Effect of Ion Implantation on Quantum Well Infrared Photodetectors

N. Hatefi-Kargan[1], P. Steenson[1], P. Harrison[1], E. H. Linfield[1], S. Khanna[1], S. Chakraborty[1], P. Dean[1], P. Upadhya[1], I. Farrer[2], D. A. Ritchie[2], B. Sherliker[3], M. Halsall[3]

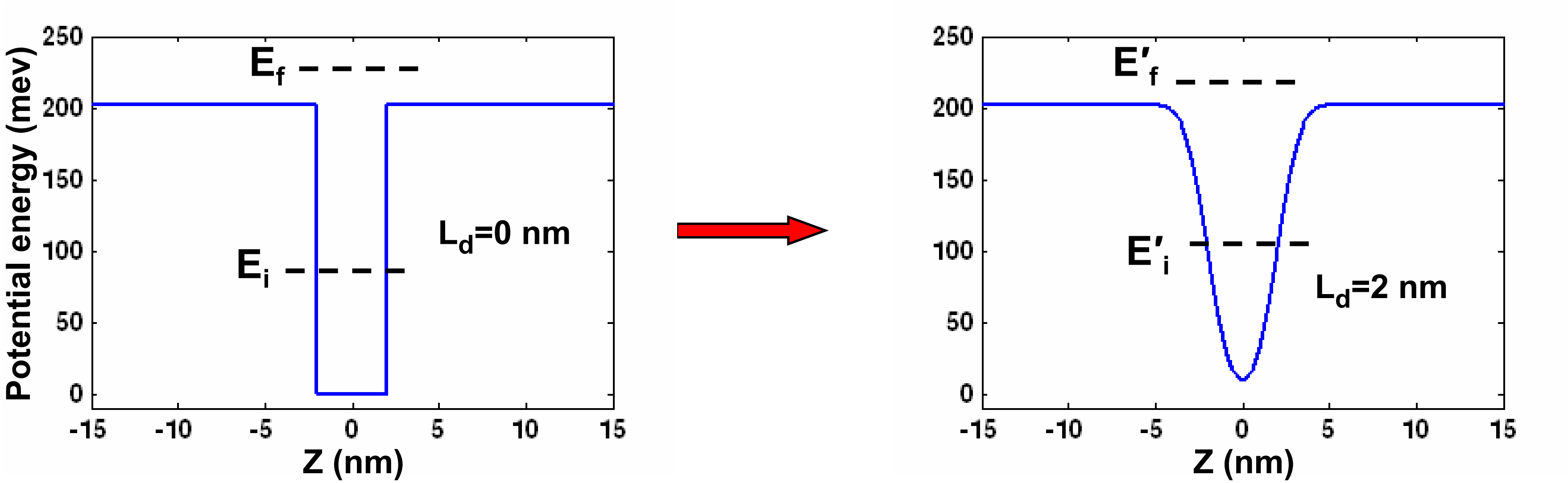
[1] School of Electronic and Electrical Engineering, University of Leeds
[2] Semiconductor Physics Group, University of Cambridge
[3] School of Electronic and Electrical Engineering, University of Manchester

Outline

- Quantum well intermixing
- Motivation
- Diffusion modelling
- Samples and experimental methods
- Results
- Summary

Quantum well intermixing

- Quantum well intermixing is a postgrowth process
- Intermixing changes the shape of the potential well and hence absorption wavelength



$E_f > E'_f$

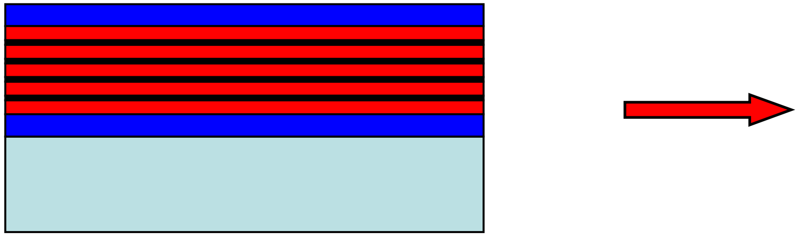
$E_i < E'_i$

Motivation

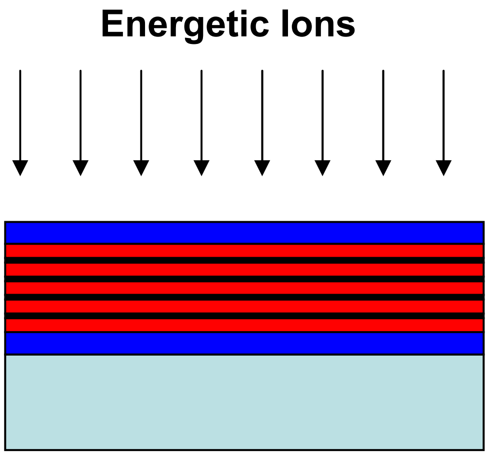
- Fabricating a spectrometer by intermixing a quantum well detector structure using ion implantation and rapid thermal annealing
- Each stripe is implanted with a different dose, giving different degrees of intermixing and hence different operating wavelength

▪ Enhancing intermixing by ion implantation

- Diffusion rate of atoms in an as-grown material is low
- Quantum well intermixing techniques are based on introducing defects to the quantum well (QW) region of an as-grown wafer



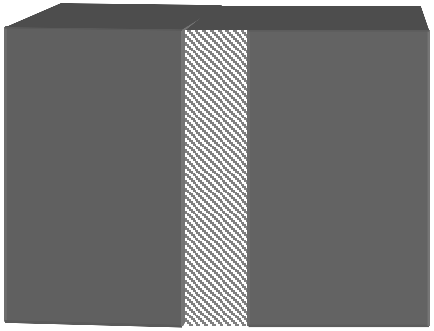
MBE grown wafer with a small amount of defects



Ion implantation increases the number of defects

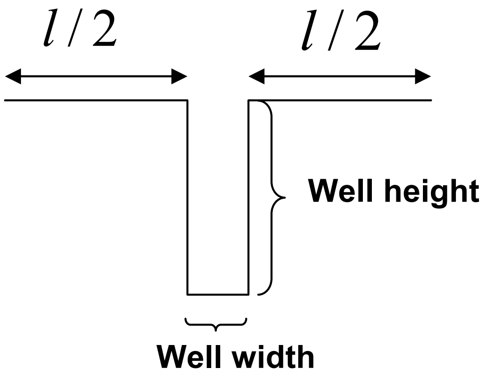
Diffusion modelling

- Diffusion equation and Schrödinger equation are solved by finite deference method
- These equations are solved in a region that contains only one quantum well



$$\partial C(z,t)/\partial t = \frac{\partial}{\partial z}(D\partial C(z,t)/\partial z)$$

$$\frac{\partial}{\partial z}(\frac{\hbar}{2m^{*}}\partial\Psi(z)/\partial z)+V(z)\Psi(z)=E\Psi(z)$$



Discretizing the equations to finite differences

Diffusion equation:

$$C(z_i, t+\delta t) = C(z_i, t) + 2D\delta t \left\{ \frac{C(z_{i+1}, t) - C(z_i, t)}{h_{i+1}(h_i + h_{i+1})} + \frac{C(z_{i-1}, t) - C(z_i, t)}{h_i(h_i + h_{i+1})} \right\}$$

Diffusion length: $L_d = 2\sqrt{Dt}$ nm

Schrödinger equation:

$$\frac{-2\hbar^2}{h_i[m^*(z_{i-1})+m(z_i)](h_i+h_{i+1})}\psi(z_{i-1}) +$$

$$\left\{\frac{2\hbar^2}{h_k[m(z_{i-1})+m(z_i)](h_i+h_{i+1})}+\frac{2\hbar^2}{h_{i+1}[m(z_i)+m(z_{i+1})](h_i+h_{i+1})}+V(z_i)\right\}\psi(z_i)+$$

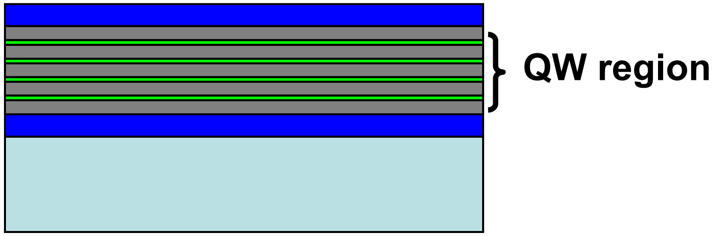
$$\frac{-2\hbar^2}{h_{i+1}[m(z_i)+m(z_{i+1})](h_i+h_{i+1})}\psi(z_{i+1})=E\psi(z_i)$$

Samples and experimental method

- Wafers were grown by MBE method

5nm GaAs / 30nm $Al_{0.29}Ga_{0.71}As$, structure with 50 periods. 3.5 nm from middle of the wells Si doped $5.5\times17\ cm^{-3}$

4nm GaAs / 50nm $Al_{0.27}Ga_{0.73}As$, structure with 50 periods. 2.5 nm from middle of the wells Si doped $1.2\times18\ cm^{-3}$

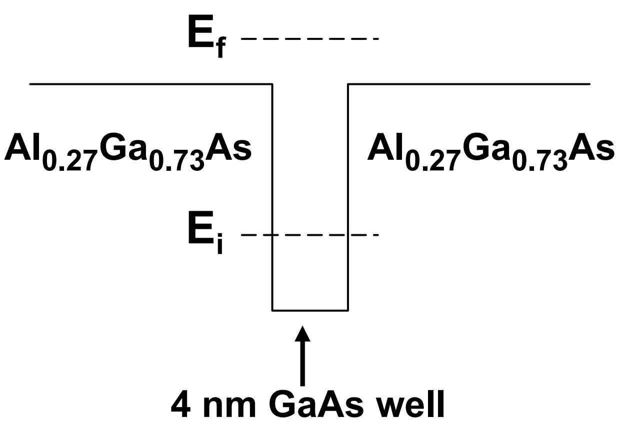


Wafer A
at 650°C

Wafer B
at 600°C

Wafer C
at 625°C

- Simulation results



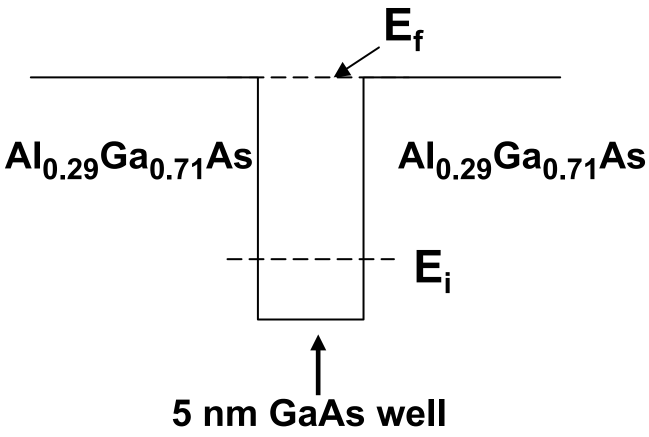
E_f

$Al_{0.27}Ga_{0.73}As$

$Al_{0.27}Ga_{0.73}As$

E_i

4 nm GaAs well



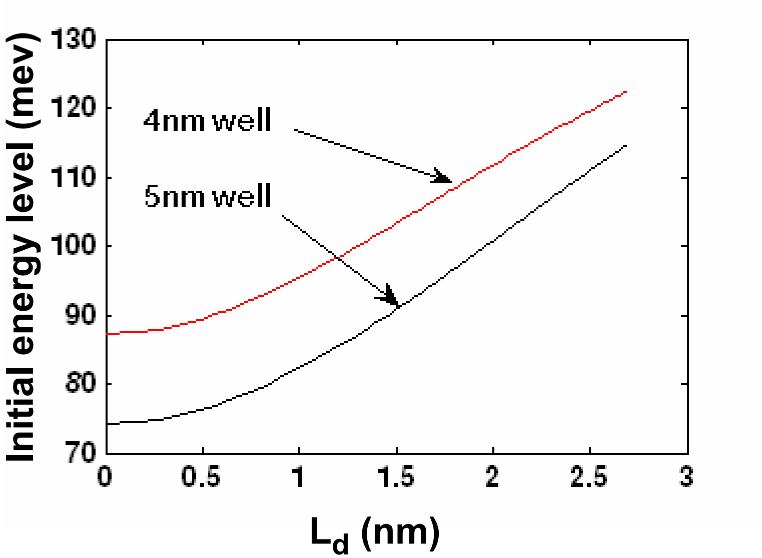
E_f

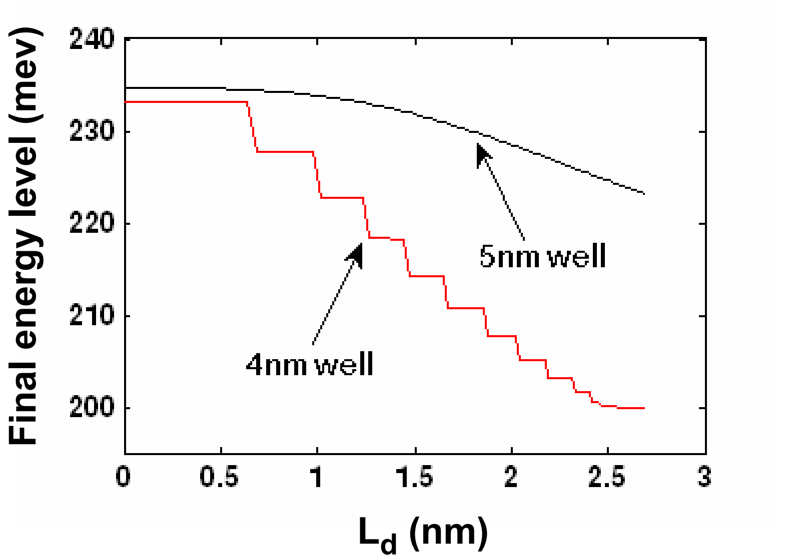
$Al_{0.29}Ga_{0.71}As$

$Al_{0.29}Ga_{0.71}As$

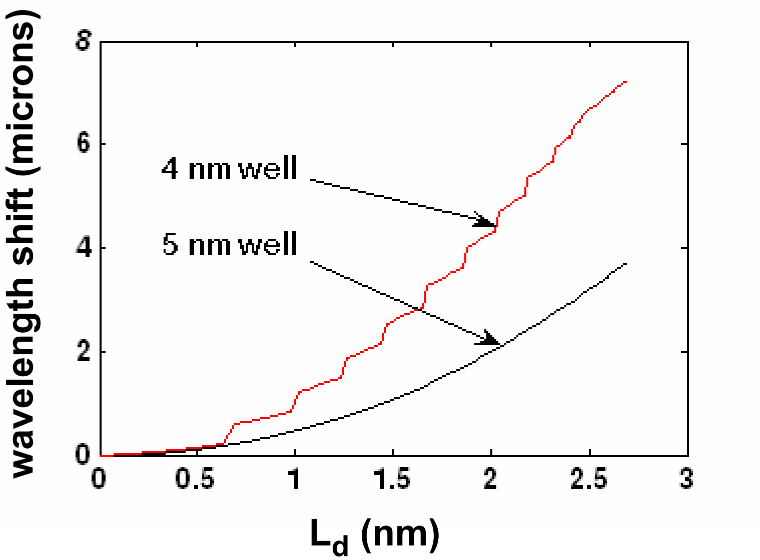
E_i

5 nm GaAs well





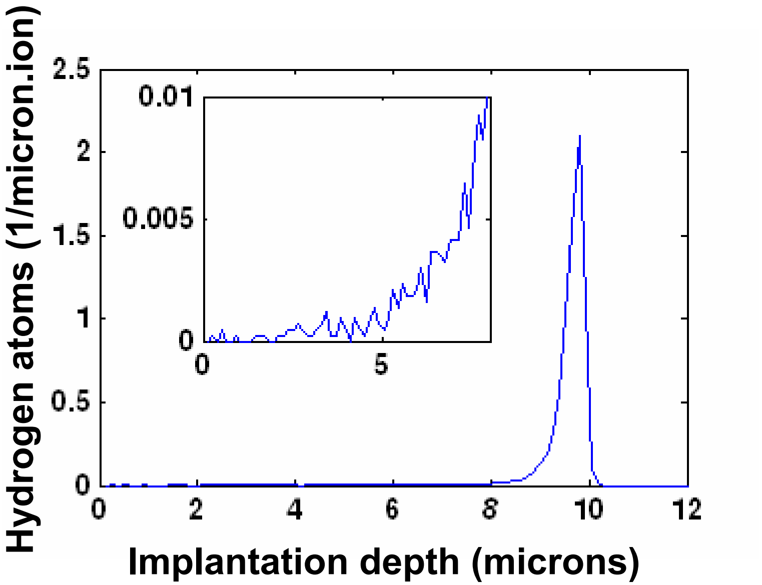
▪ Simulation results: degree of red-shift

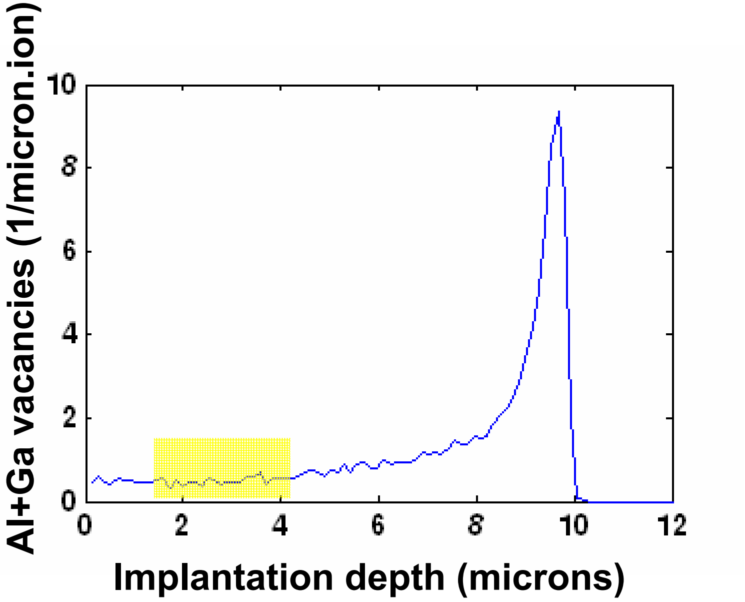


- Narrow well bound to continuum detector leads to larger red-shift than a wide well bound to quasi-bound detector

▪ Studied samples

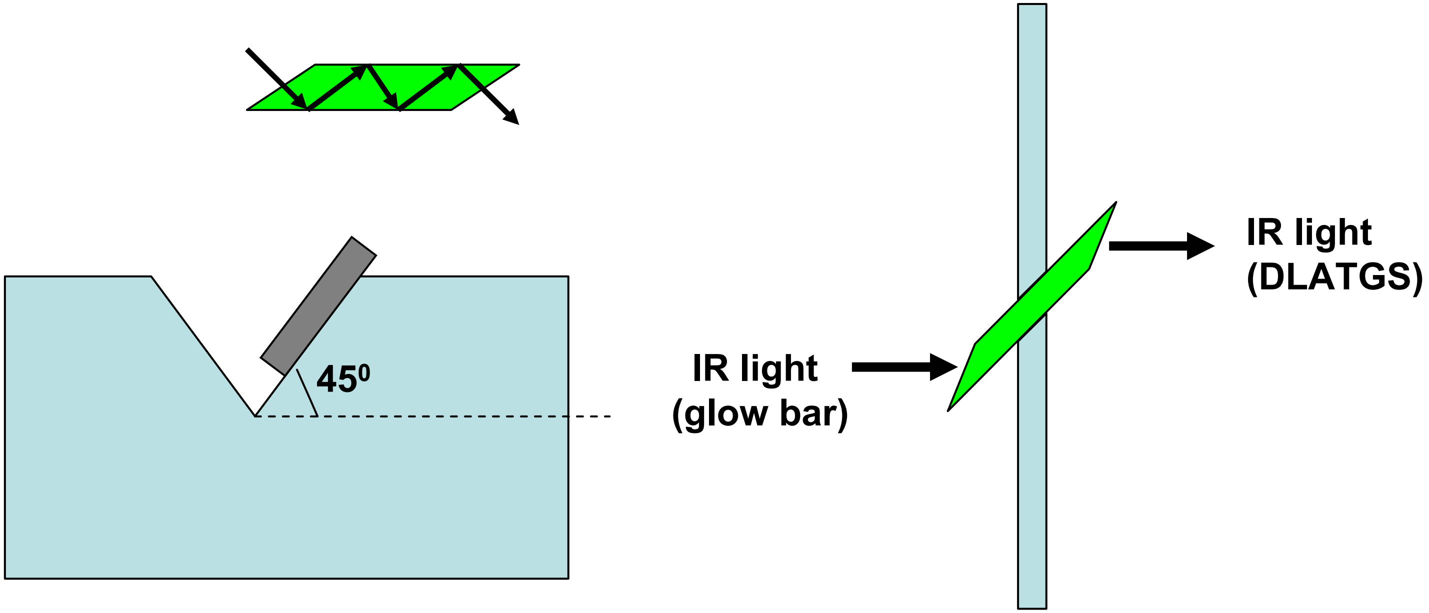
- 5mm×9mm samples are taken from the wafers
- Some samples are implanted by 1700 keV hydrogen molecules with different doses.
- Light atoms create more point defects than defect clusters
- 1700 keV hydrogen molecules creates uniform damage in active region of the samples





▪ Absorption spectra measurement method

- Absorption spectra of the samples measured at room temperature by using FTIR machine



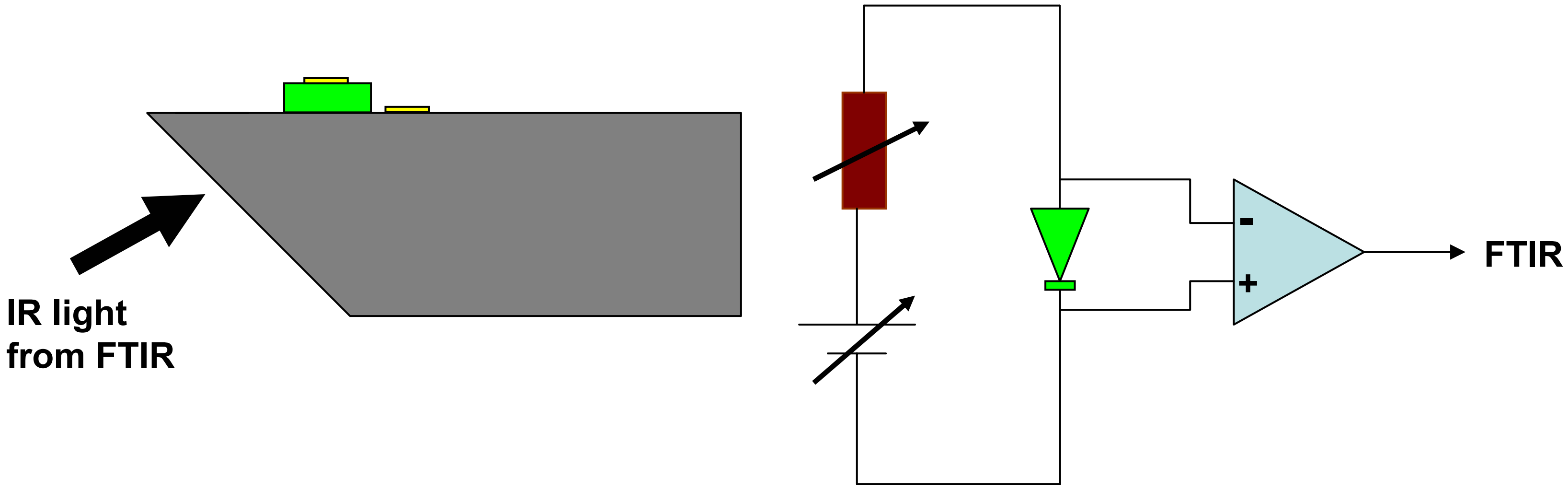
45^0

IR light (glow bar)

IR light (DLATGS)

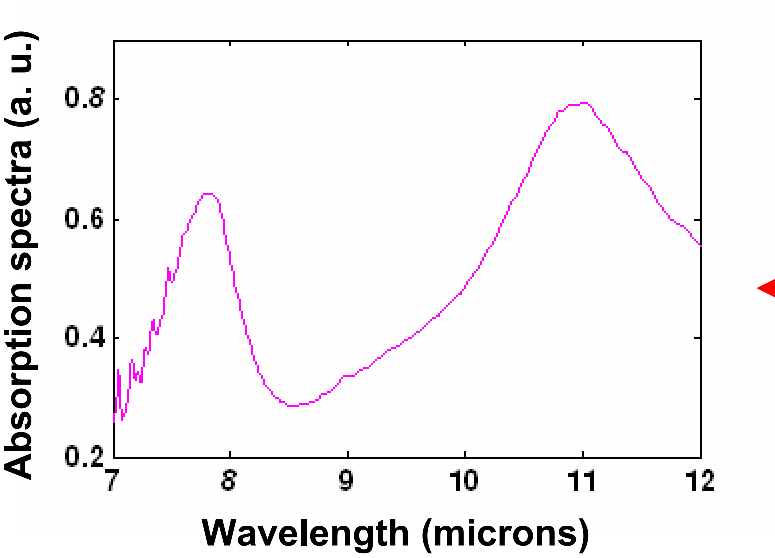
Photocurrent spectra measurement method

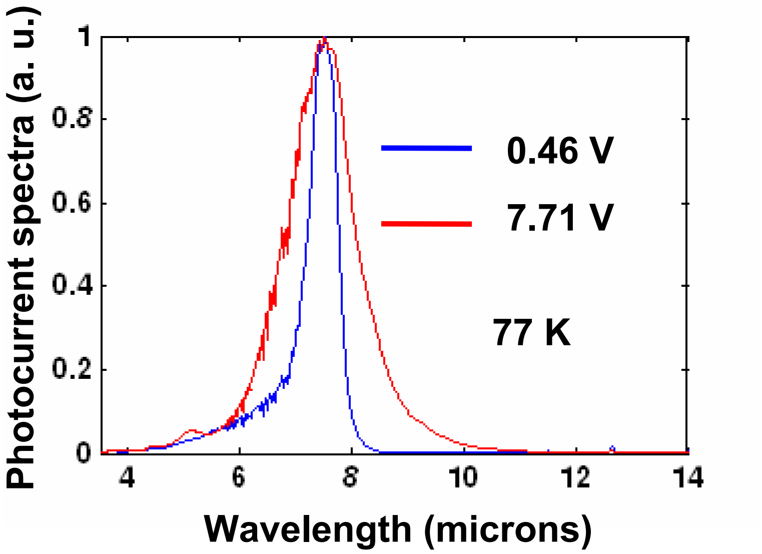
- Detectors were fabricated at the edge of a 45 degree polished sample
- Photo current spectra measured by FTIR



▪ Absorption and photocurrent spectra of an as-grown sample from wafer B

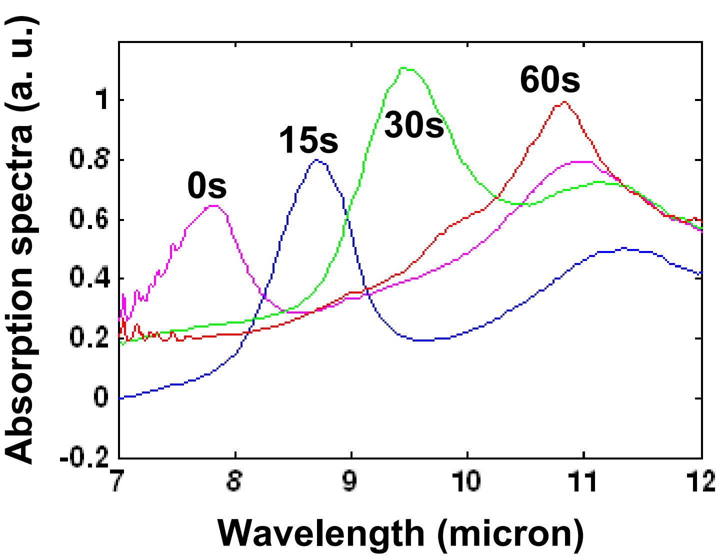
- Wafer B is the structure with 5 nm wells grown at 600ºC





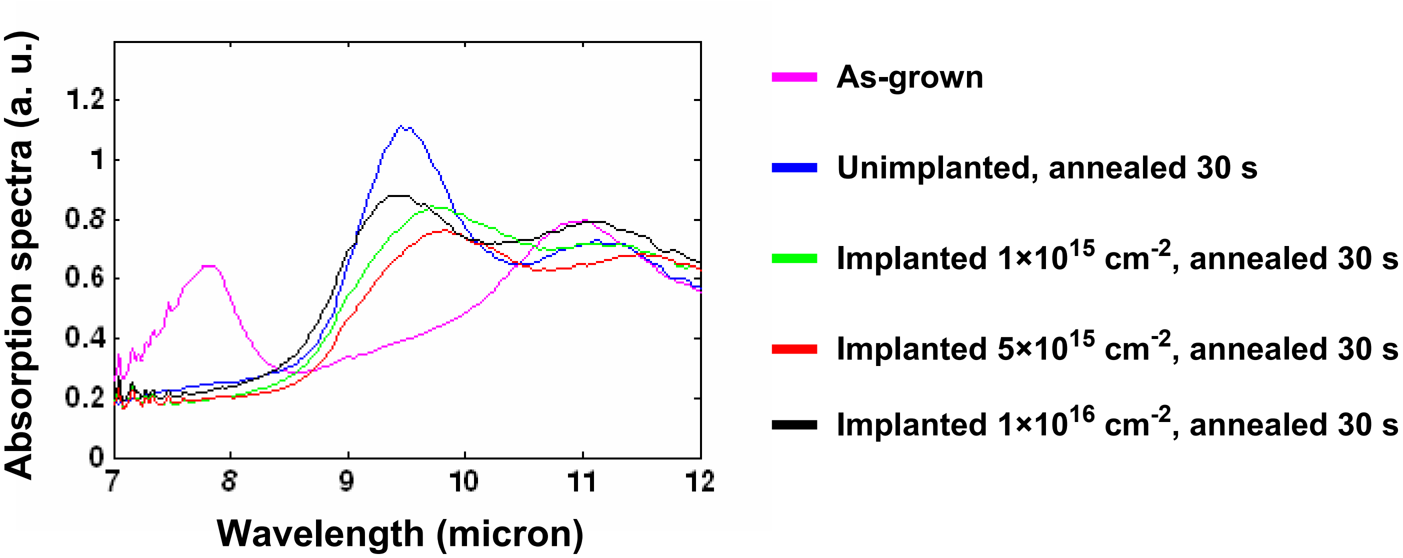
▪ Effect of annealing time on unimplanted samples from wafer B

- Annealing was done by capping samples with silicon wafers
- Annealing temperature: 950ºC
- Large red-shift: 3 microns



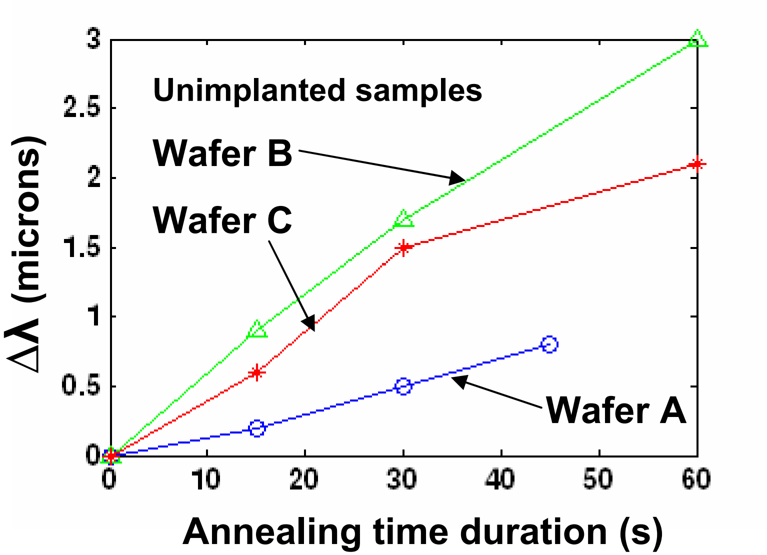
Effect of implantation on samples from wafer B

- Annealing was done by capping samples with silicon wafers
- Annealing temperature: 950ºC
- Ion implantation enhanced diffusion slightly

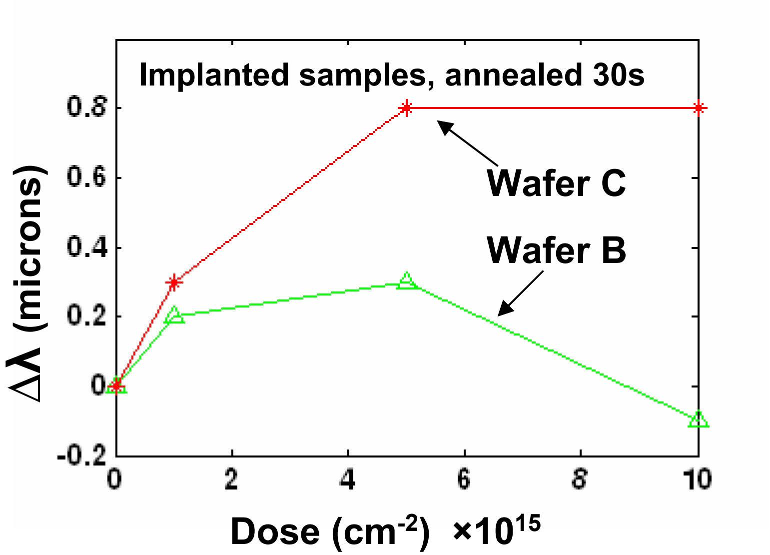


Comparison the effect of annealing, and implantation on wafers A, B, and C

$\Delta\lambda = \lambda$ (annealed) – λ (as-grown)



$\Delta\lambda = \lambda$ (implanted) – λ (unimplanted)



As-grown defects: Wafer A < Wafer C < Wafer B

Summery

- Bound to continuum detectors where the final energy is on top of the wells can lead to more red-shift than the bound to quasi-bound detectors where the final energy level is at the edge of the wells
- As-grown defects can lead to large red-shift
- Ion implantation enhances diffusion considerably if the number of as-grown defects is lower