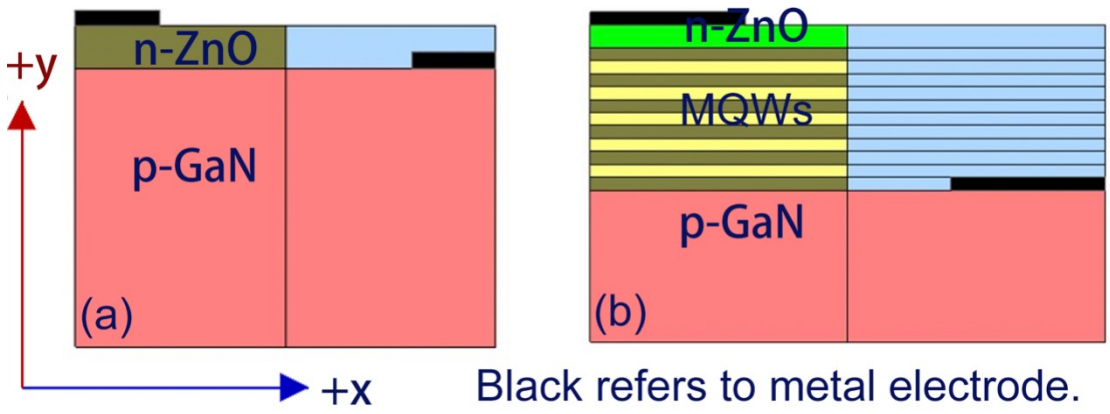
Samples	FWHM (arcsec)		
	(002)	(102) of GaN	(102) of ZnO
GaN/Al_2O_3	218	303	--

x=0	242	326	660
x=0.04	225	295	620
x=0.08	230	340	668
x=0.10	257	341	668

Table S2 The related electrical properties of films for the simulation.

	Samples	Values
p-GaN	Hole concentration	5×10^{17} cm^{-3}
	Thickness	2 μm
n-ZnO	Electron concentration	2×10^{18} cm^{-3}
	Thickness	300 nm

Figure S2. The simulated LED structures of (a) p-GaN/n-ZnO diode and (b) p-GaN/MQWs/n-ZnO diode.



The simulation package APSYS is based on finite element analysis. And it includes the physical models such as hot carrier transport, heterojunction models and thermal analysis. The detailed equations define on the band offsets or carrier concentrations are available in the manual provided by Crosslight Software Inc. (https://crosslight.com). Electron affinity parameters of GaN, MgO and ZnO refer to the following two literatures:

1. H. ZHU, et al, Ultraviolet Electroluminescence from MgZnO-Based Heterojunction Light-Emitting Diodes, J. Phys. Chem. C 2009, 113, 2980–2982.

2. H.H. Zhang, et al, Mg composition dependent band offsets of ZnMgO-ZnO heterojunctions, Phys.Chem. Chem. Phys., 2013, 15, 11231.