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UV Emitters Based on AlInGaN Quaternary Alloys

by

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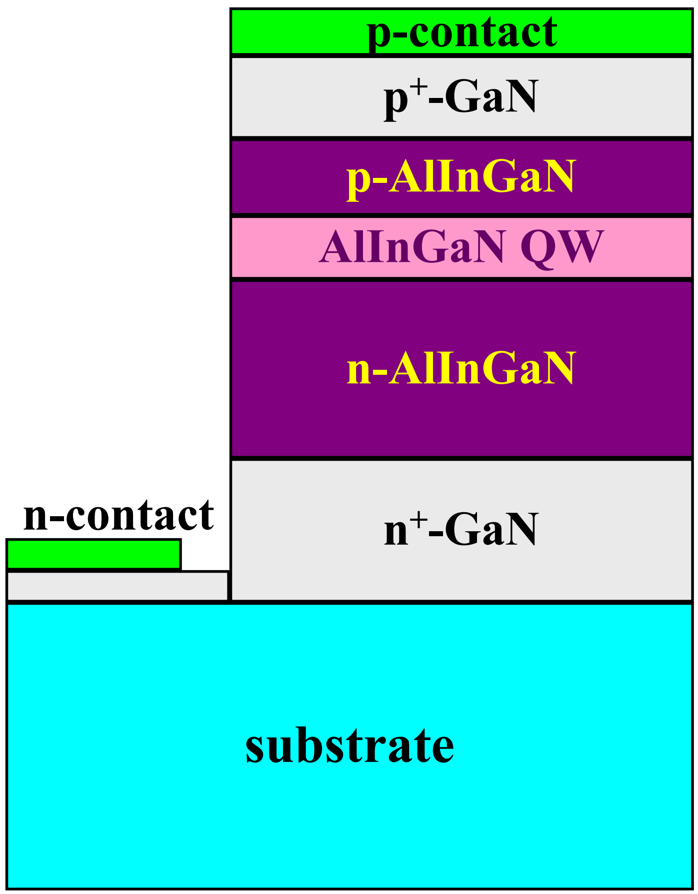
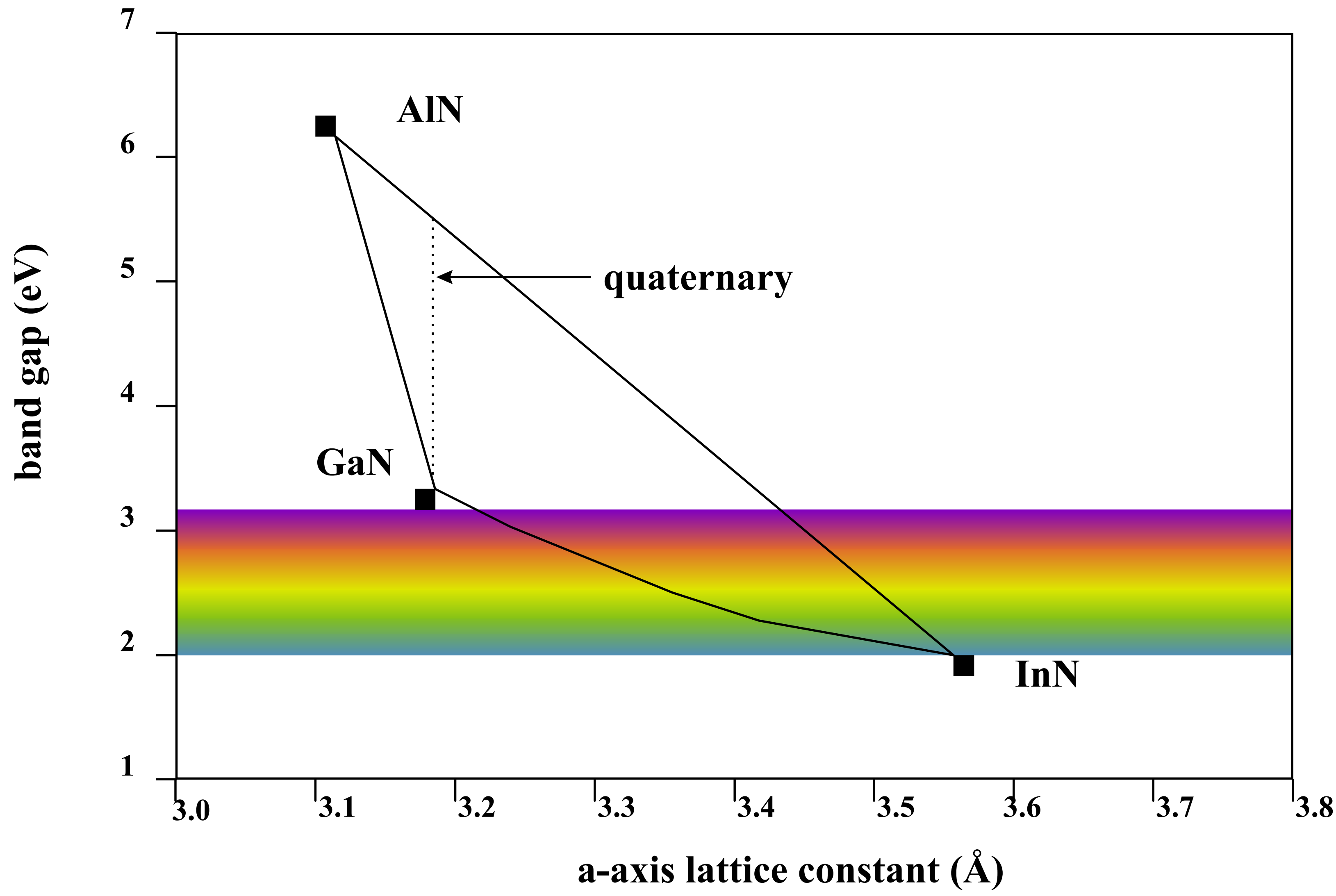
Proposed UV Emitter Structure based on AlInGaN Quaternary Alloy



Band Gap and Lattice Constant for III-Nitrides



Motivation for Quaternary Interest

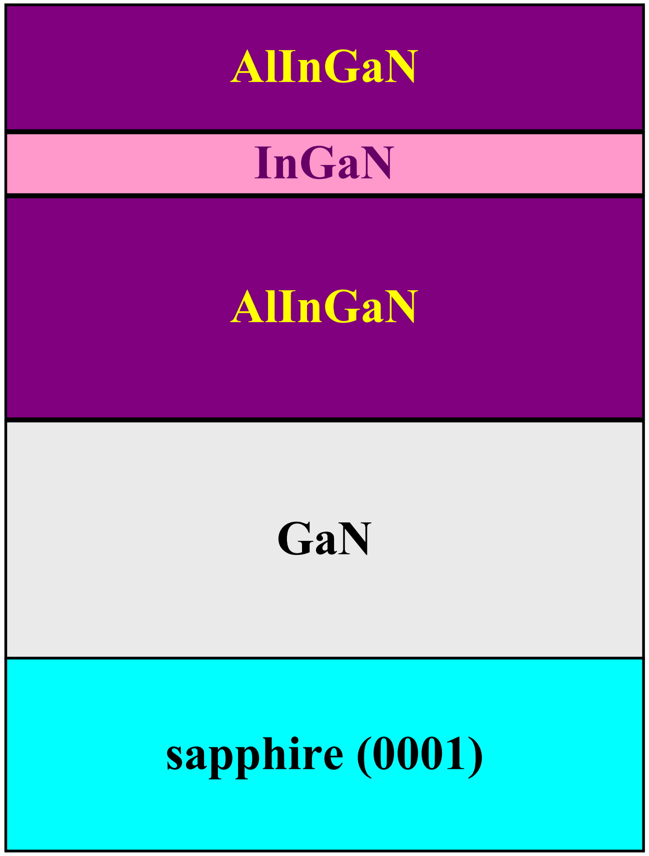
Grow active layers with E_g > 3.4 eV but lattice matched to GaN

If AlGaN is used, tensile stress from growth on GaN reduces band gap

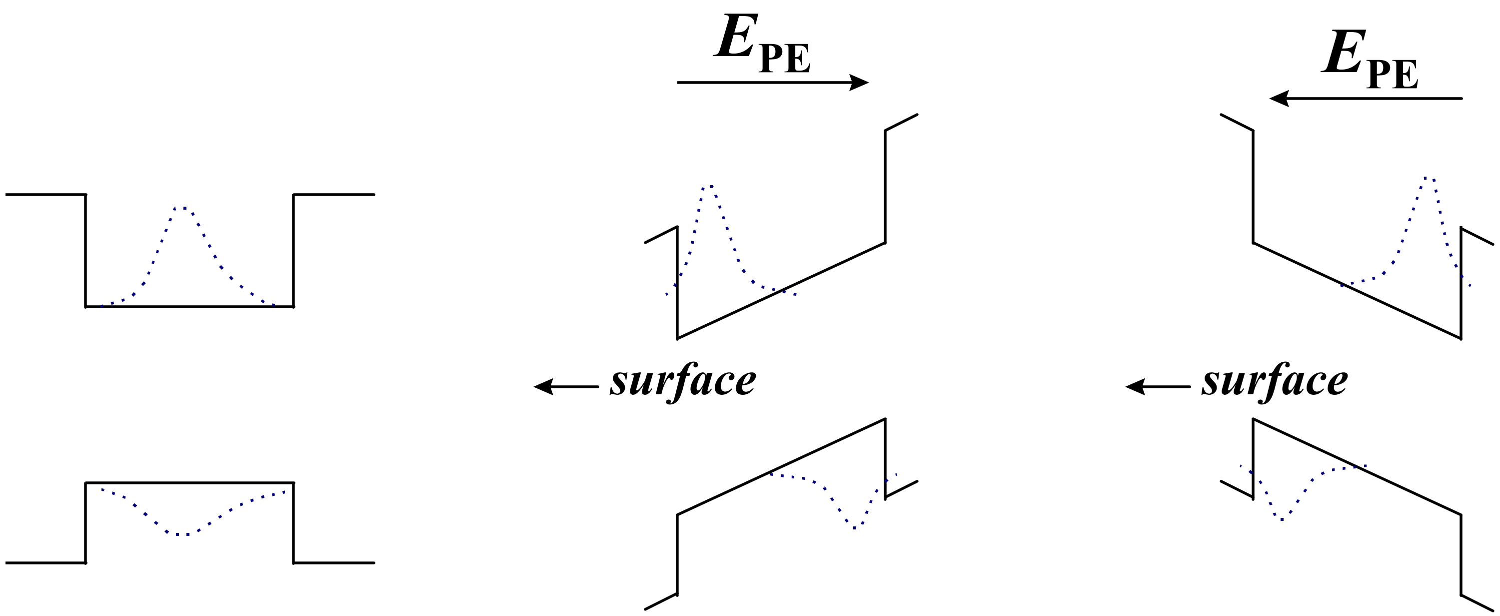
Quaternary active layer contains indium which significantly increases quantum efficiency for light emission

Strain engineering of quantum well allows maximization of oscillator strength resulting in higher radiative recombination rate

AlInGaN/InGaN Quantum Well Structure with Adjustable Strain (tensile, compressive, zero)



Band Diagrams for AlInGaN/InGaN Quantum Wells



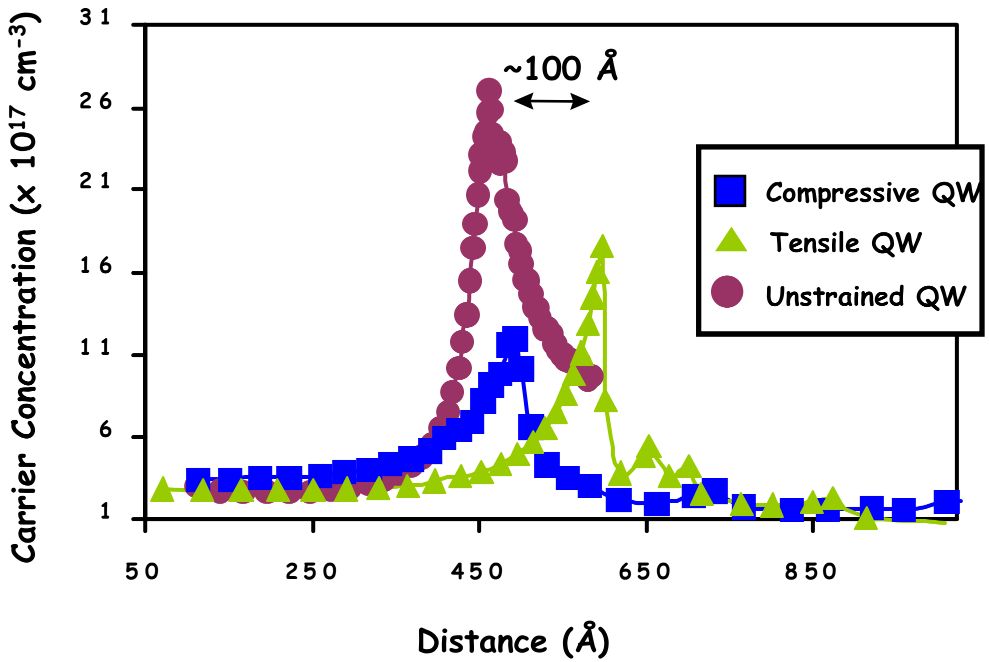
unstrained | **compressive strain** | **tensile strain**

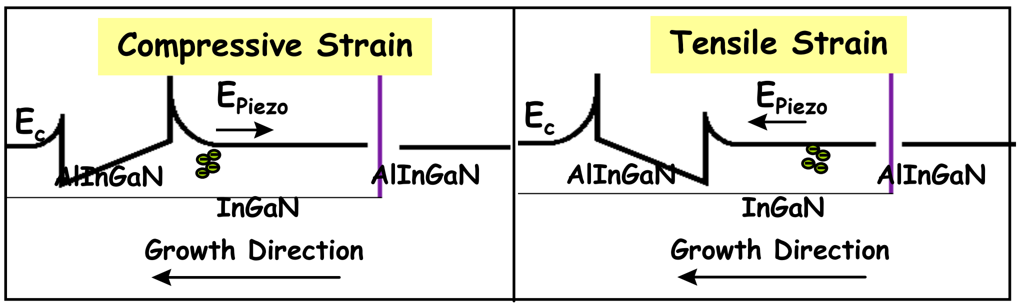
Manipulation of 2DEG via Strain Engineering Using the AlInGaN Quaternary Alloy

- AlInGaN offers the independent control of lattice constant and band gap.

- Tensile, compressive, and unstrained quantum wells can thus be achieved in the nitride system.

- The density and location of the 2DEG can be manipulated via strain engineering.





Quantum Well Peak Energy vs Strain

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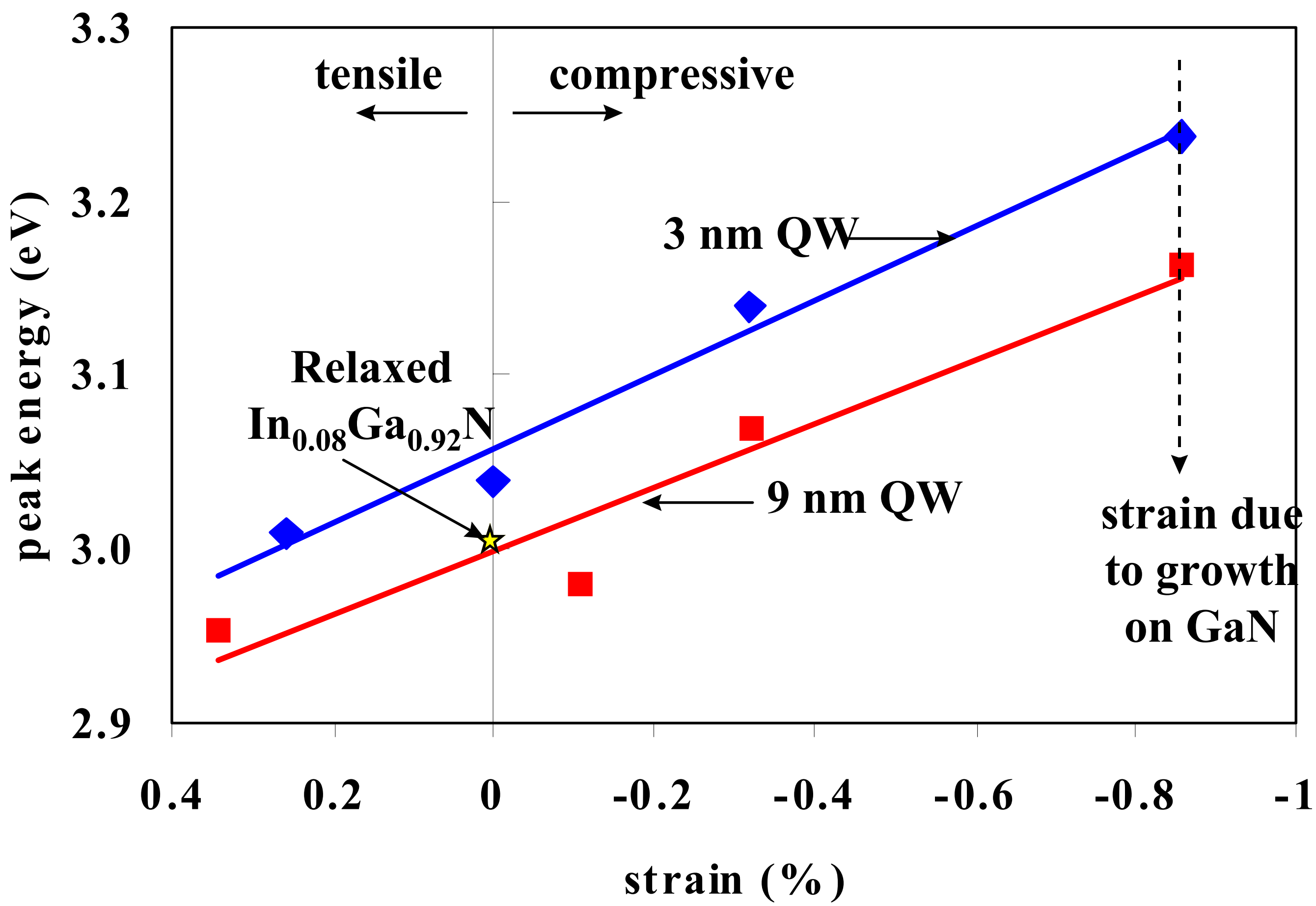
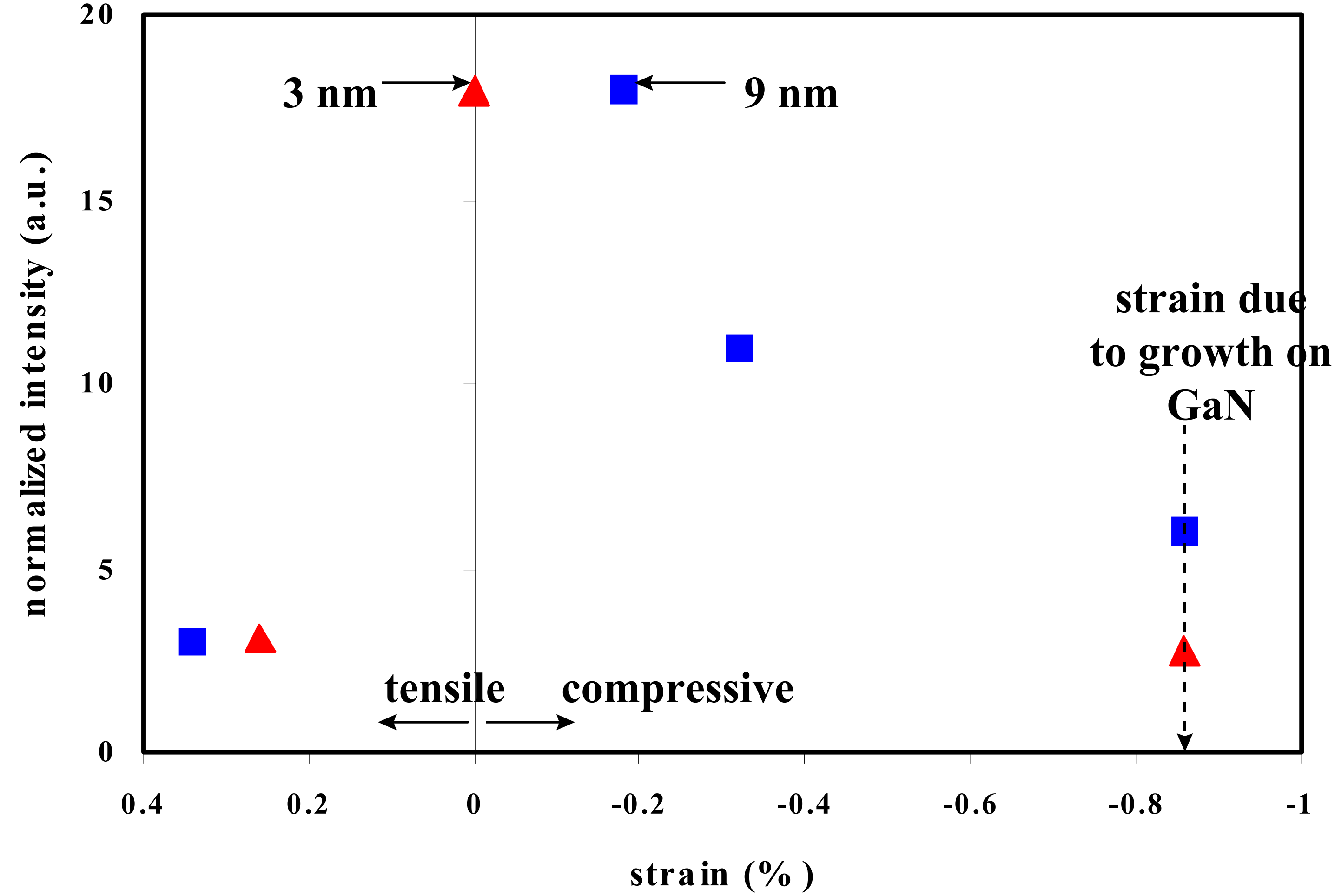
Peak energy transition reduced by 236 meV for 3 nm QWs



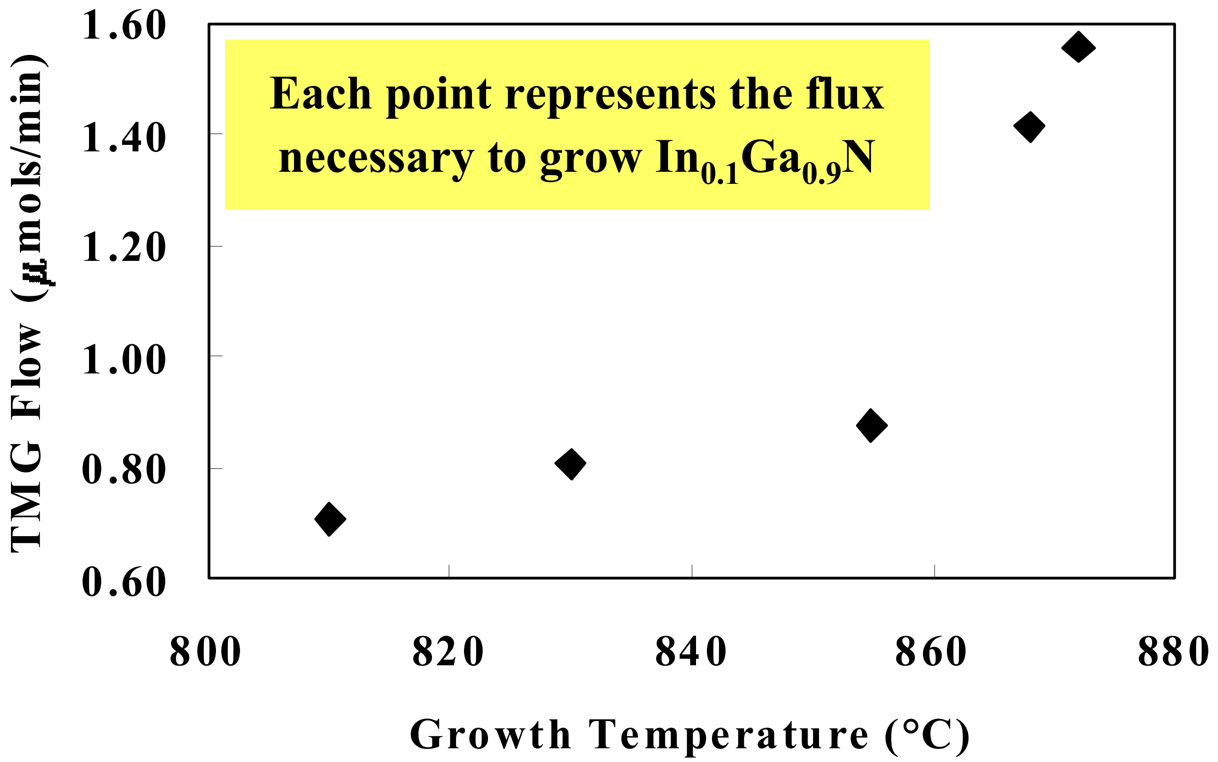
Peak Intensity vs Strain for AlInGaN/InGaN Quantum Wells at 10 K

Emission intensity is reduced for strained quantum wells



High Temperature InGaN Growth

855 °C was the threshold beyond which high quality AlInGaN was grown



Growth of InGaN with 10% InN can be performed at 875 °C with high enough growth rate and In/Ga ratio of 10

Quaternary Composition Range Investigated
(Bedair, 1995 to Present)

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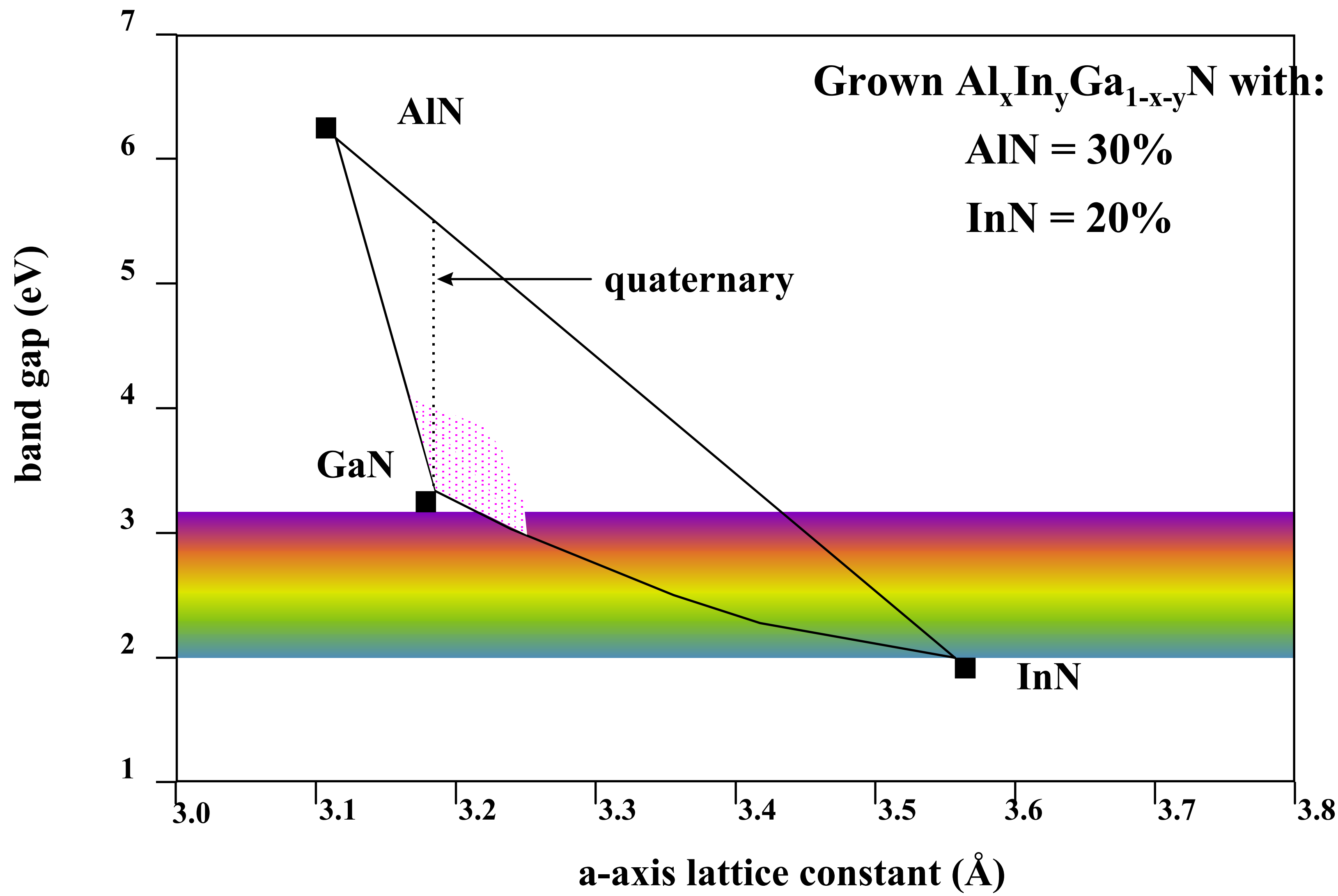

Room Temperature PL for Thin $Al_xIn_{0.09}Ga_{0.91-x}N$

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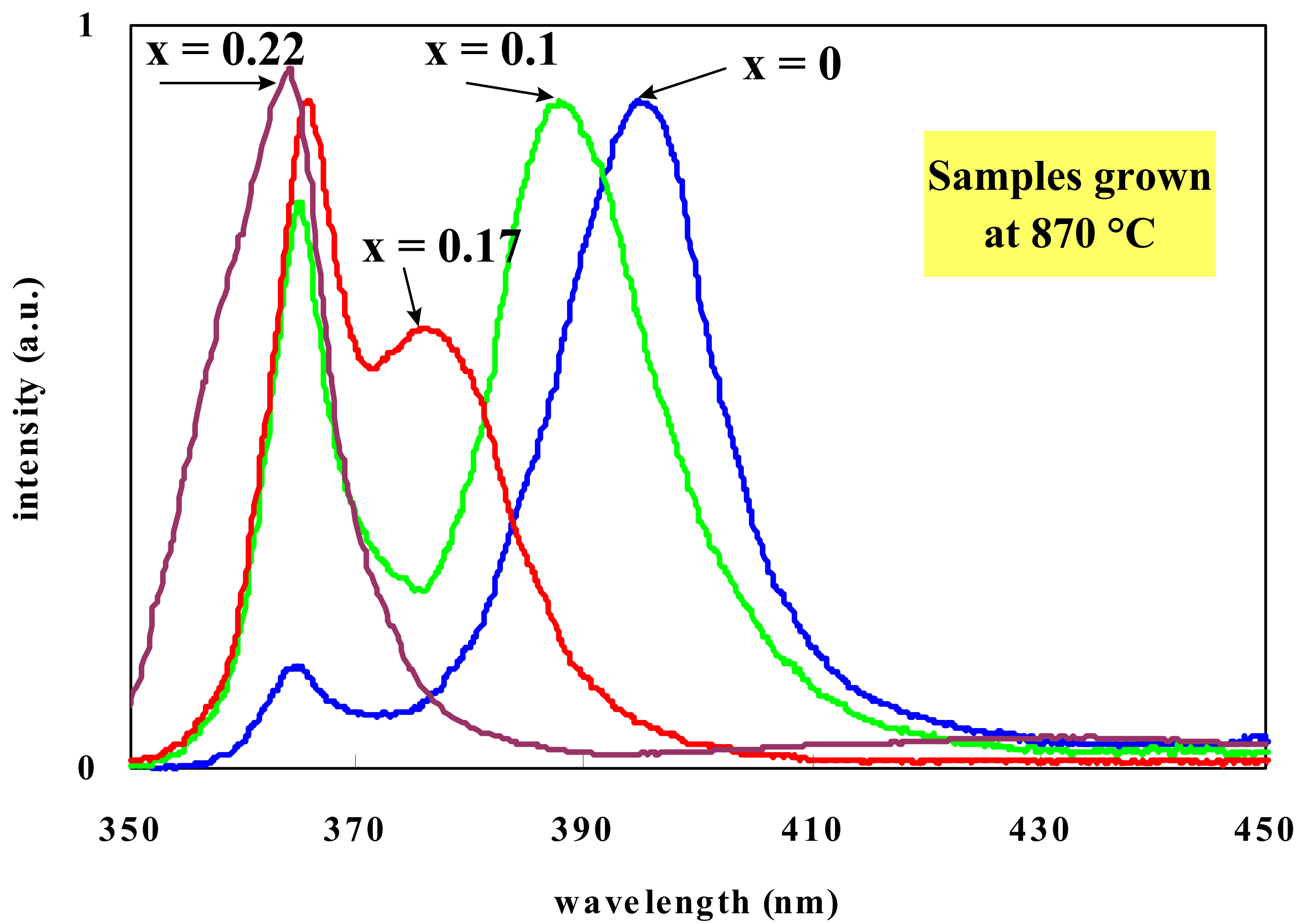
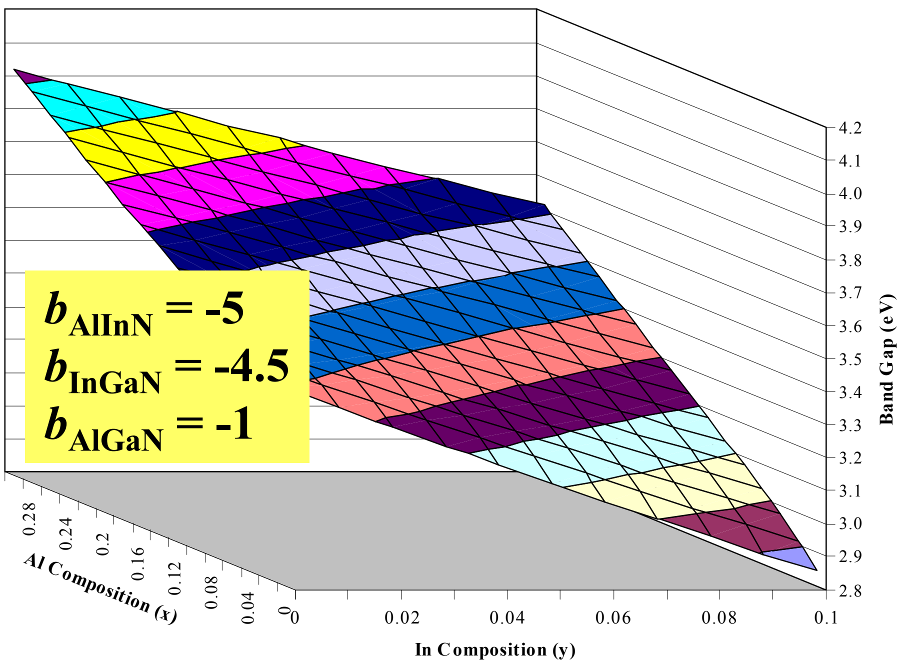
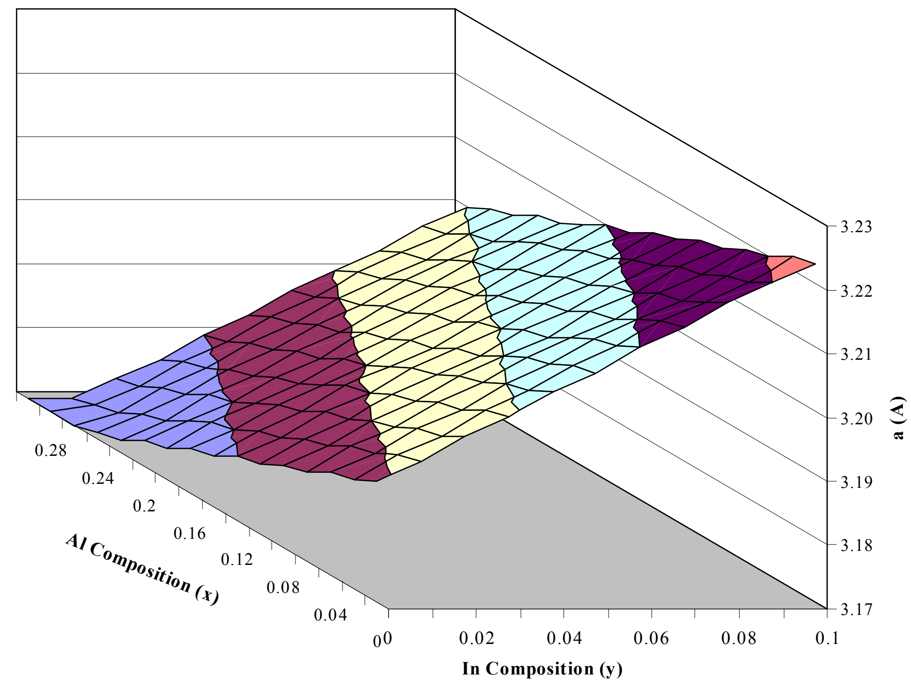


Properties of Quaternary Alloys

Band Gap



Lattice Constant (a)



Quaternary properties calculated from:

$$Q(x,y,z) = \frac{xyT_{12}\left(\frac{1-x+y}{2}\right) + yzT_{23}\left(\frac{1-y+z}{2}\right) + xzT_{13}\left(\frac{1-x+z}{2}\right)}{xy + yz + xz}$$

$$T_{ij}(\alpha) = \alpha B_j + (1-\alpha)B_i + b_{ij}\alpha(1-\alpha)$$

The Issue of Phase Separation

We have observed the presence of separated/ordered phases in $In_xGa_{1-x}N$ when $x > 0.28$

For UV emitters using AlInGaN quaternary alloys, InN content needed is much less than 28%. For example, $Al_{0.6}In_{0.12}Ga_{0.28}N$ is lattice matched to GaN and $E_g = 4.4$ eV ($\lambda = 280$ nm)

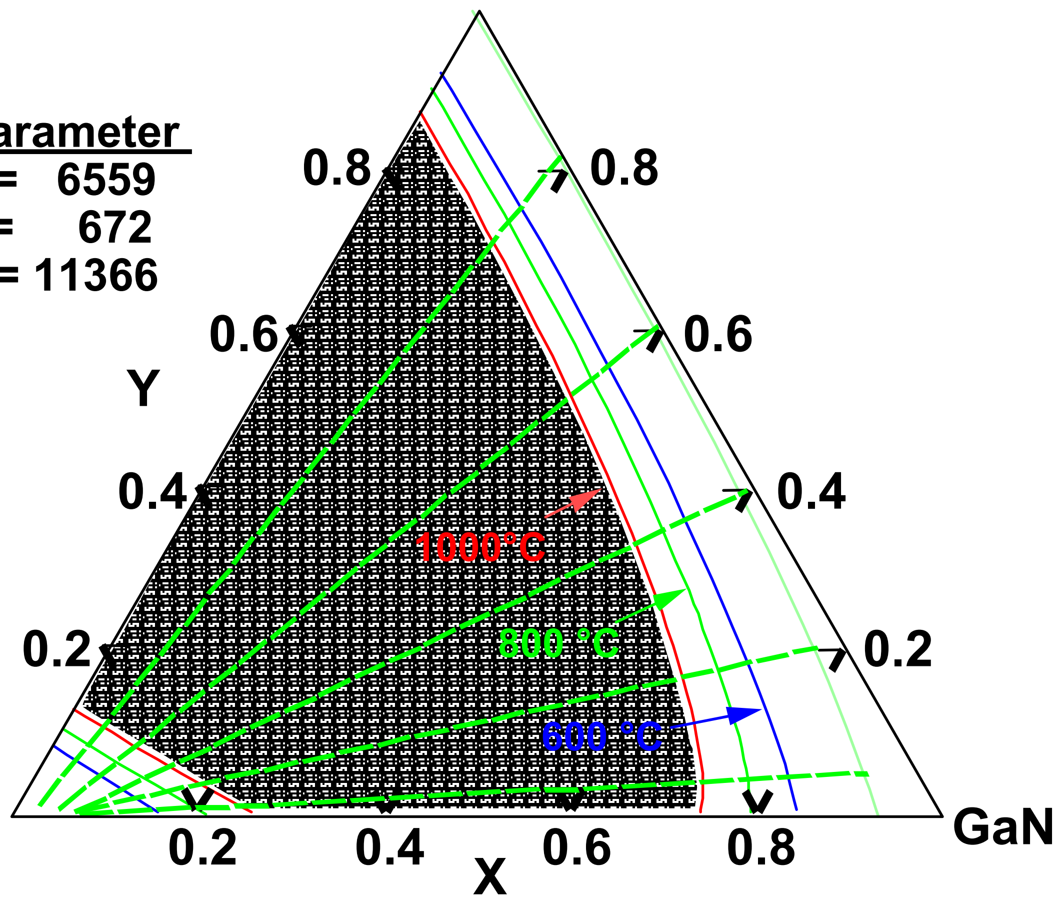
Phase separation in AlInGaN takes place in a unique way

Isotherms for III-Nitride System

Calculation by Matsuoka:

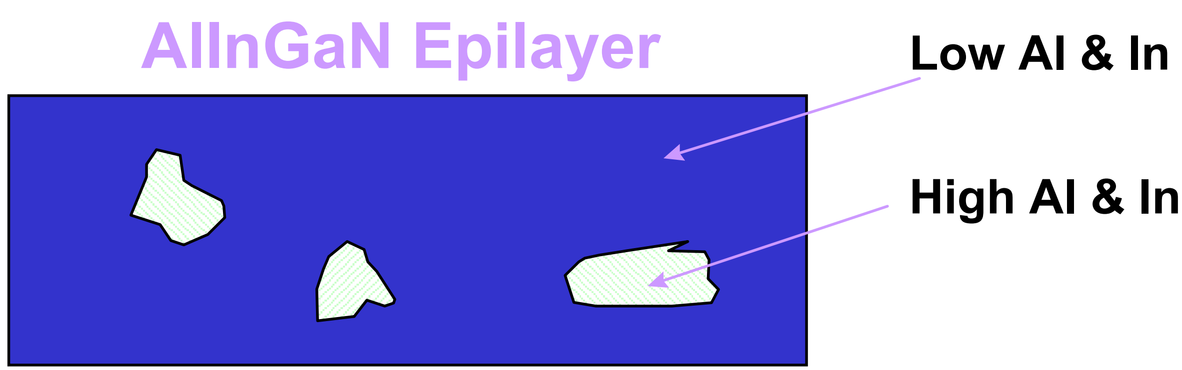
Interaction Parameter

InN - GaN = 6559
GaN - AlN = 672
AlN - InN = 11366



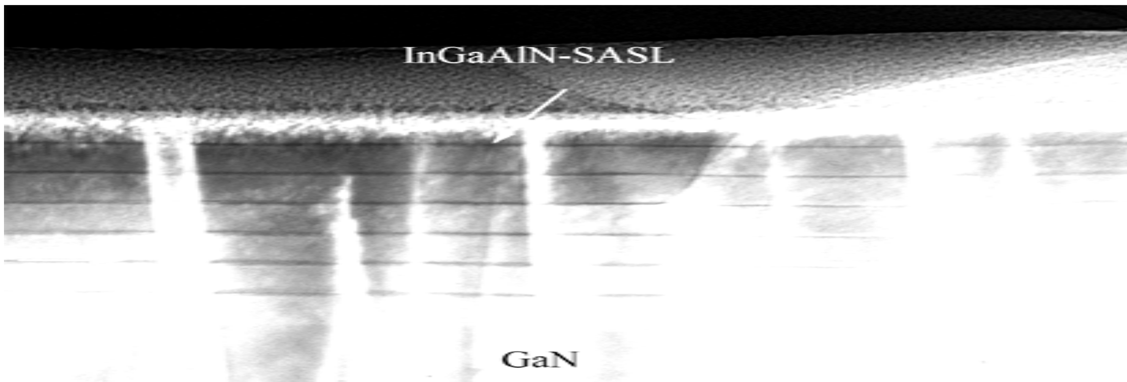
Immiscibility in AlInGaN Quaternary Alloy Allows Several Options

- Separated AlInN ternary phase from excess Al and In. (Not likely because ternary AlInN has low miscibility.)
- Separated ternary InGaN and AlGaN.
- Two quaternary alloys with high and low Al & In mole fractions.

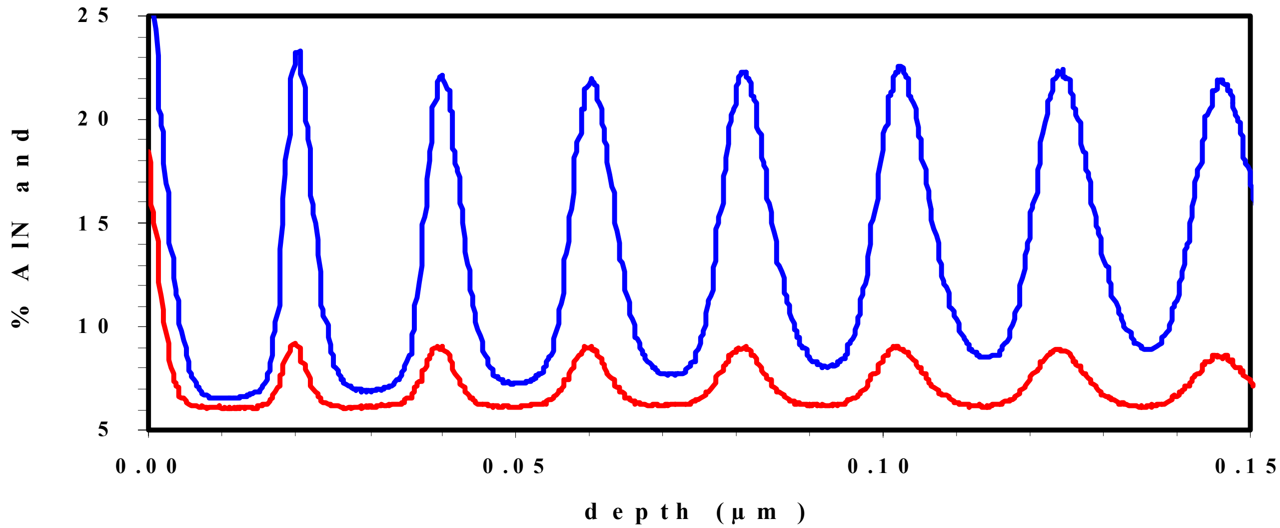


Self-assembled superlattices in AlInGaN

For high Al and In compositions, AlInGaN is susceptible to phase separation

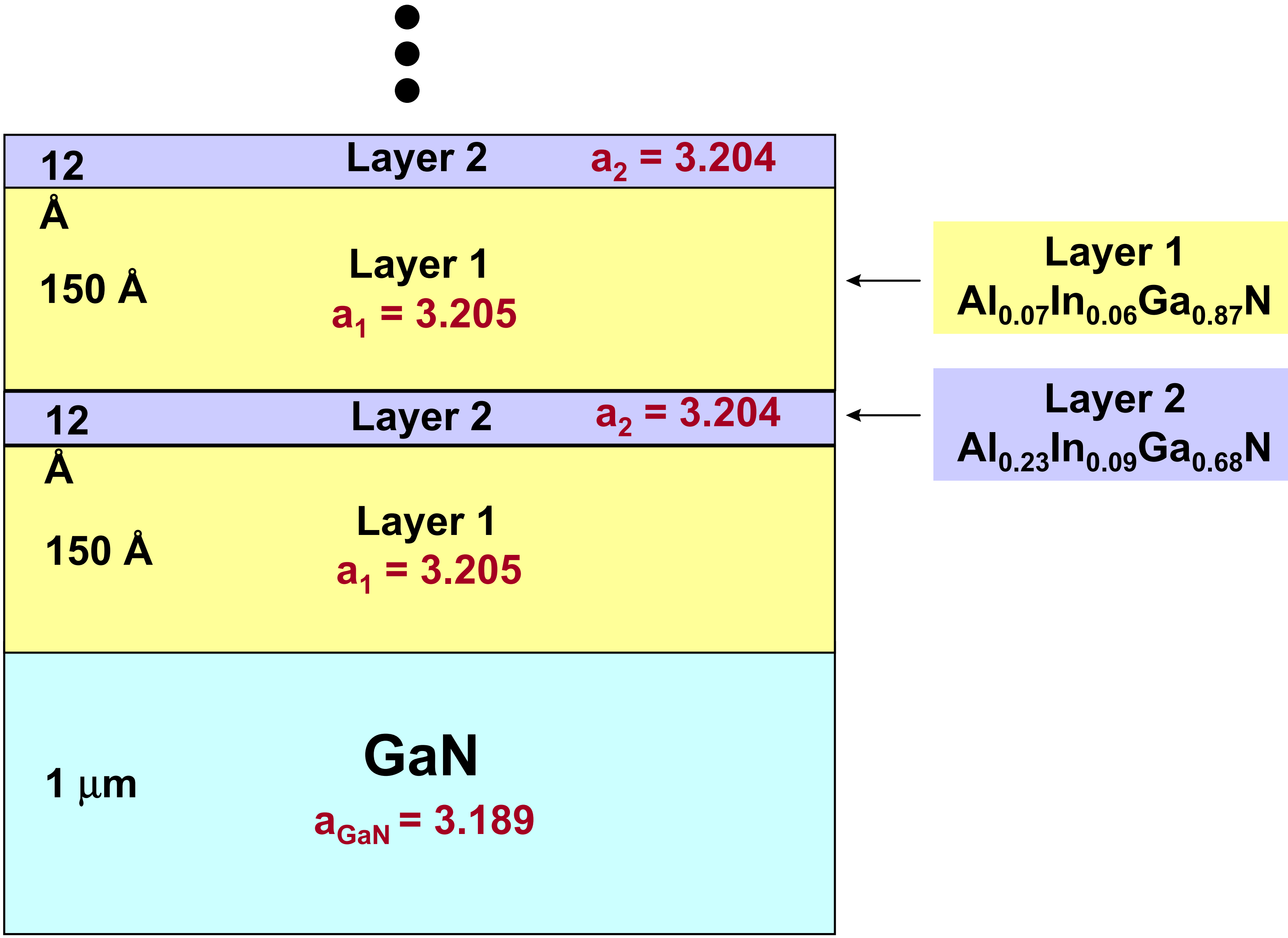


Layer 1
15 nm
Layer 2
1.2 nm

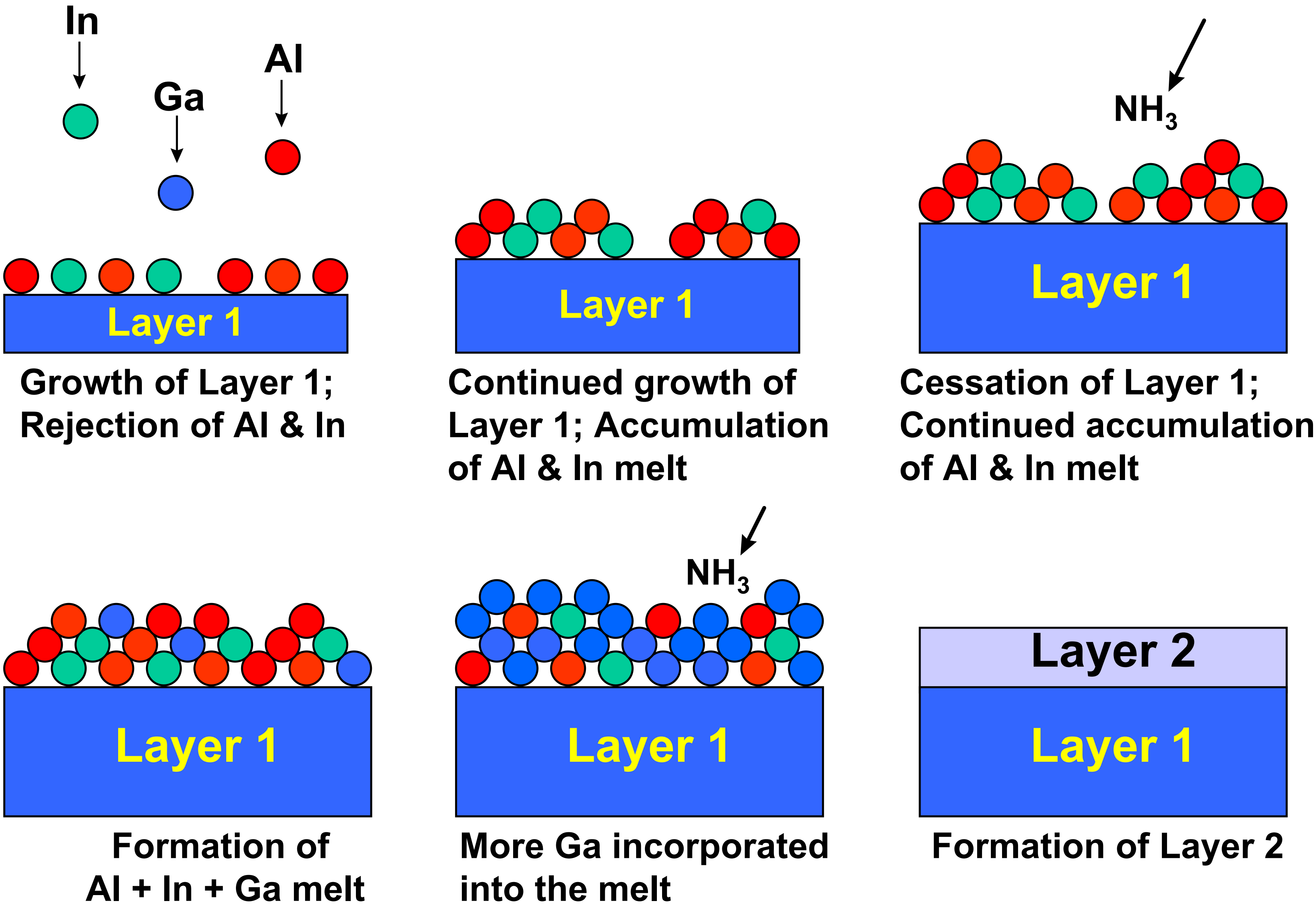


Under certain growth conditions, SASL forms with lattice matched layers

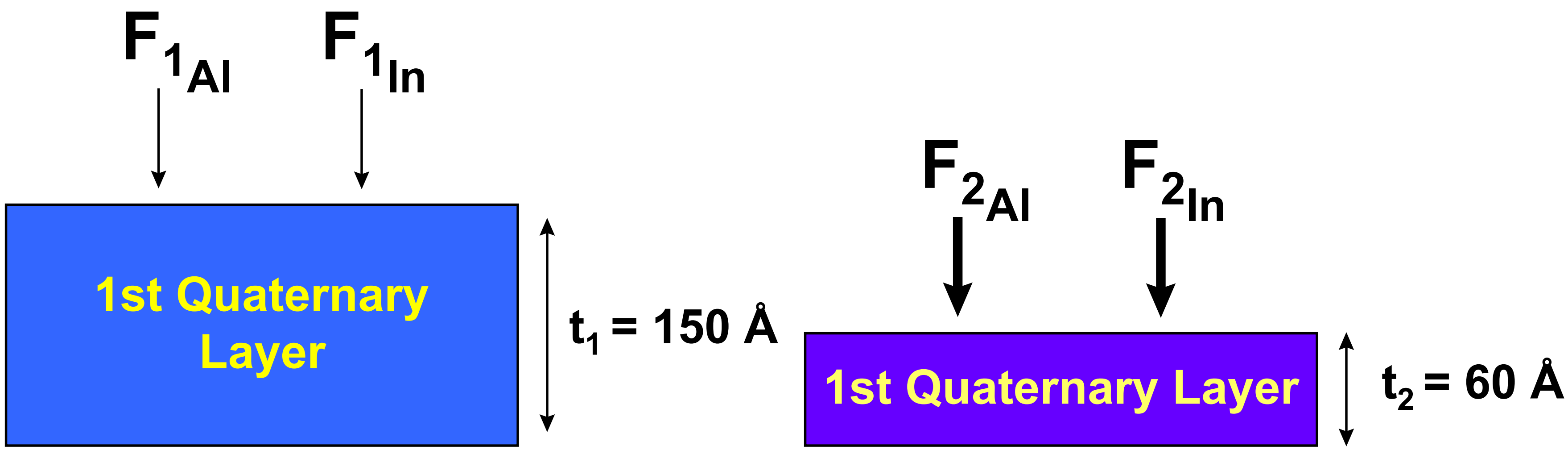
Schematic of $Al_xIn_yGa_{1-x-y}N$ SASL



Synthesis of $Al_xIn_yGa_{1-x-y}N$ SASL



Experimentally Observed Effect of Al & In Flux on SASL Layer Thickness



$$F_2 > F_1 \therefore t_2 < t_1$$

With a higher Al & In flux (F), It takes less time for the Al-In melt to accumulate and block the growth of the 1st quaternary layer.