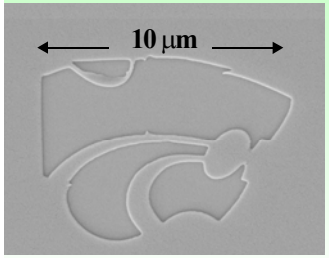
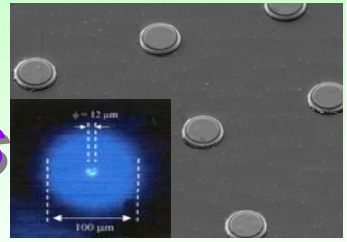
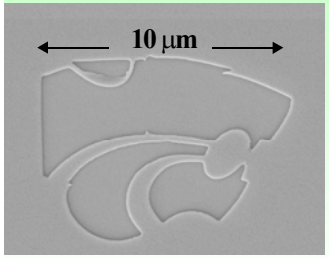


GaN Group at KSU-Physics

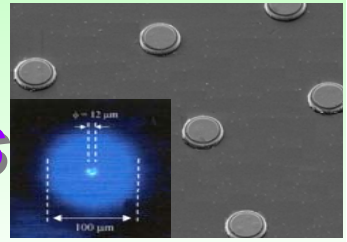


III-Nitride UV Optoelectronic Devices

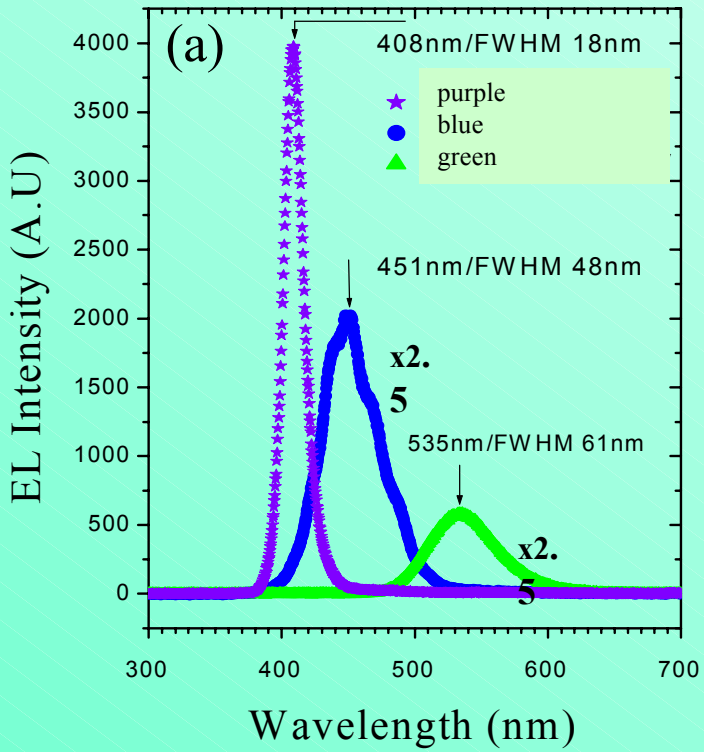
Hongxing Jiang & Jingyu Lin
Kansas State University



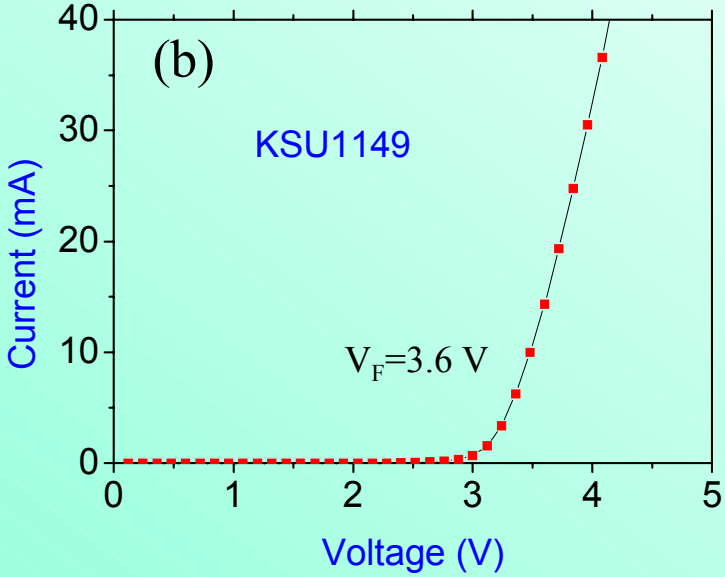
GaN Group at KSU-Physics



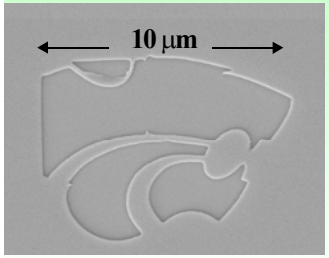
Purple, Blue, Green LED



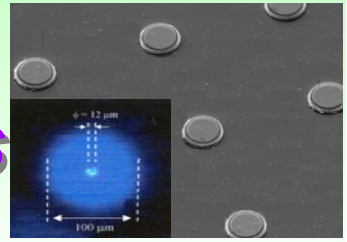
I-V curve of purple LED



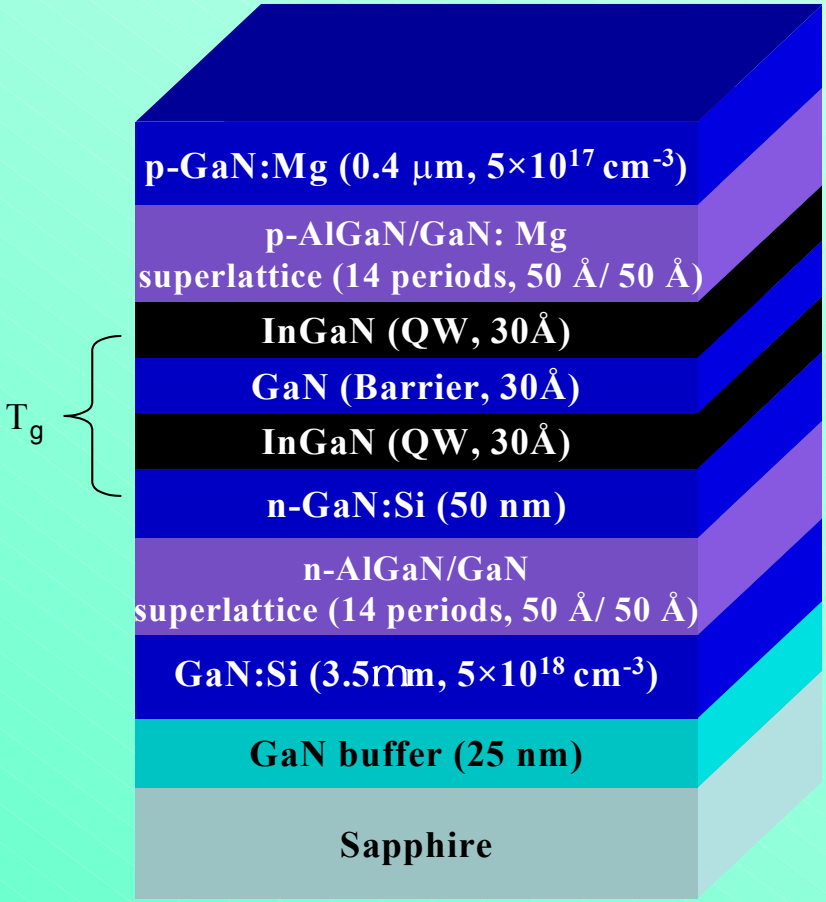
Electroluminescence (EL) spectra of our purple, blue, and green micro-LEDs based on p-GaN/InGaN/n-GaN QWs . (b) I-V characteristic of one of our p-GaN/InGaN/n-GaN QW purple micro-LEDs.



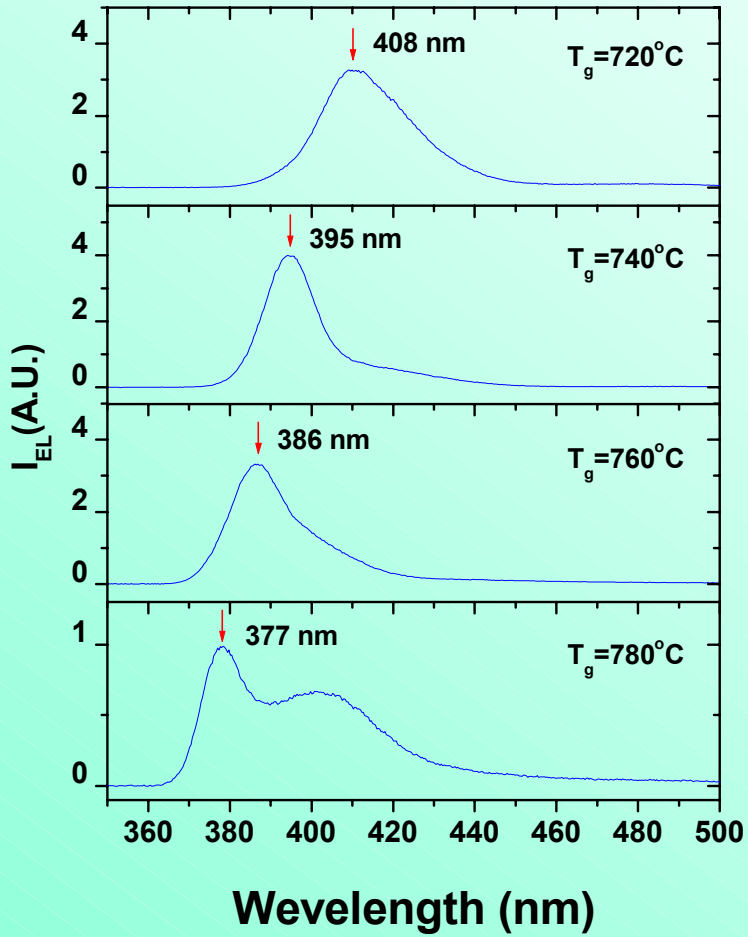
GaN Group at KSU-Physics

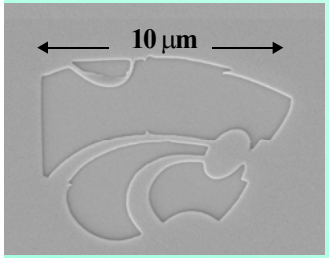


KSU-LED Structure

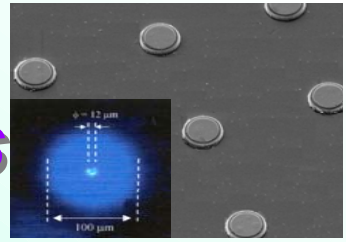


EL Spectra of KSU LEDs

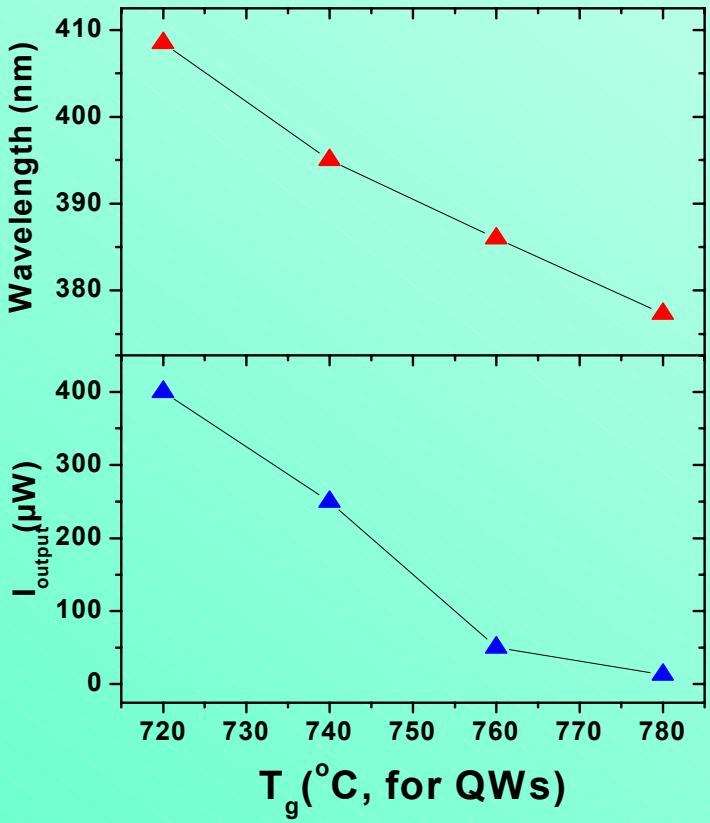


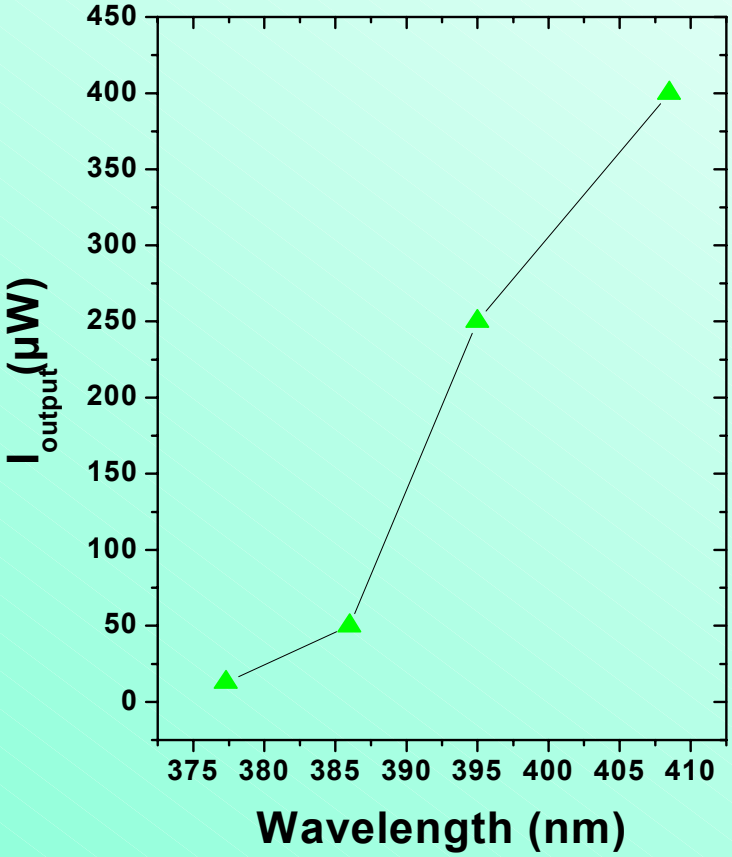


GaN Group at KSU-Physics

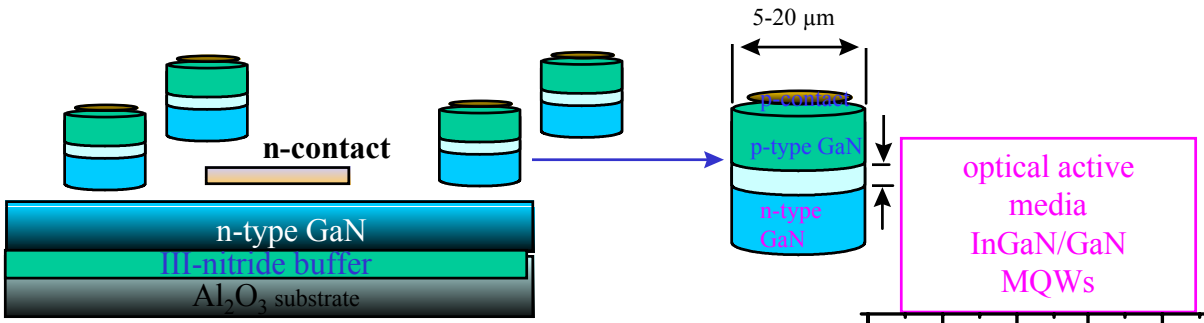


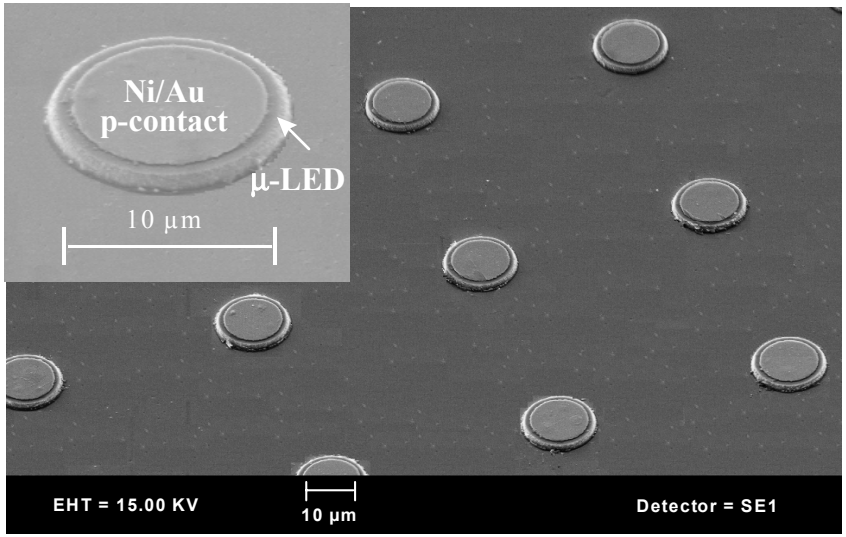
InGaN/GaN QW LED Performance Measured from Sapphire Side of Unpackaged Chips

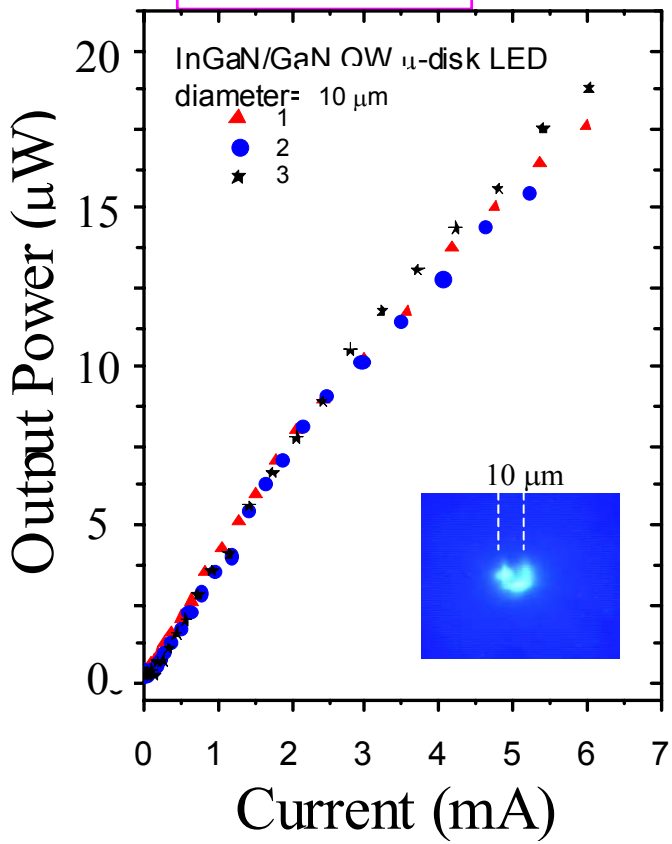




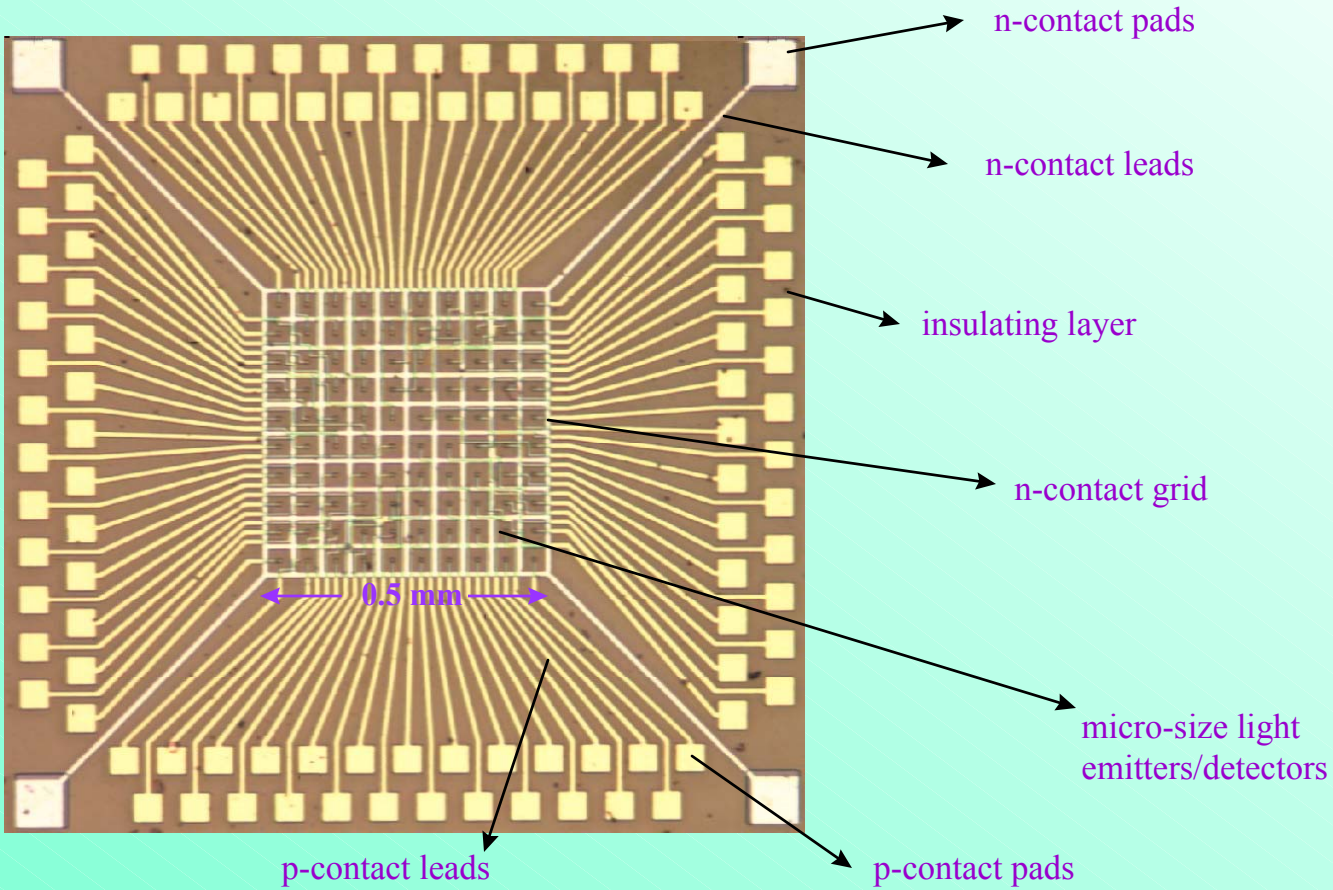
KSU Electrically Pumped Micro-size Light Emitters based on p-GaN/InGaN/n-GaN QWs





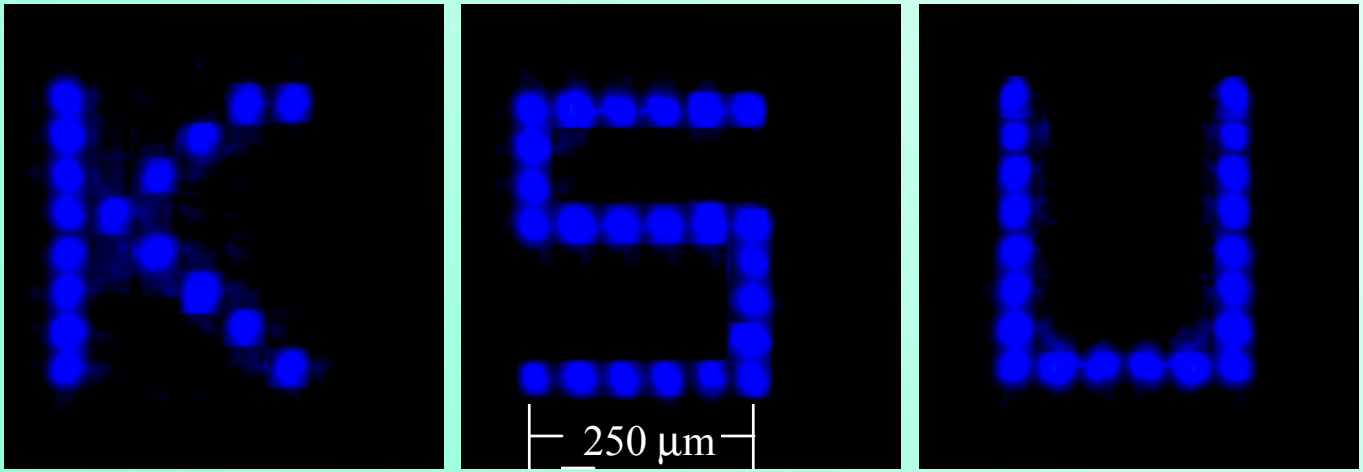


KSU III-Nitride Blue Microdisplays



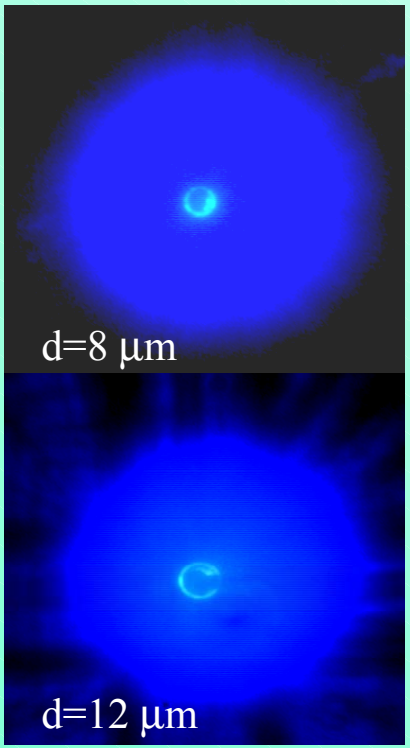
An optical microscope image (top view) of an individually addressed III-nitride micro-disk array as a microdisplay or a high resolution UV image detector fabricated by our group at KSU. The dimension of the microdisplay is 0.5 x 0.5 mm^2 (made up of 10 x 10 pixels of 10-μm in diameter). This type of technology can be utilized to further develop the requirements and specifications for III-nitride based miniaturized UV emitters and arrays.

KSU III-Nitride Blue Microdisplays

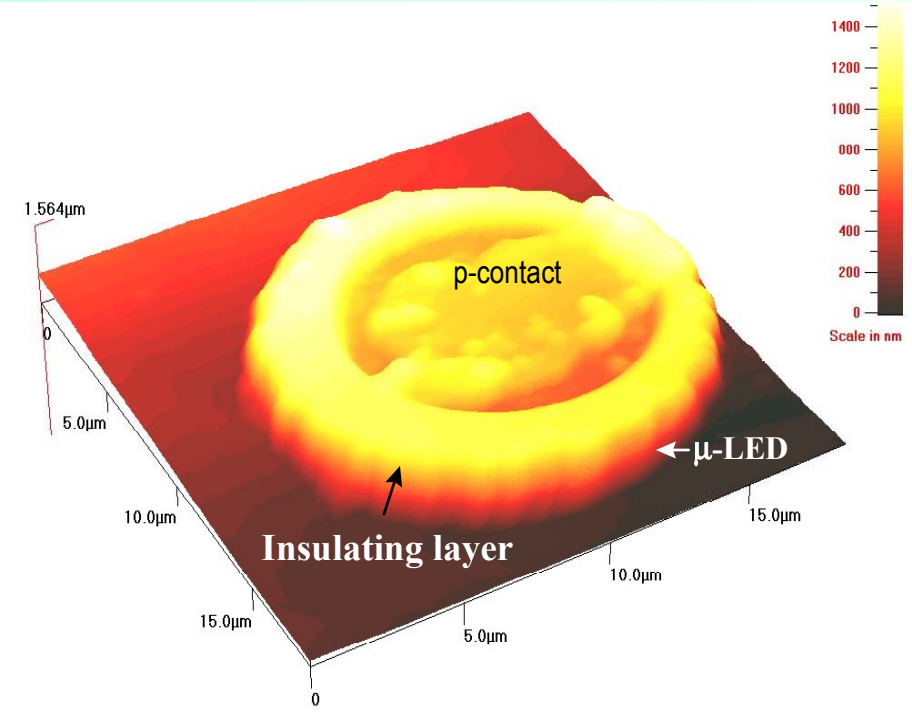


Optical microscope images (top view) of a KSU III-nitride blue microdisplay in action, displaying letters "KSU", demonstrating the operation of the World's first semiconductor microdisplay.

KSU III-Nitride Blue Micro-LEDs

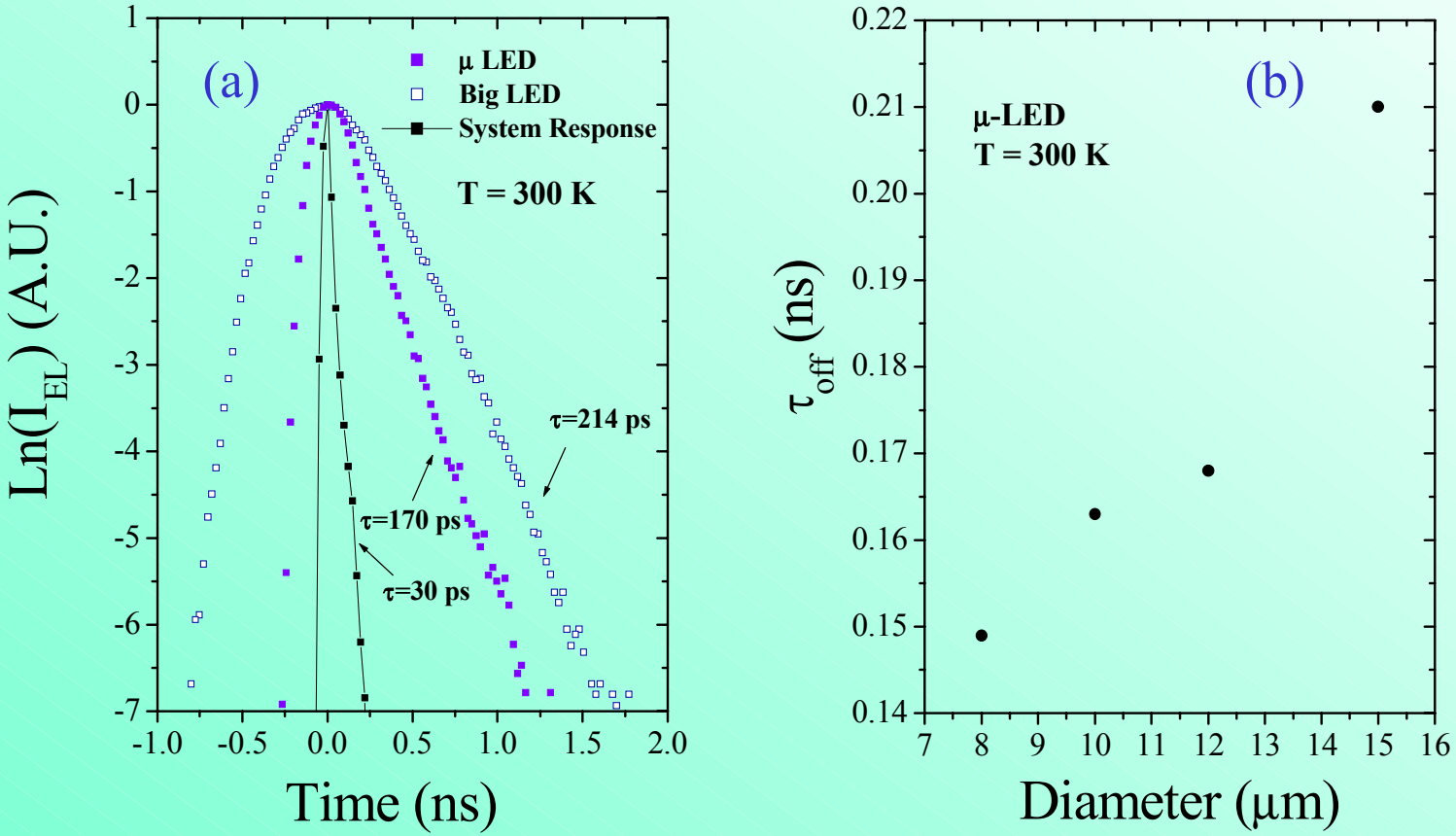


Optical microscope images of individual μ-disk LEDs in action



An AFM image showing a micro-LED within a fabricated microdisplay of Fig. 2. The roughness seen in the p-type contact area indicated that further improvements in p-type materials as well as contacts are needed.

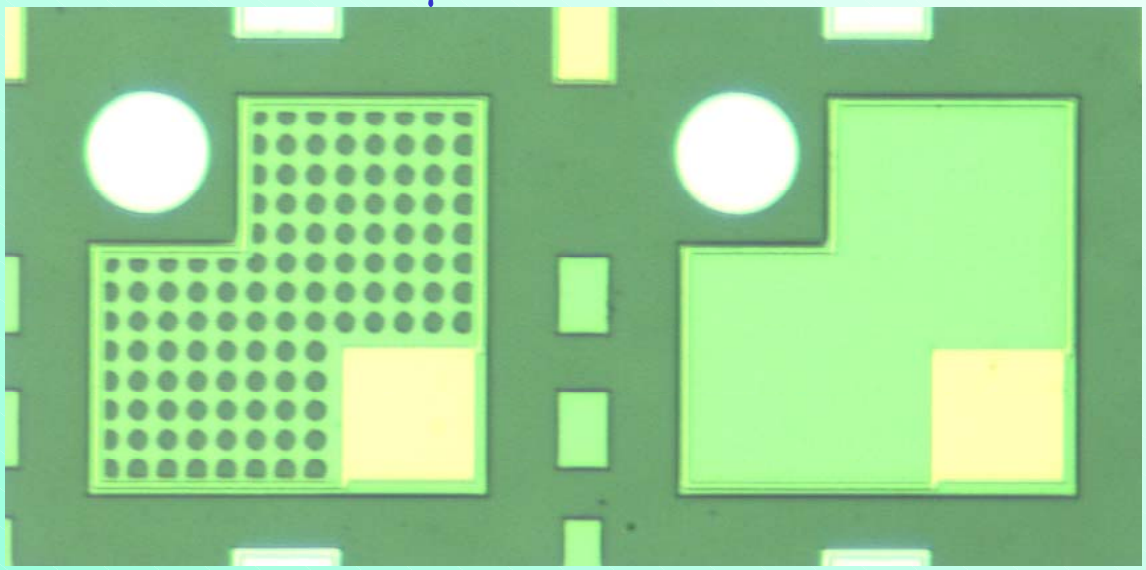
Transient Responses of III-nitride μ-LEDs



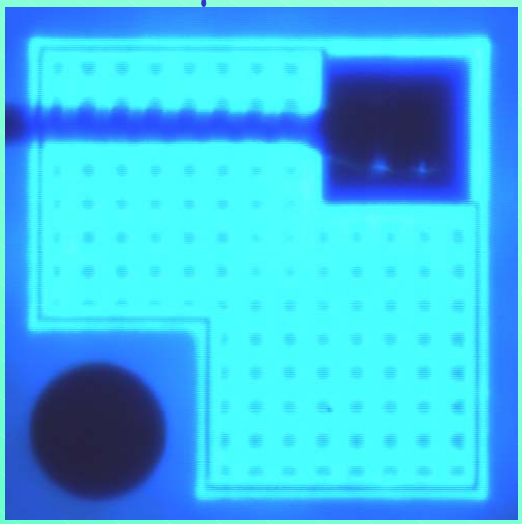
(a) Transient responses of a microdisk LED of 12 μm in diameter and a broad-area LED (300 x 300 μm^2) in response to picosecond electrical pulses. The turn on time of the microdisk LEDs is on the order the system response (< 35 ps). (b) The size dependence of the turn-off time of the microdisk LEDs.

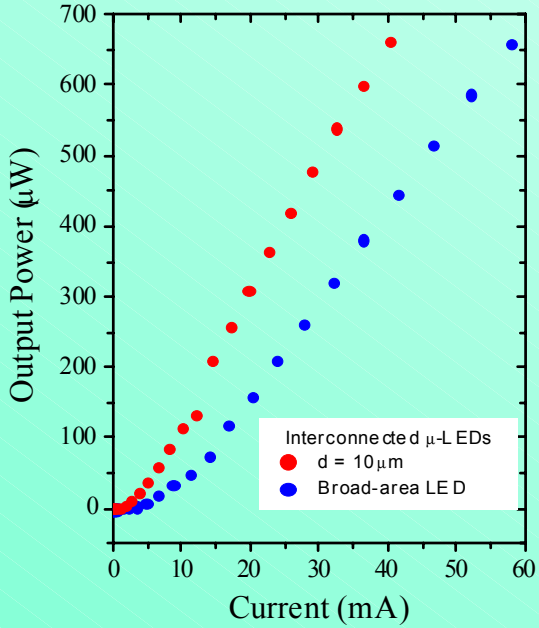
KSU interconnected μ-LEDs fitted into a 300 x 300 μm² area

KSU 300 x 300 μm² conventional-LED

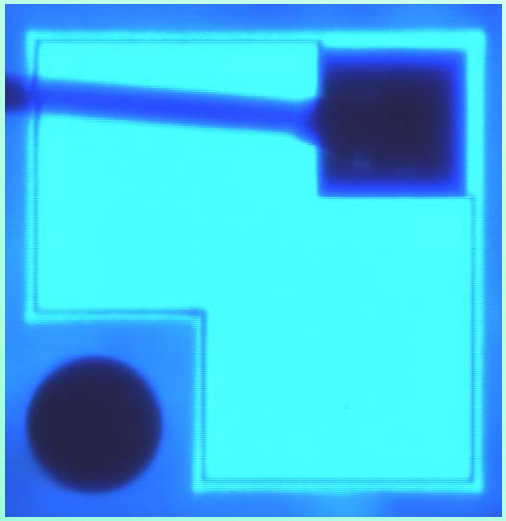


Interconnected μ-LEDs fitted into a 300 x 300 μm² area in action



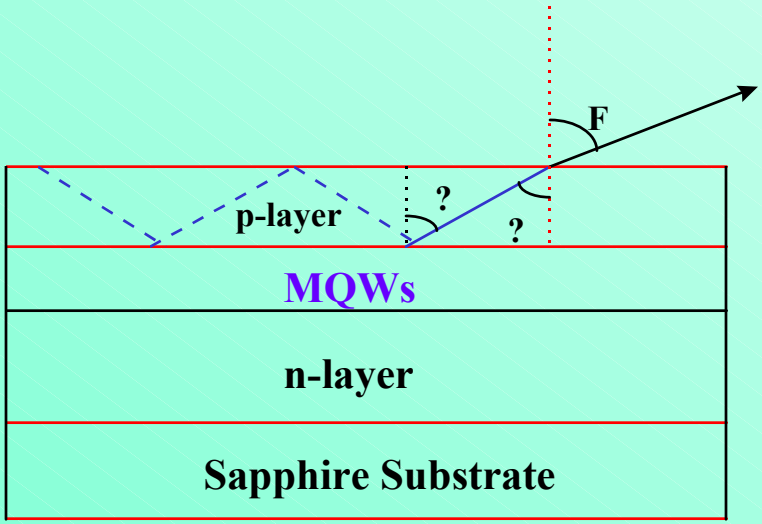


300 x 300 μm² conventional-LED in action

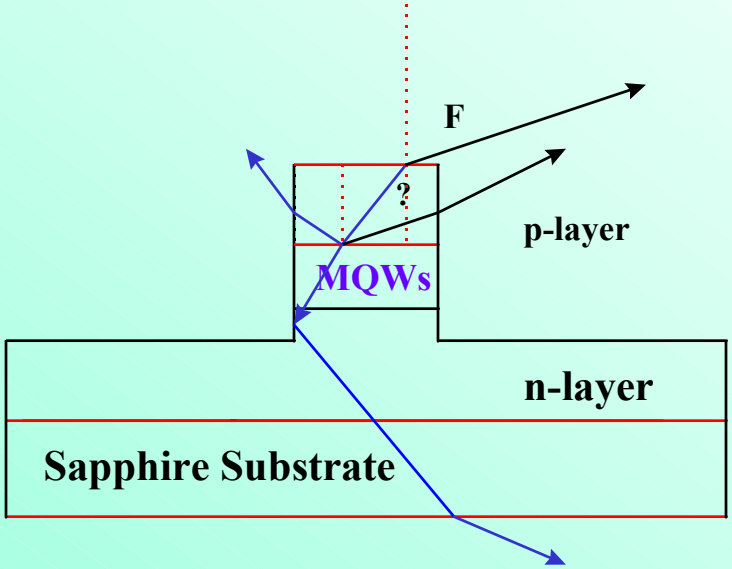


Extraction Efficiency is Enhanced in Interconnected μ -LEDs

Conventional LED



μ -LED



$$R = \frac{\int_0^{2\pi}\int_0^{\theta_c} \sin\theta \, d\theta \, d\Phi}{\int_0^{2\pi}\int_0^{\pi/2} \sin\theta \, d\theta \, d\Phi} = (1 - \cos\theta_c) = 8.3\%$$

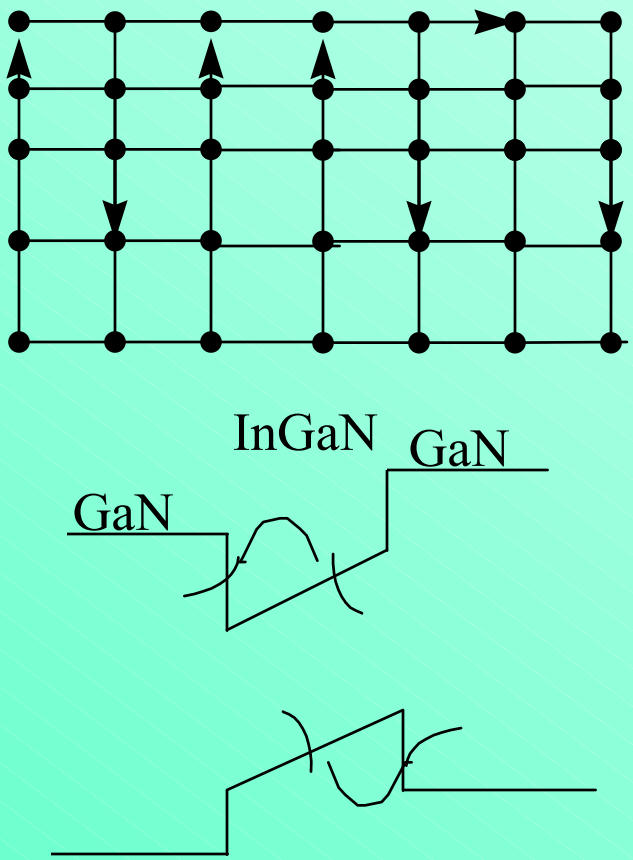
$$P_{output} \sim \zeta_{int} C_{ex}$$

ζ_{int} : Internal Quantum efficiency
C_{ex} : Extraction efficiency

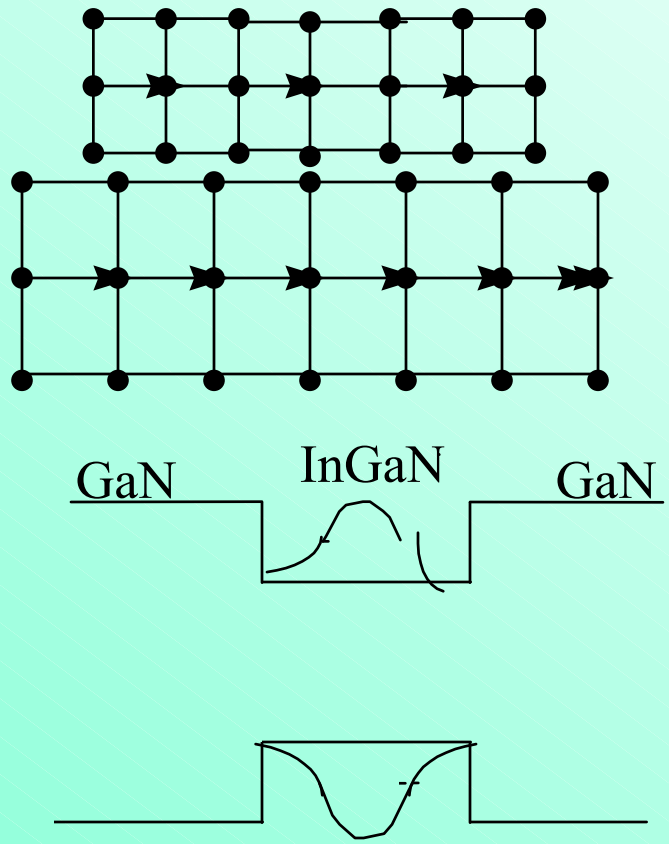
Internal Quantum Efficiency is Enhanced in Interconnected μ -LEDs due to a Possible Reduction of Piezoelectric Field

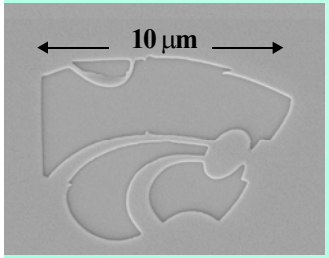
Strain Effects

(a) Strained

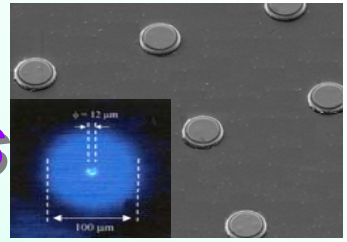


(b) Unstrained

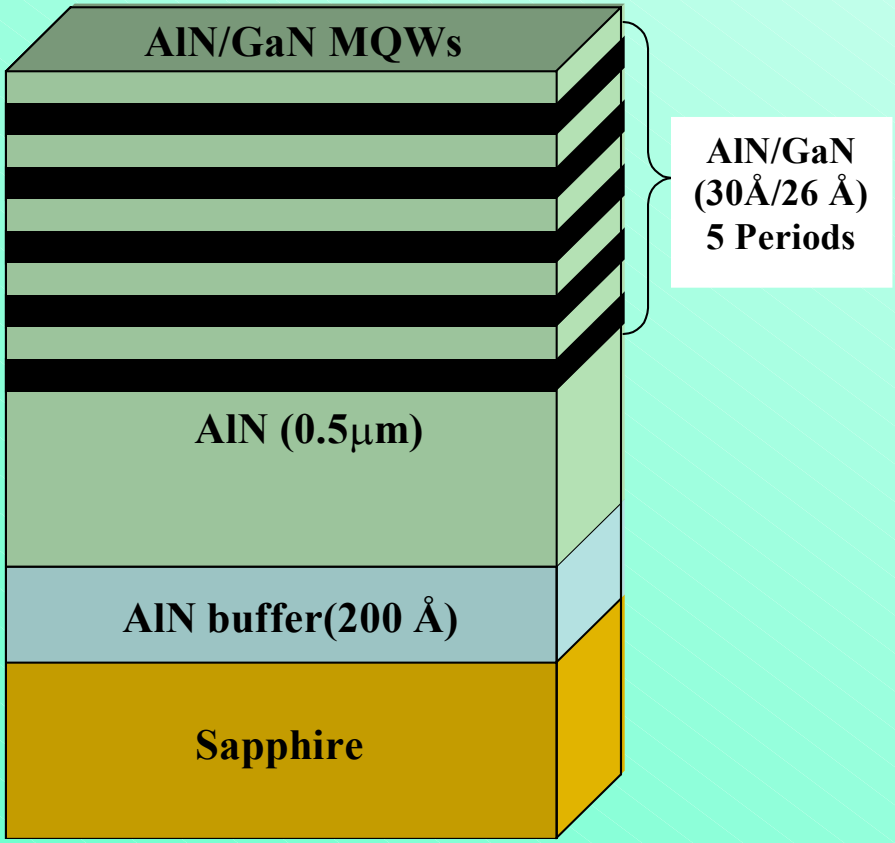


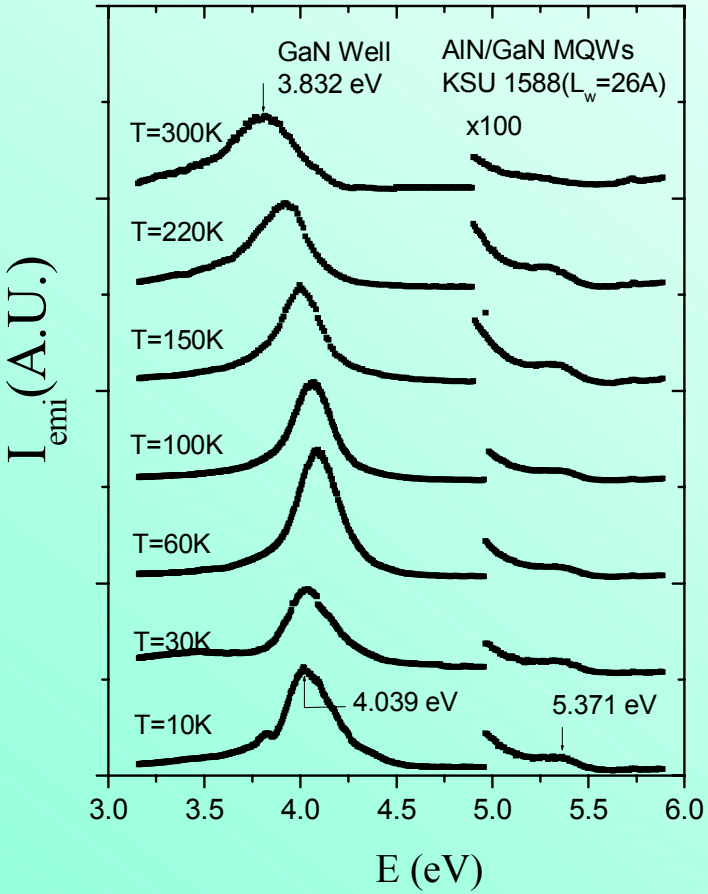


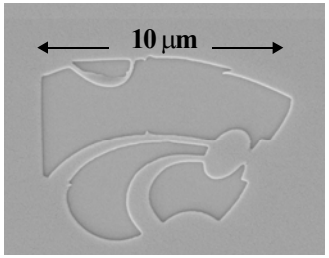
GaN Group at KSU-Physics



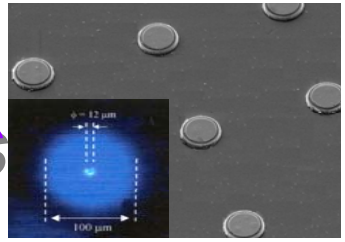
Working Toward UV Emission Wavelength

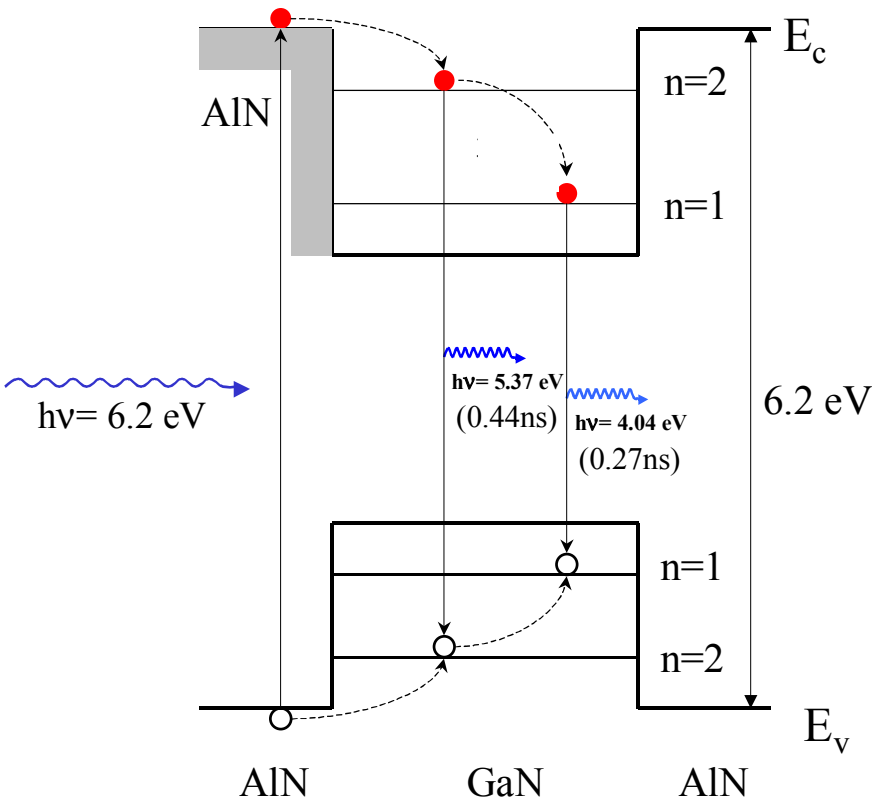


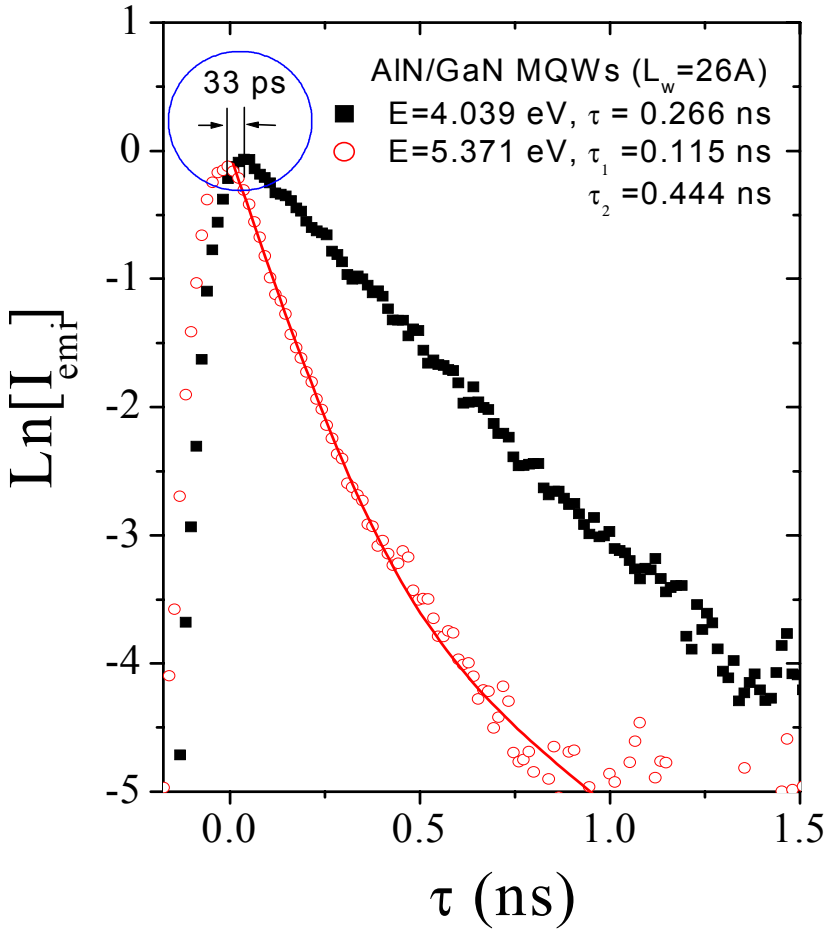


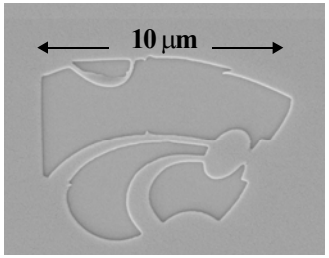


GaN Group at KSU-Physics

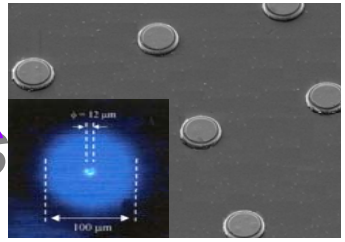




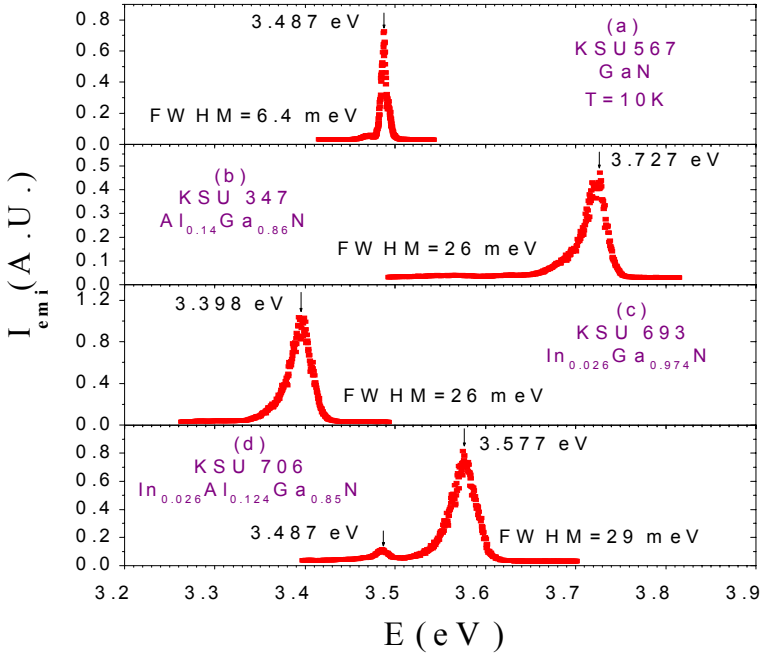




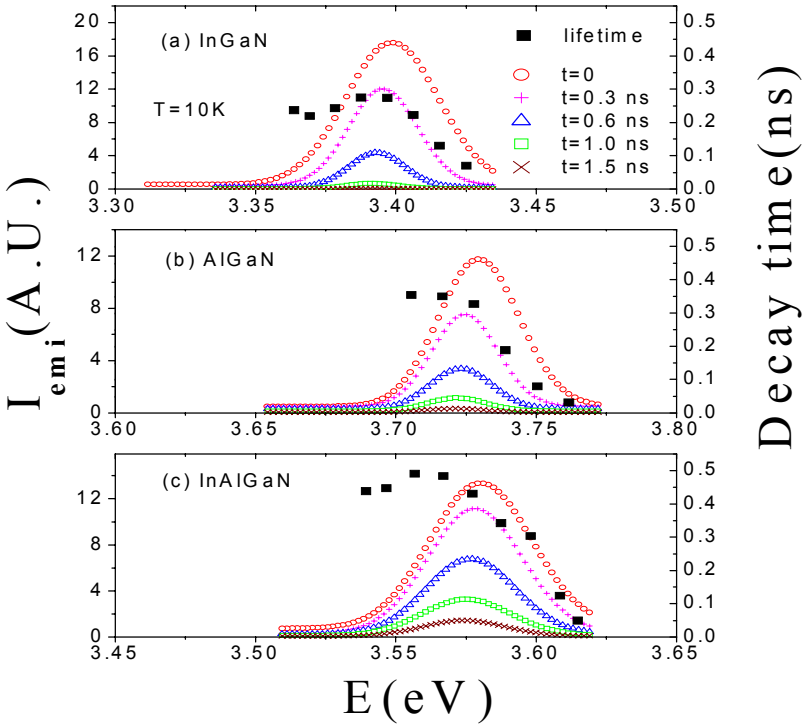
GaN Group at KSU-Physics

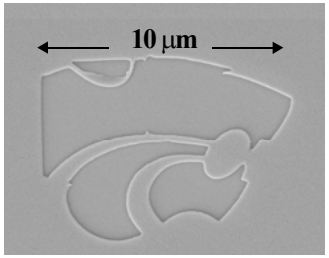


Enhanced Emission Efficiency in InAlGaN

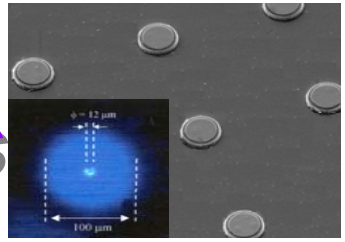


Time-resolved PL Spectra of InGaN, AlGaN, InAlGaN

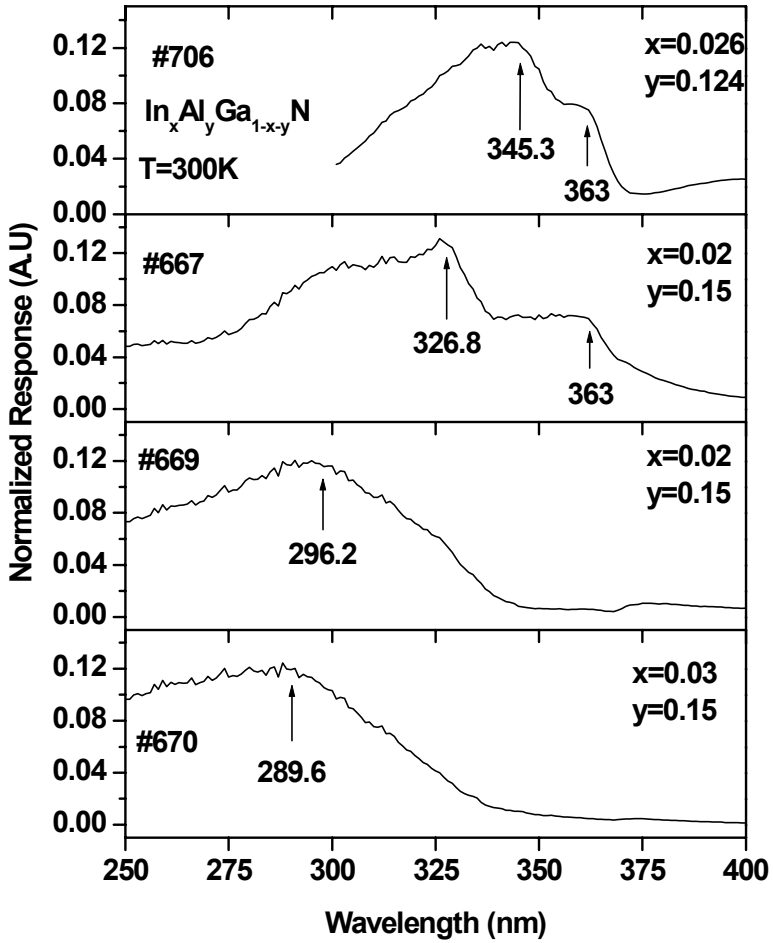




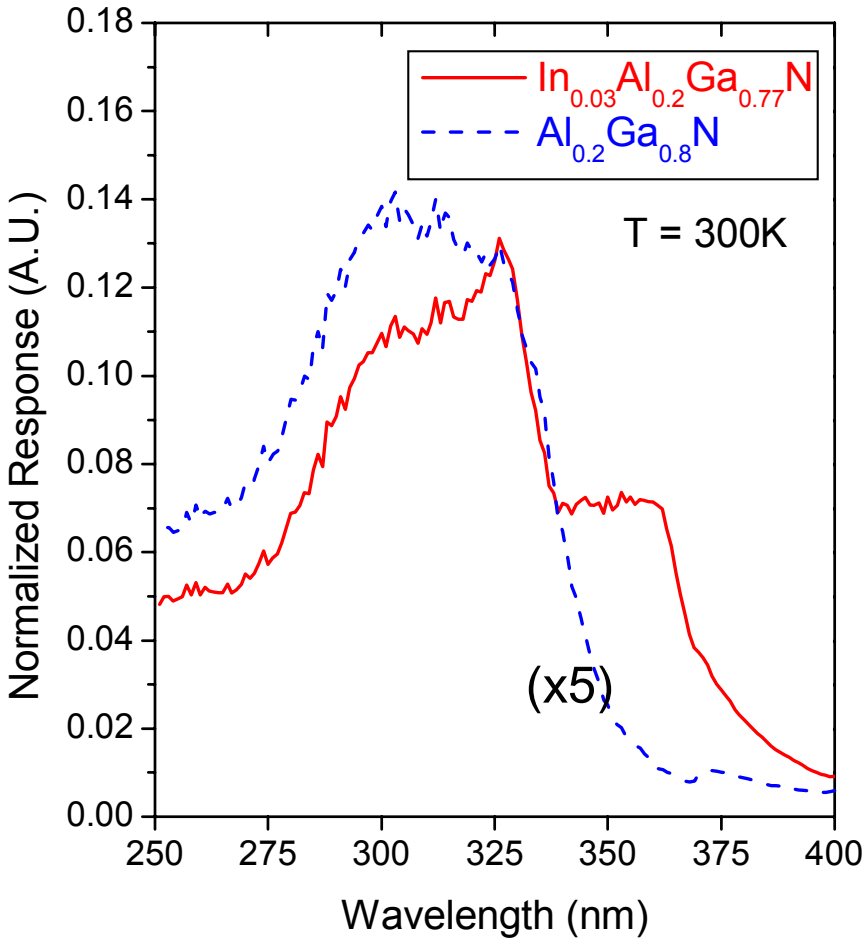
GaN Group at KSU-Physics



UV Detector based on InAlGaN Quaternary Alloys



Enhanced Detection Efficiency in InAlGaN



Our studies have revealed that $In_xAl_yGa_{1-x}N$ quaternary alloys with lattice matched with GaN epilayers (y~4.8x) have the highest optical quality. More importantly, we can achieve not only higher emission energies but also higher emission intensity (or quantum efficiency) in $In_xAl_yGa_{1-x-y}N$ quaternary alloys than that of GaN. The quantum efficiency of $In_xAl_yGa_{1-x}N$ quaternary alloys was also enhanced significantly over AlGaN alloys with a comparable Al content. These results strongly suggested that $In_xAl_yGa_{1-x-y}N$ quaternary alloys open an avenue for the fabrication of many novel optoelectronic devices such as high efficient light emitters and detectors, particularly in the UV region.