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High Performance Grating-Outcoupled Surface Emitting(GSE) Lasers Using Quantum Well Intermixing

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Outline

- 1st ion implantation result summary
- 2nd simulations of interdiffusion
  - Brief introduction of Diffusion
  - Simulation results
- Future Work

1st ion implantation result summary

- Ion implantation: 100keV energy, dose 5e14 cm-2, substrate temp 200C
- Disordering observed in BDR regions:
  - Maximum wavelength shift: 17.1 nm, RTA @ 675C, 12 mins
  - Wavelength shift of 15 nm occurred, RTA @ 800C, 3 mins
- Dielectric encapsulation Challenges:
  - During RTA, SiNx of 400 A couldn’t hold at high temperature for long time: RTA @ 675C greater than 2 mins

2^{nd} ion implantation

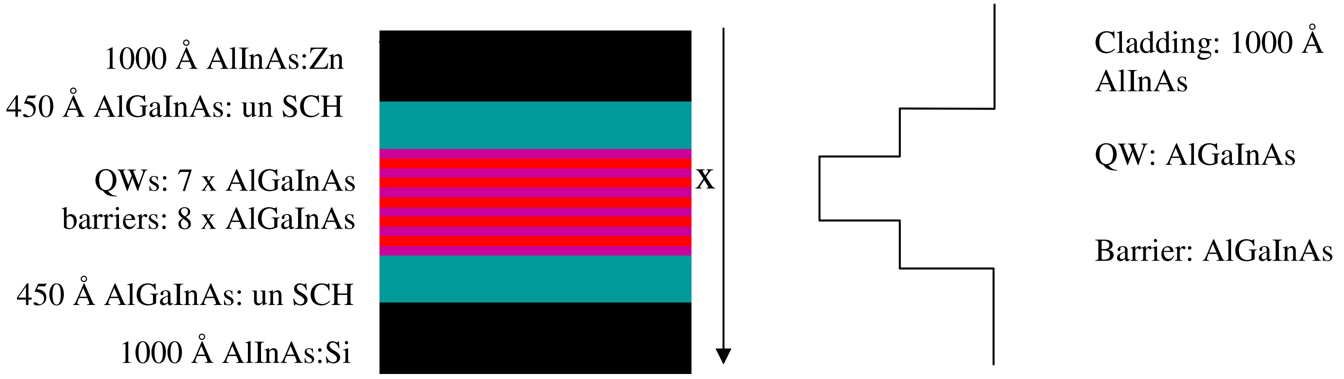
- Same ion implantation conditions
- AlGaInAs (1550nm and 1310nm) wafers and InGaAsP wafers

Brief introduction of Diffusion

- **Fick's first law of diffusion** $$J = -D\partial N(x,t)/\partial x \qquad (1)$$
- **Continuity equation for particle flux** $$\partial N/\partial t = -\partial J/\partial x \qquad (2)$$
- **Fick's second law of diffusion** $$\partial N/\partial t = D\partial^2 N/\partial x^2 \qquad (3)$$
- **Solutions of interest are in the form:** $$N(x,t) = N_0 erfc(x/2\sqrt{Dt}) \qquad (4)$$

J is the particle flux, N is the concentration of the particle, D is the diffusion coefficient, N_0 is the particle concentration at the interface (x=0).

Solutions after matching boundary conditions of the quantum well structure: Single QW Simulation



$$D = D_0 \exp(-E_A / kT) \quad (5)$$

$$L_d = \sqrt{D \cdot t} \quad (6)$$

$$y(x) = y_0 + \frac{\Delta y_0}{2}\left[erf\left(\frac{(L_x + 2x)}{4L_d}\right) + \left[erf\left(\frac{(L_x - 2x)}{4L_d}\right)\right]\right] \quad (7)$$

D is the diffusion coefficient, E_A is activation energy, k is Boltzmann's constant, T is temperature, y(x) is the compositional profile, y_0 is the initial composition profile, Δy_0 is the composition difference between quantum well and barrier. Lx is the quantum well width, Ld is the diffusion length, x is the growth direction

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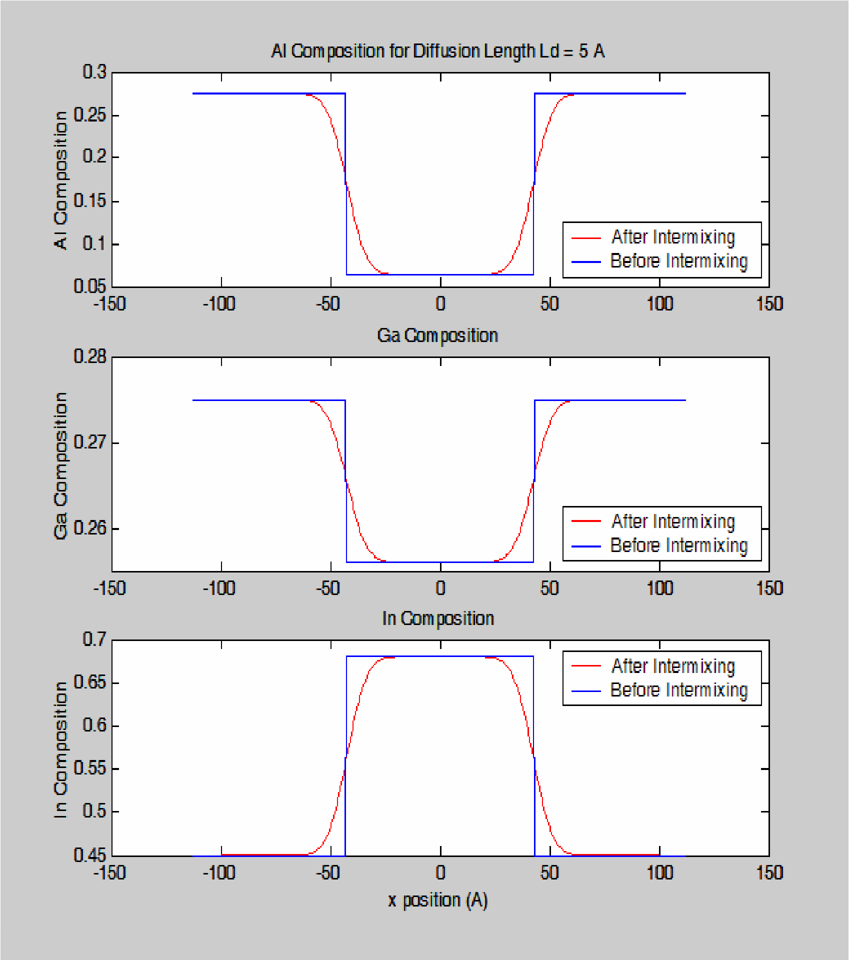
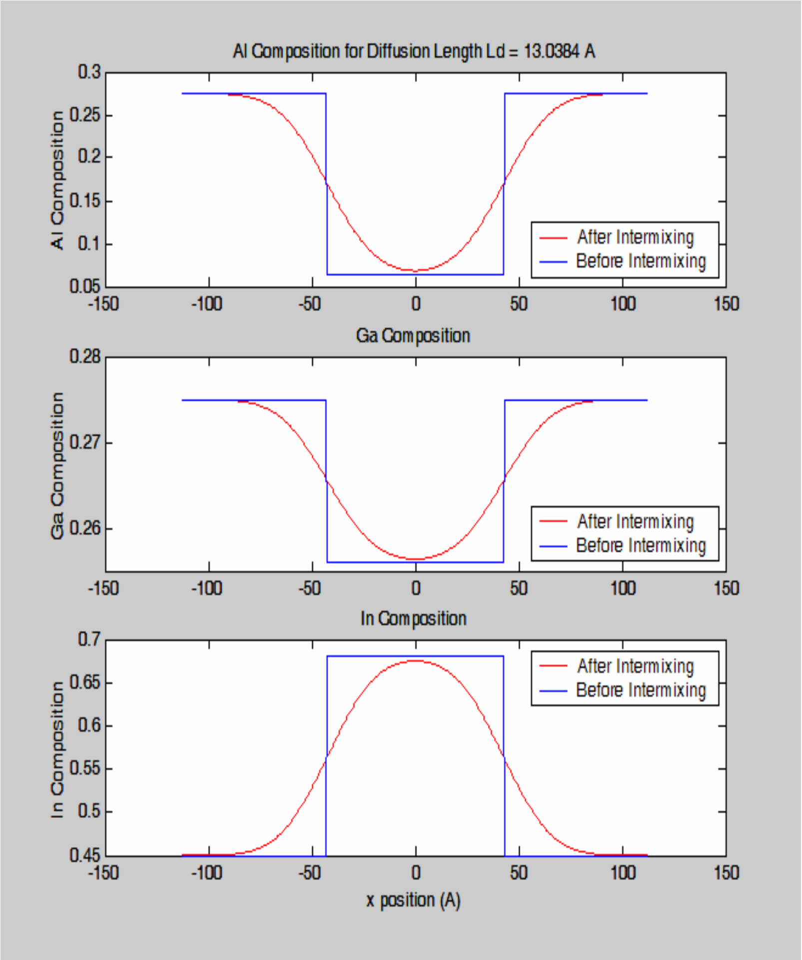
Simulations for different diffusion lengths (1)





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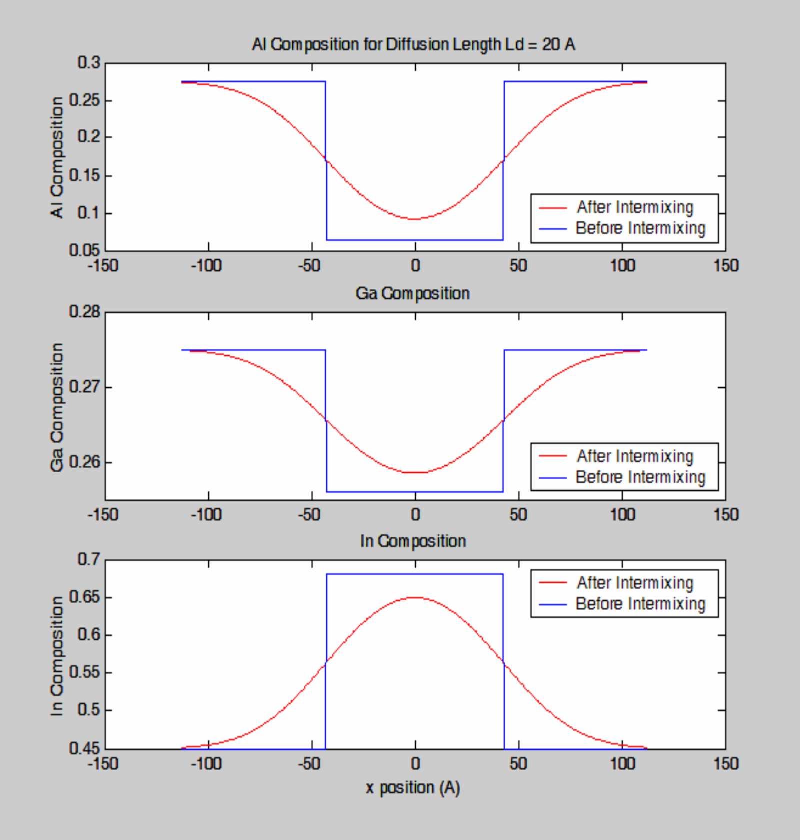
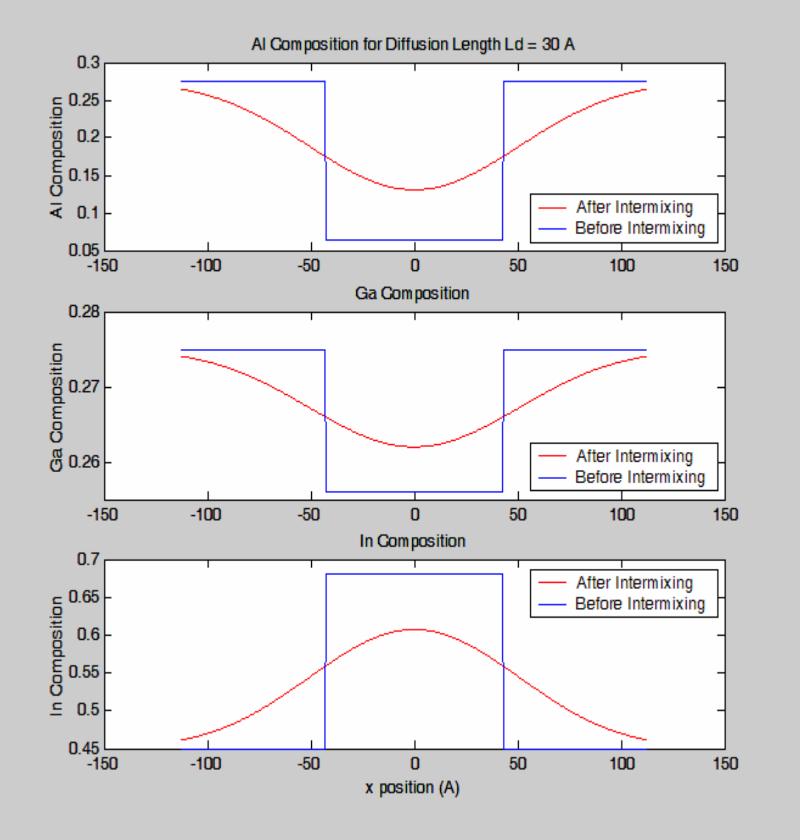
Simulations for different diffusion lengths (2)





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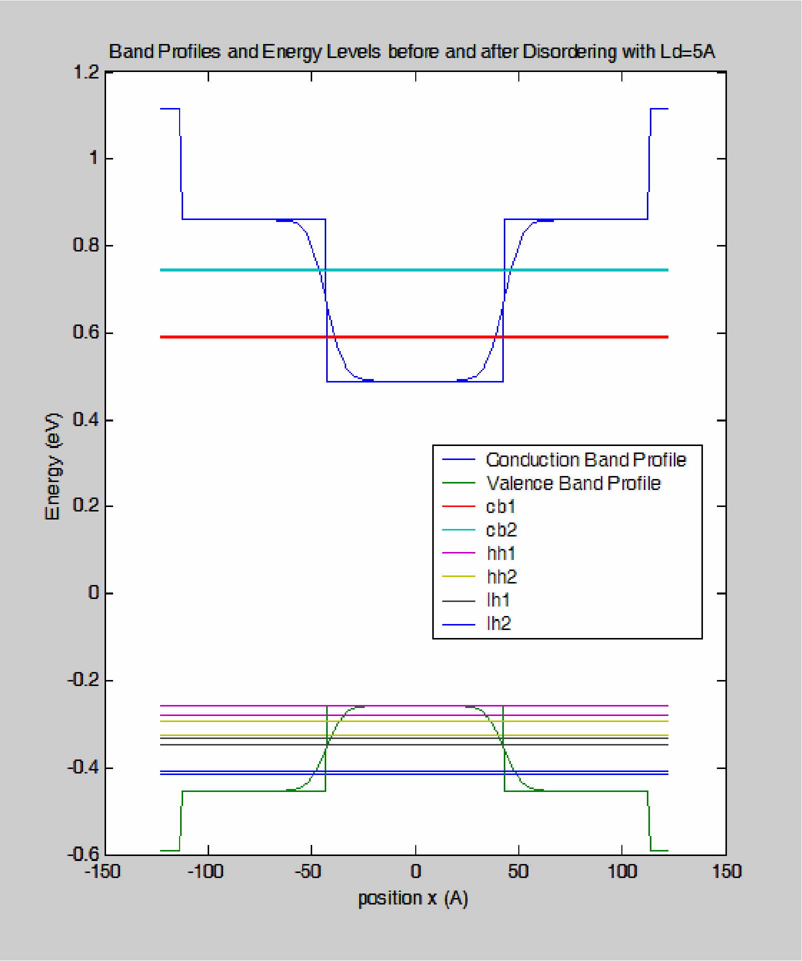
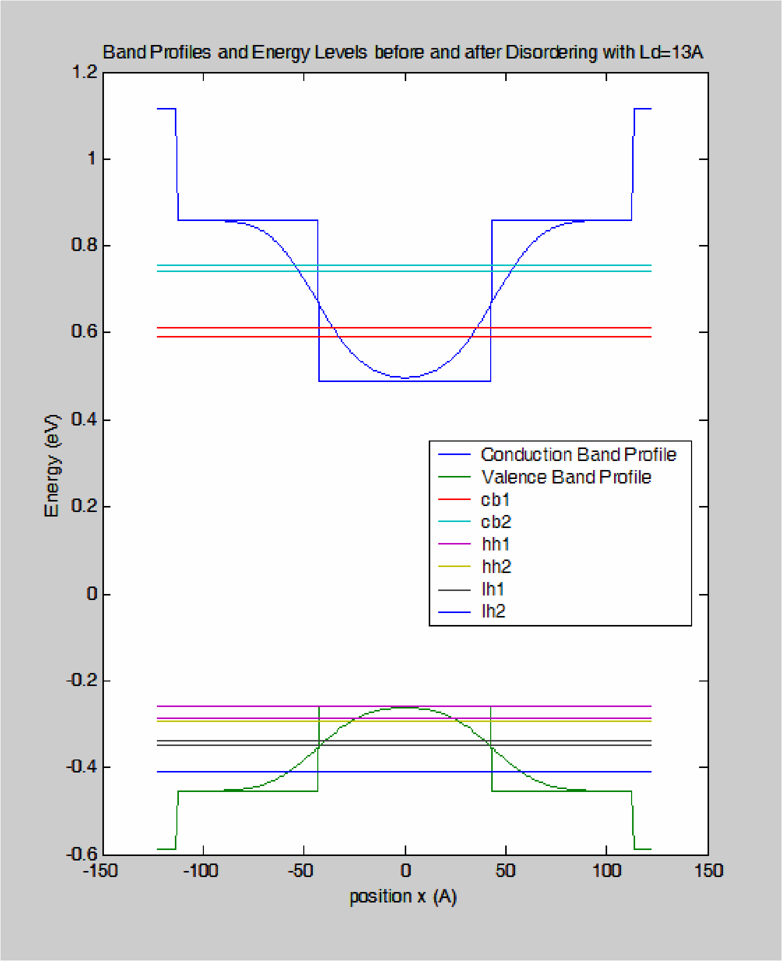
Simulations for different diffusion lengths (3)





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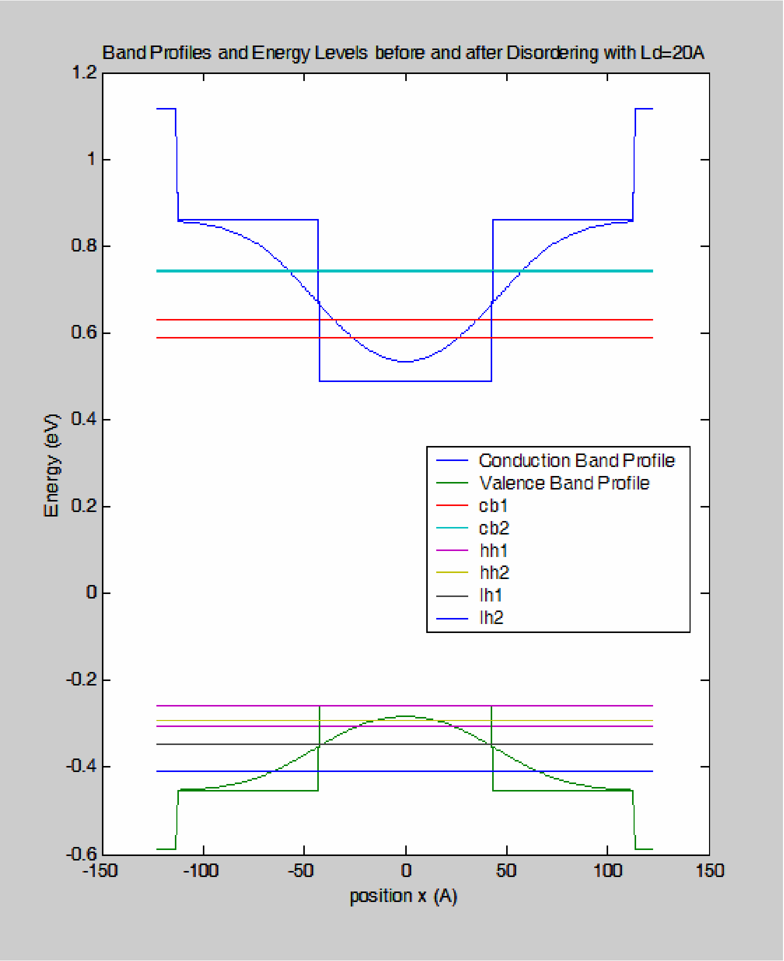
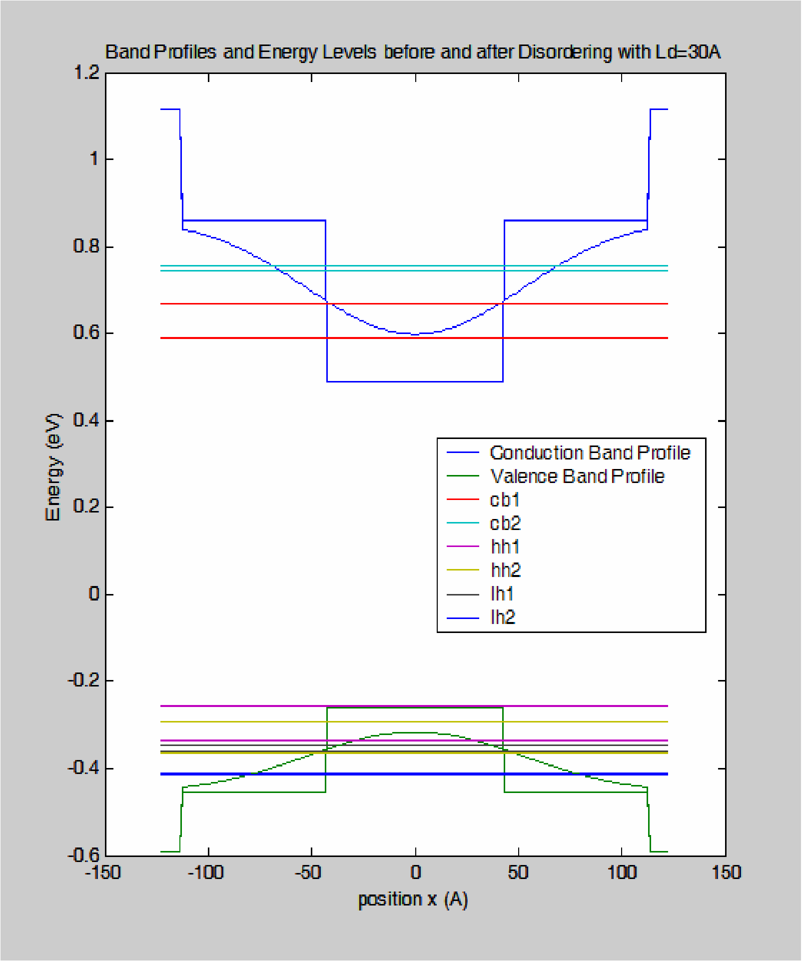
Simulations for different diffusion lengths (4)


Band Profiles and Energy Levels before and after Disordering with Ld=20A


Band Profiles and Energy Levels before and after Disordering with Ld=30A

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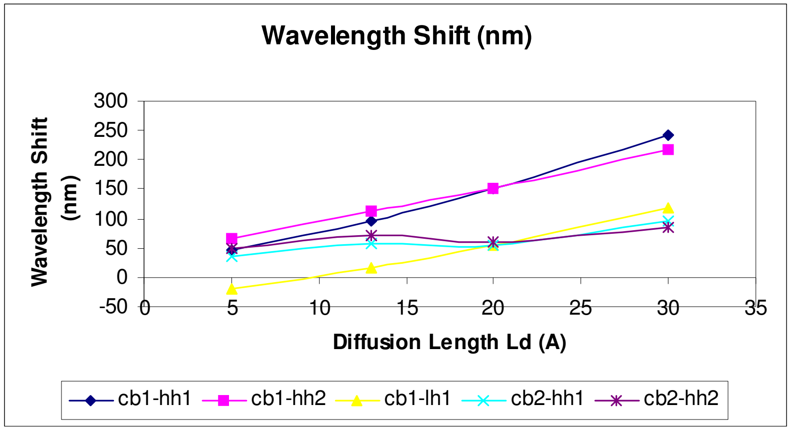
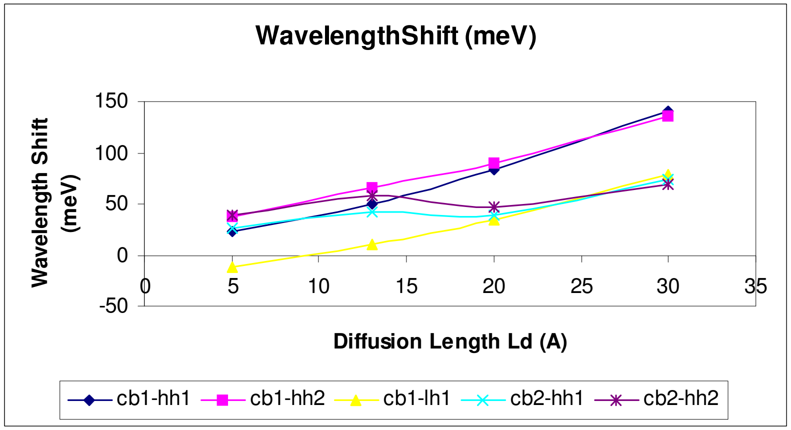
Simulations Summary





Ld (A)	Transition	λ Shift (meV)	λ Shift (nm)
5	cb1-hh1	23.8	47.0
13	cb1-hh1	49.4	94.7
20	cb1-hh1	82.8	152.5
30	cb1-hh1	140.4	242.5

Material composition difference between QW and barriers of our laser structure: Al: 0.221, Ga: 0.019, In: 0.23
the shift for Ld = 30 A: 140.4 meV, Lz = 85A
RTA@675C, 12 mins, shift ~9meV, corresponding to Ld<5 A

In simulations of GaAs/$Al_{0.3}Ga_{0.7}As$ system, the material composition difference between QW and barriers: Al: 0.3, Ga: 0.3. the shift for Ld = 30 A: ~50 meV, Lz = 80A.
(90A GaAs/100A $Al_{0.3}Ga_{0.7}As$ RTA@950C, 12 sec, shift 40 meV, corresponding to Ld~= 30 A.

* (O'Brien (1991), Interdiffusion of III-V Semiconductor Quantum Well Heterostructures and Its Applications to Integrated Electro-Optical Devices, PhD thesis, Cornell University)

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Diffusion Coefficient D and Diffusion Lengh Ld

- **Activation Energy: E_A**
- **Coefficient D_0**
- **RTA Temperature: T**
- **RTA time: t**

$$D = D_0 \exp(-E_A / kT) \quad (5)$$

$$L_d = \sqrt{D \cdot t} \quad (6)$$

Future Work

- 2nd ion implantation
  - Preprocess: photolithography and etching.
- Simulations
  - Investigate diffusion mechanism, refine the diffusion model.
  - Study how quantum well thickness and material composition differences play roles in quantum well intermixing.
  - Continue research on AlGaInAs material systems
  - Compare with InGaAsP material systems