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# OMVPE Regrowth and Transverse QW Functionality for Photonic Integrated Circuits

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Sandia National Laboratories

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# Outline

- OMVPE vs. MBE for regrowth
- Advantages in manipulating QWs in the transverse direction
- Regrowth for Photonic Integrated Circuits
- Case 1: Regrowth for AlGaAs\InGaAs PIC
- Case 2: Regrowth and QWI for InGaAsP\InP PIC

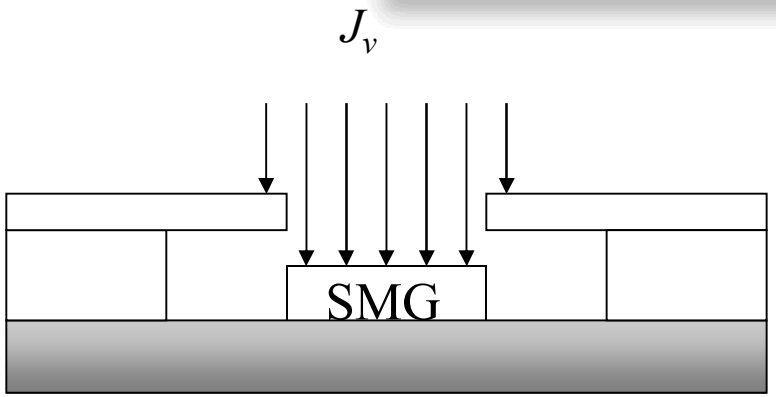
    Monolithic Integration Platform

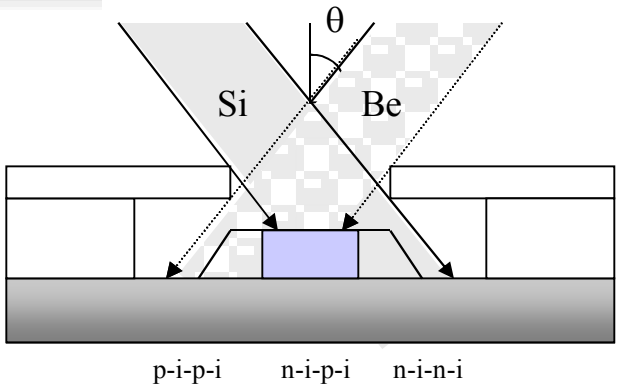
    Device Improvements

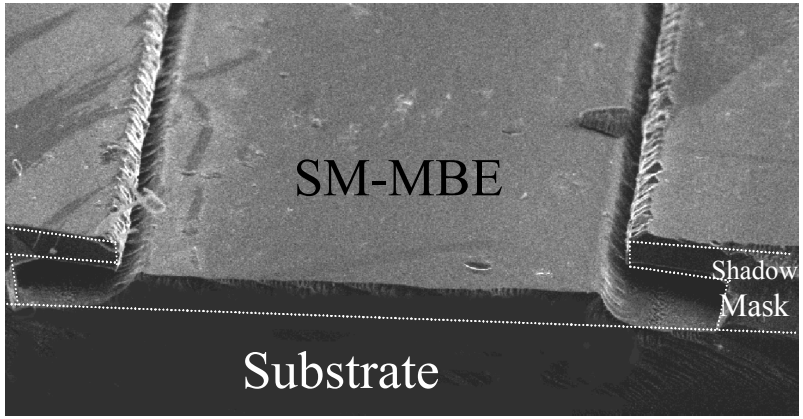


# Why OMVPE Regrowth? Ballistic Growth Model

$$J_v = 1.12 \times 10^{22} \frac{pA}{L^2 (MT)^{1/2}} \cos(\theta) \frac{molecules}{cm^2 \sec}$$




Low mean free path in MBE described by ballistic growth regime

# Why OMVPE Regrowth? Diffusive Growth Model

## Flux equations

$$J_v = b - \left(\frac{N}{\tau_v}\right) \quad \text{I}$$

$$J_s = -D_s \frac{\partial N}{\partial s} \quad \text{II}$$

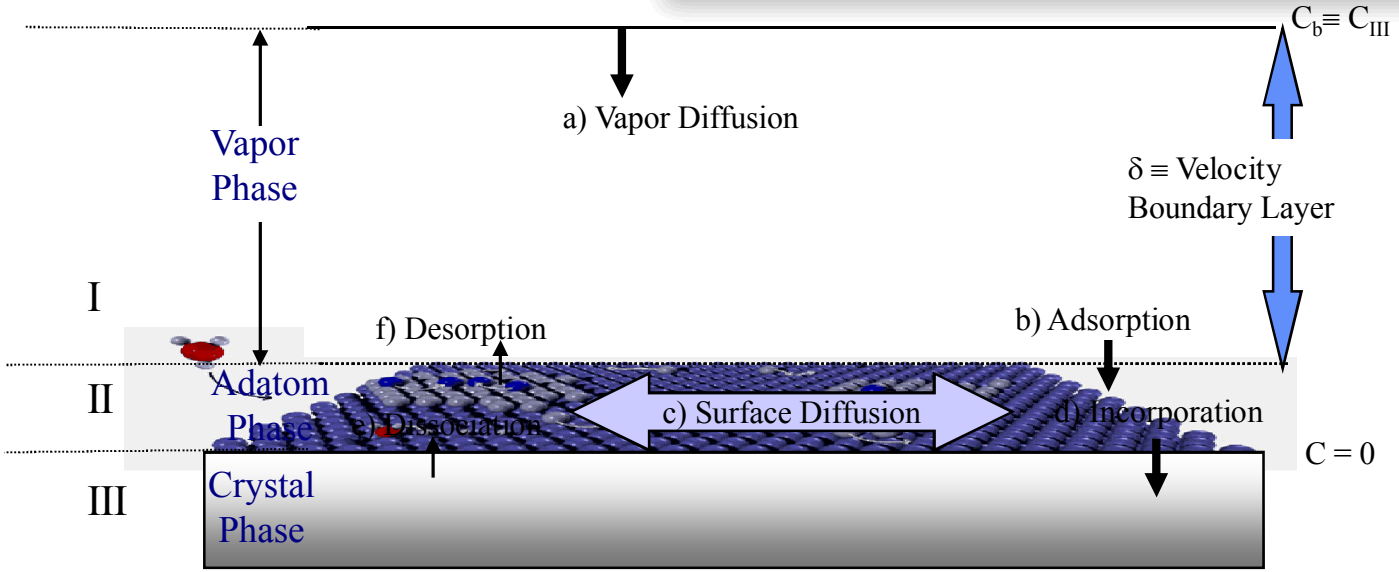
$$J_c = \left(\frac{N}{\tau_c}\right) - f \quad \text{III}$$

## Continuity equation

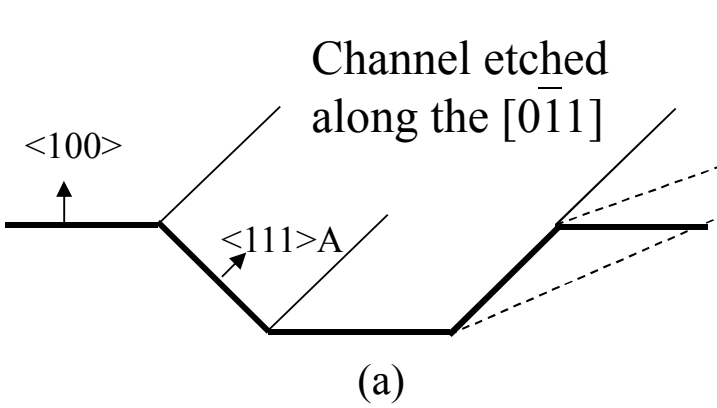
$$\frac{\partial N}{\partial t} = J_v - \frac{\partial J_s}{\partial s} - J_c$$

$$= D_s \frac{\partial^2 N}{\partial s^2} - \frac{N}{\tau} + (1-R)\sqrt{\frac{kT}{2\pi m}}\rho + f$$

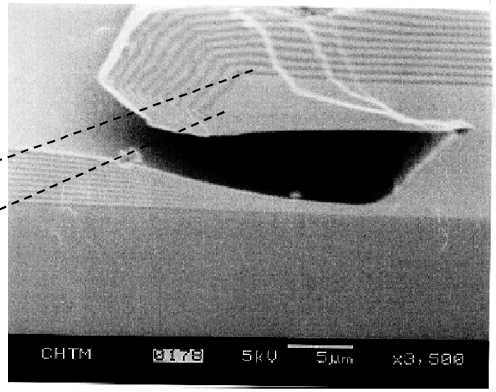
$$where, \frac{1}{\tau} = \frac{1}{\tau_c} + \frac{1}{\tau_v}$$



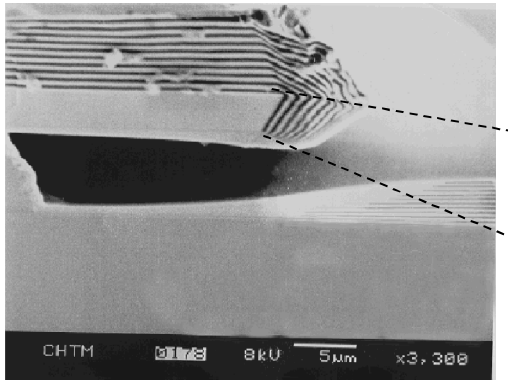
# Smooth Nonplanar Regrowth in 3D

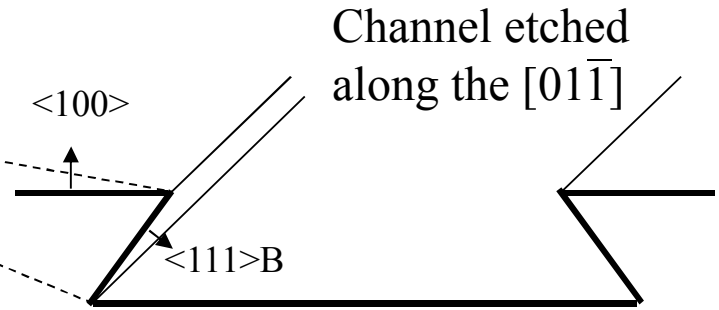



(a)

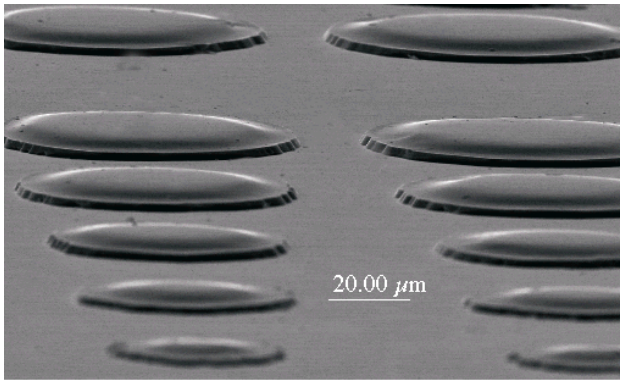






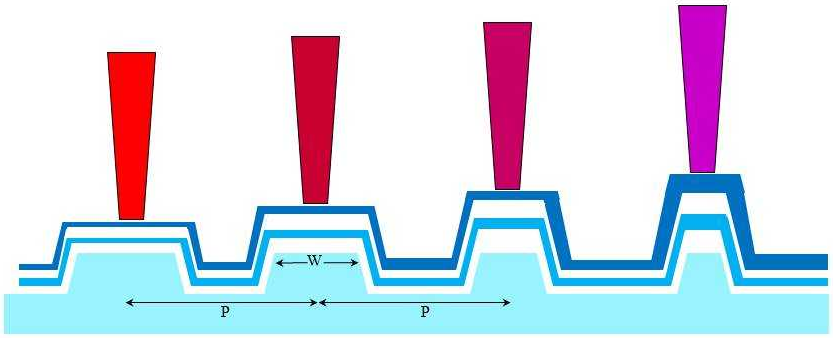




(b)

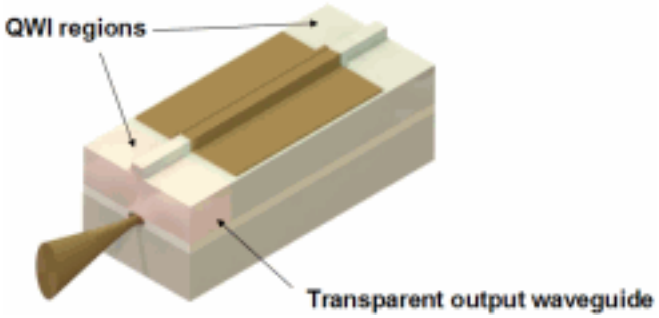


# “Why [Mess] Up a Perfectly Good QW?”

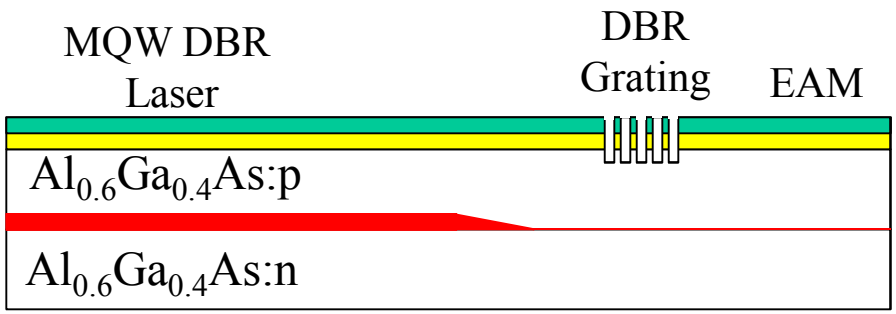
*Peake 1994*




Multiple Wavelength VCSEL

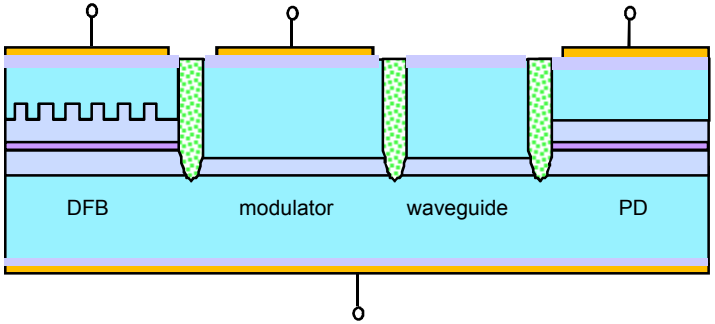



High Power Laser
Reduce COD with extended cavity

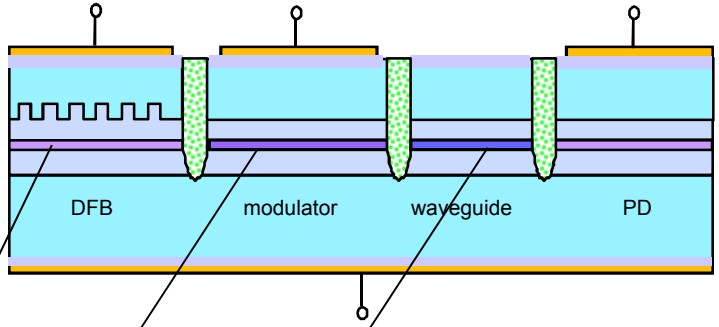



Photonic Integrated Circuit by SAE
after Coleman et al., 1997

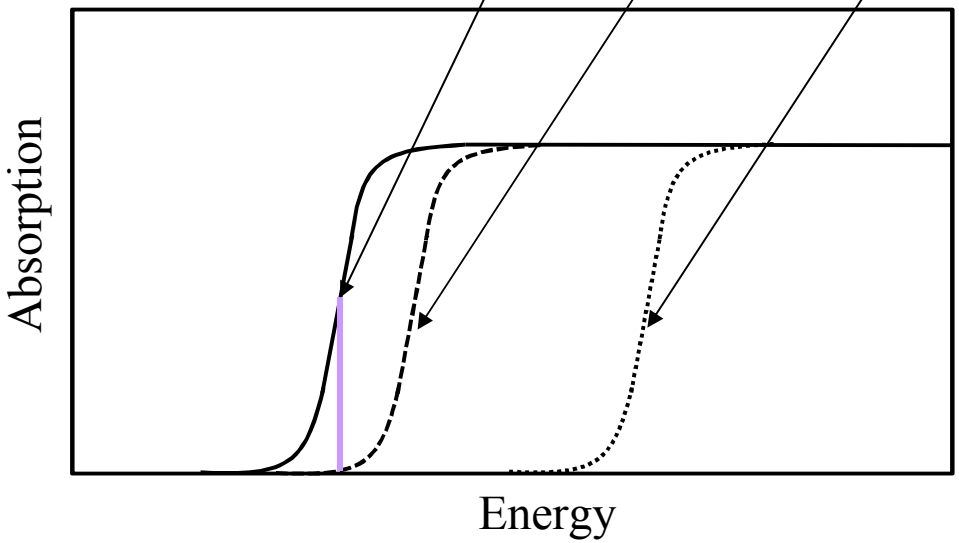
# Photonic Integrated Circuit Bandgaps




Remove QWs and Regrow Clad and Contact




QW Intermixing



# General Regrowth Guidelines

**Understand pregrowth history**

**Stable, low-defect surface**

**Clean, oxide free regrowth interface**

**Preserve underlying materials\topology**

**Rapid increase to growth temperature**

**Modify growth rate (V/III) to eliminate voids**

**Modify growth rate (V/III) to planarize**

# Case 1: AlGaAs\InGaAs Regrowth

## GaAs Regrowth Pretreatment

**Before introduction in reactor:**

Acetone, Methanol, IPA

1:20 $NH_4OH:H_2O$

DI

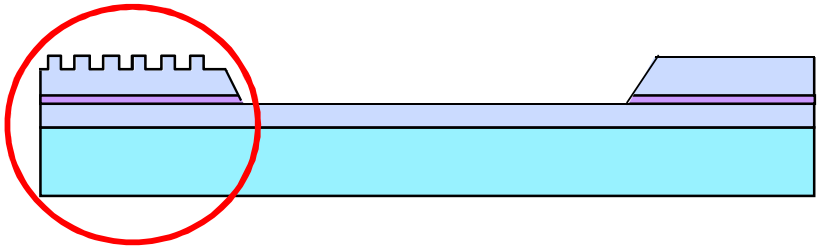
**In reactor:**

Preheat at 300$^oC$ for 5 min. under $H_2$

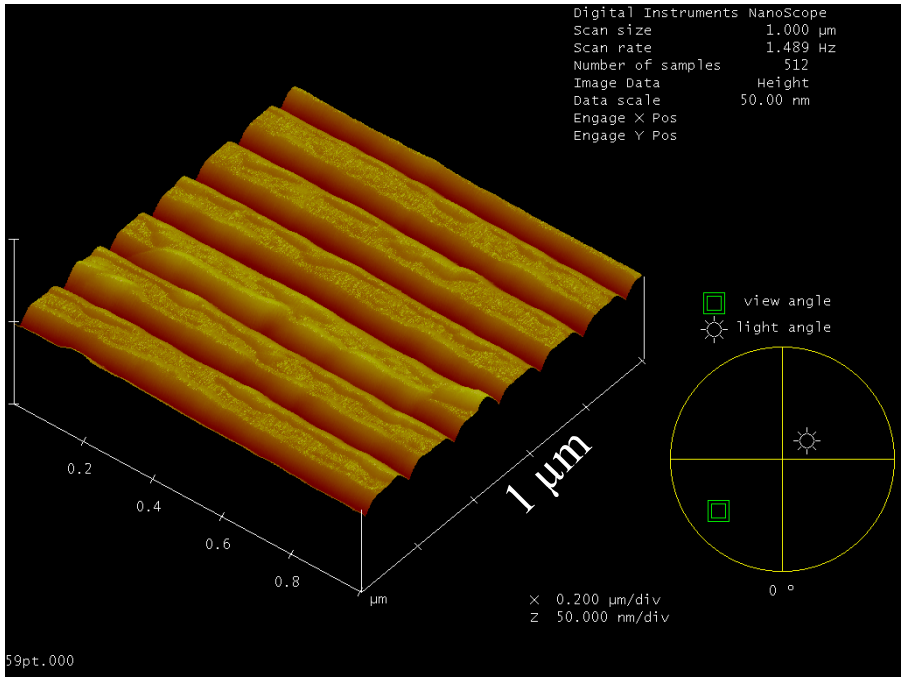
Ramp to Tgrowth in 5 min. under $AsH_3$

# Regrowth Inititation

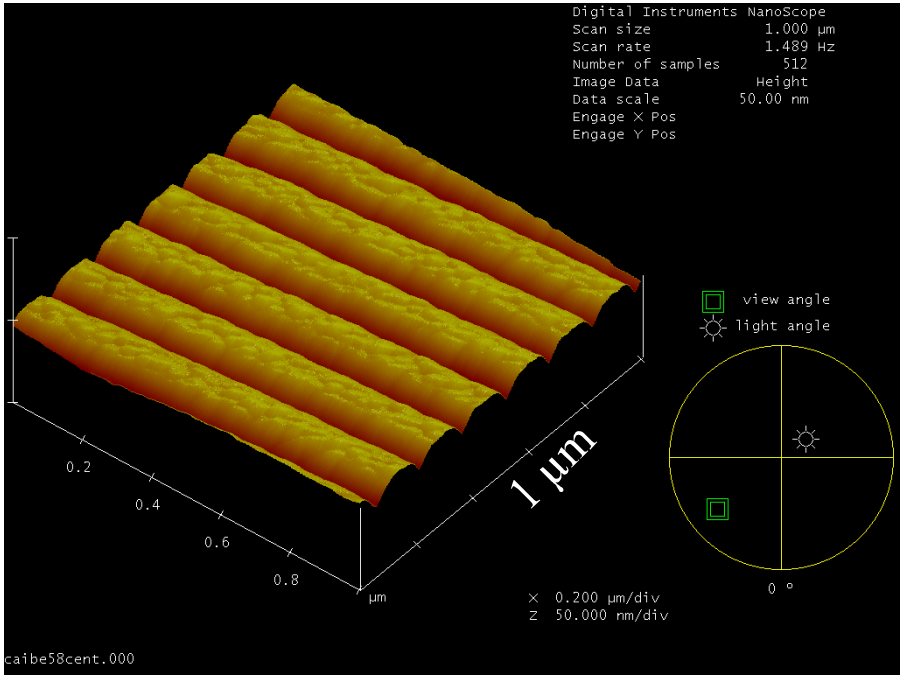
Low T
Preserve grating



High T
Grow good material

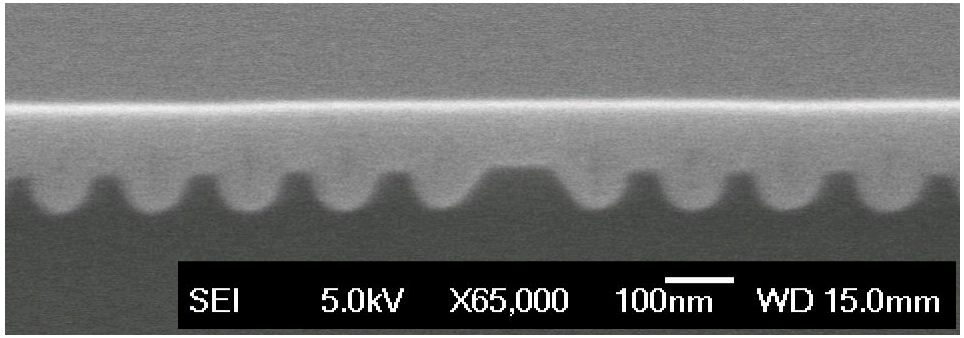



Pregrowth



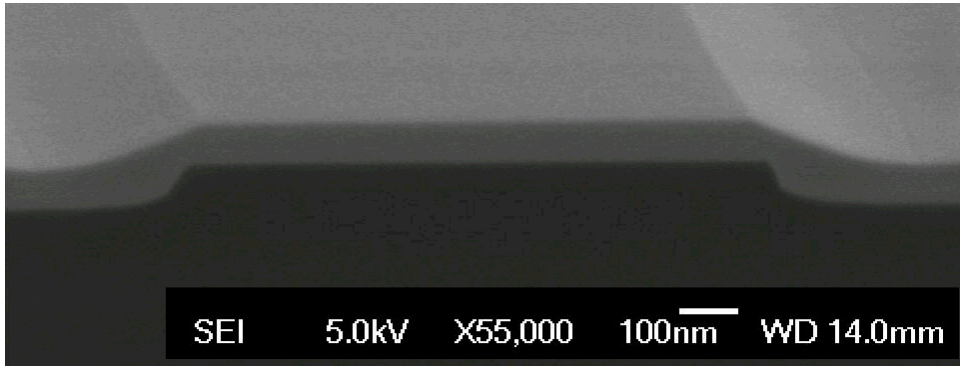

After Preheat in Chamber

# AlGaAs Regrowth



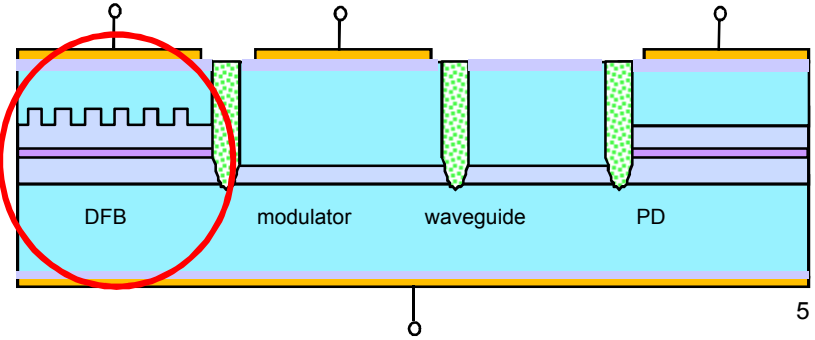

- Low growth rate
- Good preservation of gratings
- Good conformity, planarization
- Suitable for regrowth on DFB gratings

- Normal growth rate
- Good planarization
- Good conformity
- Suitable for regrowth to integrate DFB, detector, and phase modulator

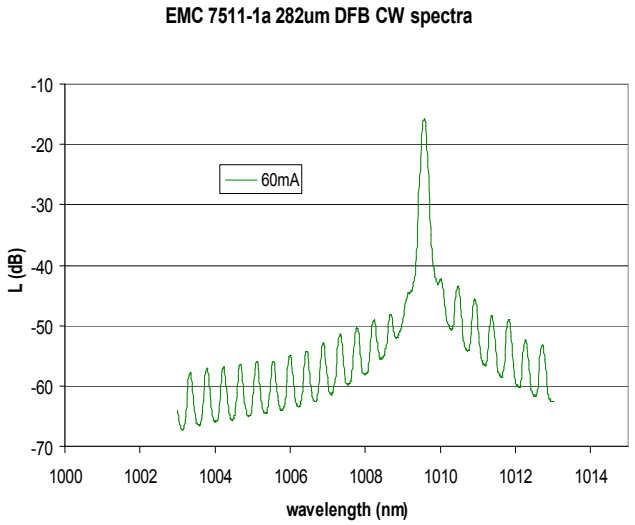


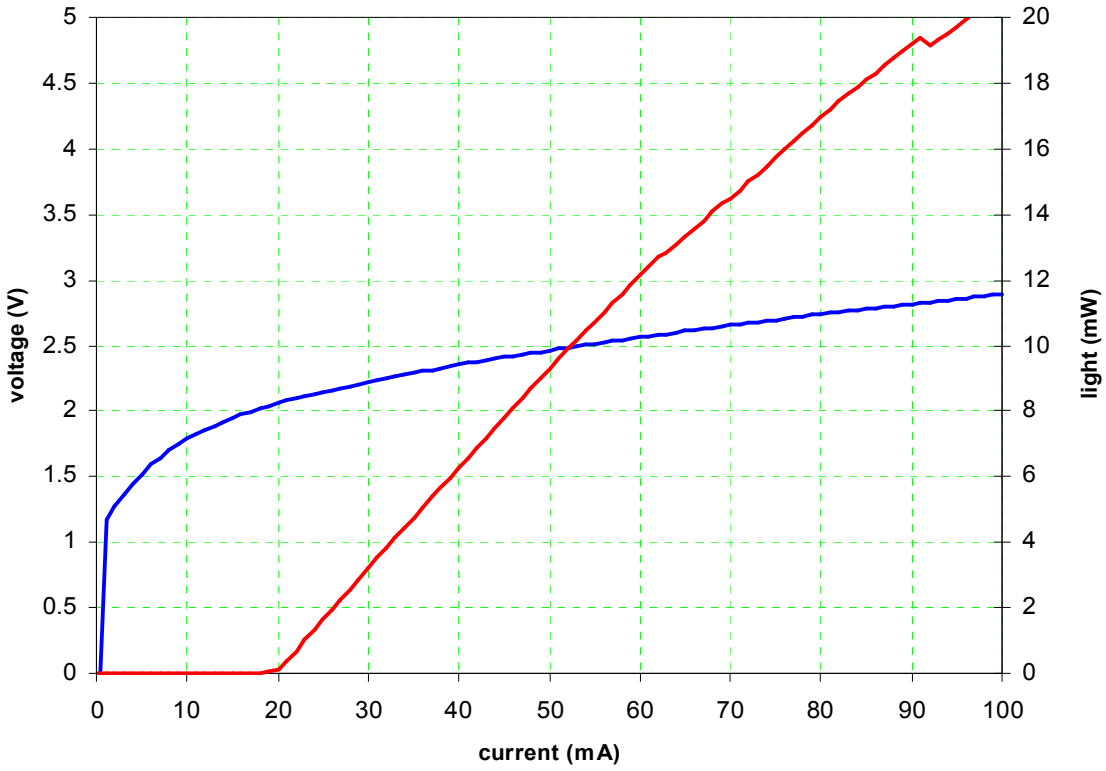

Each regrowth was 1000A of 30% AlGaAs on GaAs patterns

# PIC-DFB Laser Performance




- Singlemode CW lasing with ~30dB SMSR



# Case 2: InP Regrowth and QWI

## InP pretreatment

**Before introduction in reactor:**

BOE for 5 minutes

UV/Ozone for 60 minutes

BOE for 5 minutes

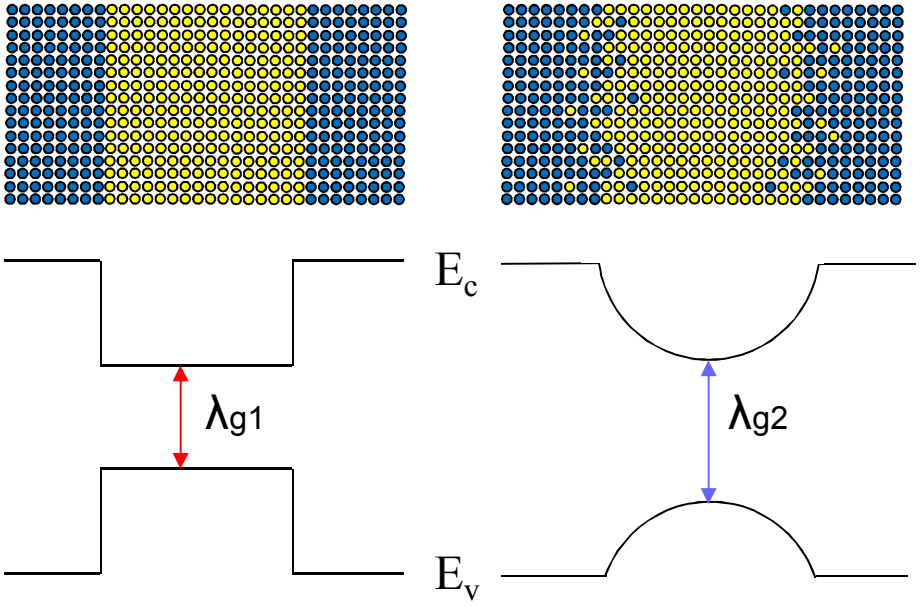
DI for 5 minutes

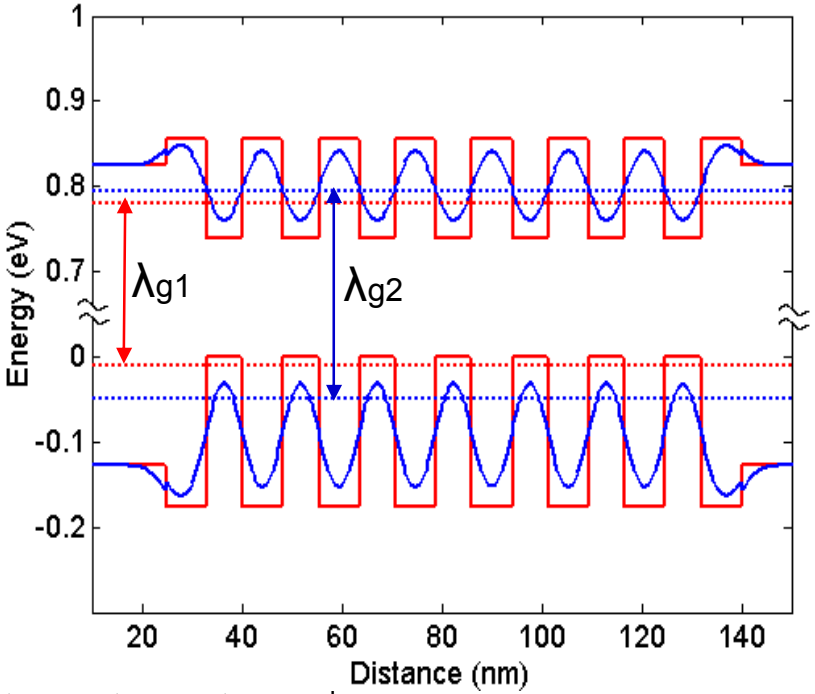
**In reactor:**

Preheat at 300$^{o}$C for 5 min. under $H_2$

Ramp to Tgrowth in 5 min. under $AsH_3$

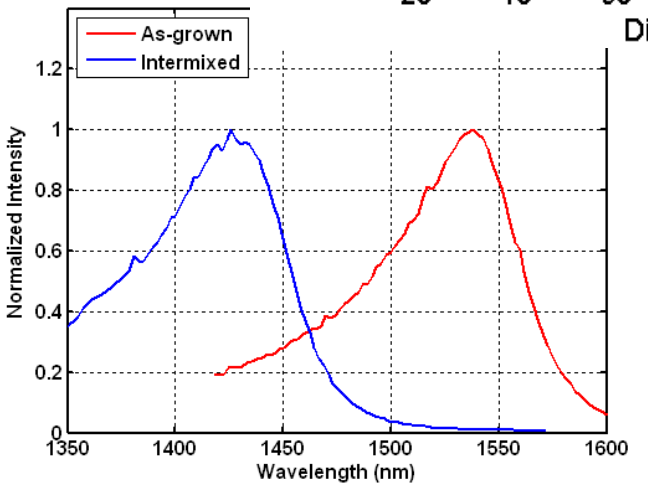
# Quantum Well Intermixing



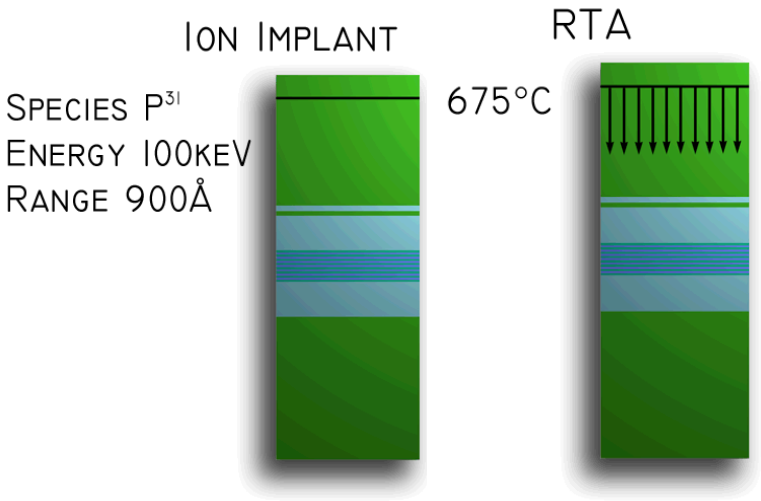

Shift absorption edge to higher energy

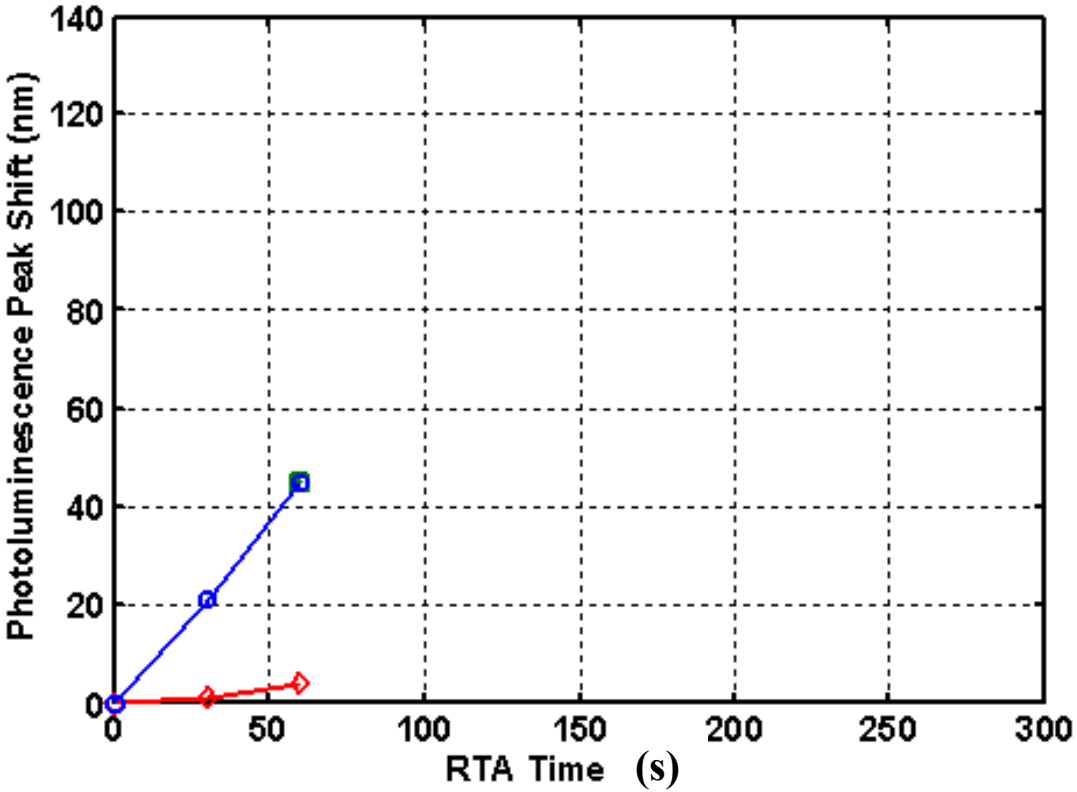
Blue shift wavelength



# Monolithic Integration Platform

- Integrate devices with different functionalities
  - Ability to program QW bandgap wavelength
  - Non-shifted band-edge for lasers/SOAs/PDs
  - Intermediate band-edge for EAMs
  - Maximal shift for low loss waveguides



# Monolithic Integration Platform

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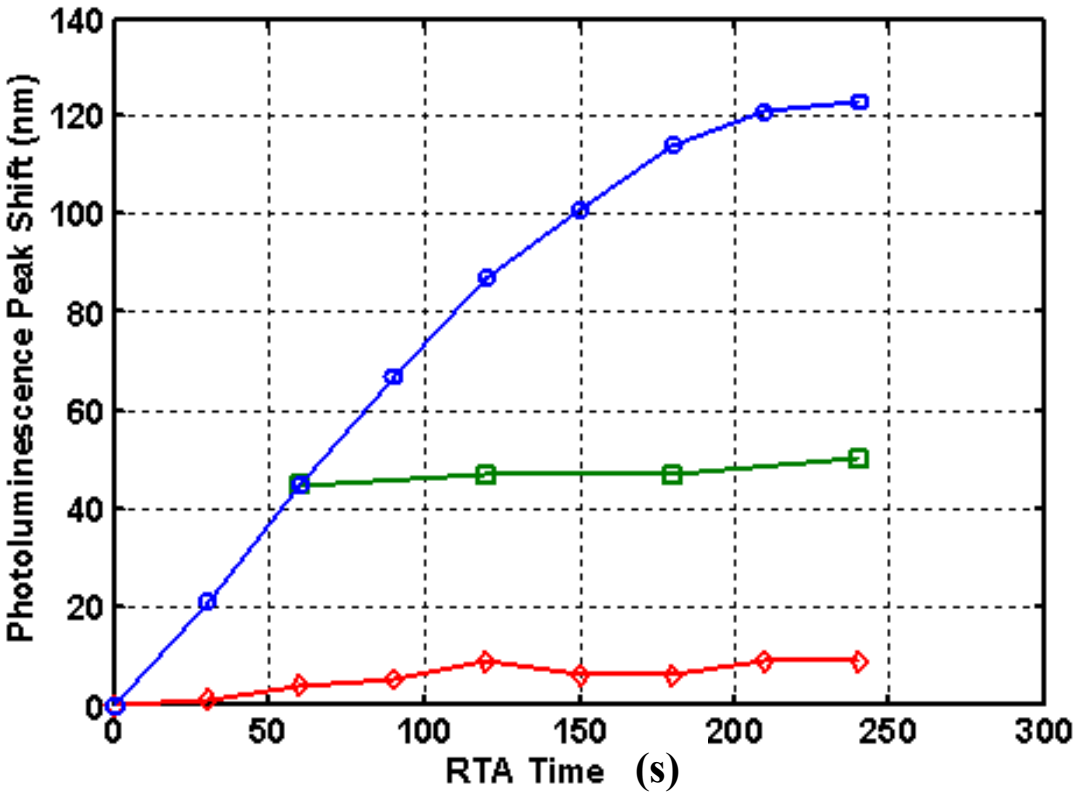
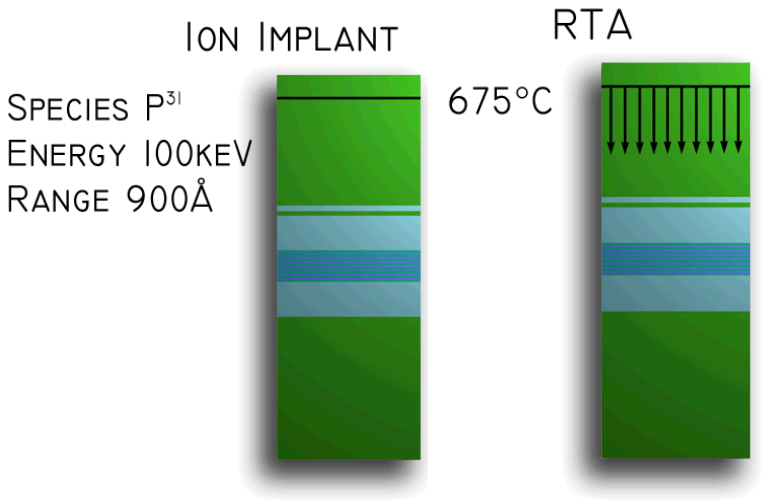
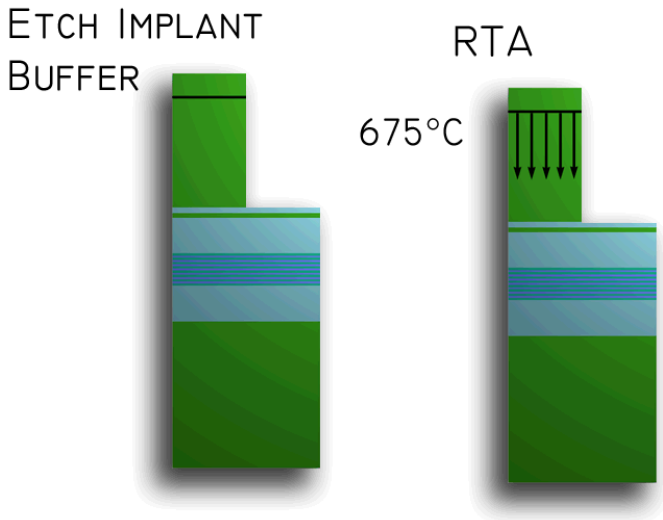
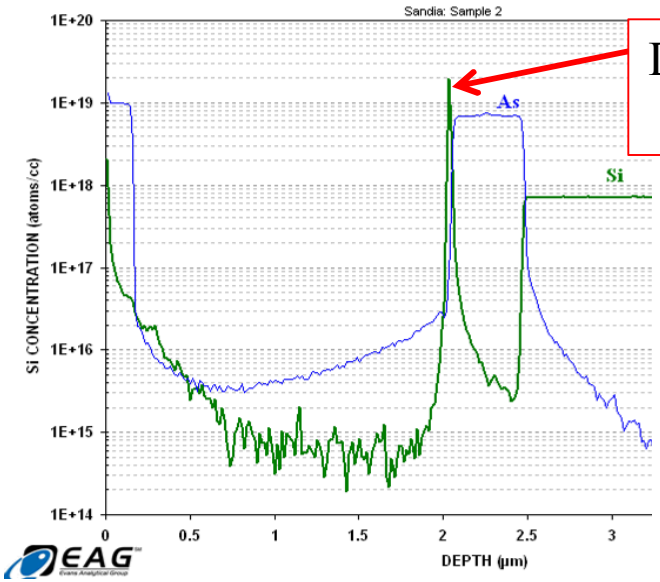


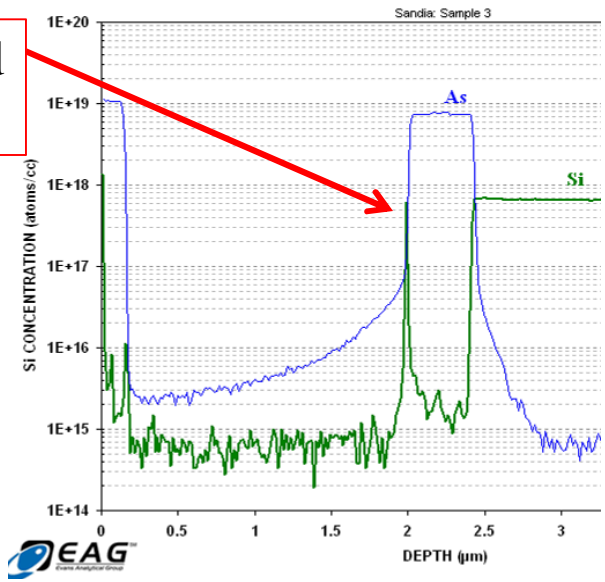



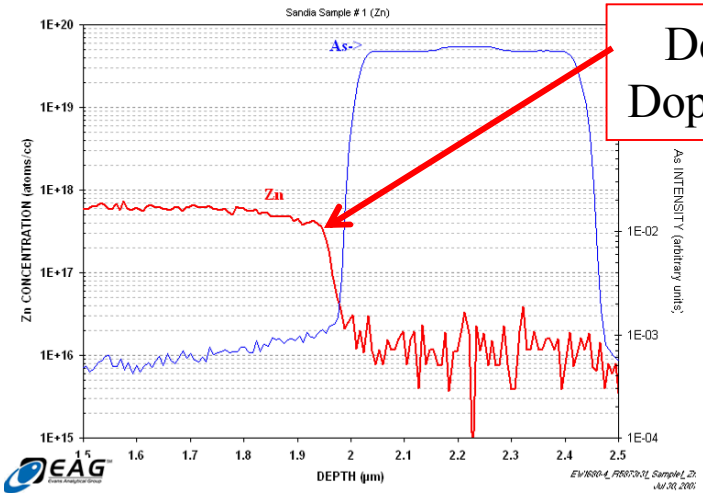
# Regrowth Interface Study- Doping



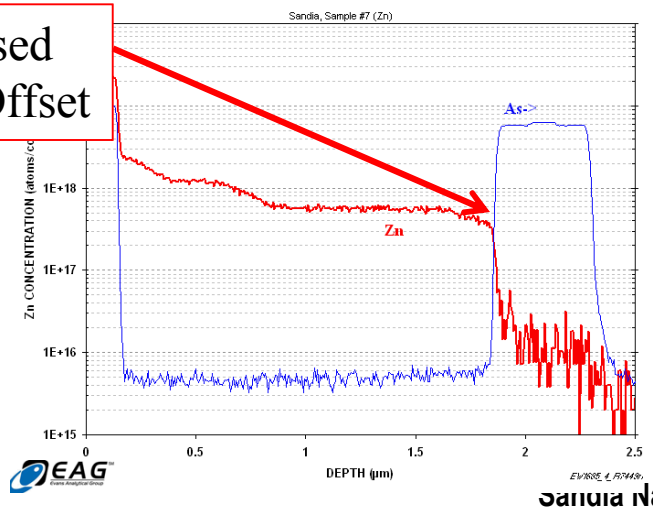

Decreased Si spike




+ in-situ activation

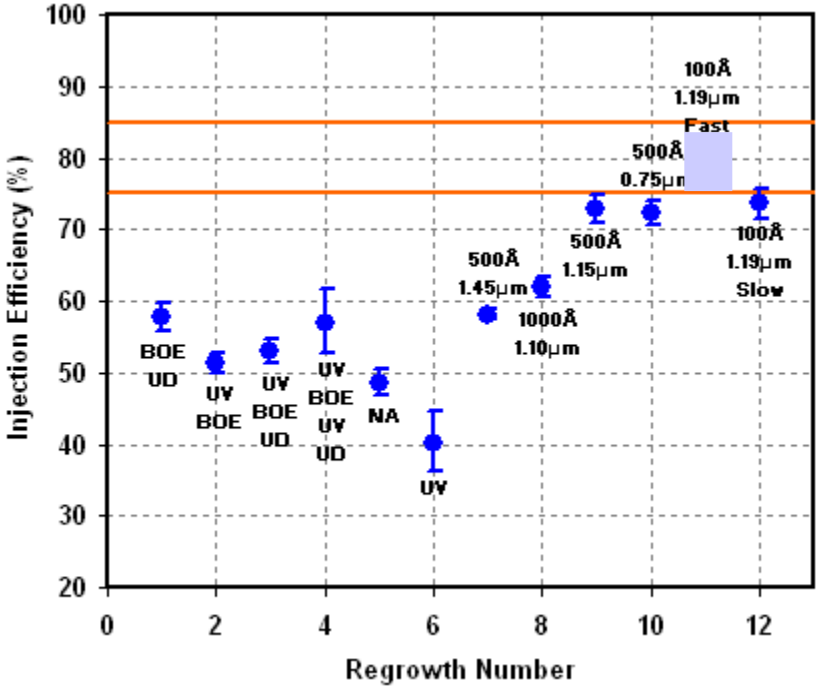


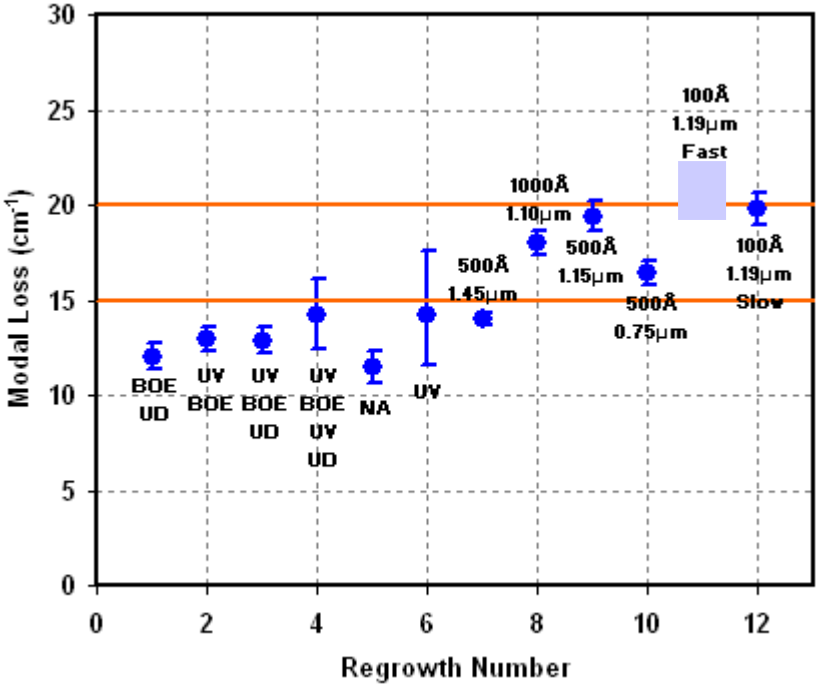

Decreased Doping Offset



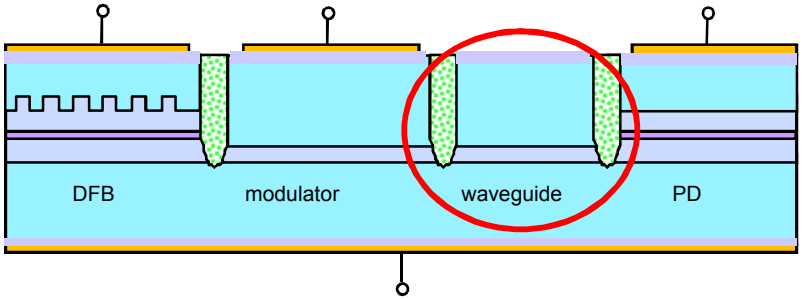
# Regrown Broad Area Laser Summary

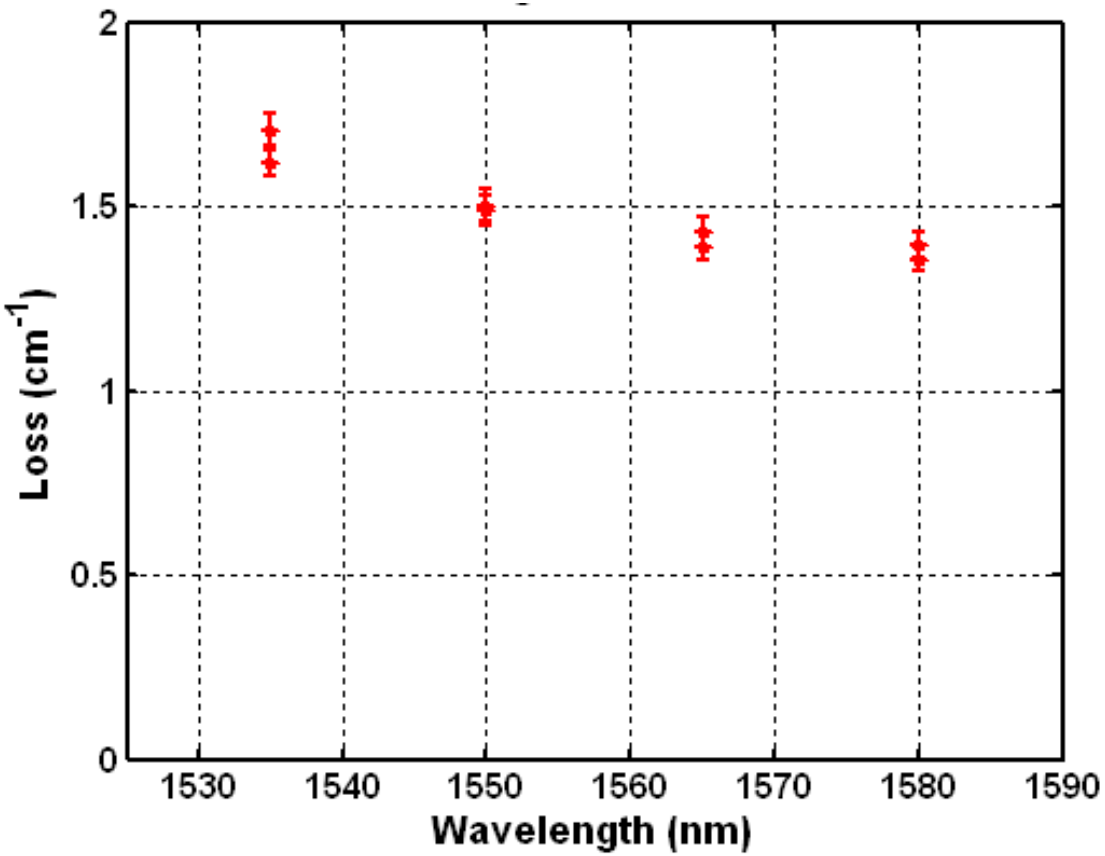
- Injection efficiency ($\eta_i$)
  - Increased from 40% to 80% with surface prep and Zn profile
  - Prep: must perform BHF dip and load upside down into reactor
  - Doping setback = 100Å
- Modal loss ($\alpha_i$)
  - Increased from 12cm$^{-1}$ to 20.8cm$^{-1}$ with reduced doping setback
  - 20.8cm$^{-1}$ not unreasonable since BALs usually demonstrate +4cm$^{-1}$ higher loss than ridge lasers



# InP PIC-DFB Waveguide Performance

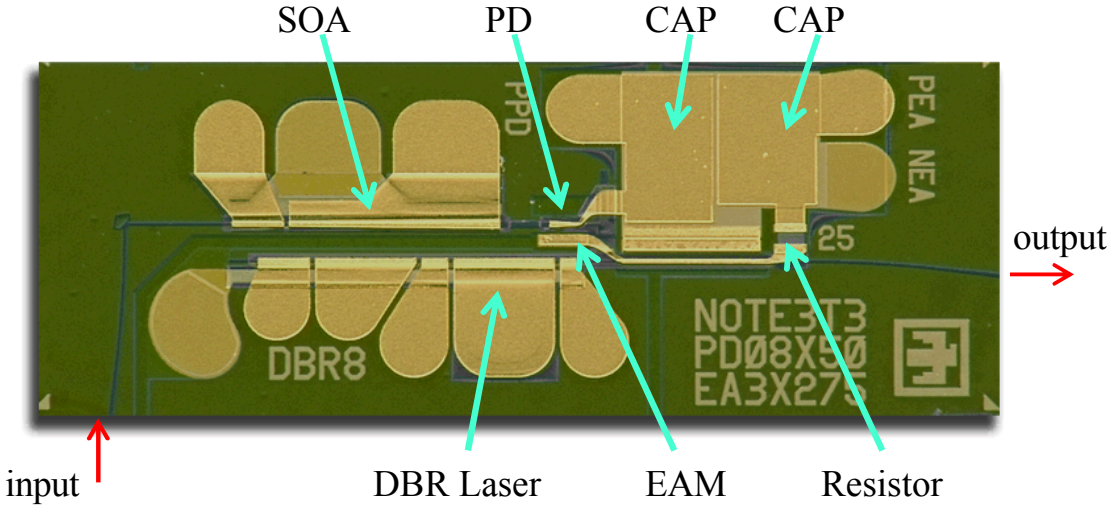


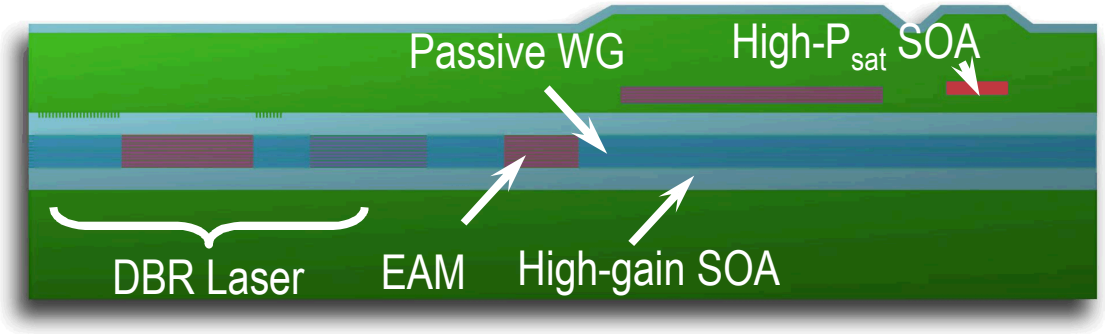



# InGaAsP\InP PICs for Multi-λ, High-Performance Optical Circuits

1550 nm wavelength

- State-of-the-art discrete photonic component performance from a single chip
  - Light generation, modulation, amplification, routing, switching and detection
- 40Gb/s optical transceivers
- WDM systems for avionics networks




## Diverse Set of Devices

DBR and DFB Lasers,
Electroabsorption Modulators,
Waveguides, High-gain SOAs,
High Power Saturation SOAs,
Evanescent Photodetectors

## PIC Functionalities

Transmitters, Receivers,
Logic Gates (AND, NOT, etc…),
RF Channelizing Filters,
Injection Locked Lasers