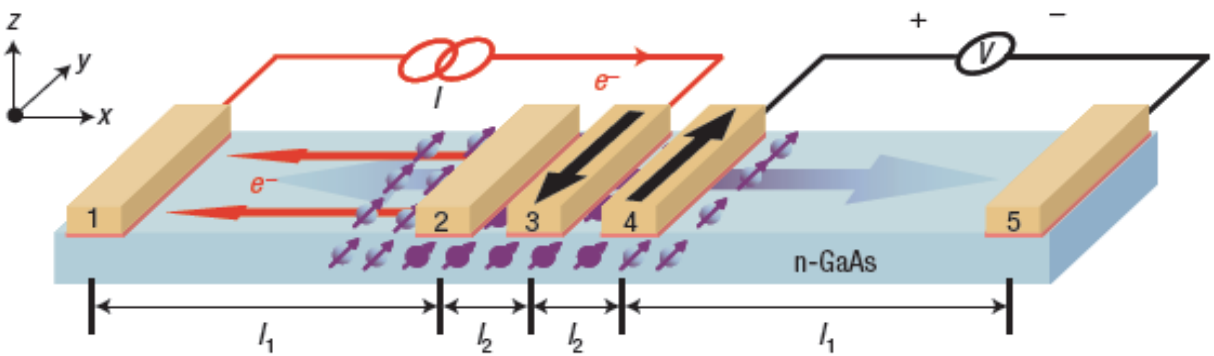
Fe – GaAs(001) Interface

A Case Where High Energy XPS Might help Optimize Spin Injection Efficiency in Spintronic Devices

Philip Ryan – Ames Laboratory / Argonne National Laboratory

J-W Kim, D. Keavney, R. Rosenberg L. Assoufid - Argonne National Laboratory
Justin Shaw - National Institute of Standards and Technology
Charles M. Falco - University of Arizona

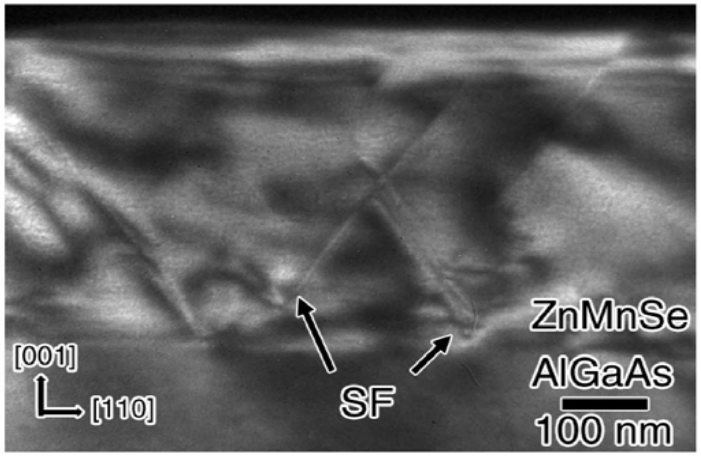
Fe-GaAs(001) based Prototypical Spin-Valve Device



Xiaohua Lou et al. Nature Physics, V 3, 197, (2007)

Interfacial Structural Disorder And Spin Injection Efficiency

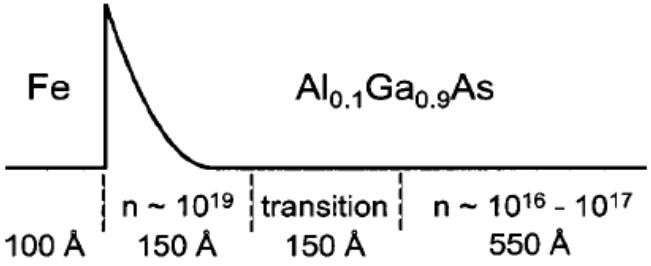
- R. M. Stroud et al correlated interface microstructure with spin injection efficiency
Phys. Rev. Lett. 89, 166602-1 (2002)



Fe-AlGaAs(001) Spin LED :
Tailored Schottky Barrier

- R. M. Stroud et al correlated interface microstructure with spin injection efficiency
Phys. Rev. Lett. 89, 166602-1 (2002)

-A. T. Hanbicki et al. demonstrated ~30% Spin Injection Efficiency Fe-AlGaAs system
Appl. Phys. Lett. 80,1240, (2002) And 82, 4092 (2003)



Fe-GaAs(001) Prototypical Spin Injection System

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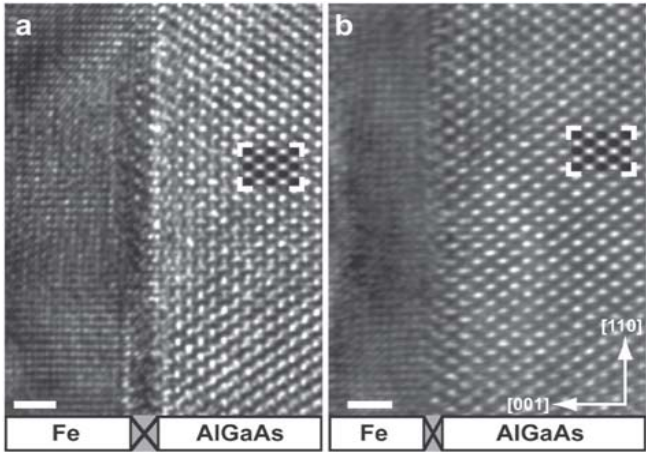
Appl. Phys. Lett. 80,1240, (2002) And 82, 4092 (2003)

- C. Adelmann et al. demonstrated ~50% Spin Injection Efficiency but with a post growth anneal at 250°C
Phys. Rev. B, 71, 121301, (2005)

Fe-GaAs(001) Prototypical Spin Injection System

-Thomas Zega et al. Phys. Rev. Lett. 96, 196101 (2006) used HRTEM to correlate a 44% spin injection increase with interfacial structural order.



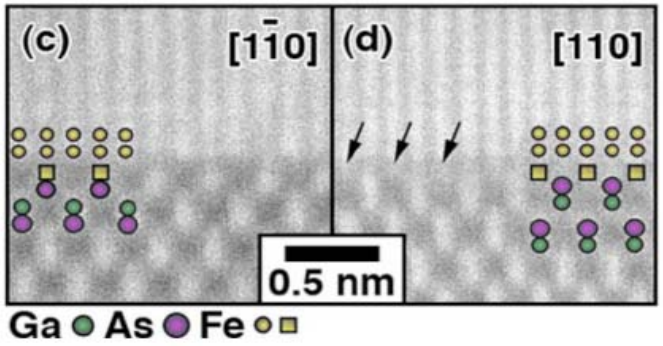
AsGrown Spin LED

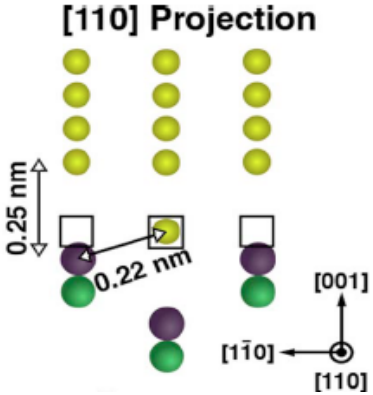
Annealed Spin LED

Fe-GaAs(001) Prototypical Spin Injection System

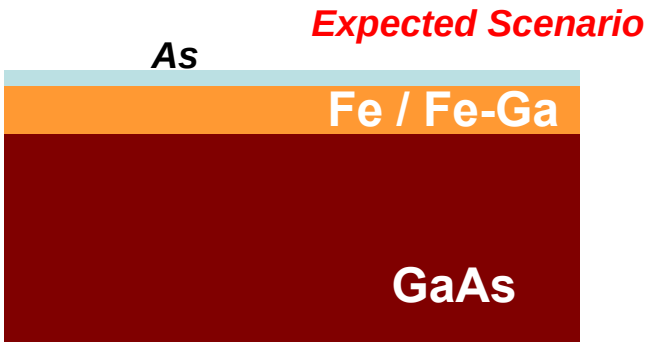
-Thomas Zega et al. Phys. Rev. Lett. 96, 196101 (2006) used HRTEM to correlate a 44% spin injection increase with interfacial structural order.

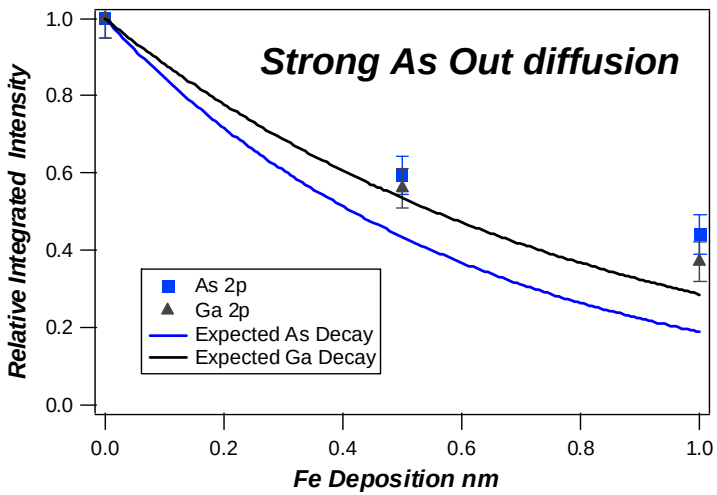
-James M. LeBeau et al. Appl. Phys. Lett. 93, 121909 (2008)

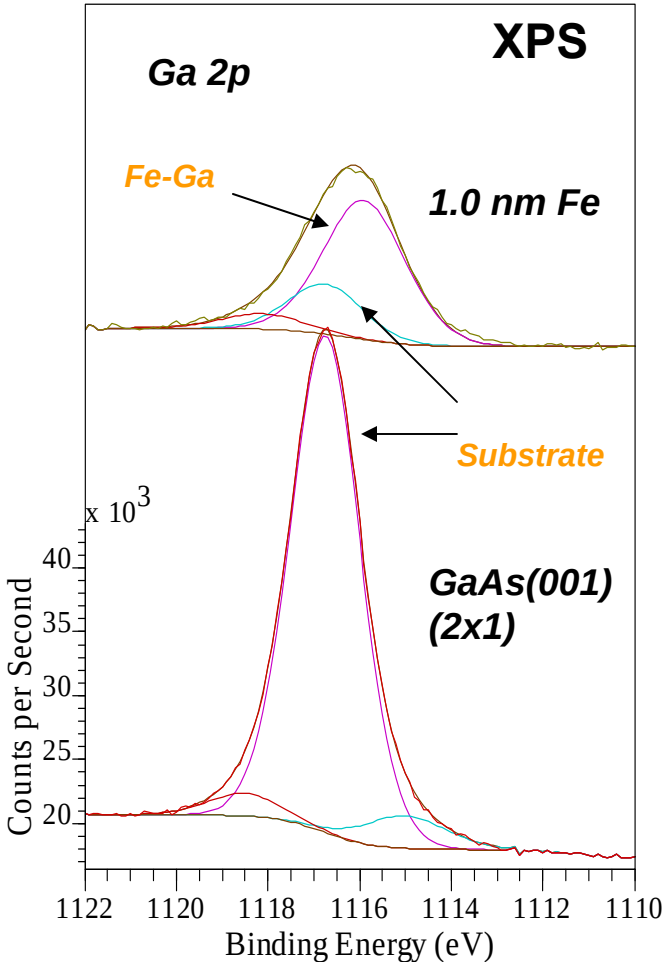




Room Temperature Deposition Fe on GaAs(001)

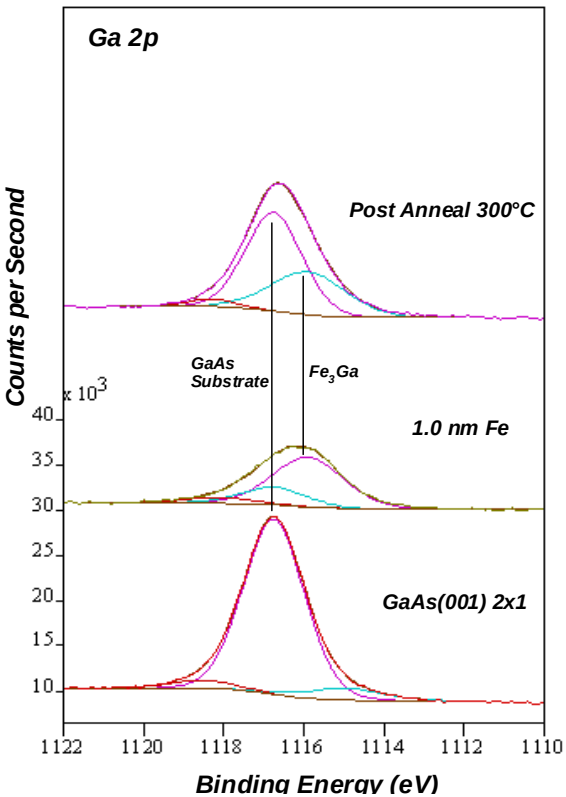


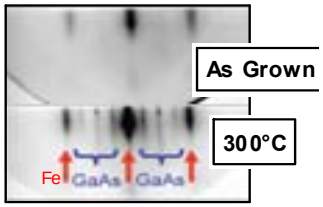


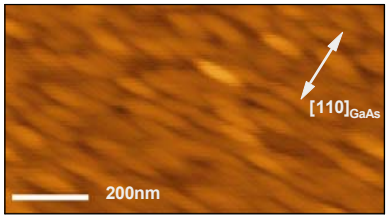


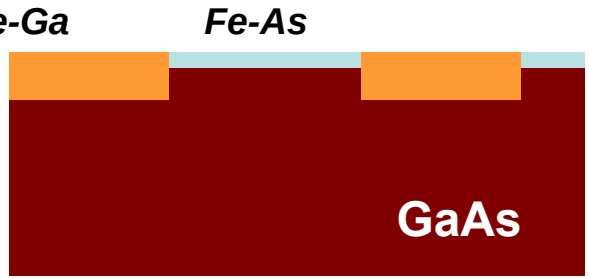
In Brief, What We Find…….

- *0.4 – ~1.5nm Fe Deposition on GaAs(001)*
- *Surface Chemical Segregation*
- *Fe-Ga - Island Structures 100nm x 200nm*
- *Fe –As Disordered & Intermixed Regions*

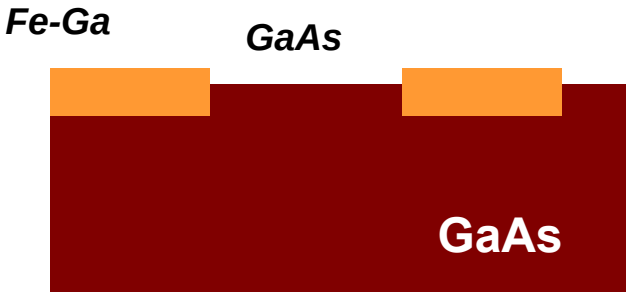






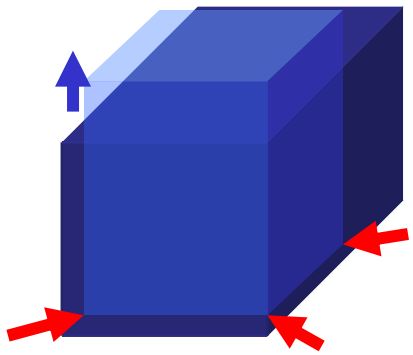


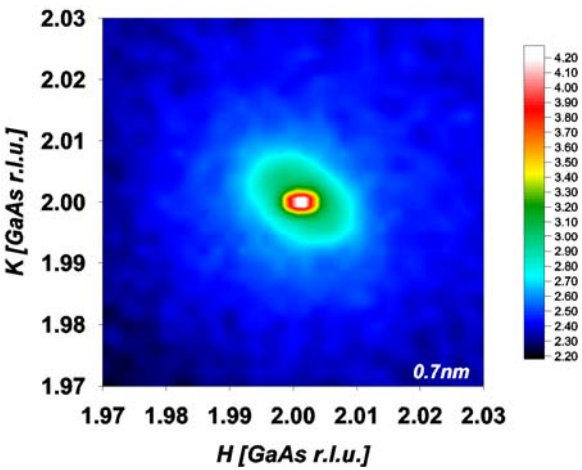
As Grown at Room Temperature



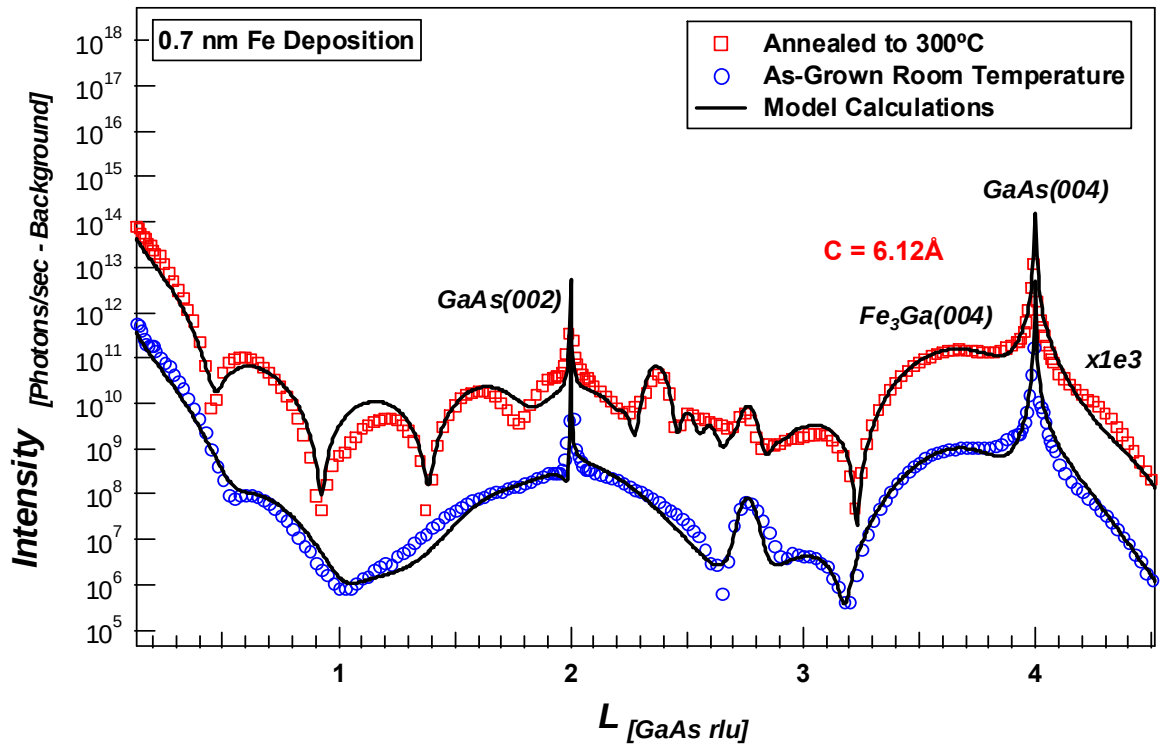
Annealed > ~200°C

Fe_3Ga on GaAs(001)





Fully strained up to 1.0nm



- Fully strained Fe : 2.9486 Å

-Measured lattice parameter : 3.06 Å ???

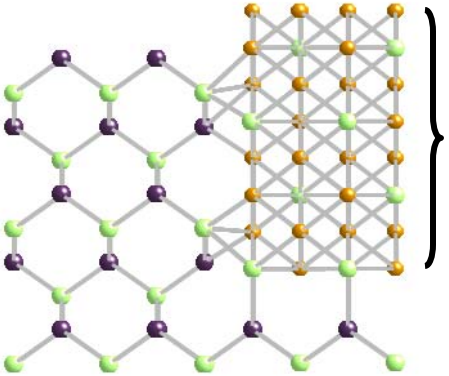
-Fe_3Ga 5.807Å – ~6.16Å (Volume Conservation)

- 0.7nm - ~65% Substrate Coverage for both systems

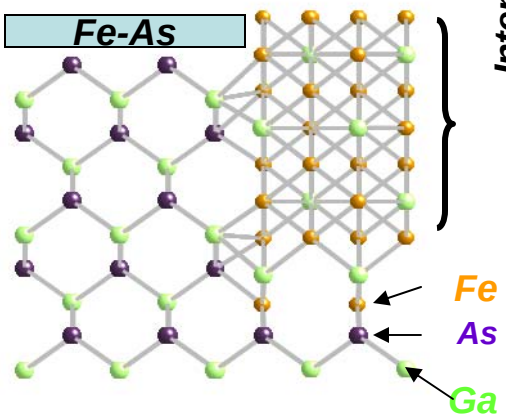
- Partially buried system

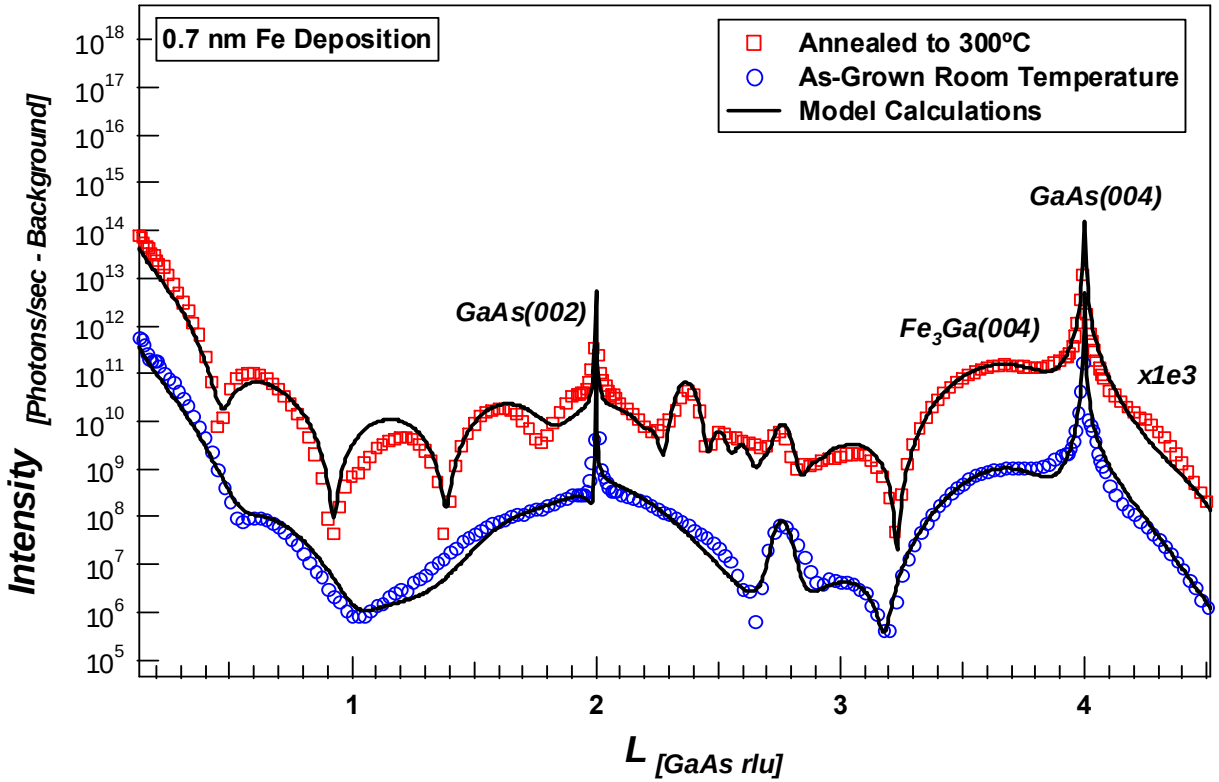
-Significant Disorder Suppression with Annealing

Annealed



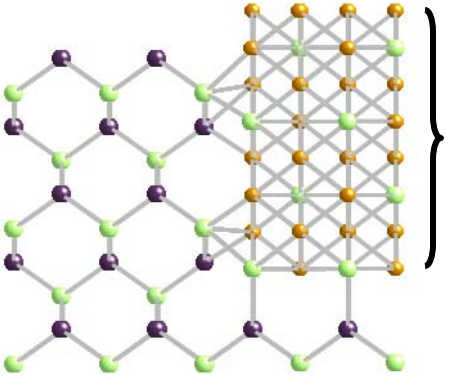
As Grown



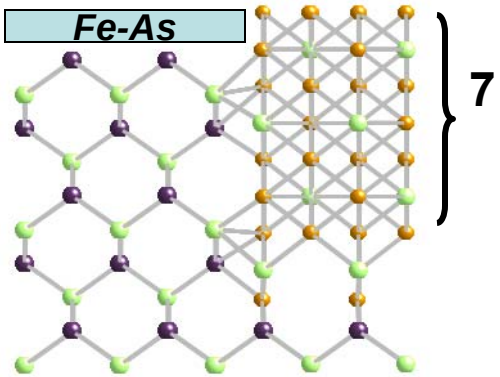


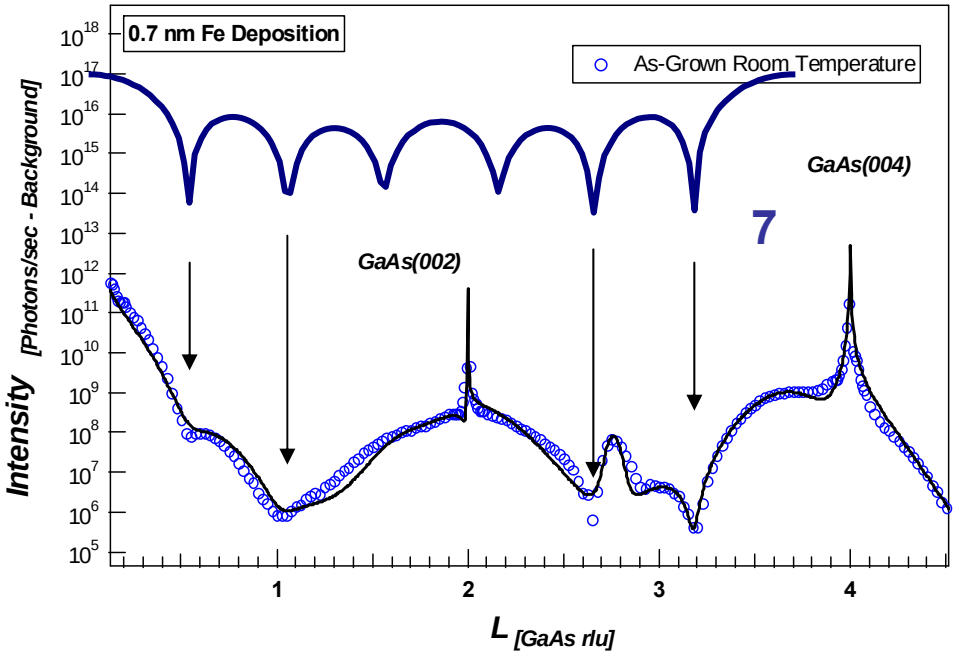
Epitaxial Structure of Fe on GaAs(001)

Annealed



as-grown





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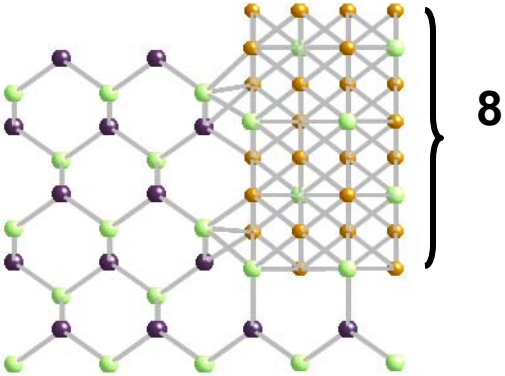

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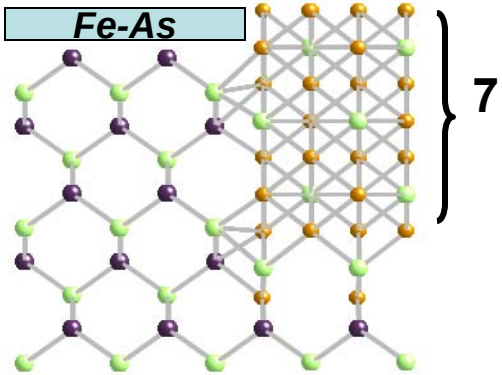
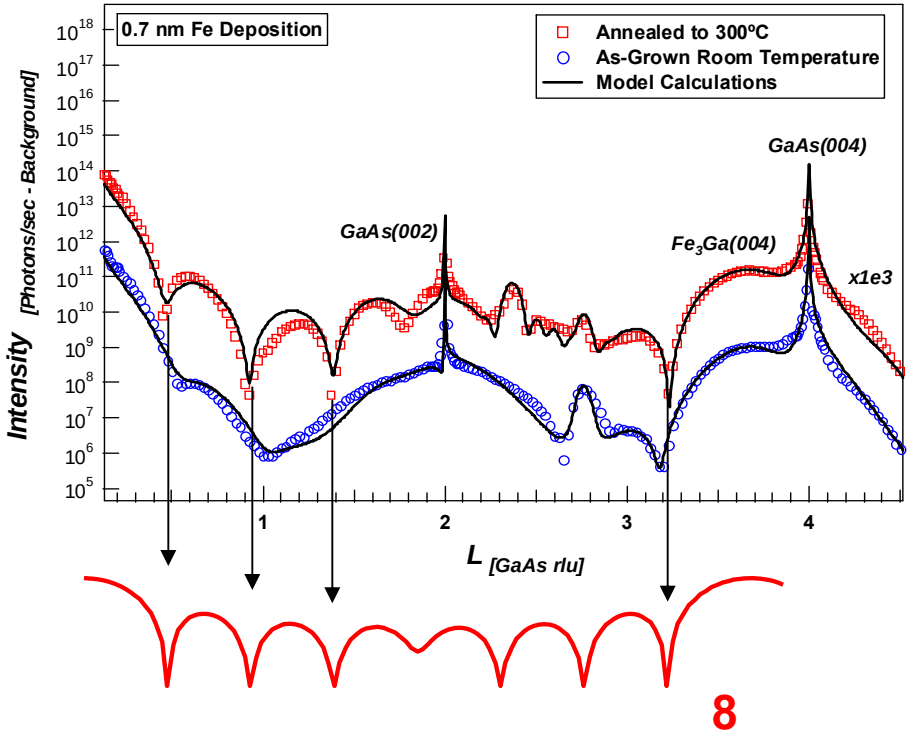


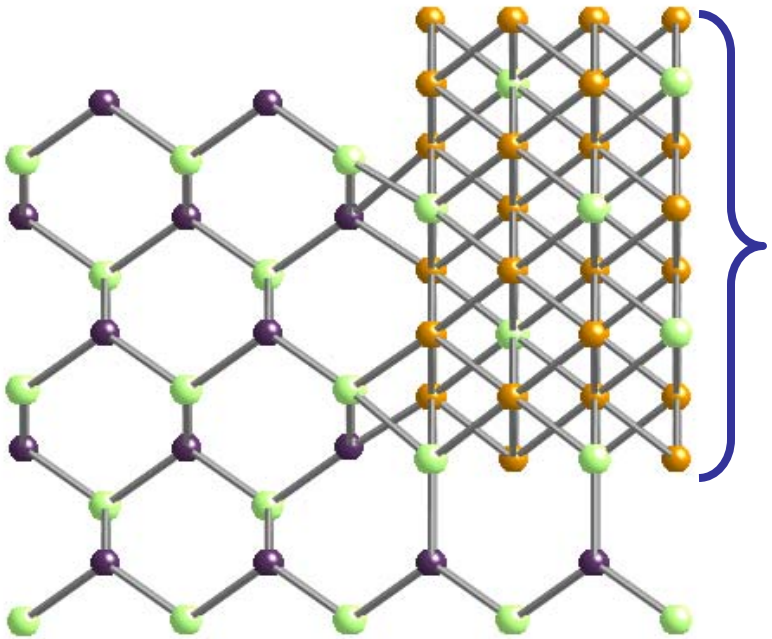


Fe K - Resonant X-Ray Diffraction

Fe K edge : 7.112 keV

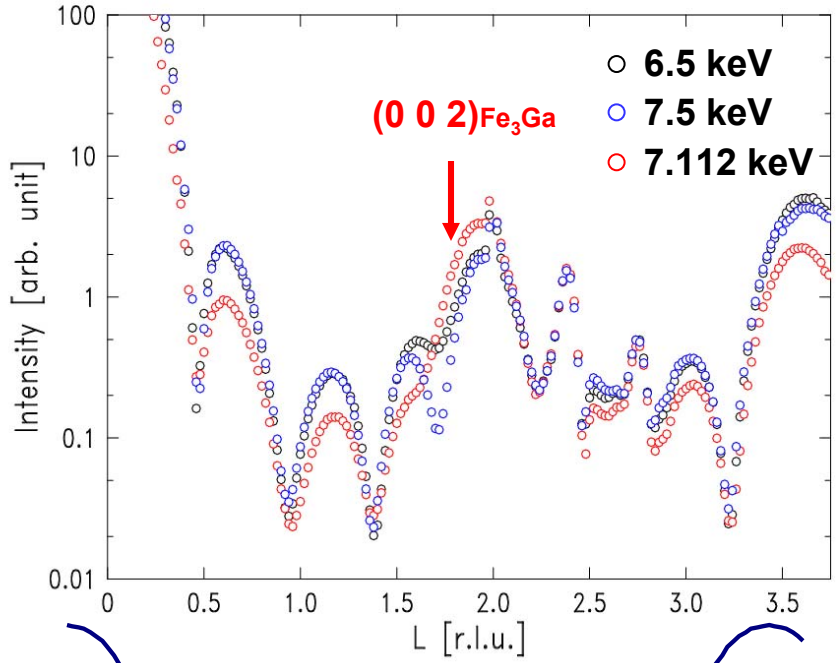
Intensity of $(0\ 0\ 2)_{Fe_3Ga}$

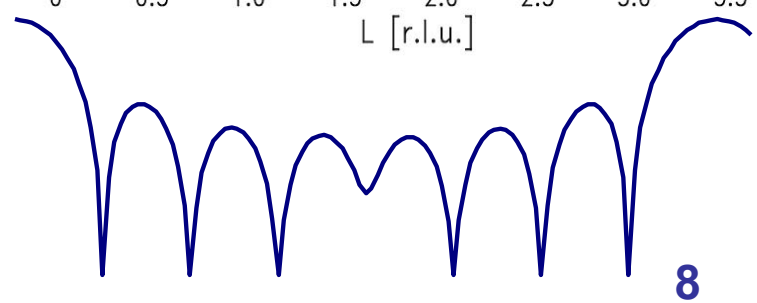
$$F^2 \sim |f_{Ga} - f_{Fe}|^2$$



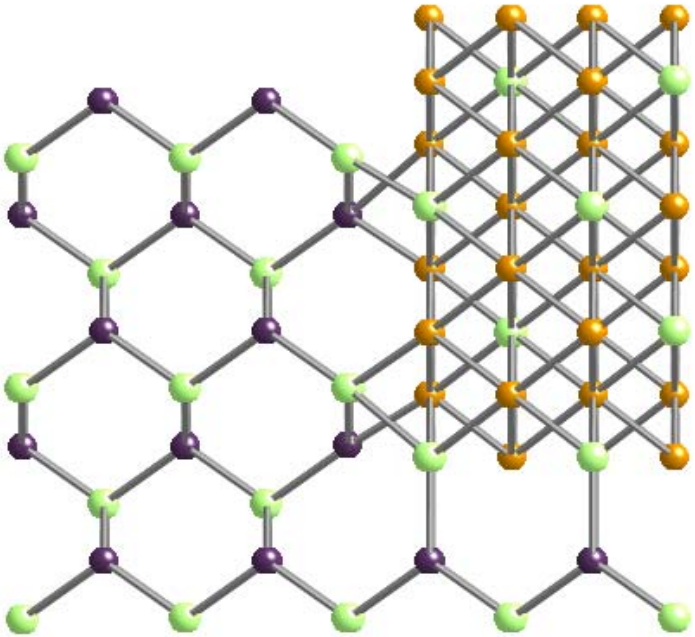
8 layers

300°C Anneal 0.7nm System

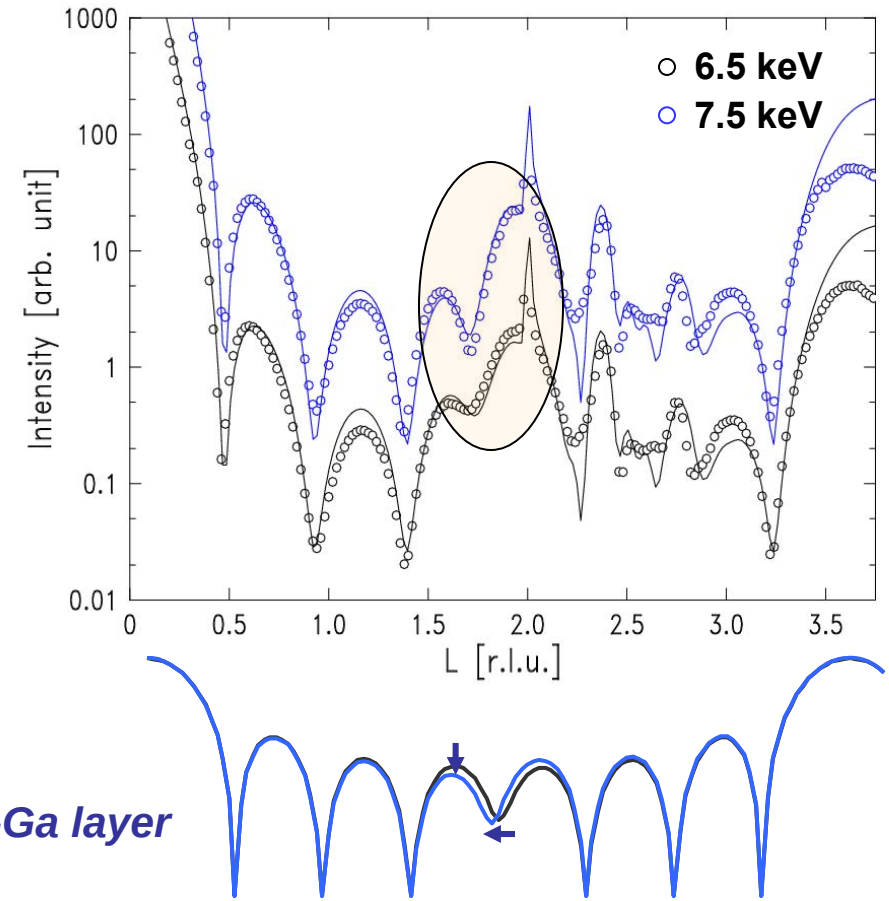




Resonant X-Ray Anomalous Diffraction



Fe-Ga layer

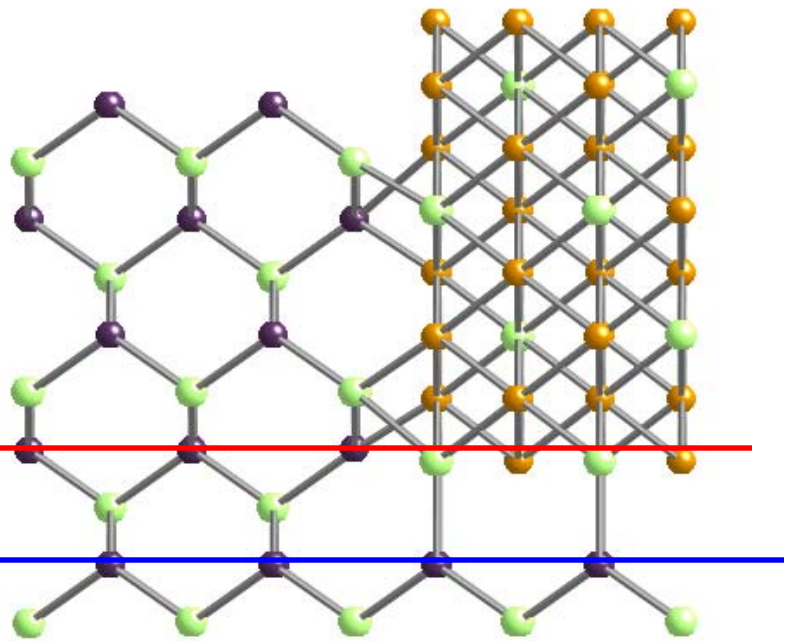


E < Fe K (6.5 keV) : f_{Fe} = 23.8 + 0.55i

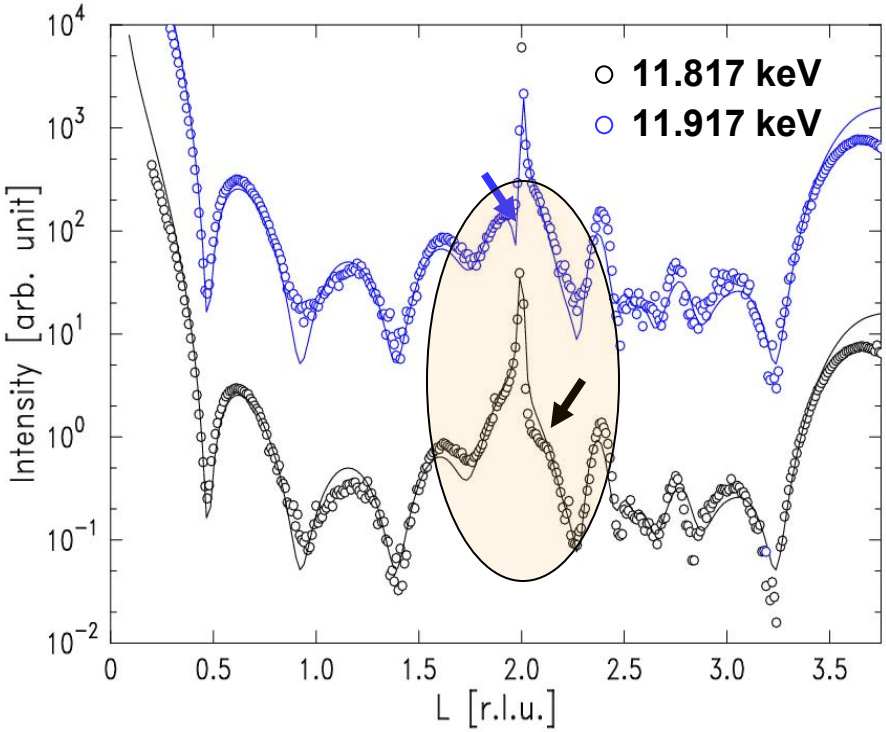
E > Fe K (7.5 keV) : f_{Fe} = 23.8 + 3.58i

Resonant X-Ray Anomalous Diffraction

As K edge : 11.867 keV

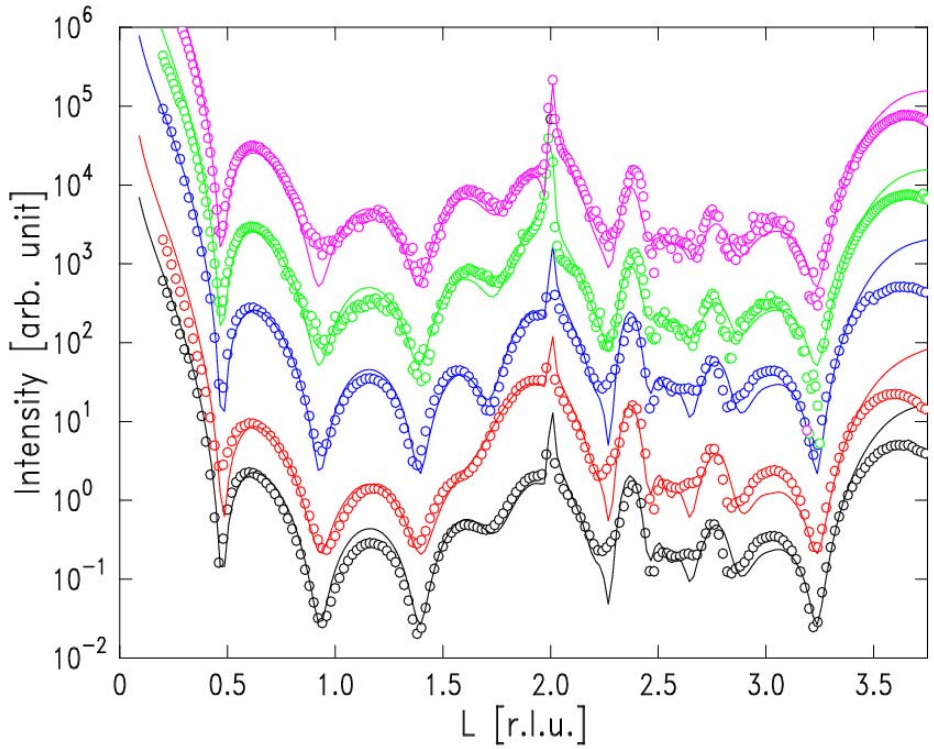


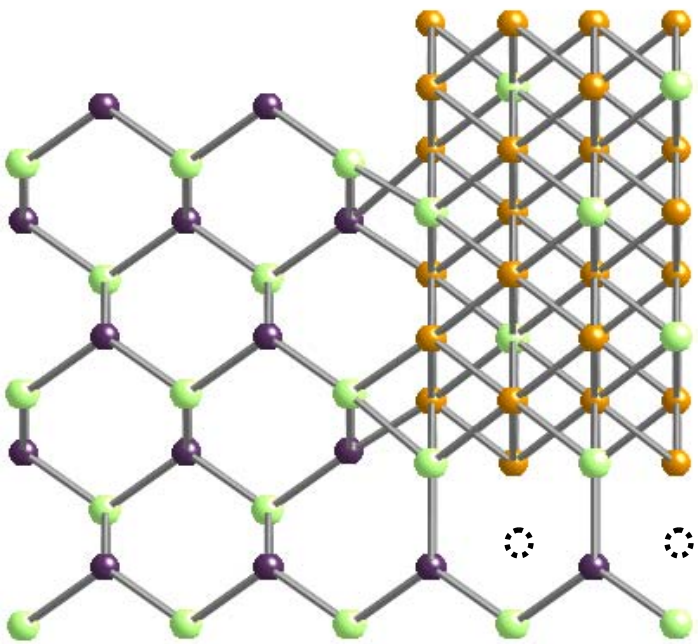
First Substrate Layer is As



E < As K (11.817 keV) : f_{As} = 28.9 + 0.53i
E > As K (11.917 keV) : f_{As} = 29.0 + 3.81i

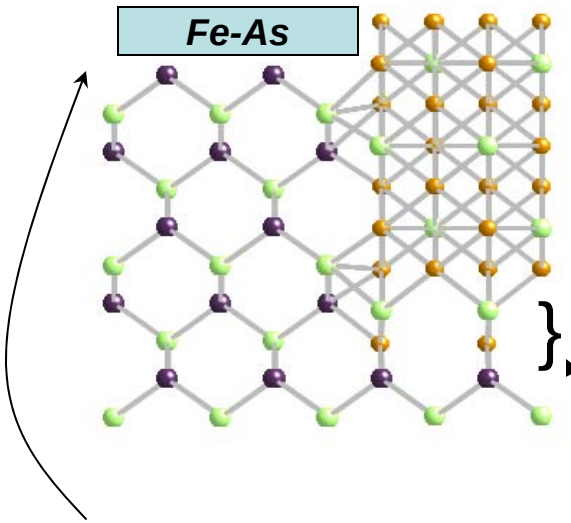
Resonant Anomalous Diffraction

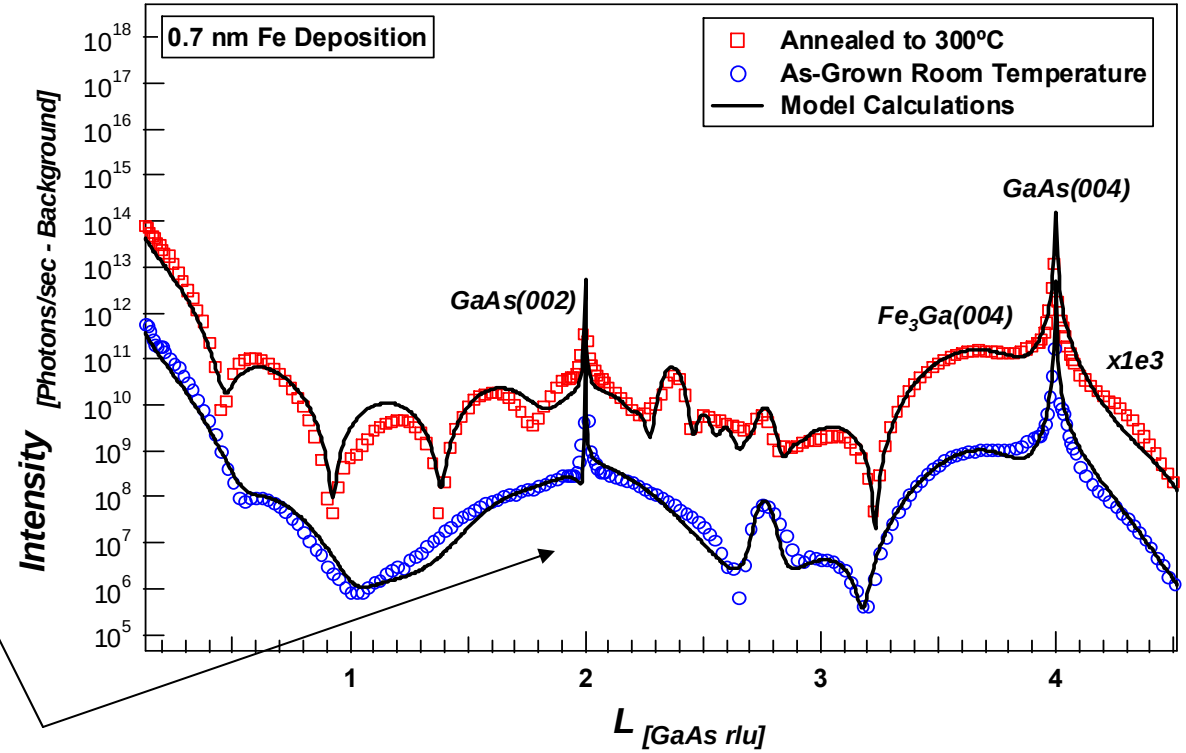




Interface distance = 0.24 nm

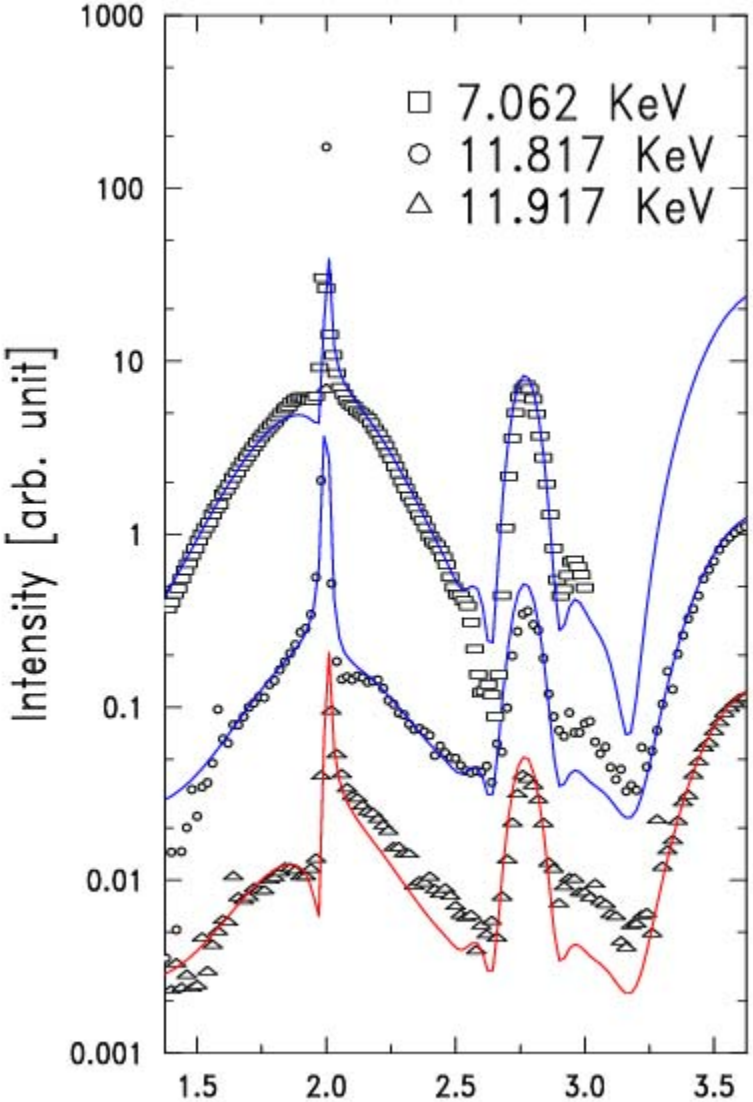
As Grown Interfacial Structure

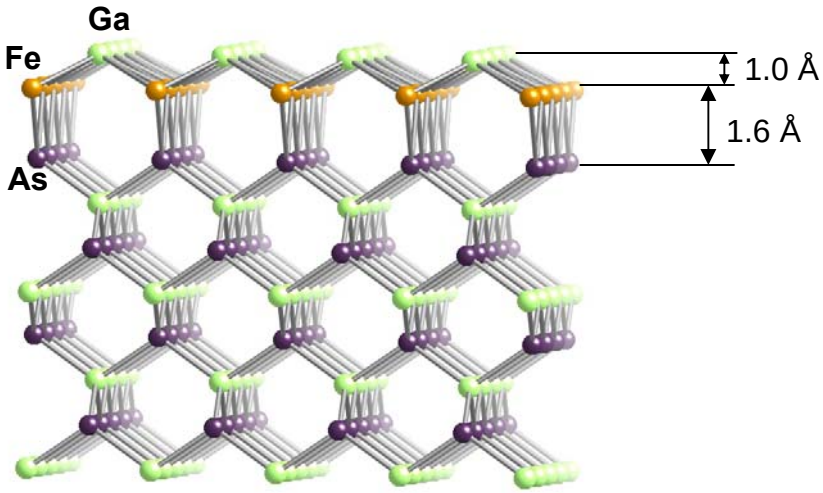




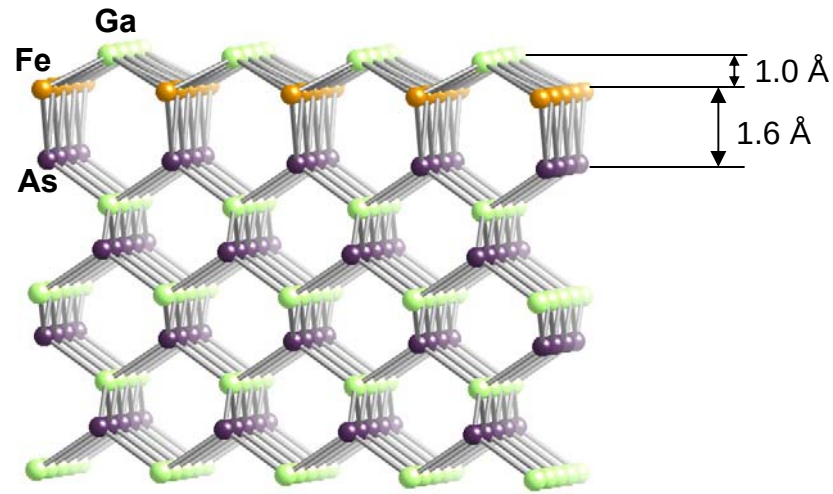
Broad Feature – Bilayer
= Full (GaAs) - Coverage

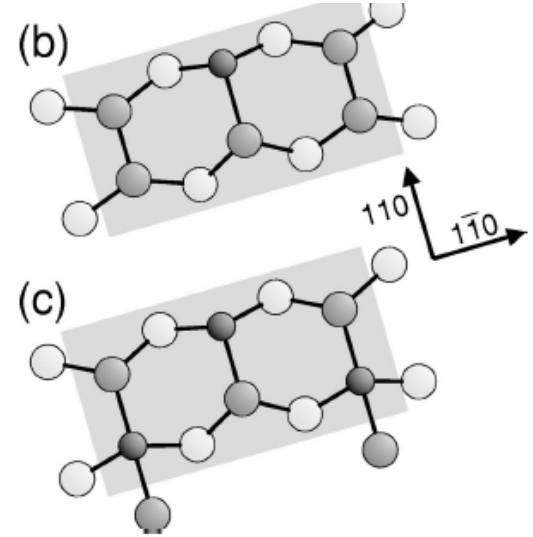
As Grown Interfacial Structure





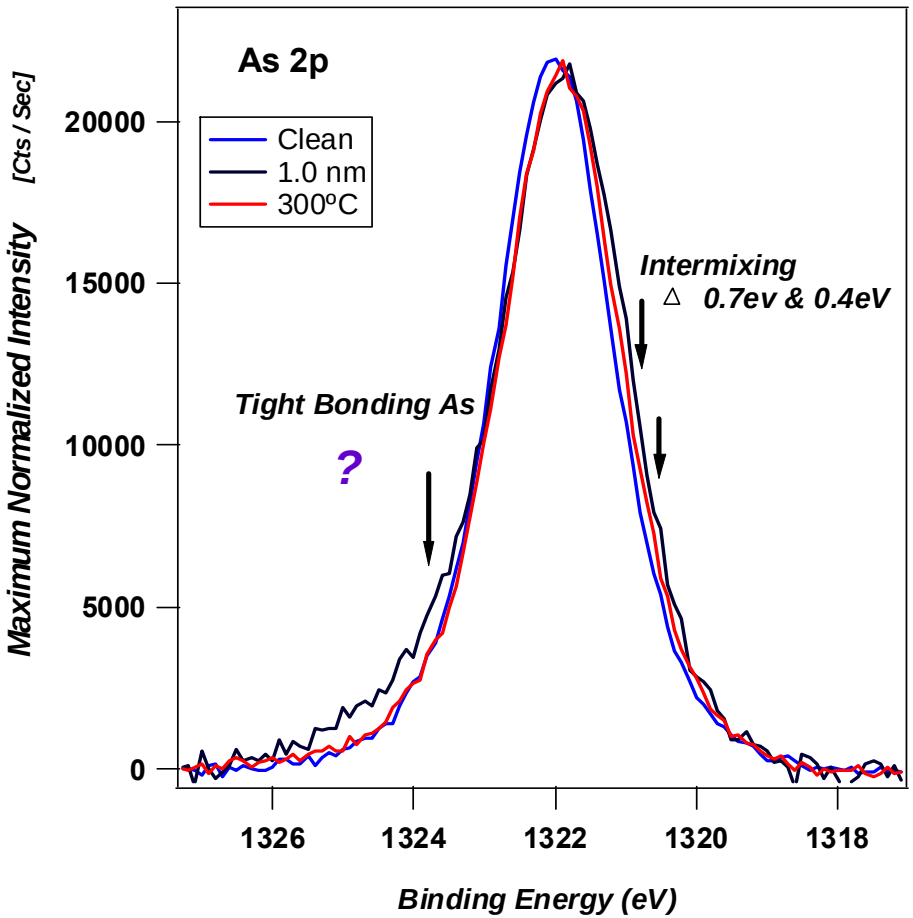
Pre-Anneal Structure

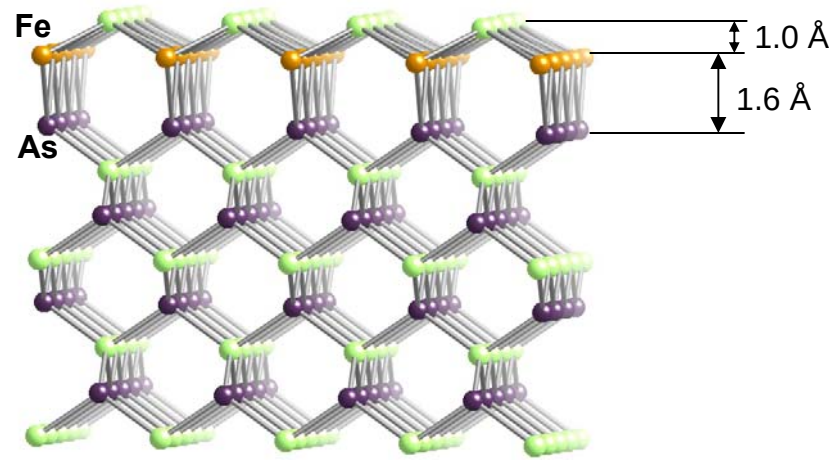


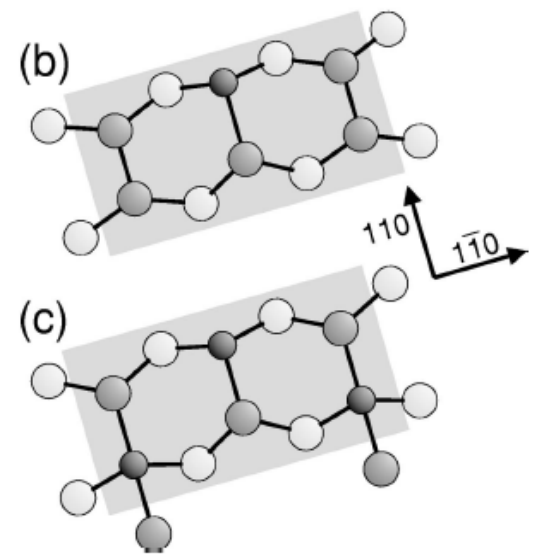


Predicted Tight Sub-Surface Fe-As bonding ???
Steve Erwin et al. Phys. Rev. B. 65 205422

Pre-Anneal Structure







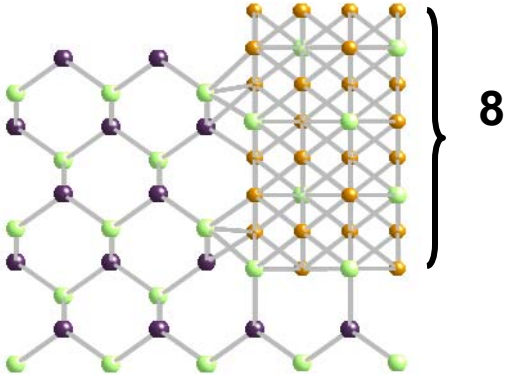
Predicted Tight Sub-Surface Fe-As bonding ???

Steve Erwin et al. Phys. Rev. B. 65 205422

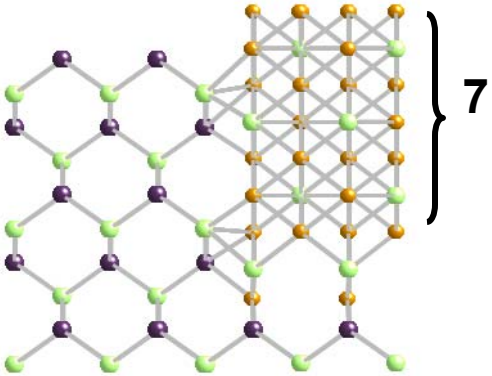
Summary and Speculation

- *Fe_3Ga Formation on Ga rich (4x6), (2x1) GaAs (001)*
- *Chemical Segregated Regions:*
- *Speculation of an interfacial Fe-Ga bilayer*
  - *Back Bonding of Fe – As ??*
- *Interfacial Atomic Reconstruction with low Temp. Annealing*
- *With full Fe_3Ga coverage,*
  - *Cannot fully remove interfacial Bilayer*
- *High energy Core level XPS might be able to monitor the buried interfacial chemical bonding changes.*

Annealed



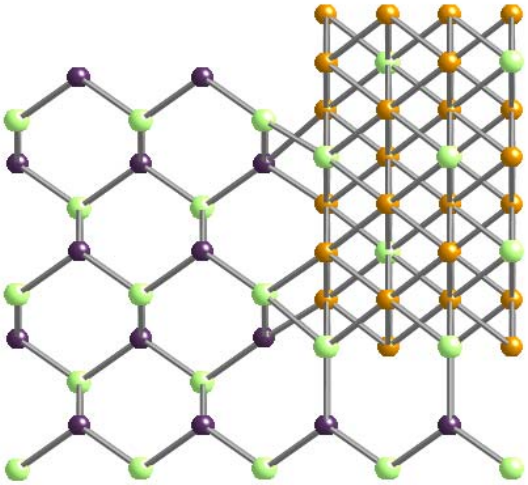
as-grown

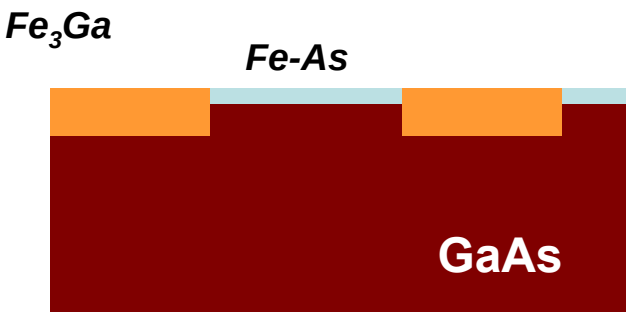


Summary

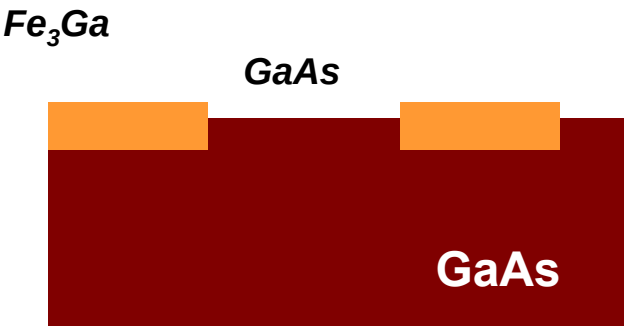
Annealed System

- ***Partially Buried Fe_3Ga***
- ***8 Layers : Fe_3Ga***
- ***First Fe_3Ga layer Fe-Ga***
- ***First Substrate full layer is As***
- ***Interface Distance 0.24nm***
- ***Partial Intermediate occupancy??***





As Grown at Room Temperature



Annealed > ~200°

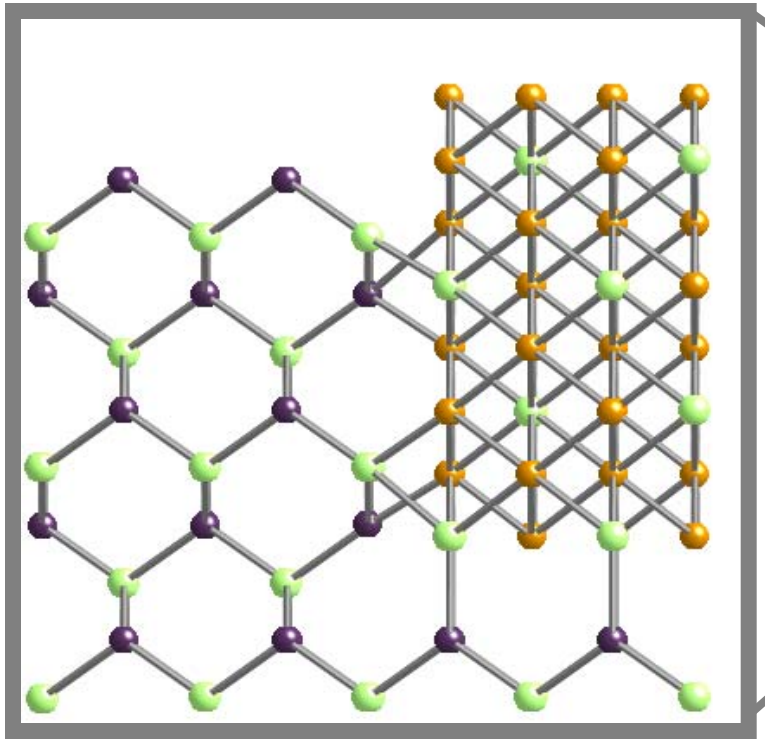
Resonant Anomalous X-Ray Diffraction

Annealed Structure

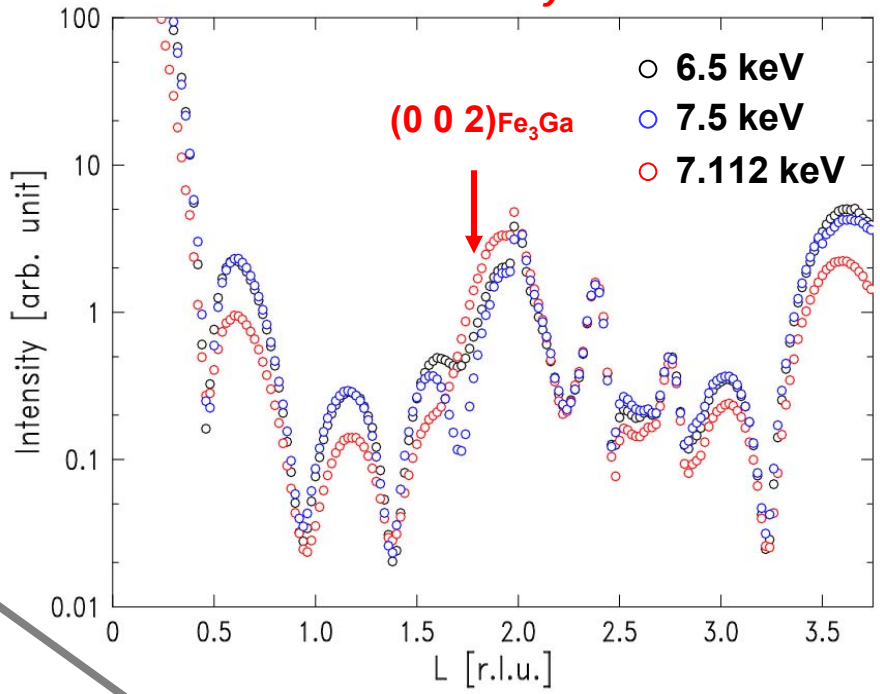
Fe K edge : 7.112 keV

Intensity of (0 0 2)$_{Fe_3Ga}$

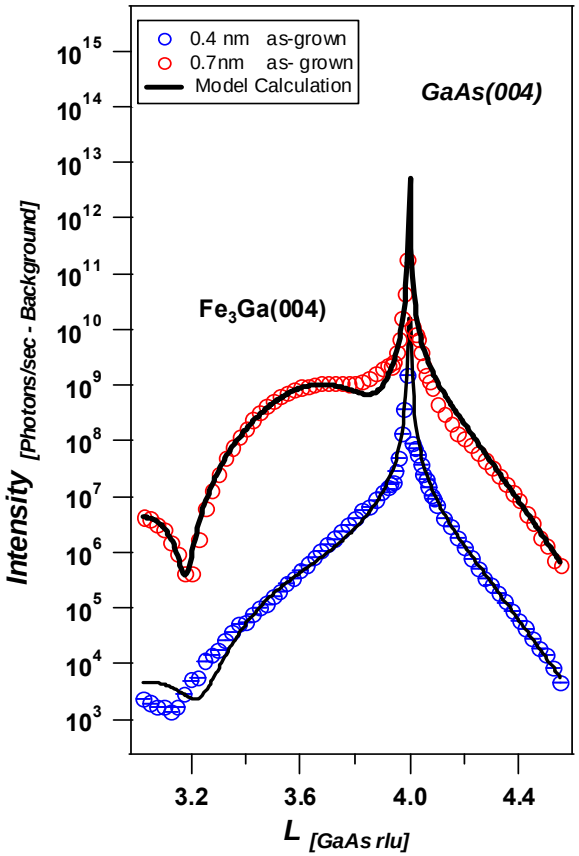
$$F^2 \sim |f_{Ga} - f_{Fe}|^2$$

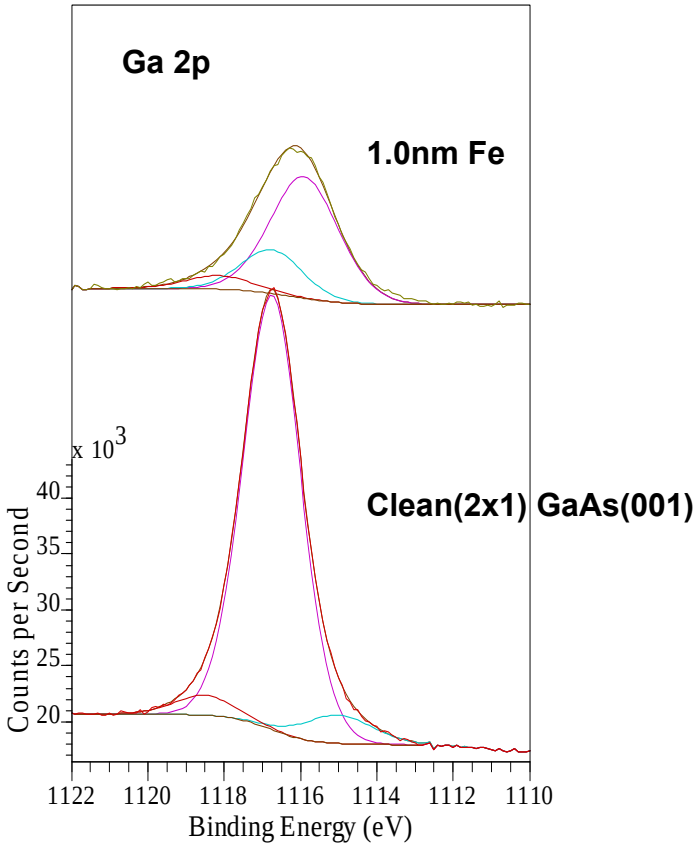


300°C Anneal 0.7nm System



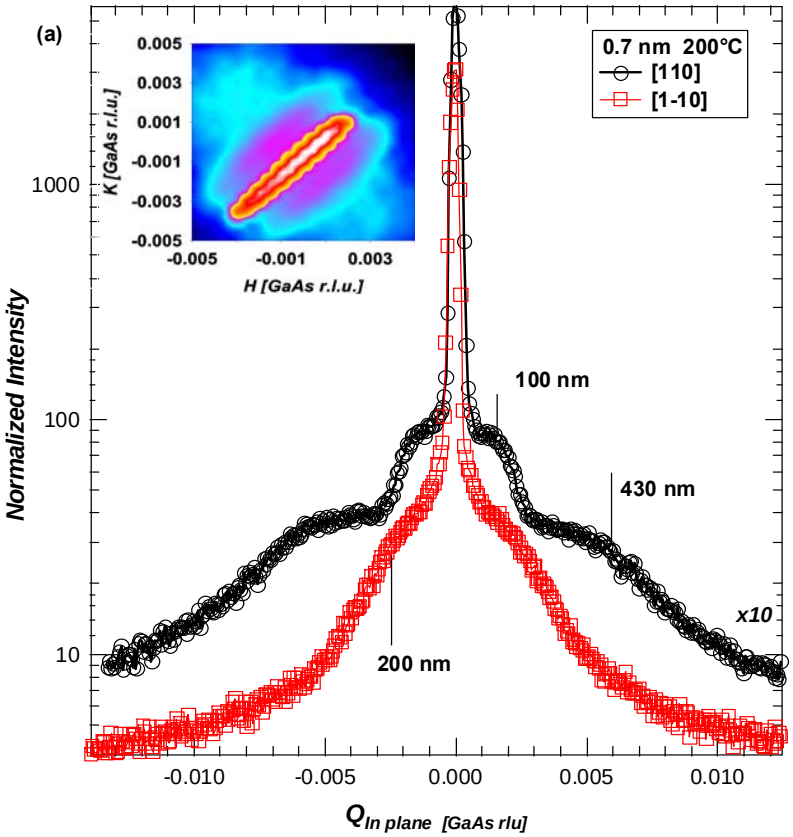
Fe??-GaAs(001)

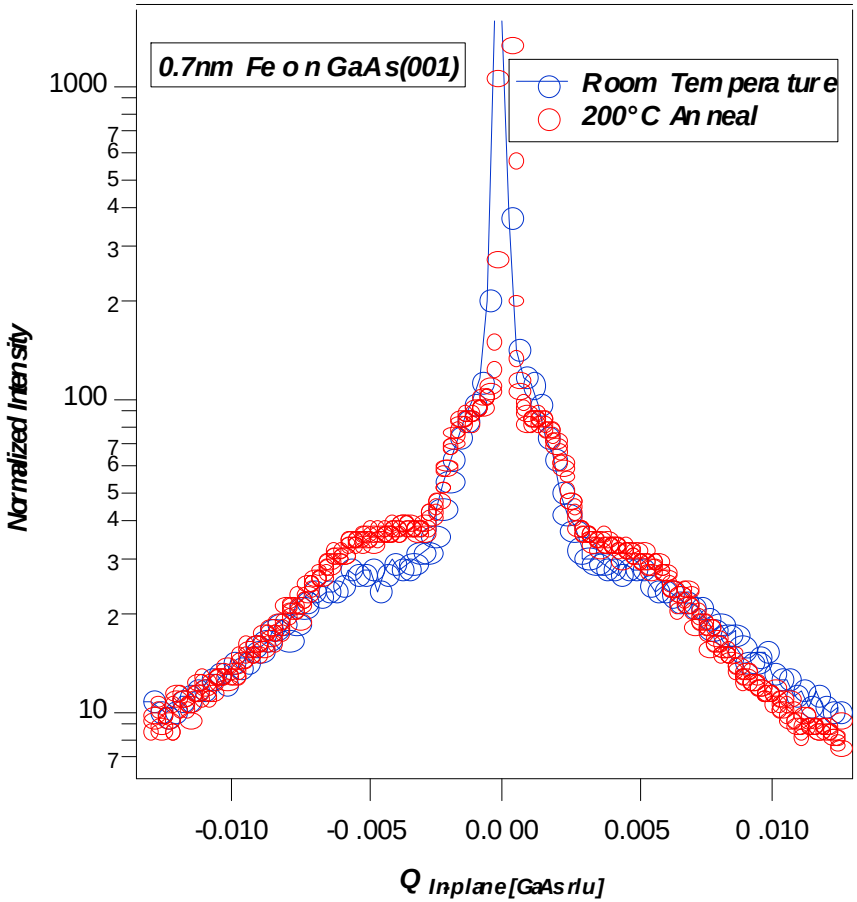

0.4 nm as-grown
0.7nm as- grown
Model Calculation
GaAs(004)
Fe3Ga(004)
Intensity [Photons/sec - Background]
L [GaAs rlu]
3.2
3.6
4.0
4.4


Ga 2p
1.0nm Fe
Clean(2x1) GaAs(001)
x 10^3
Counts per Second
Binding Energy (eV)
1122
1120
1118
1116
1114
1112
1110

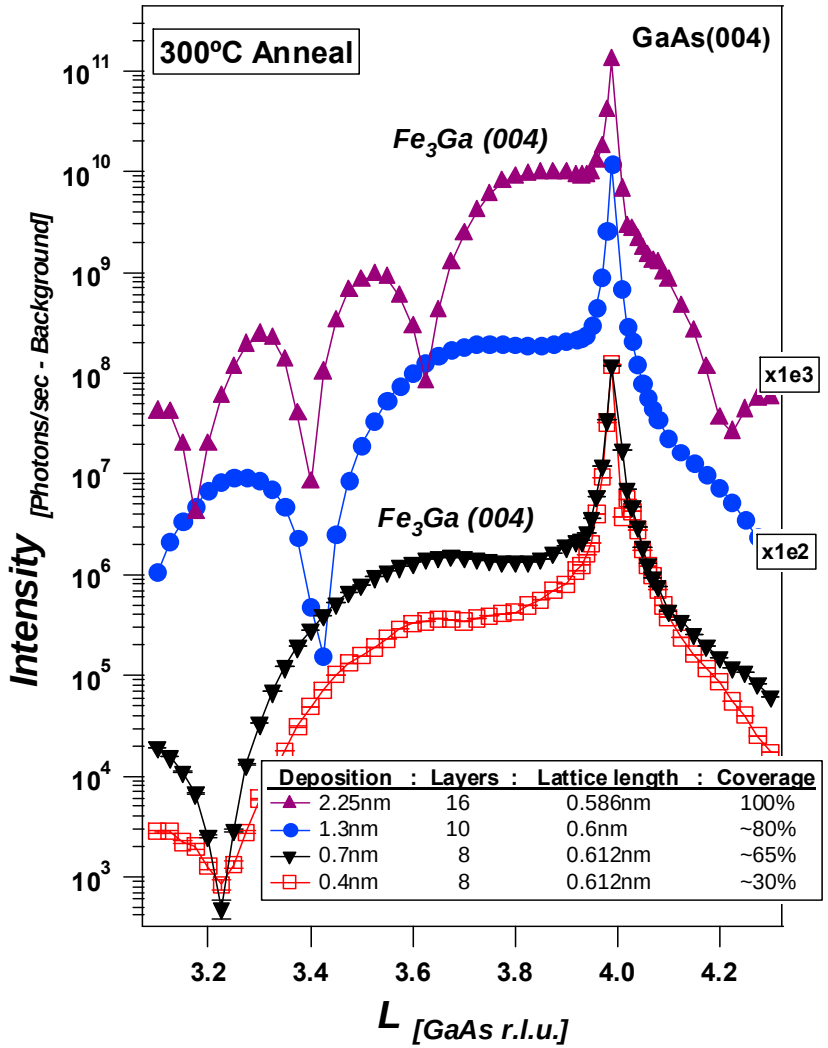
In plane Distribution of Fe on GaAs(001)

Low Temperature annealing - Reveals….

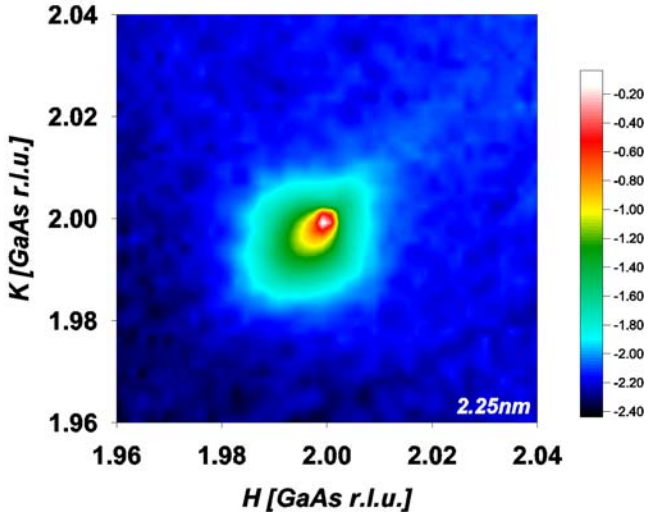


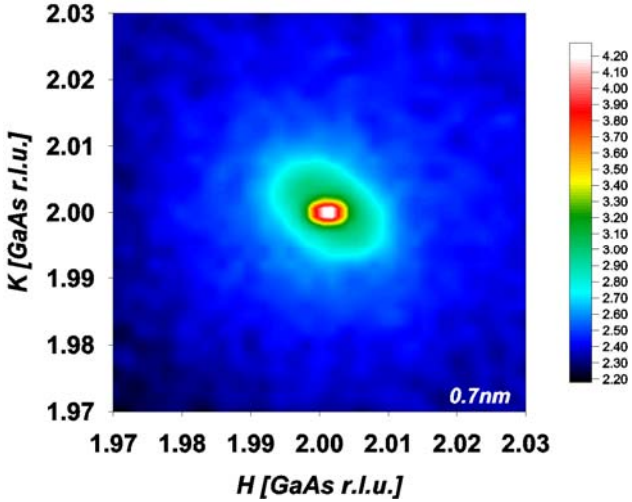


Fe_3Ga-GaAs(001) Prototypical Spin Injection System



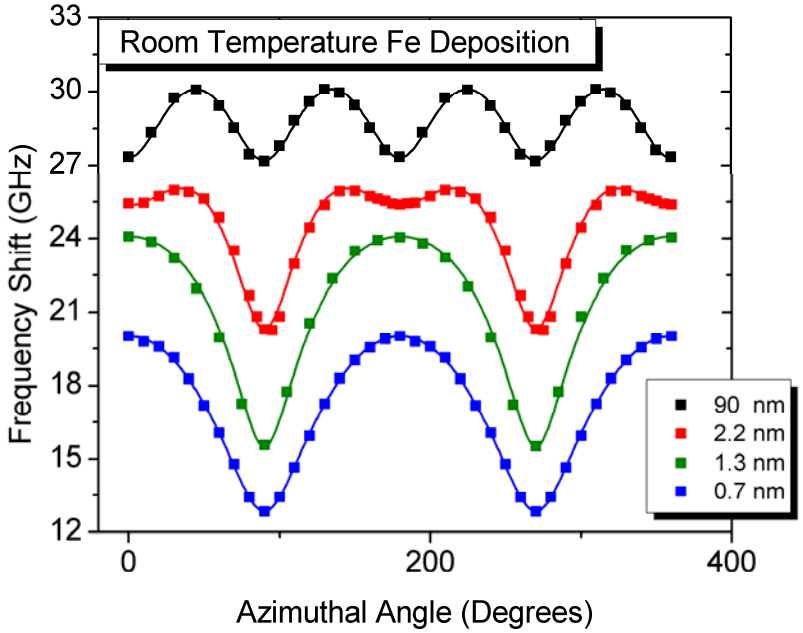
Lattice Relaxed

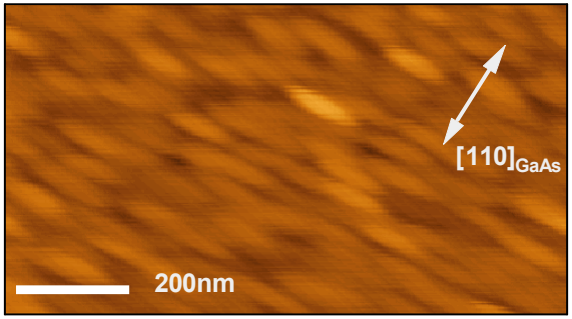


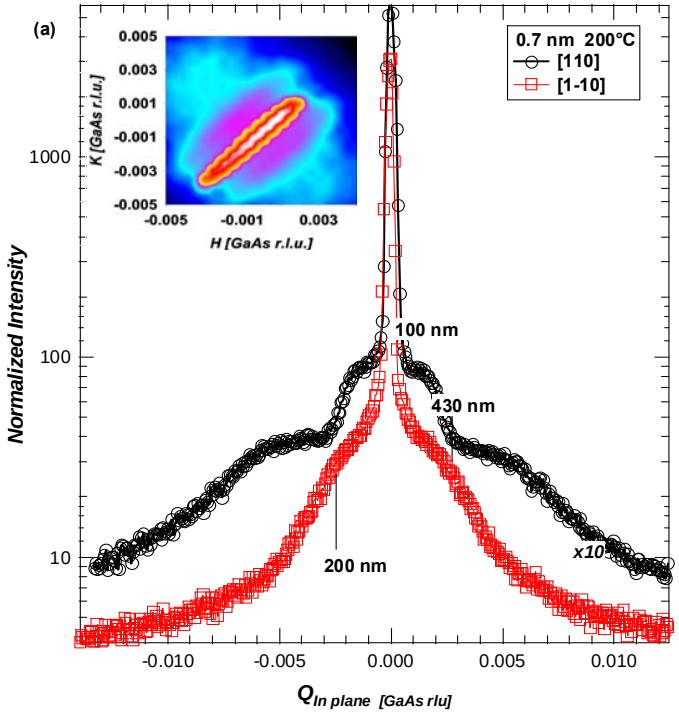


Lattice Matched

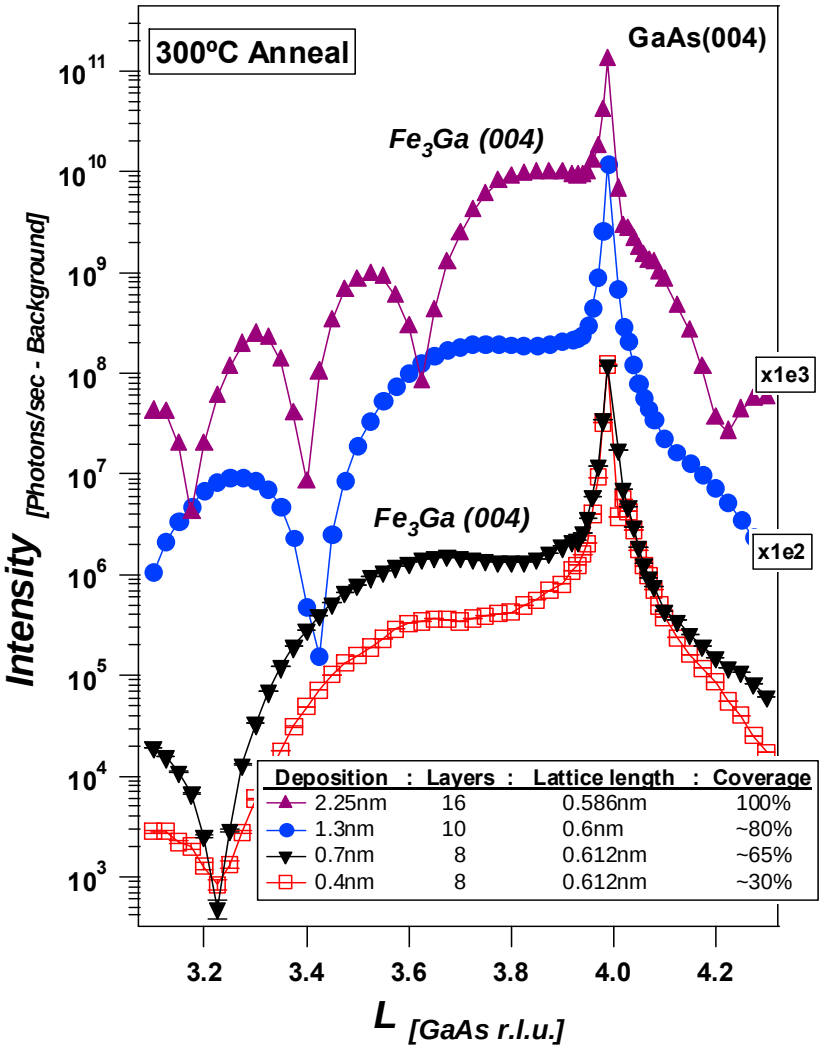
Uniaxial In-Plane Magnetic Anisotropy

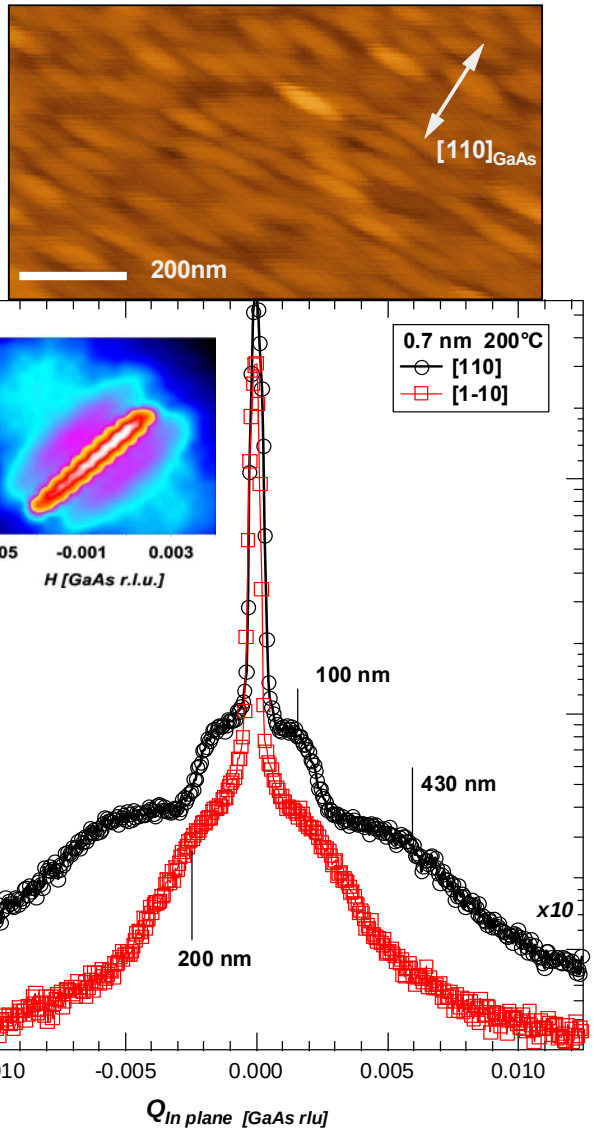




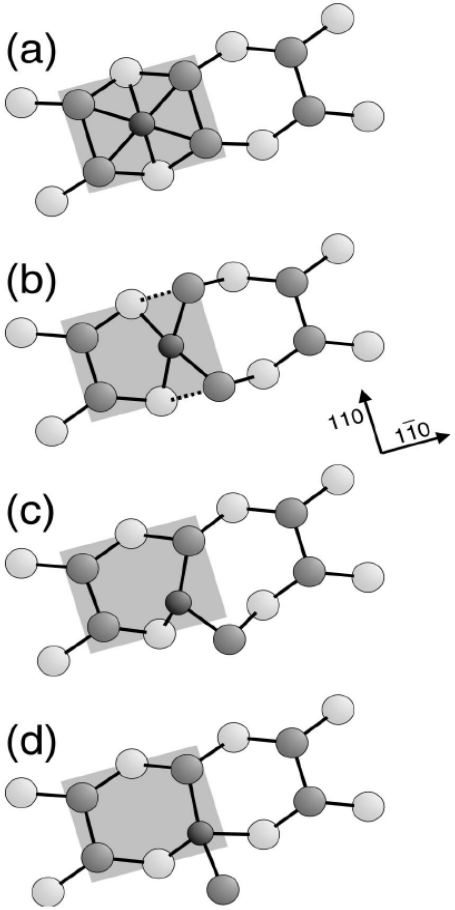


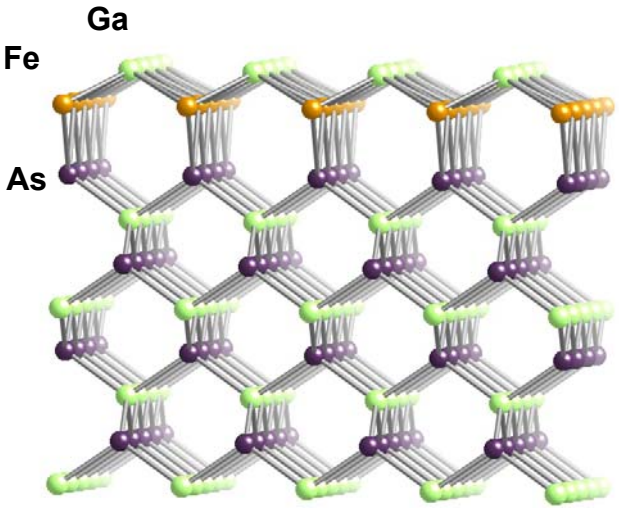
Fe_3Ga-GaAs(001) Prototypical Spin Injection System





PHYSICAL REVIEW B **65** 205422





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