Optical Characterization of Epitaxially Integrated High-Contrast Photonic Structures

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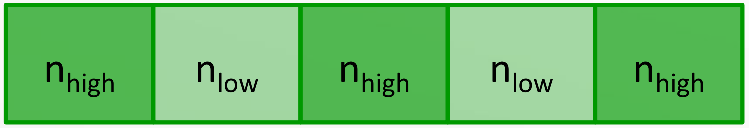
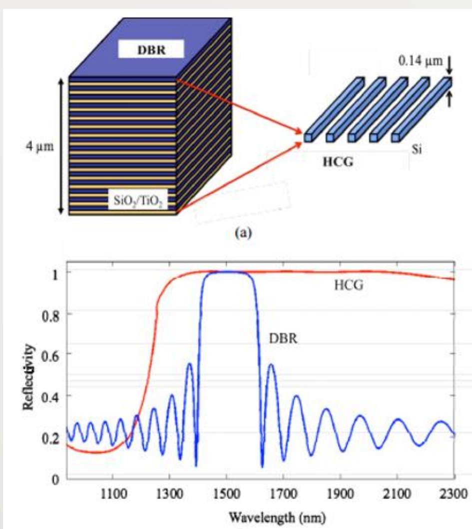
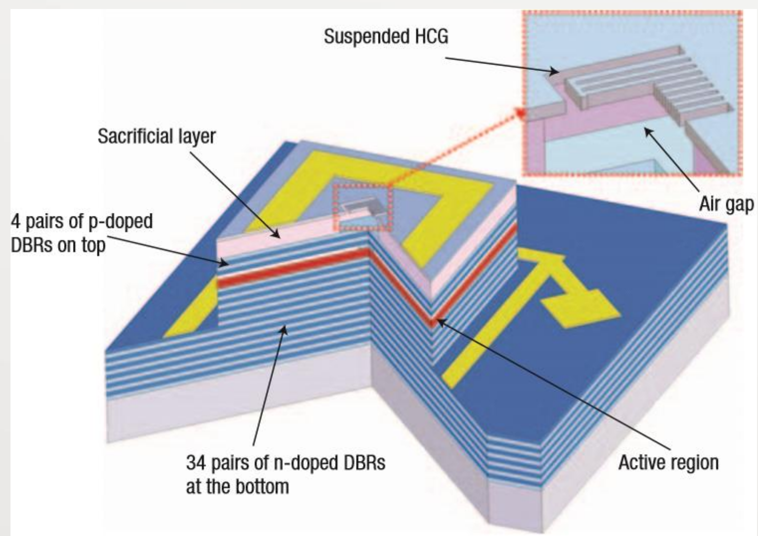
NASCENT
NSF
National Nanotechnology Coordinated Infrastructure

Motivation



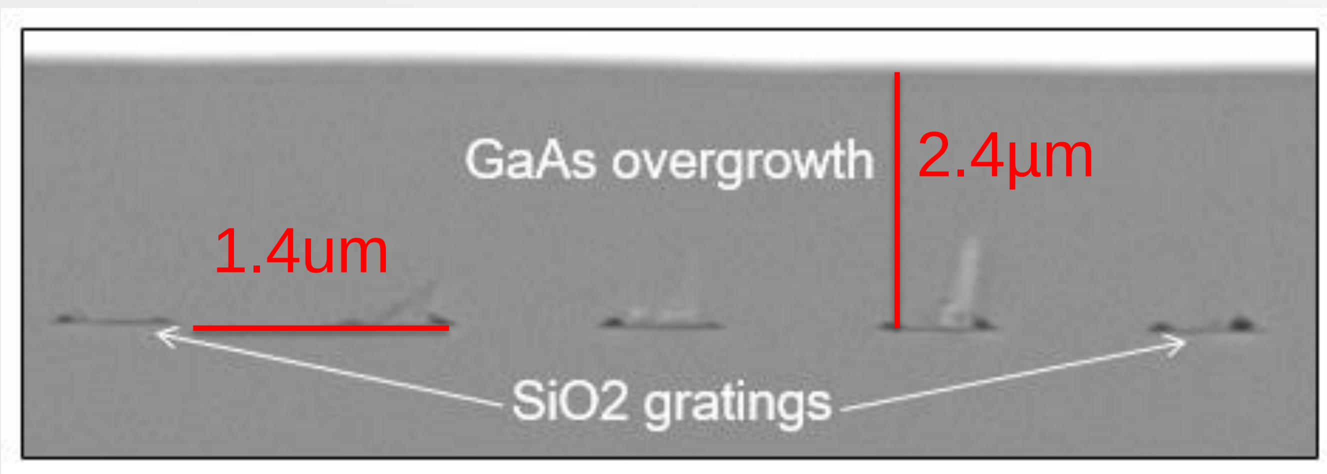
- High-contrast grating:
  - Structures utilizing low and high index dielectric materials
- Applications:
  - Broadband Reflective Mirrors/Transmitters/Absorbers
  - Optical Switching/Filters



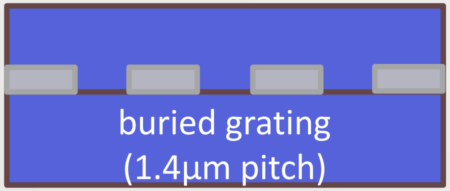


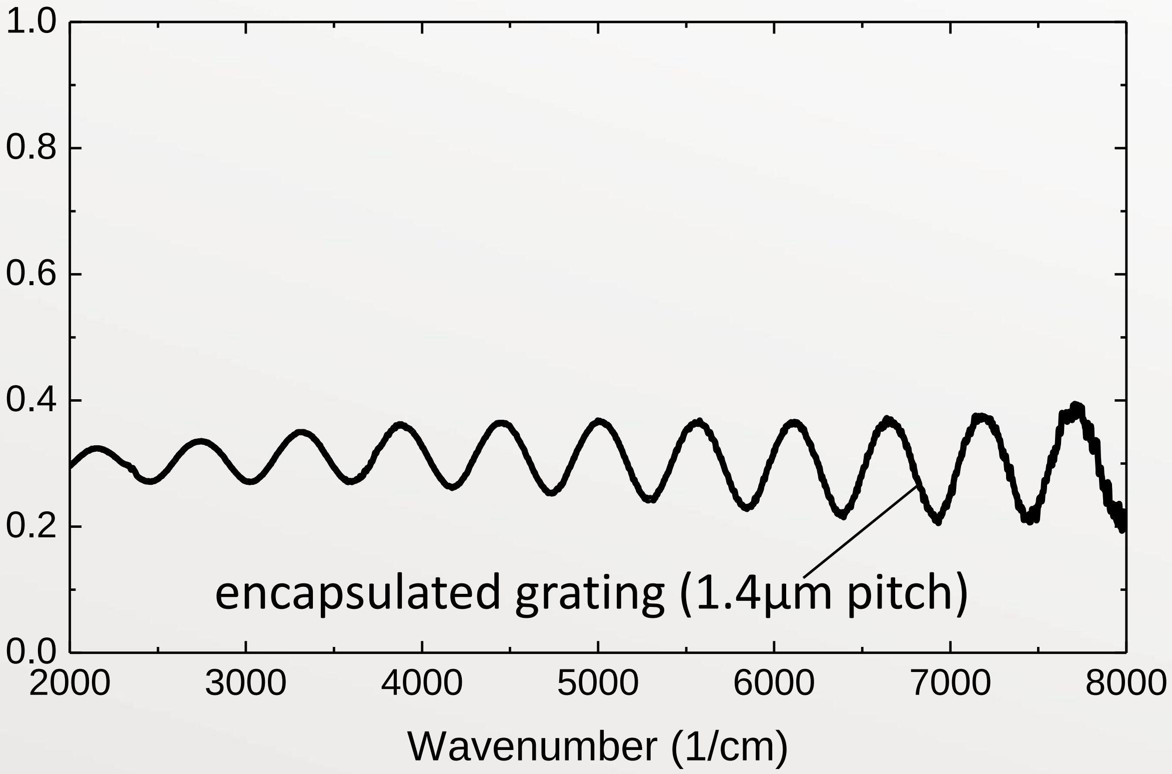
Material System

- Epitaxially integrated system grown via Molecular Beam Epitaxy
  - Patterned SiO_2 grating fabricated on GaAs wafers
  - Encapsulation and planarization of SiO_2 gratings via selective/regrowth processes

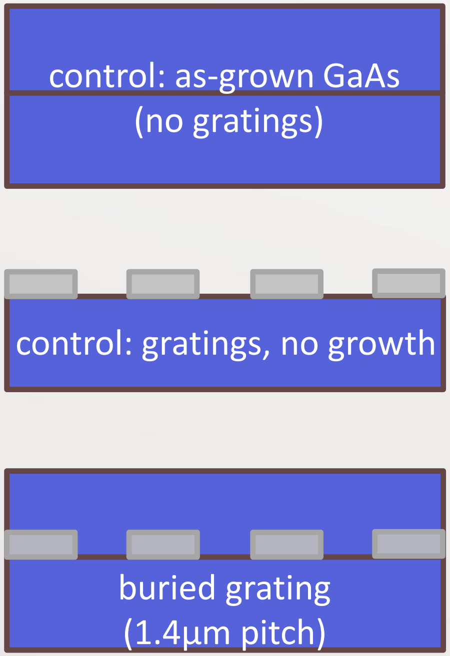


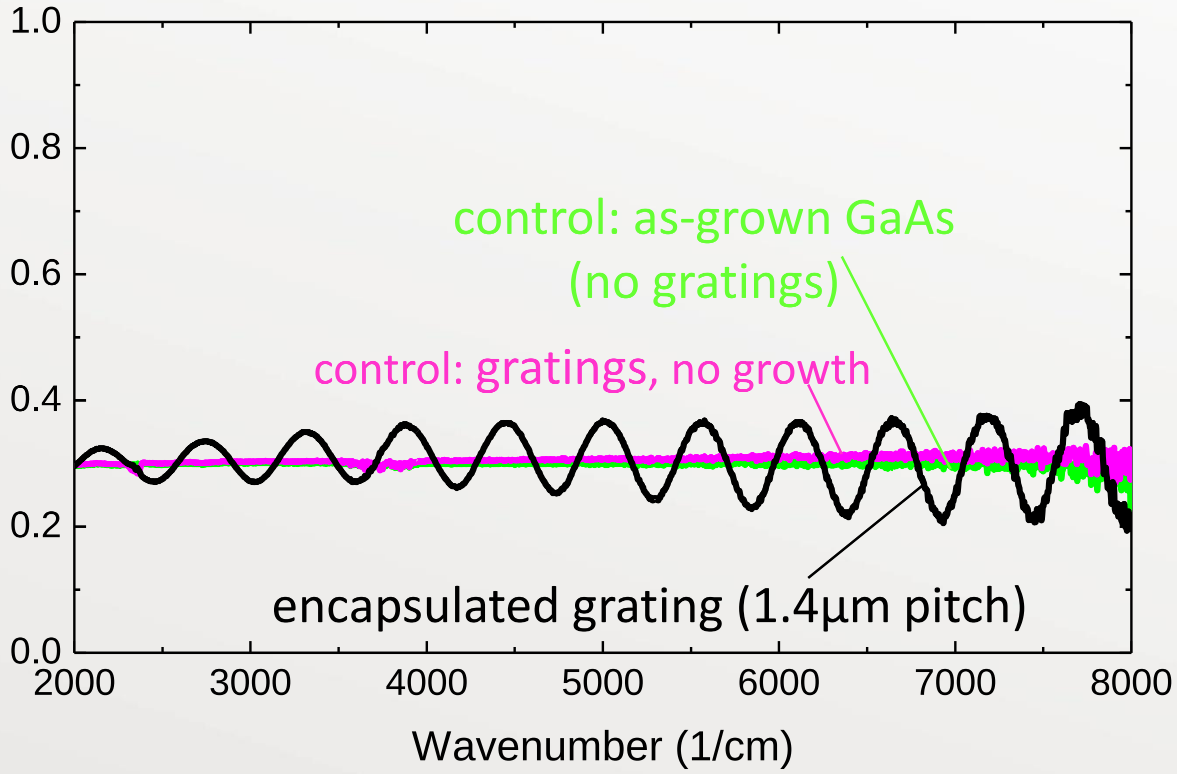
Fourier Transform Infrared Spectroscopy



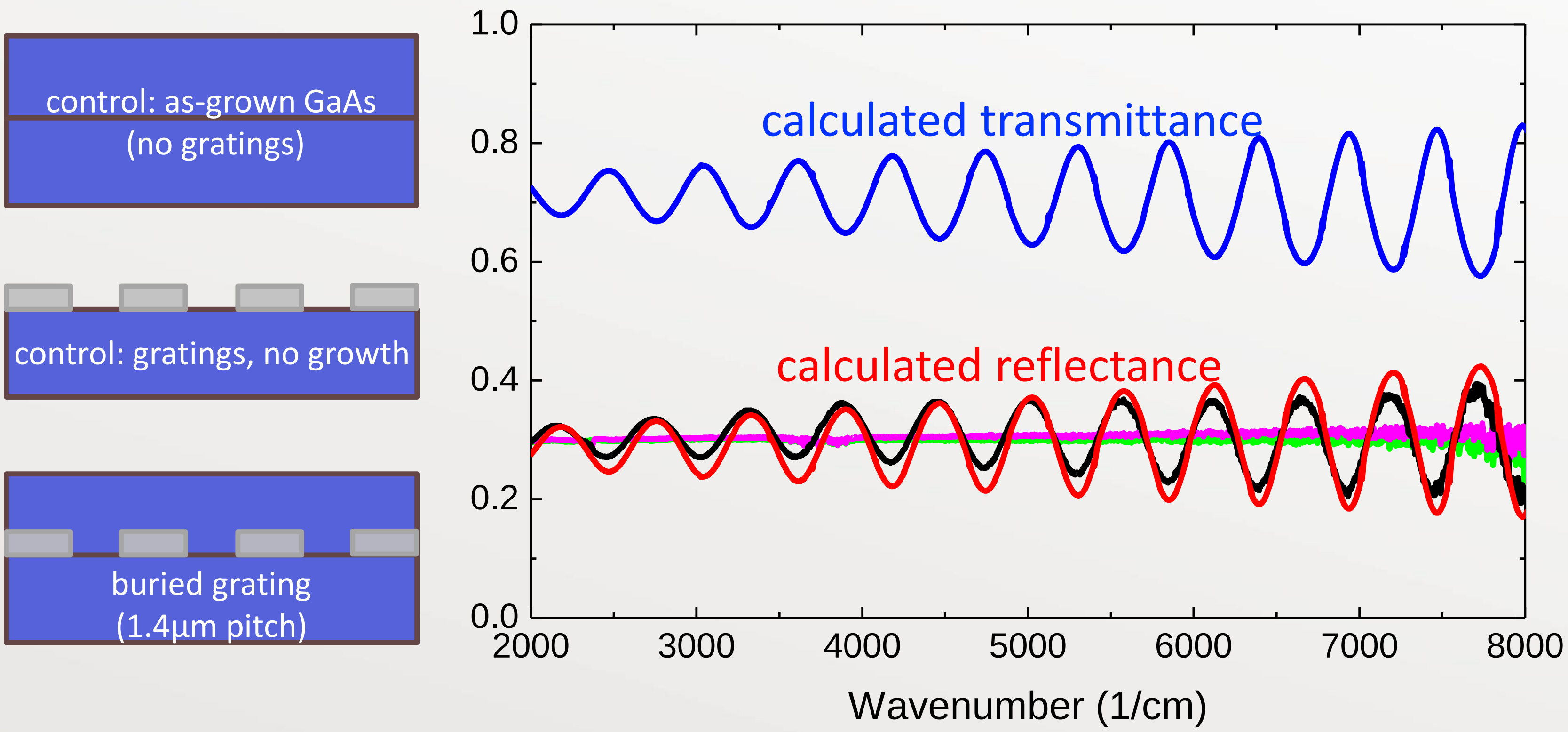


Fourier Transform Infrared Spectroscopy

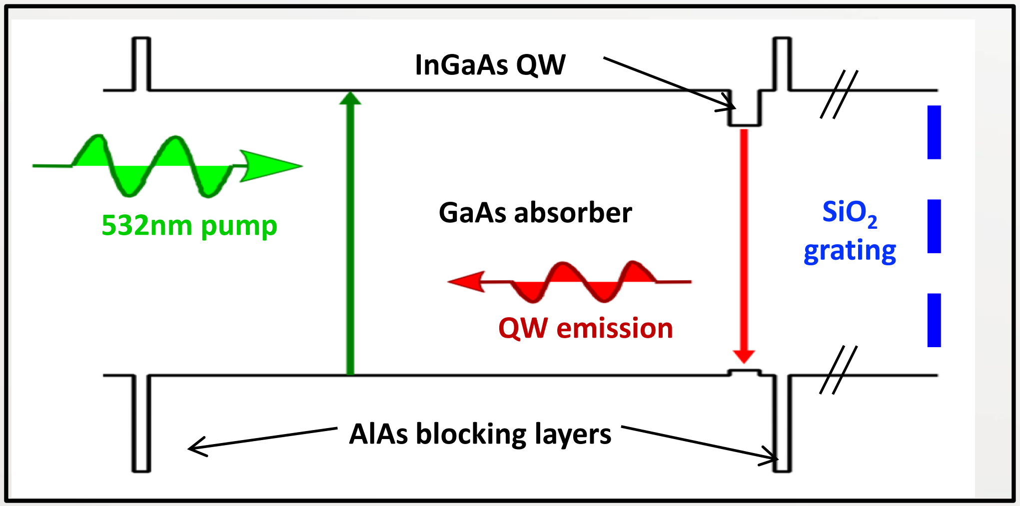


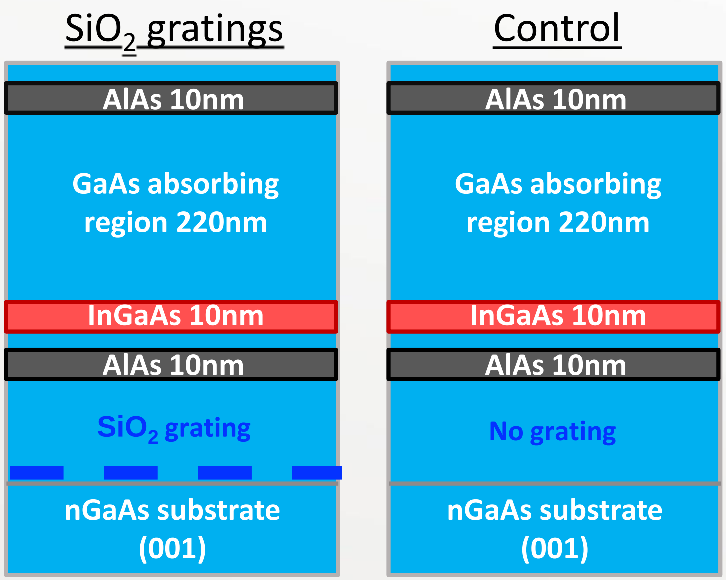


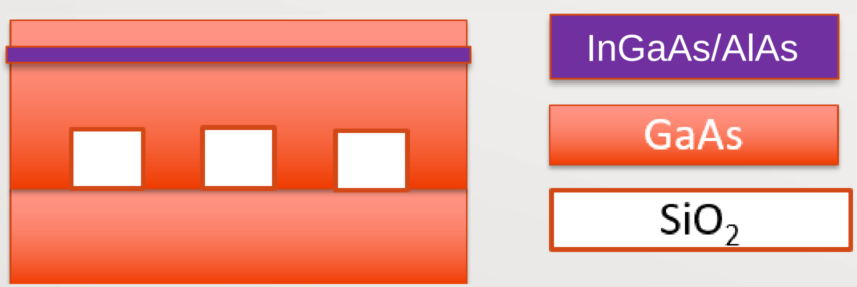
Fourier Transform Infrared Spectroscopy



Optical Test Structure





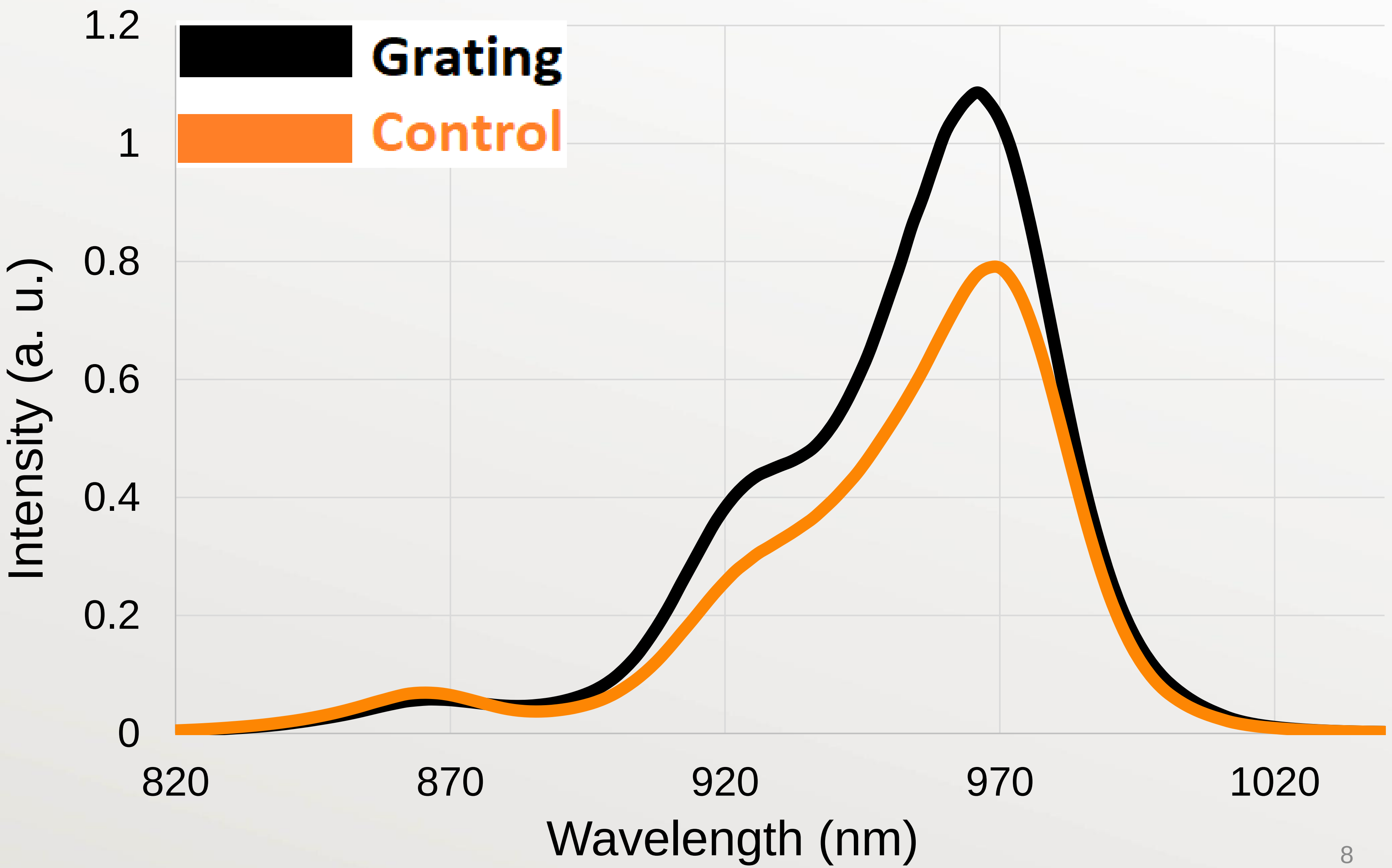


250 nm thick

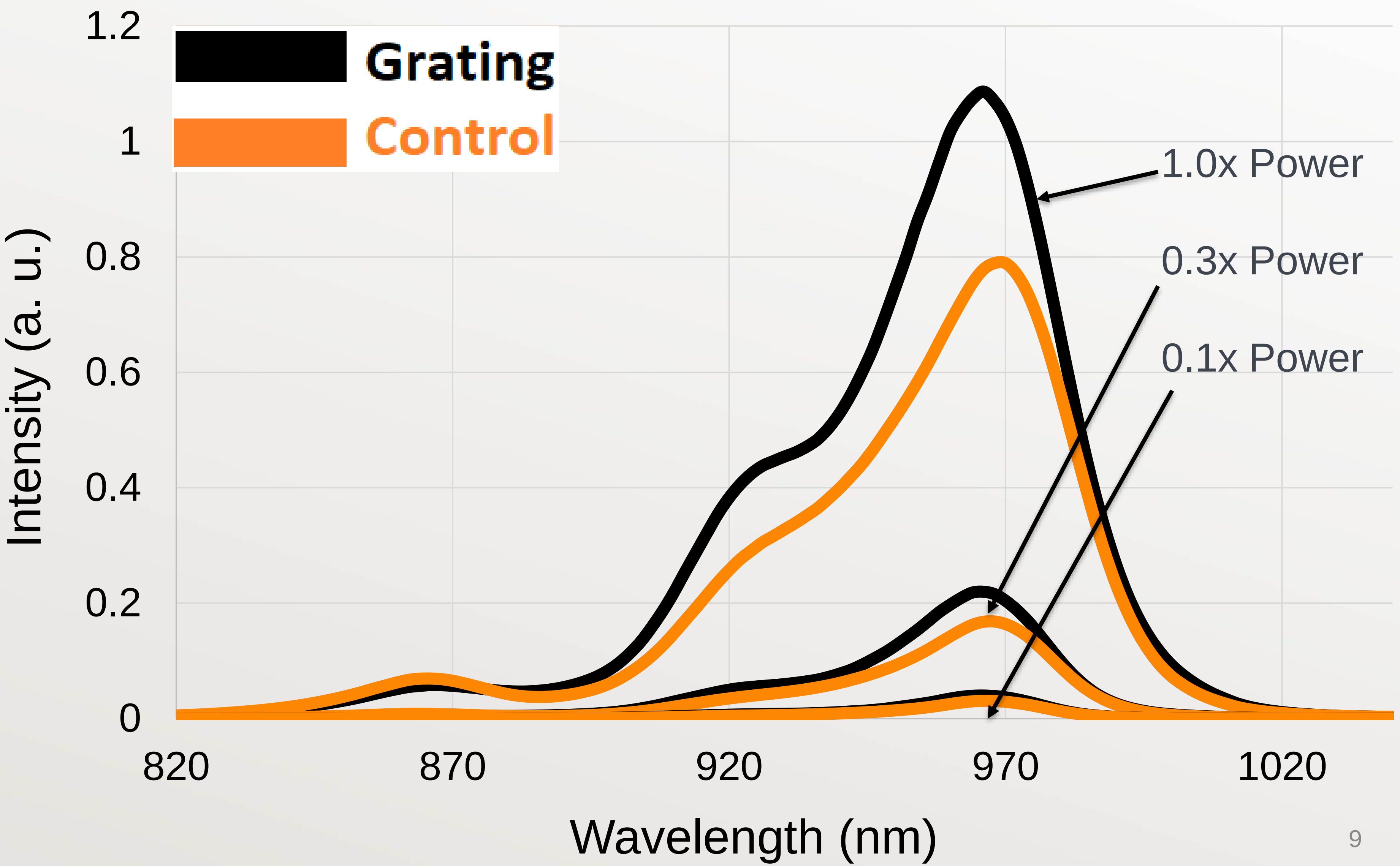
2.4 um overgrowth

25 nm thick 700 nm wide

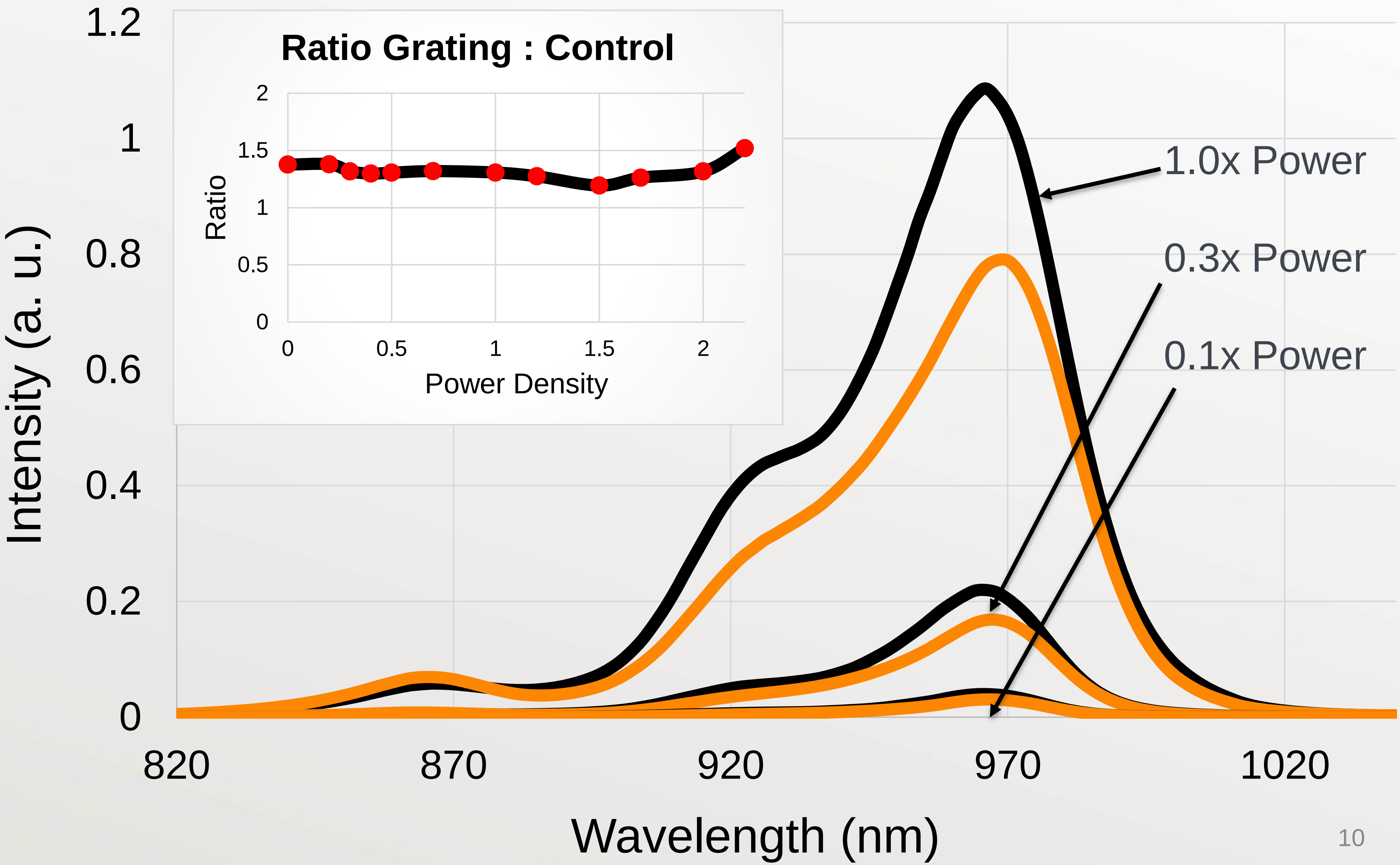
Excitation-dependent Photoluminescence



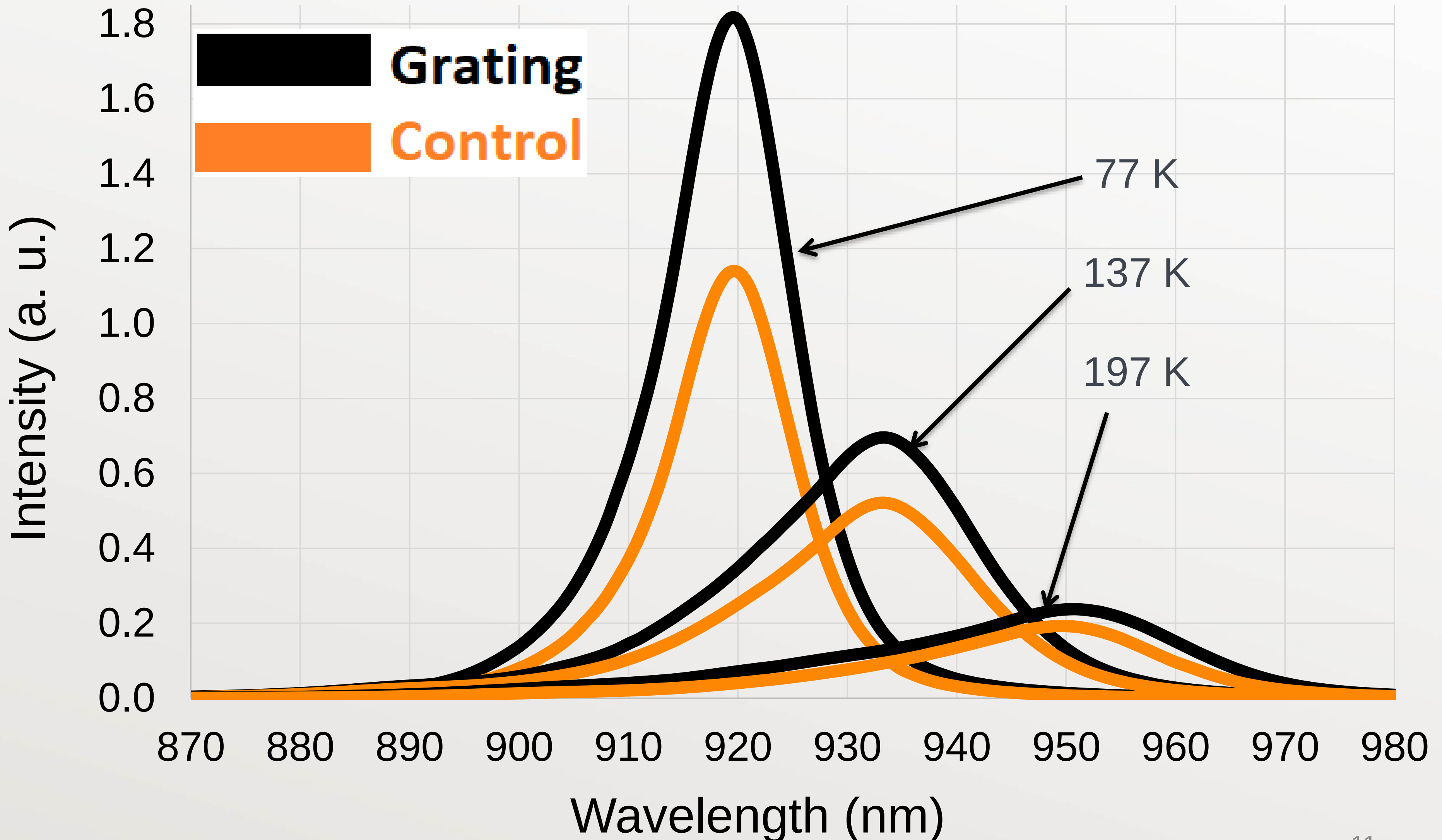
Excitation-dependent Photoluminescence



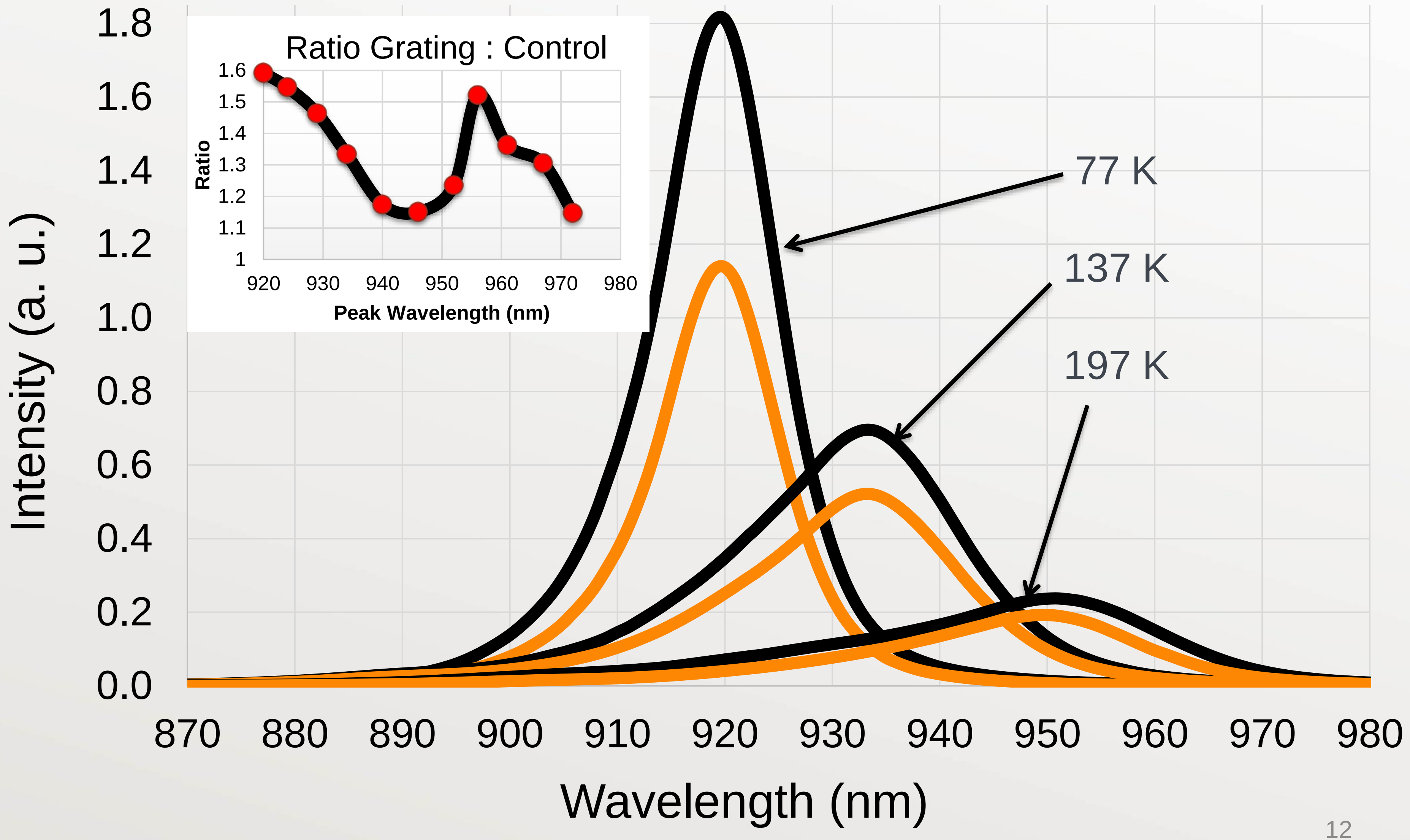
Excitation-dependent Photoluminescence



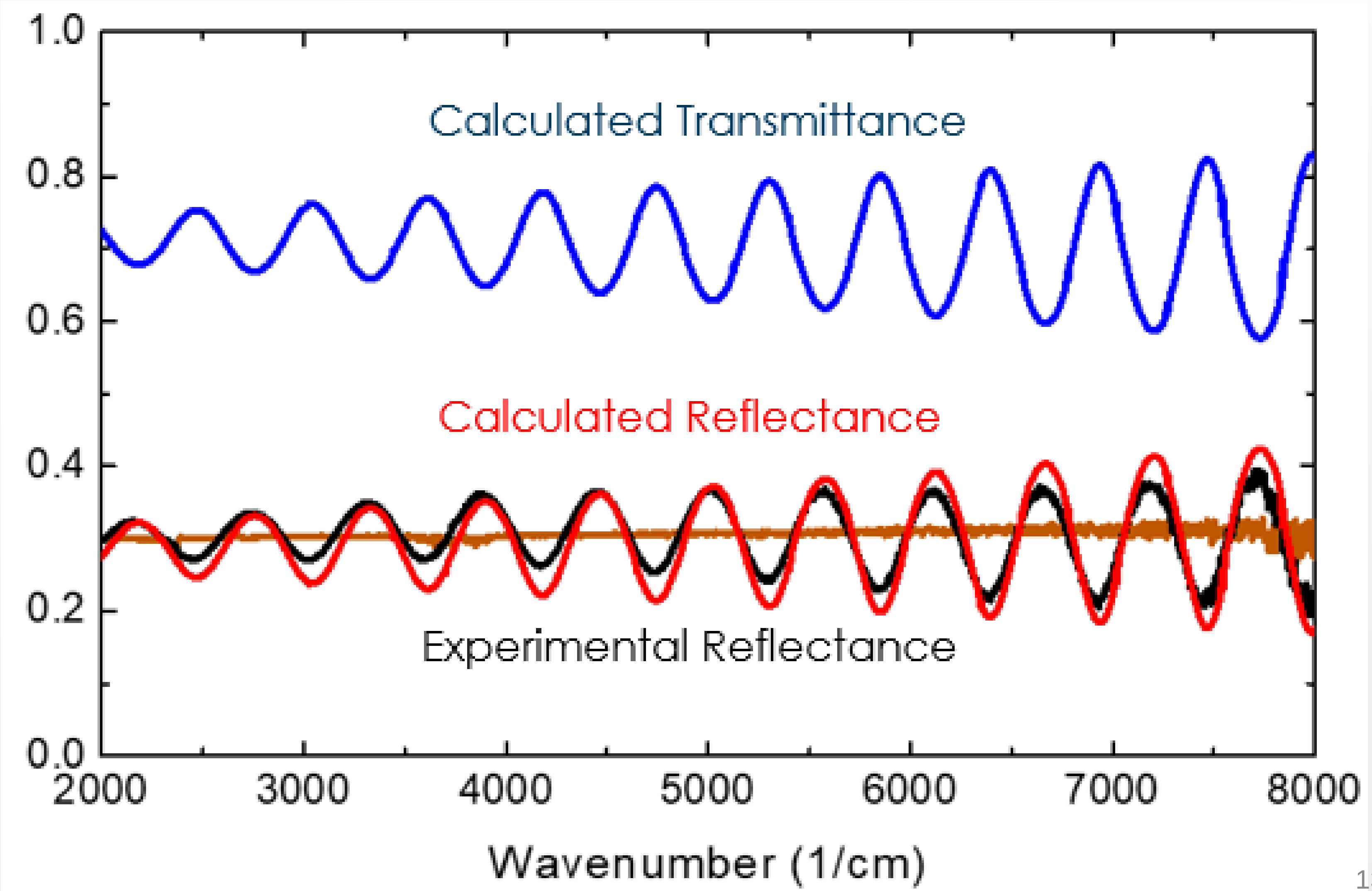
Temperature-dependent Photoluminescence



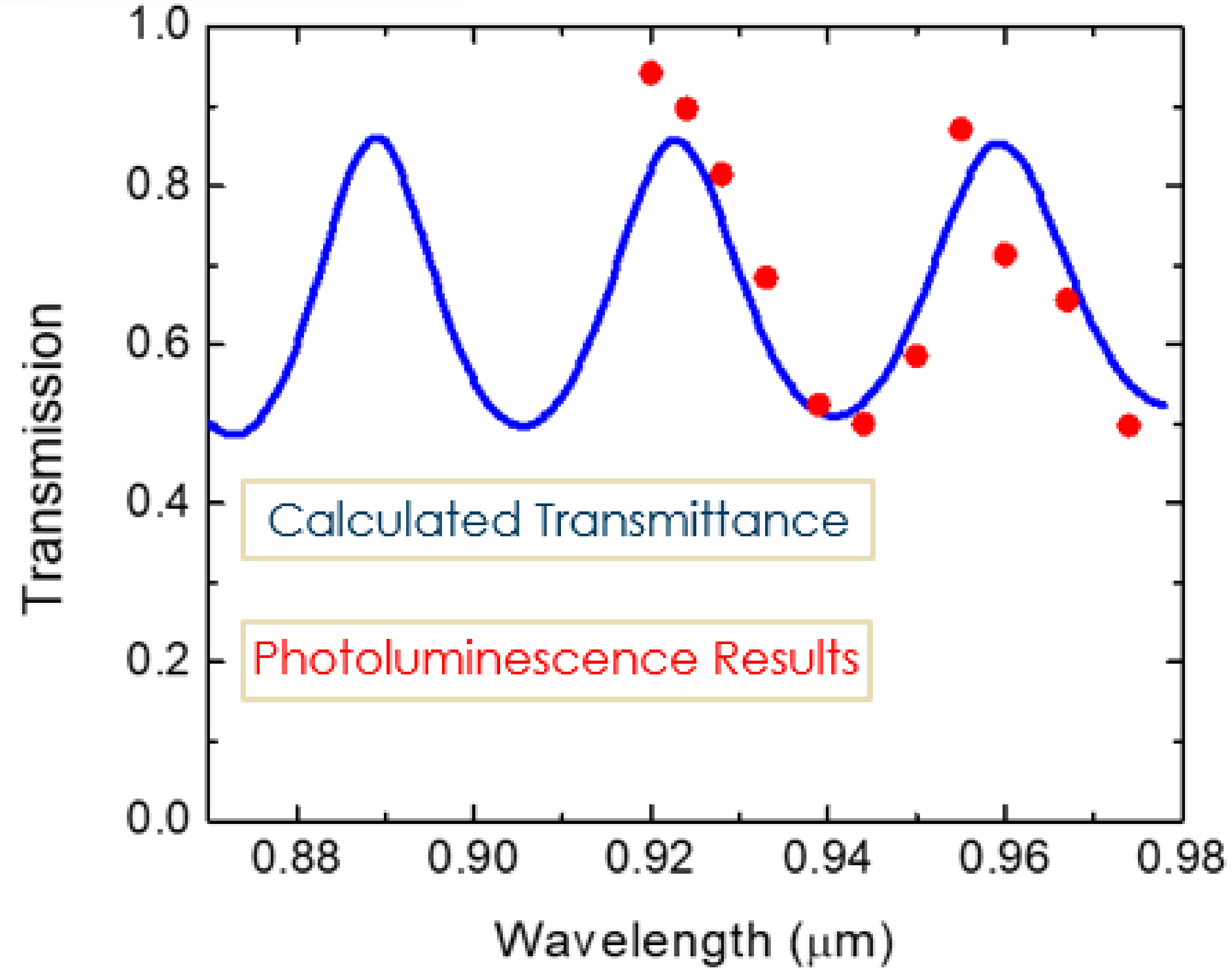
Temperature-dependent Photoluminescence



Interference fringes evident in FTIR evident in PL

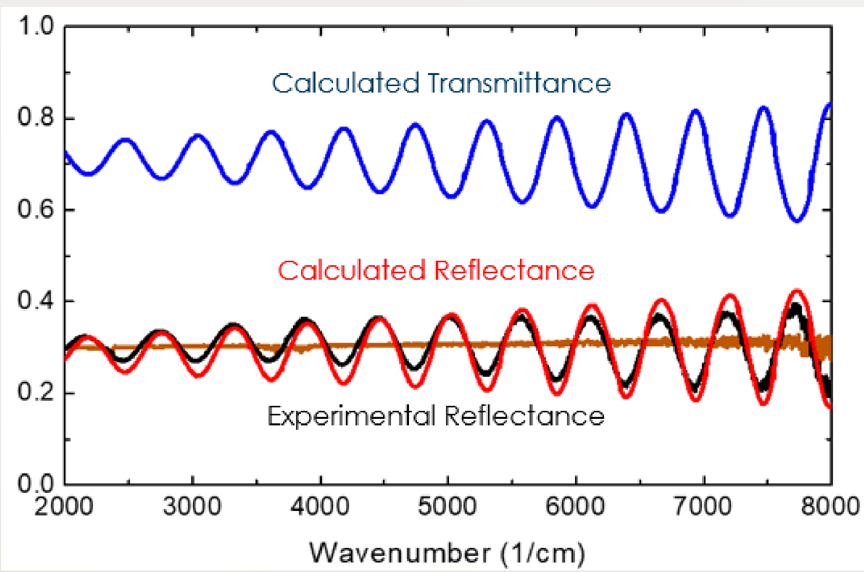


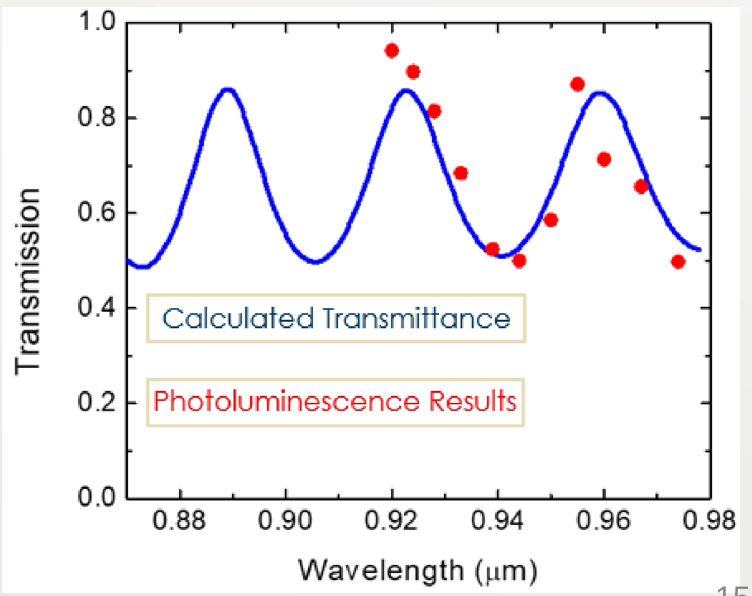
Interference fringes evident in FTIR evident in PL



Summary

- Optical characterization of epitaxially encapsulated high-contrast gratings was performed with FTIR and PL
- Reflectivity was measured and confirmed with theory
- PL was comparable to control
  - Enhancement is partly due to changes in transmissivity





Acknowledgements

Mentor Dan Ironside
PI Seth Bank
LASE Group
National Nanotechnology Coordinated Infrastructure
Fellow REUs
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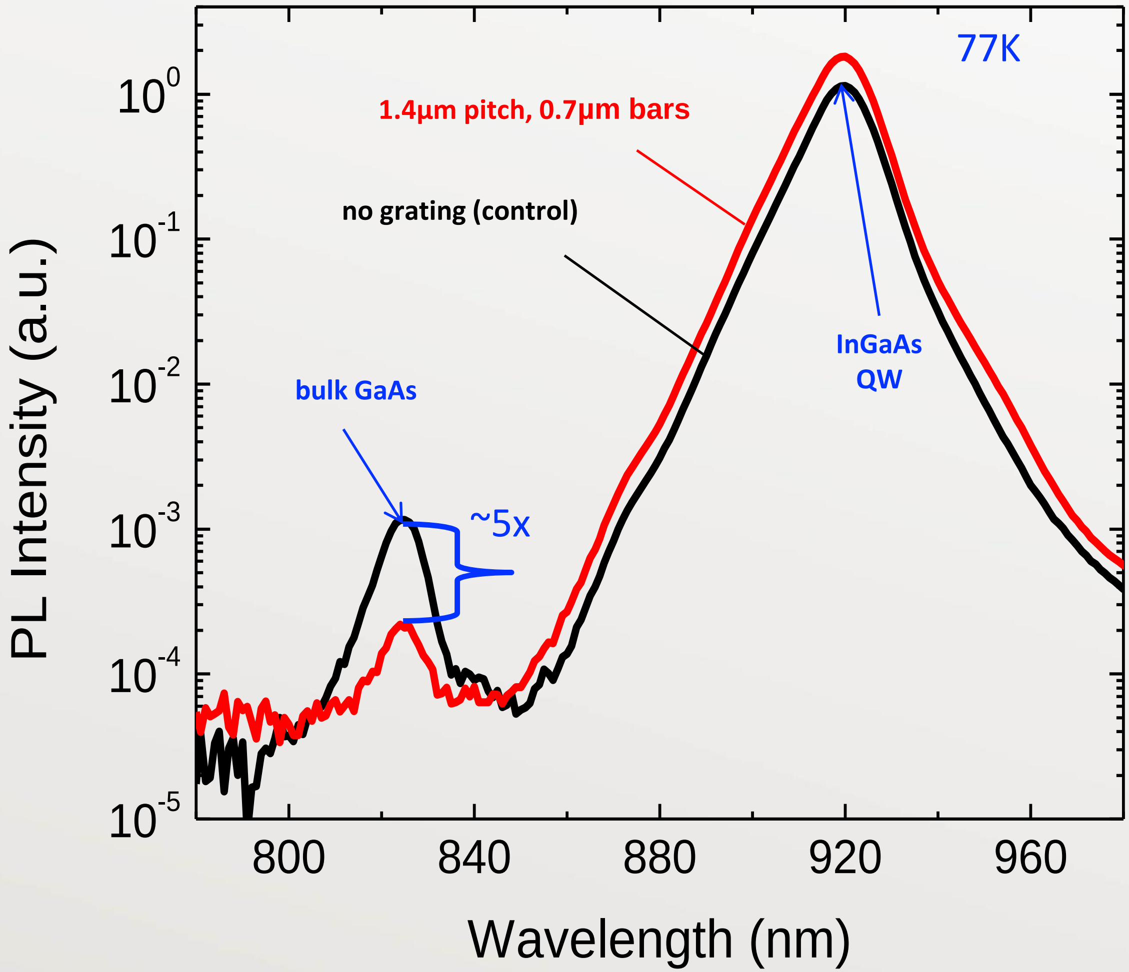
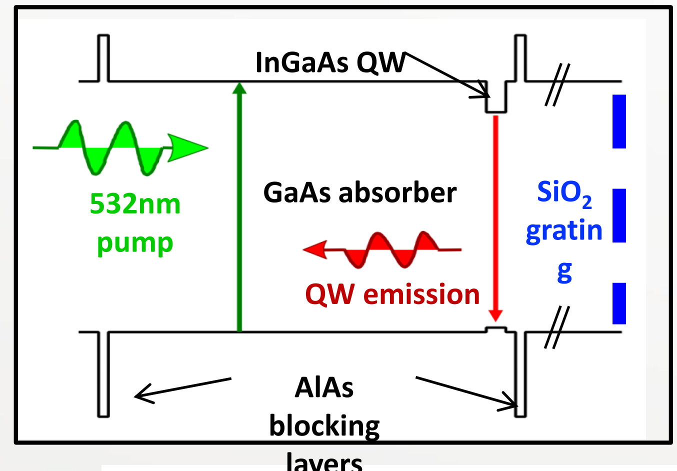
LASE Laboratory for Advanced Semiconductor Epitaxy

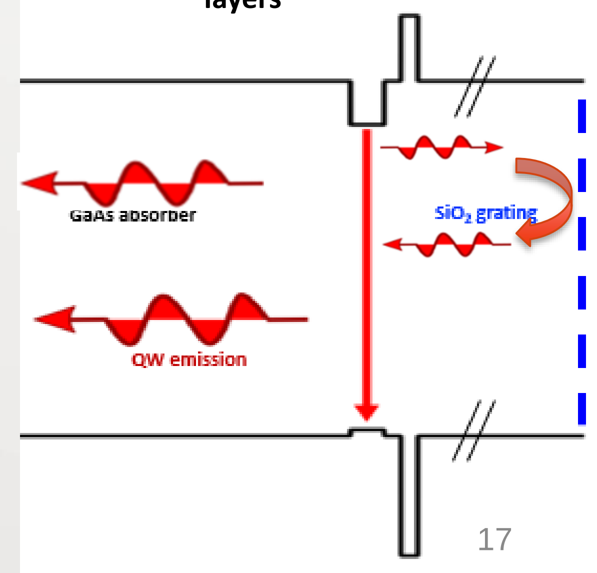
NSF

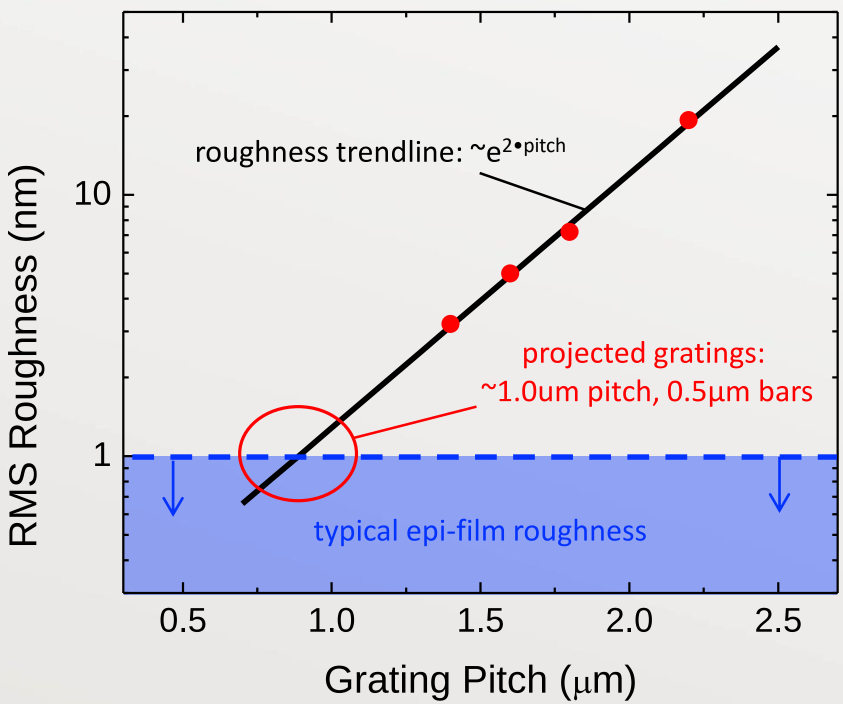
National Nanotechnology Coordinated Infrastructure

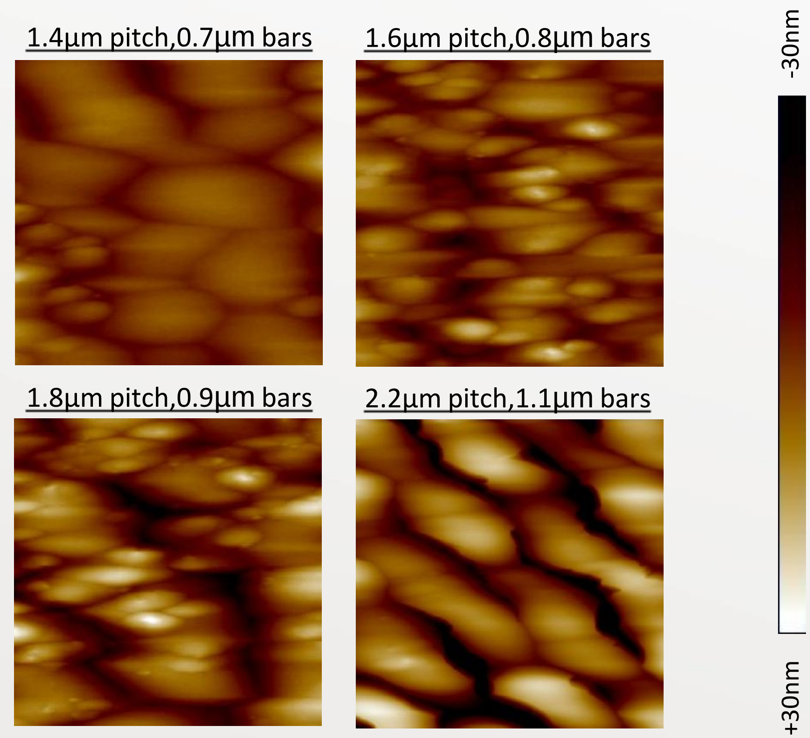
Recollection



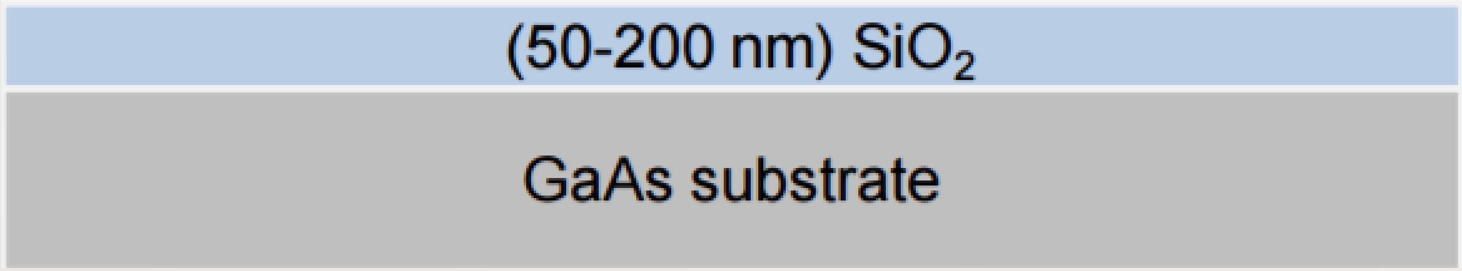




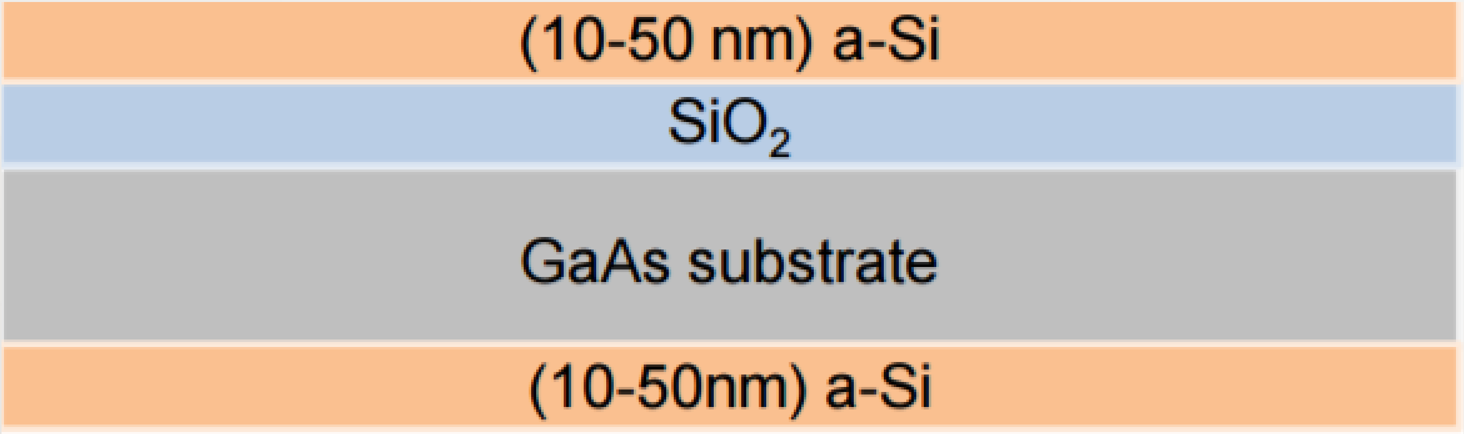

roughness trendline: ~e^2•pitch
projected gratings:
~1.0um pitch, 0.5µm bars
typical epi-film roughness
RMS Roughness (nm)
10
1
0.5
1.0
1.5
2.0
2.5
Grating Pitch (µm)


1.4µm pitch,0.7µm bars
1.6µm pitch,0.8µm bars
1.8µm pitch,0.9µm bars
2.2µm pitch,1.1µm bars
-30nm
+30nm

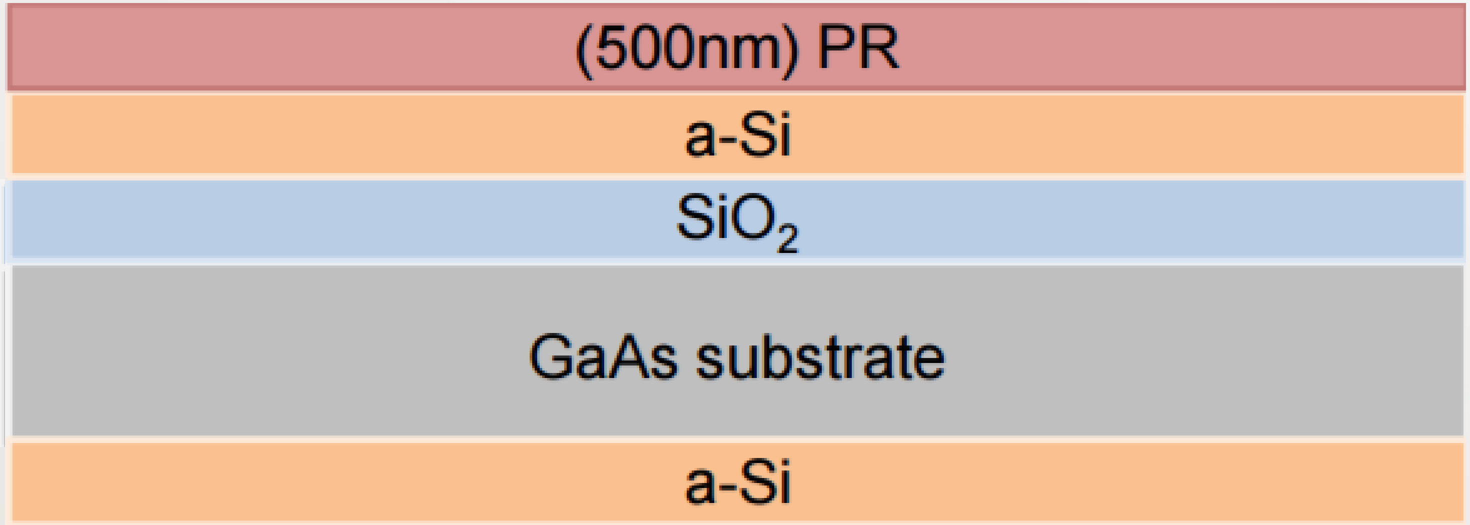
Grating Fabrication
PECVD



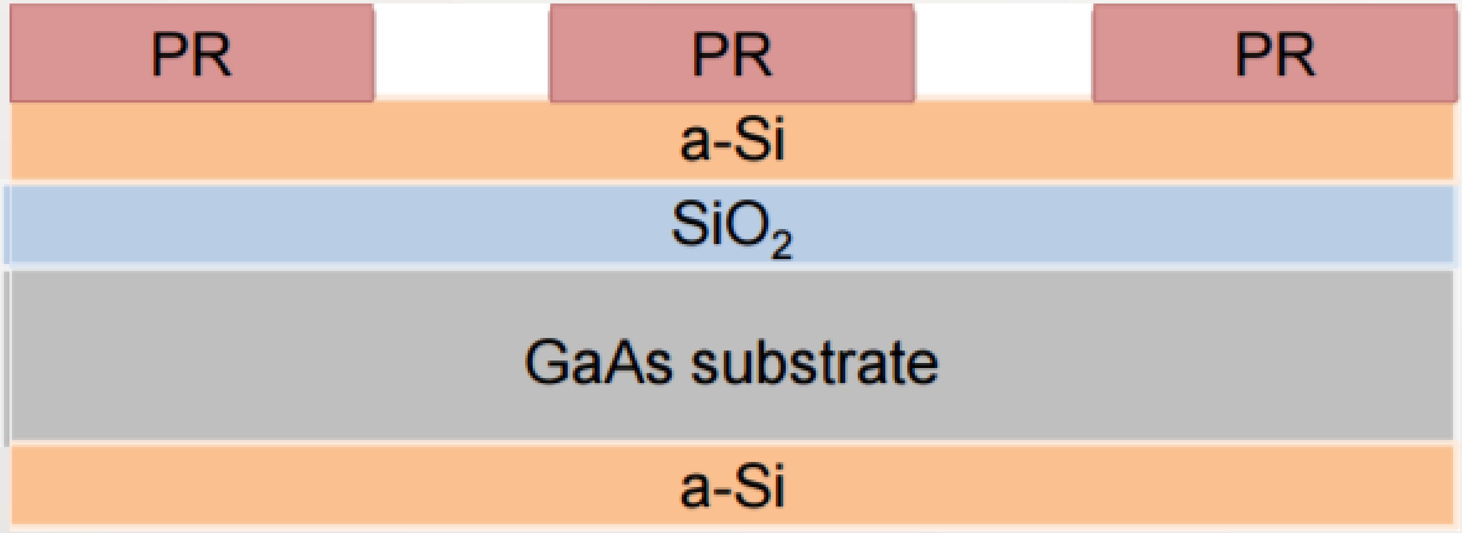
Grating Fabrication
Sacrificial Layer



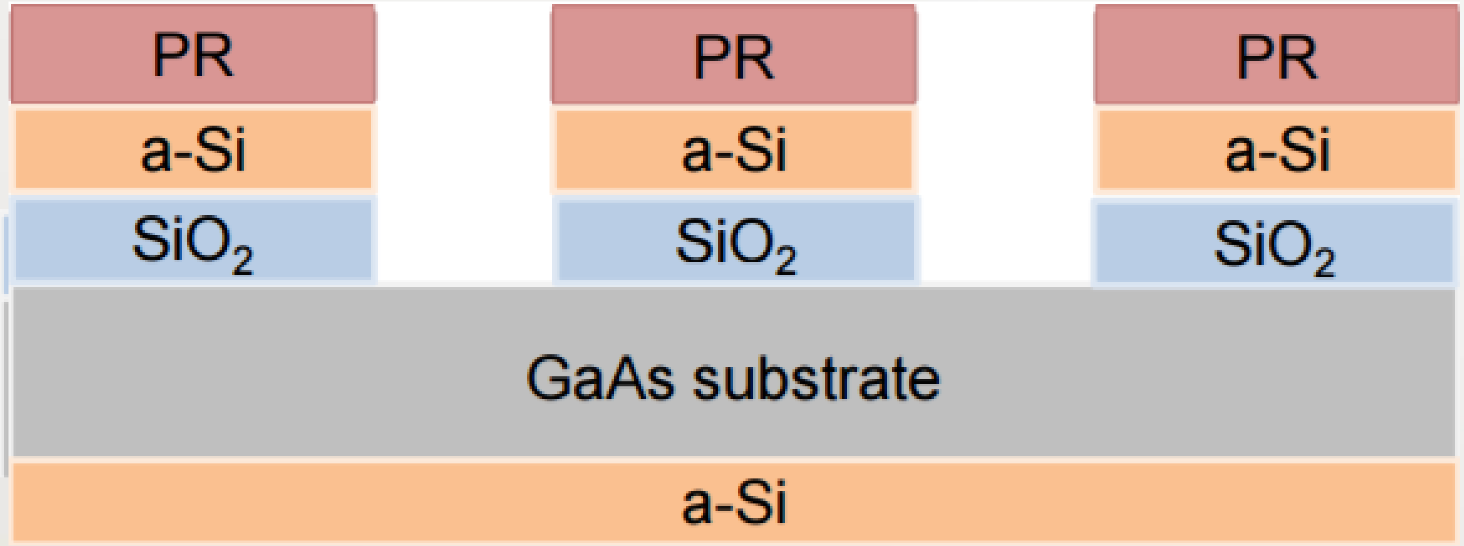
Grating Fabrication
Spin-Coat Photoresist



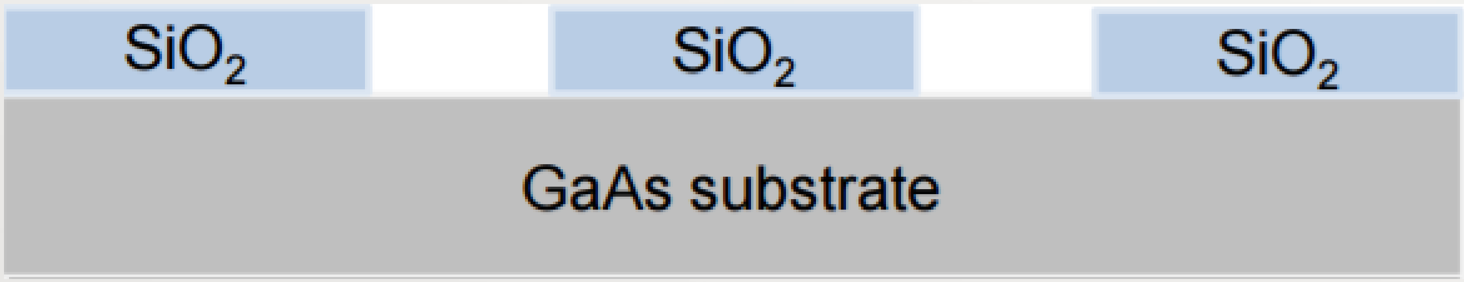
Grating Fabrication
UV Lithography



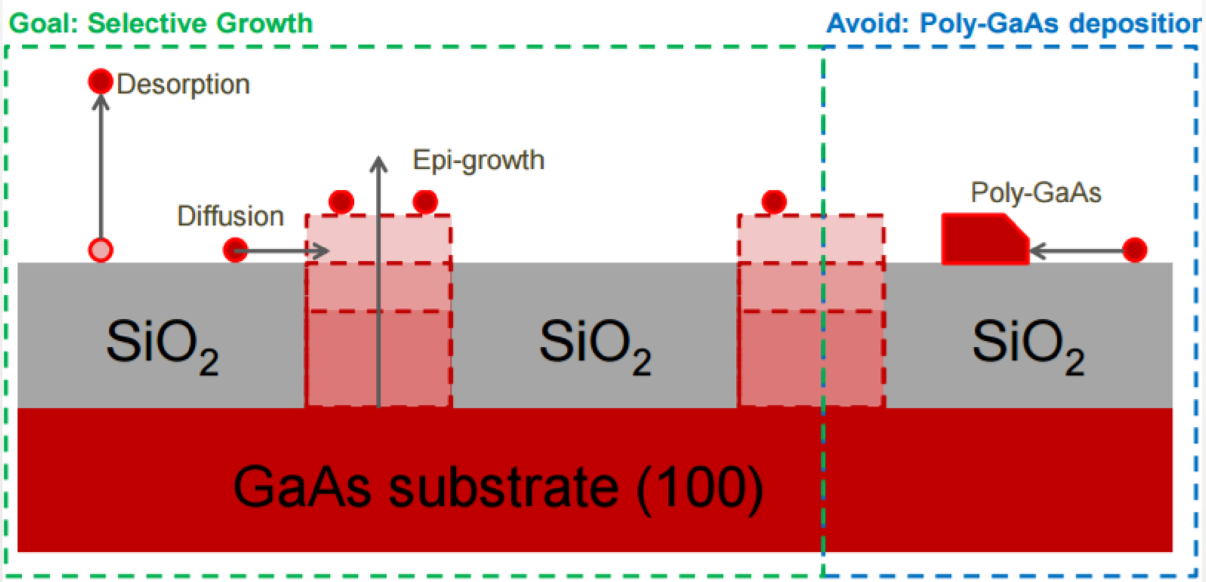
Grating Fabrication
Dry Etch

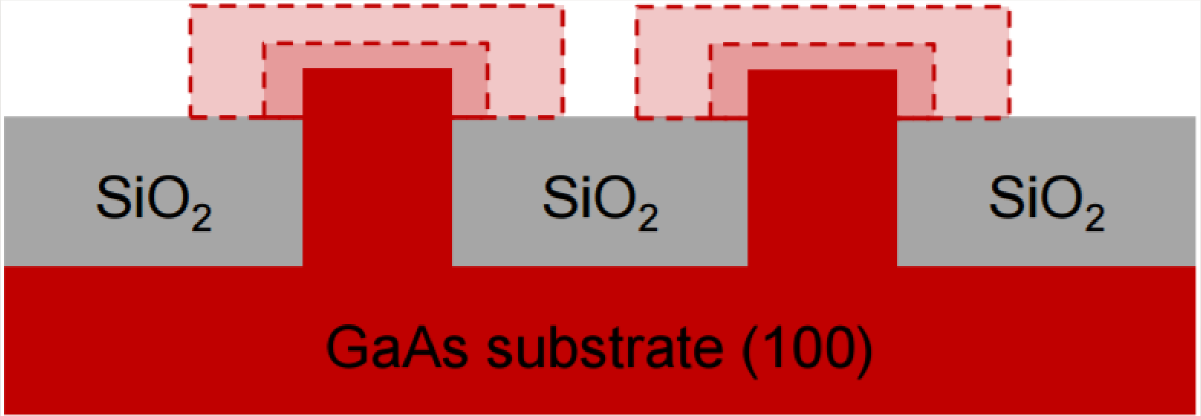


Grating Fabrication
Wash

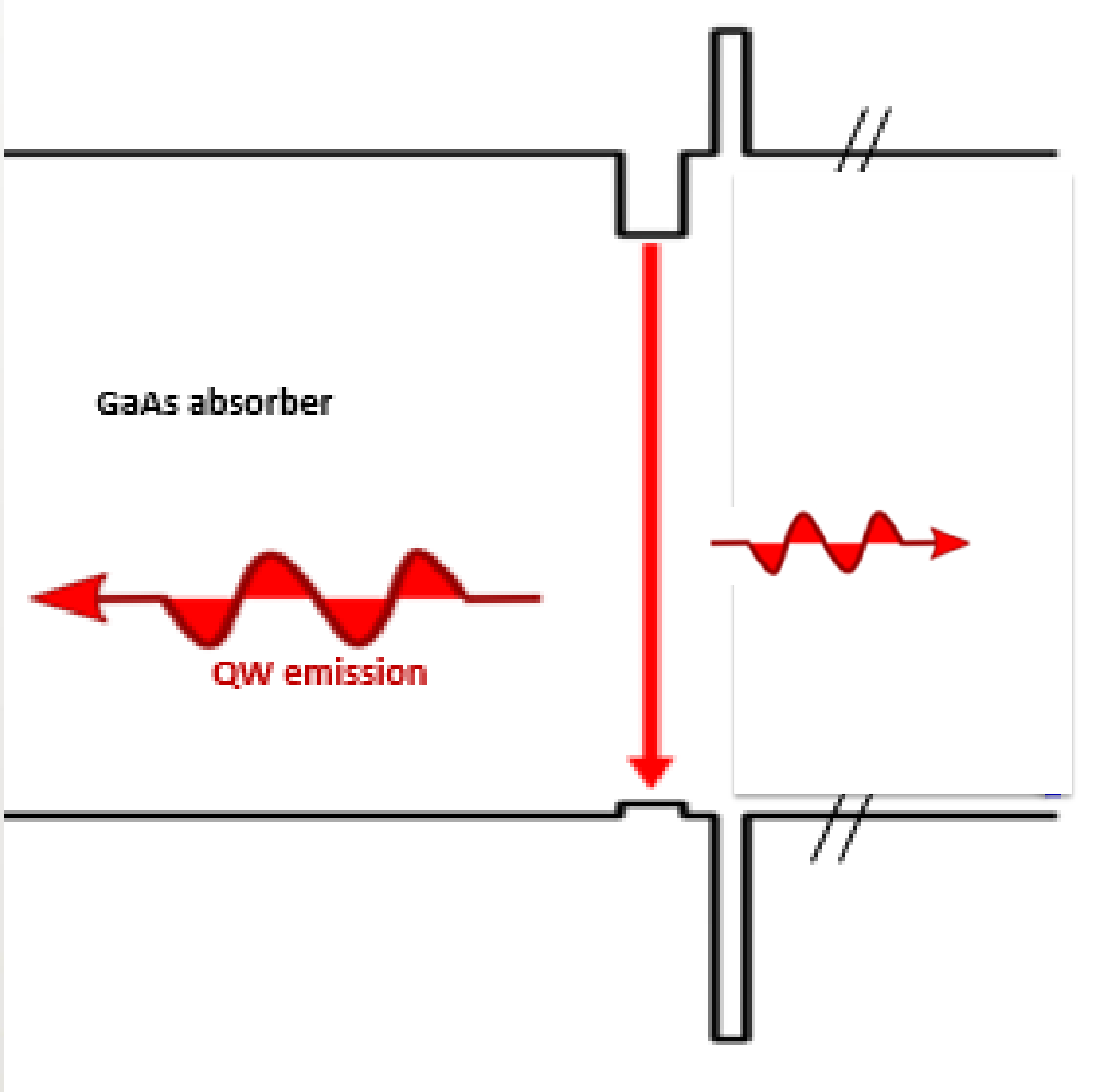


GaAs Overgrowth





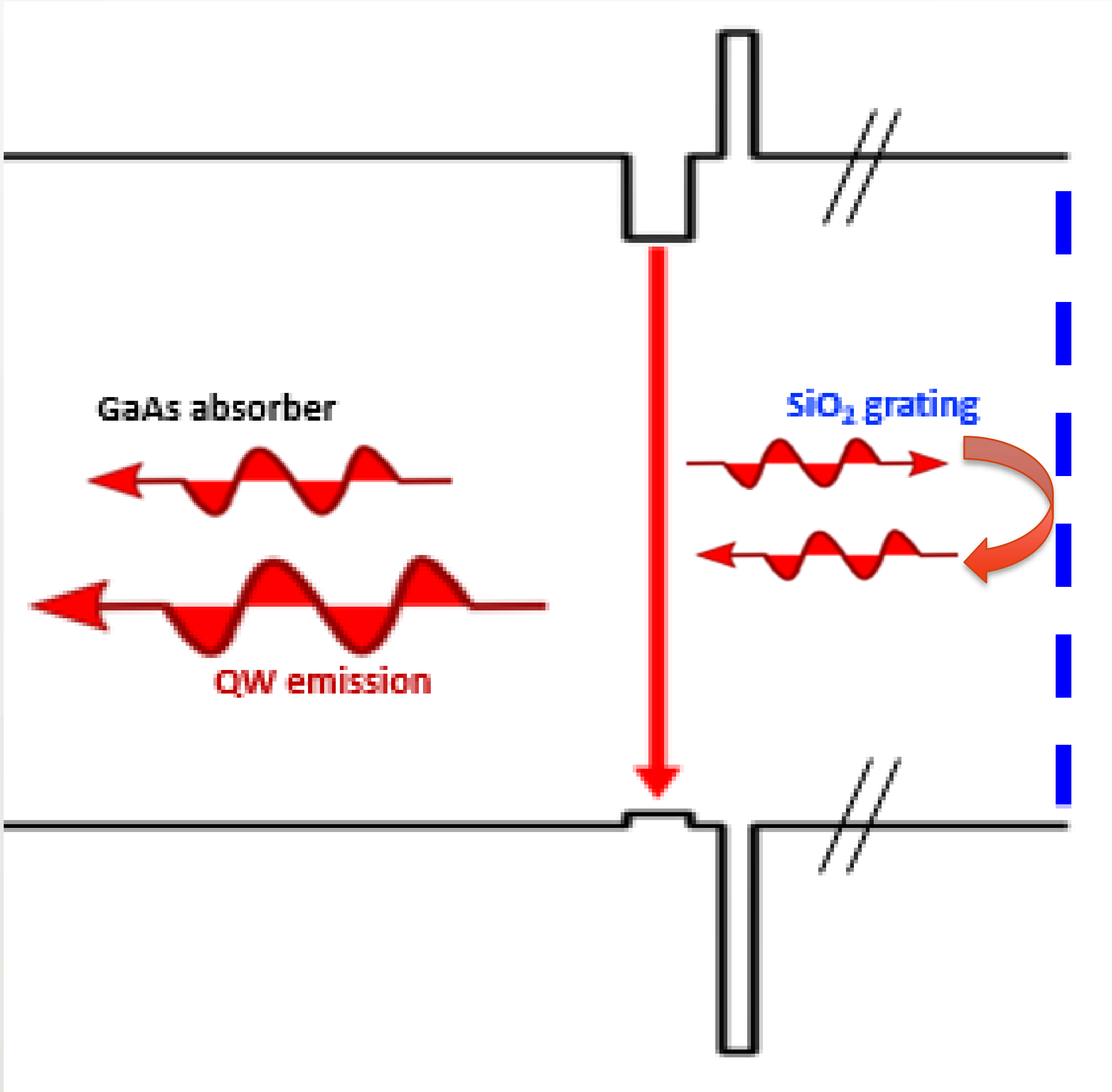
D
E
T
E
C
T
O
R



No Backscatter

No Reabsorption

DETECTOR

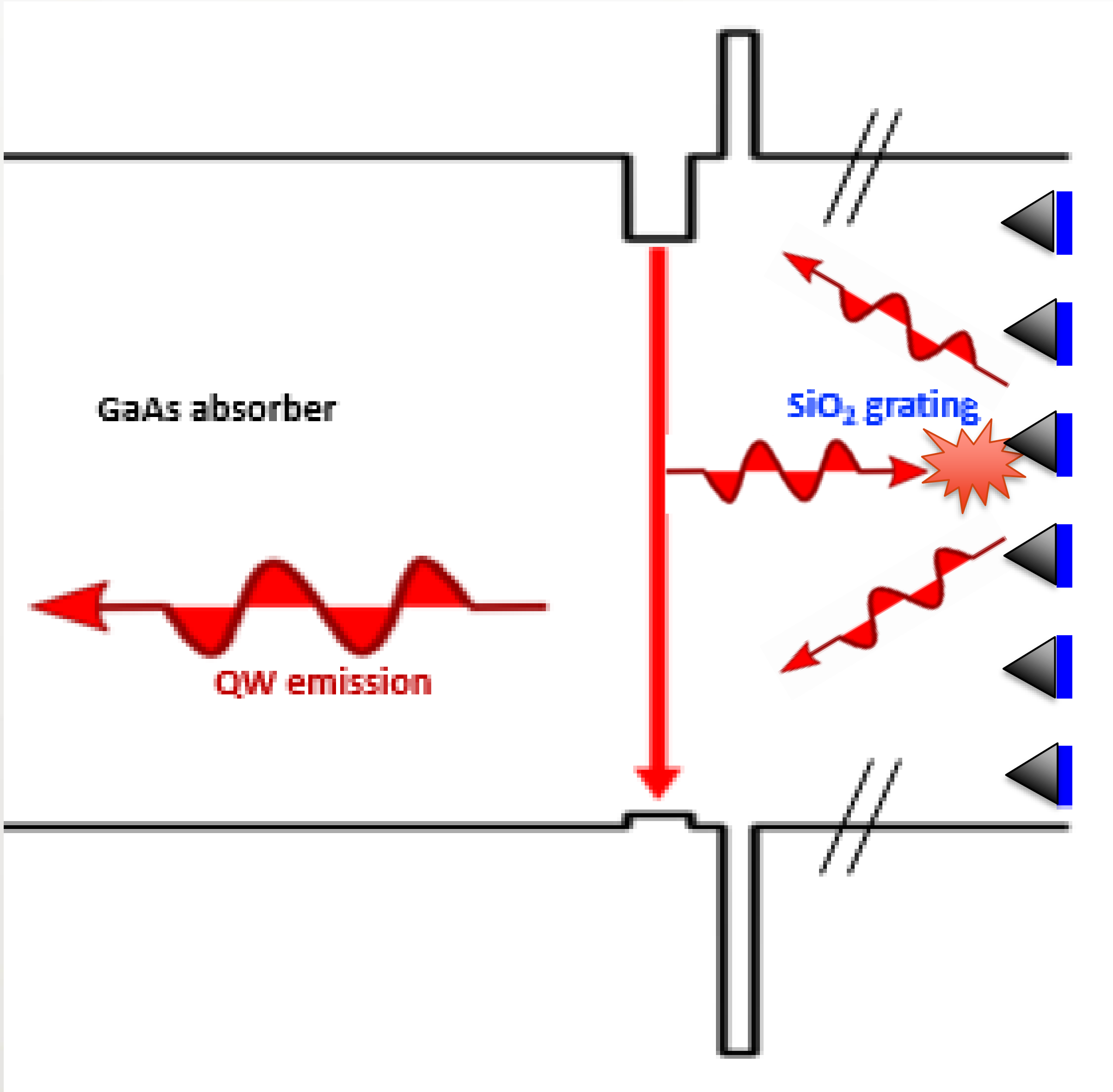


Specular Backscatter

Reabsorption

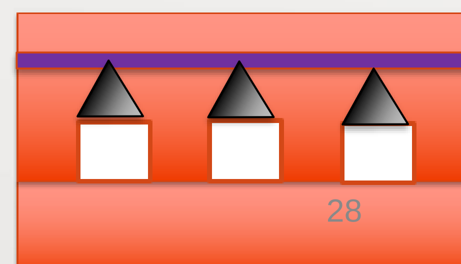
Enhanced PL

D
E
T
E
C
T
O
R

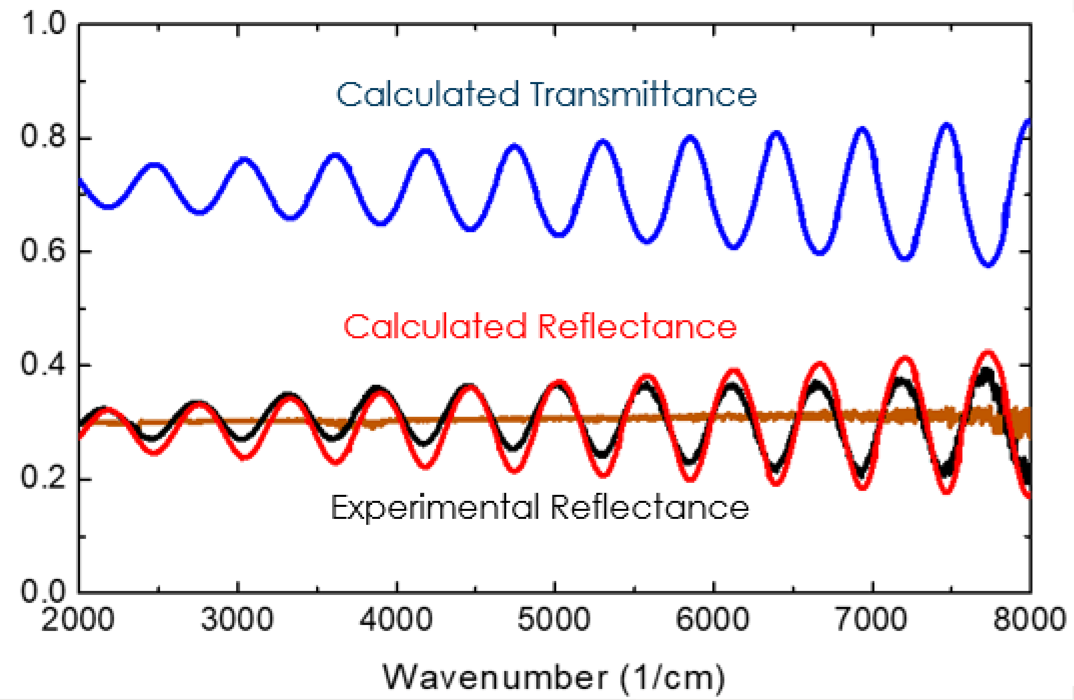


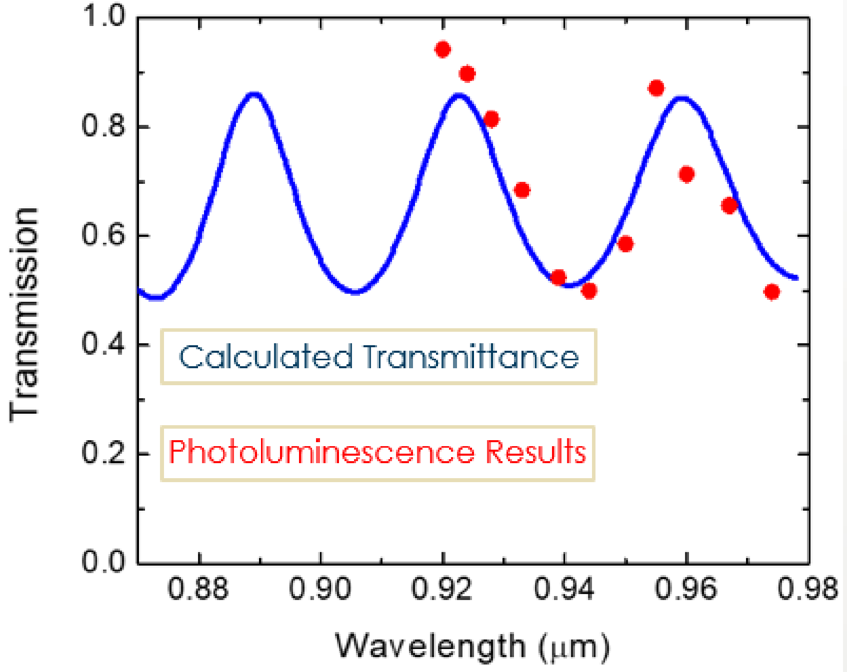
Diffuse Backscatter

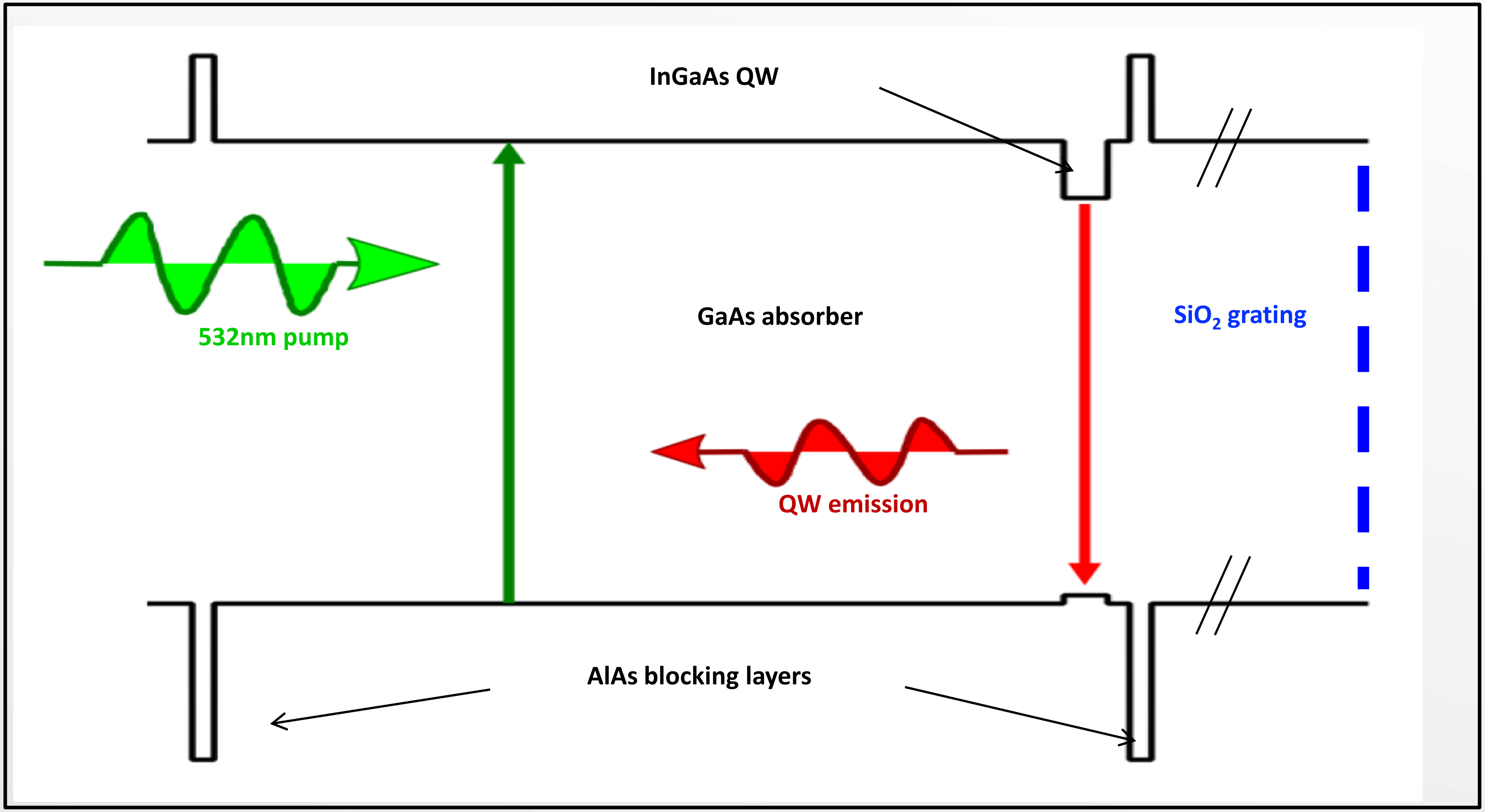
No Reabsorption

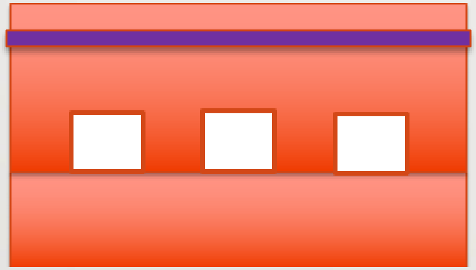


Interference fringes evident in FTIR evident in PL



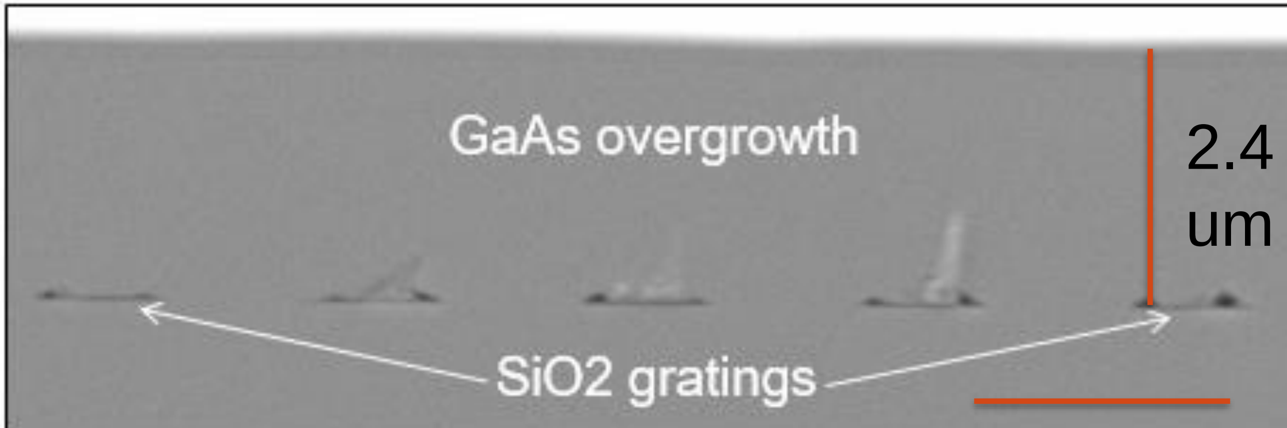



InGaAs QW
532nm pump
GaAs absorber
SiO_2 grating
QW emission
AlAs blocking layers

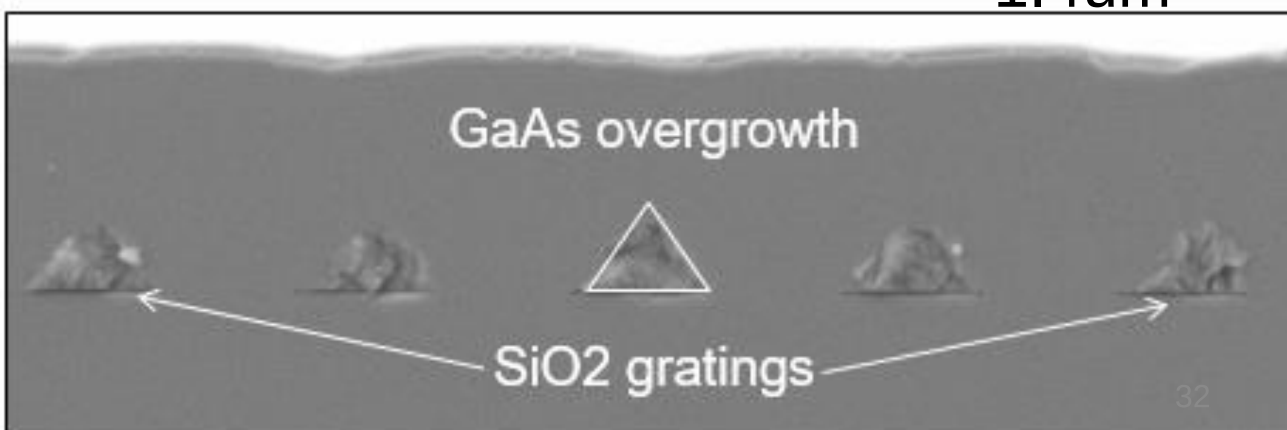


Polycrystalline GaAs Formation

240 cycles of PSE, 2.4μm of continuous growth

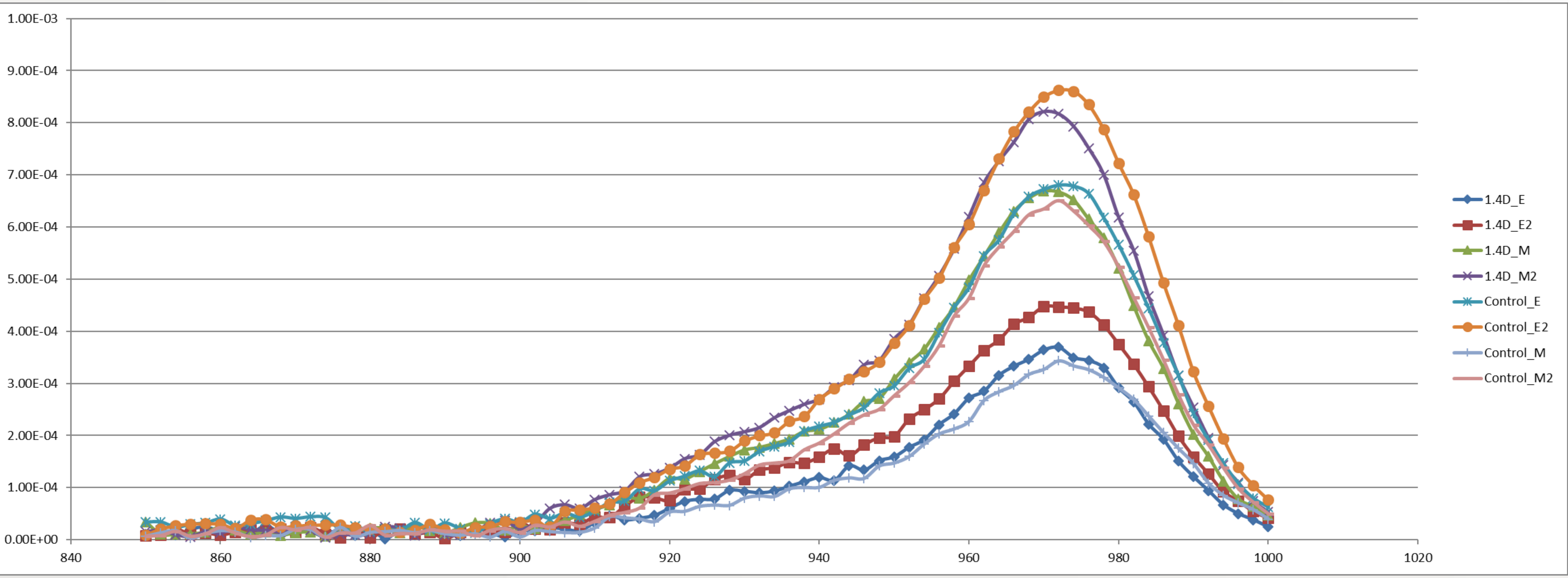


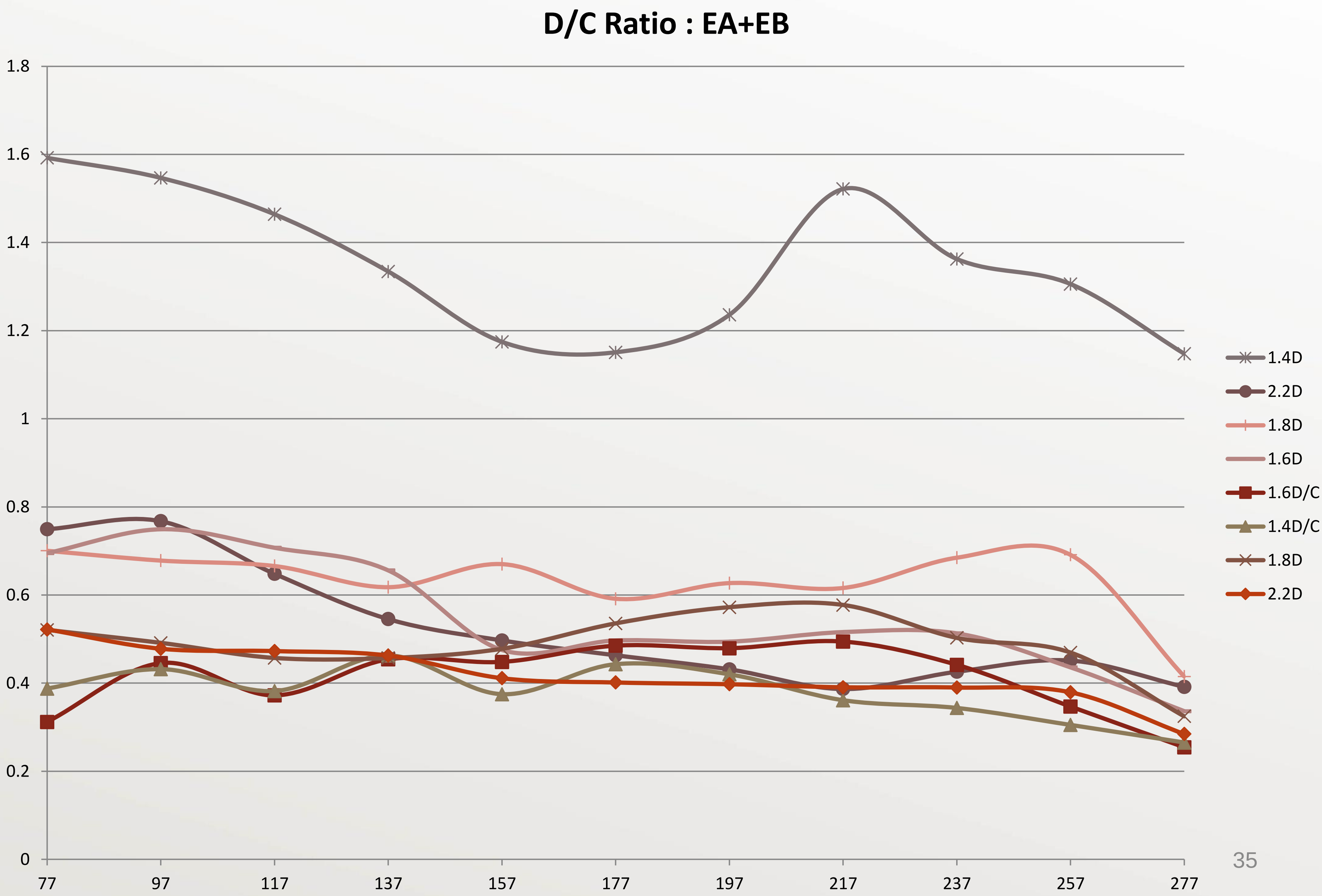
control: no PSE, 2.4μm continuous growth only



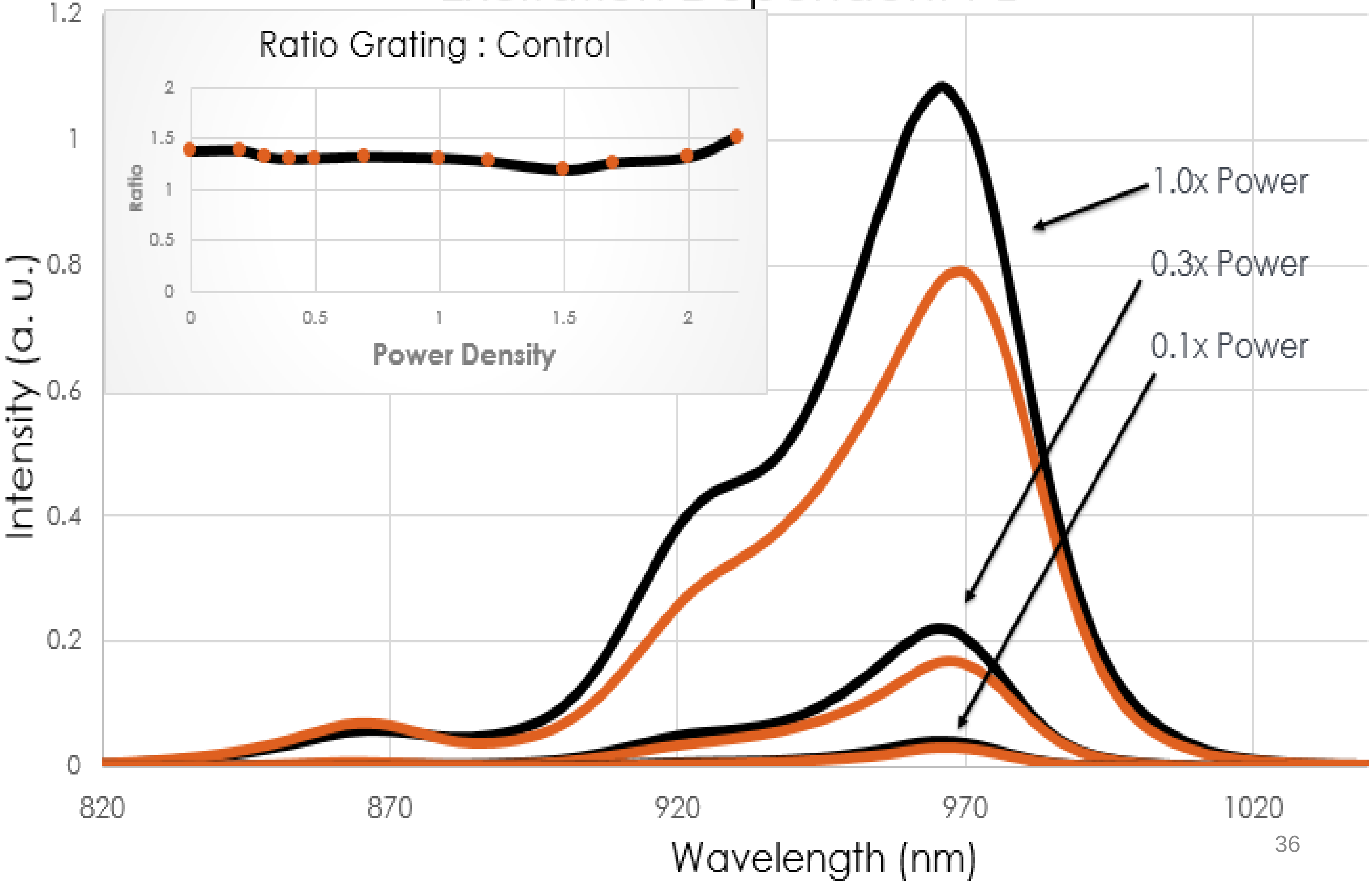
Why Dielectric Metastructures?

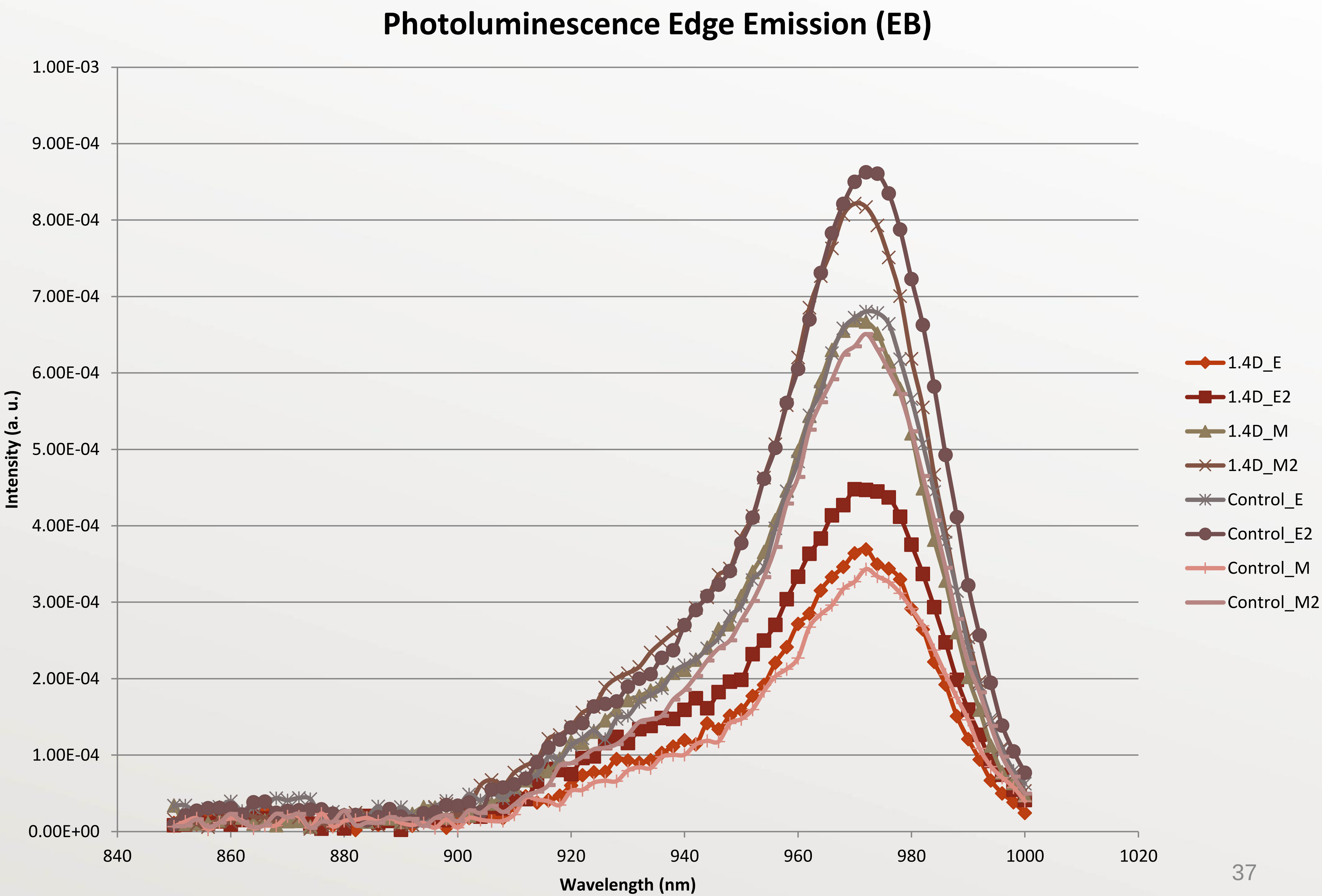
- Lossless broadband reflection
- Less material than DBR


1.00E-03
9.00E-04
8.00E-04
7.00E-04
6.00E-04
5.00E-04
4.00E-04
3.00E-04
2.00E-04
1.00E-04
0.00E+00
840
860
880
900
920
940
960
980
1000
1020
1.4D_E
1.4D_E2
1.4D_M
1.4D_M2
Control_E
Control_E2
Control_M
Control_M2

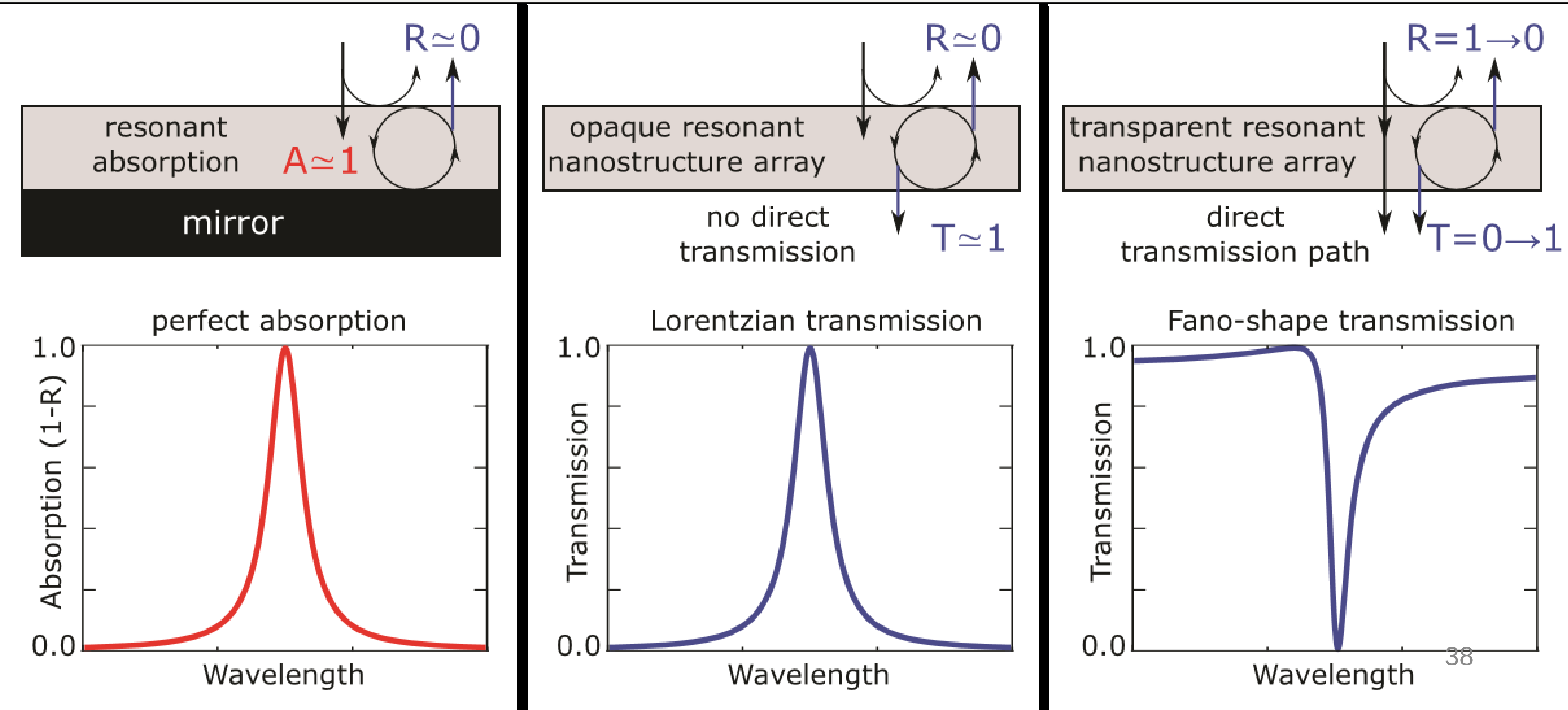

D/C Ratio : EA+EB
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
77
97
117
137
157
177
197
217
237
257
277
1.4D
2.2D
1.8D
1.6D
1.6D/C
1.4D/C
1.8D
2.2D

Excitation Dependent PL

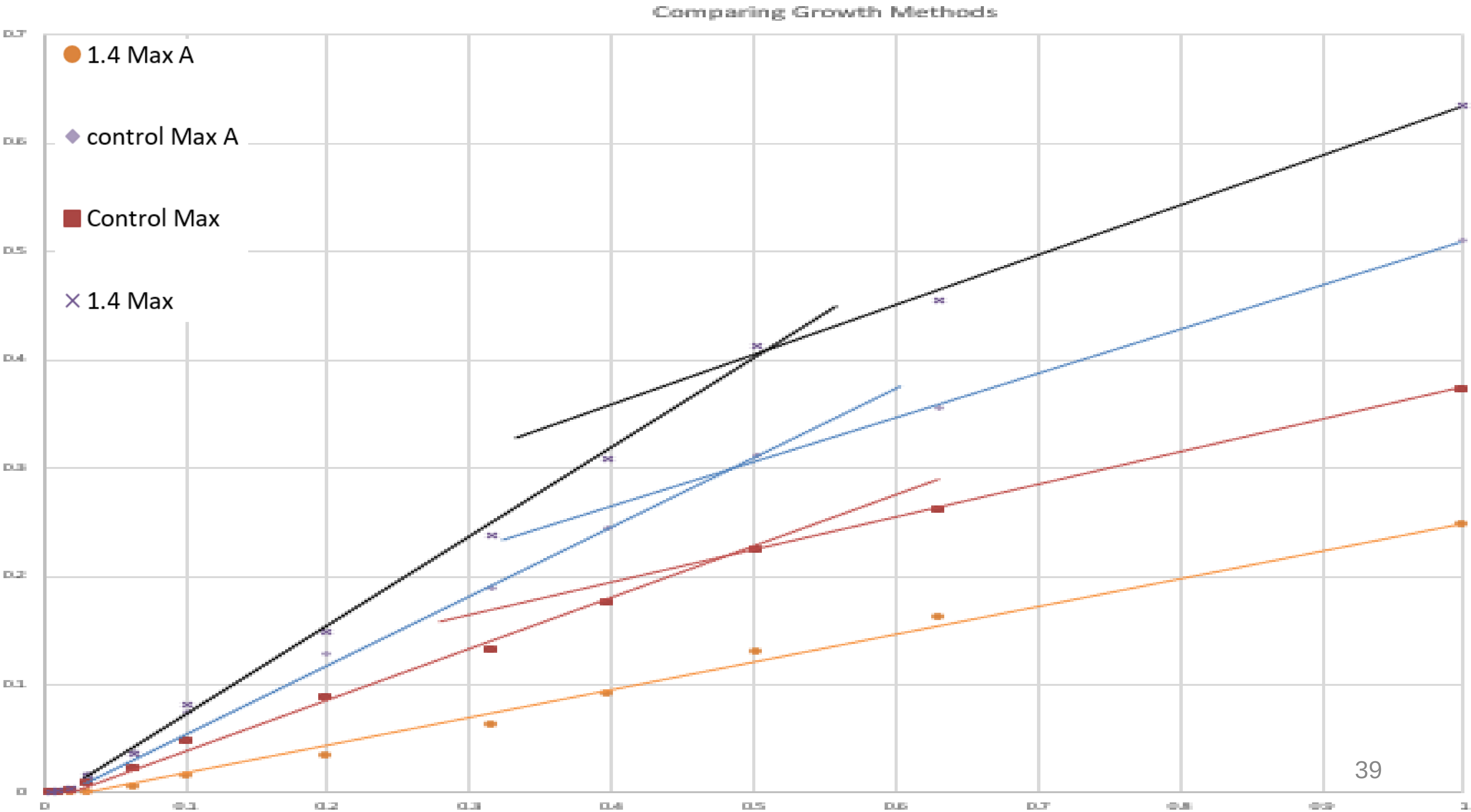


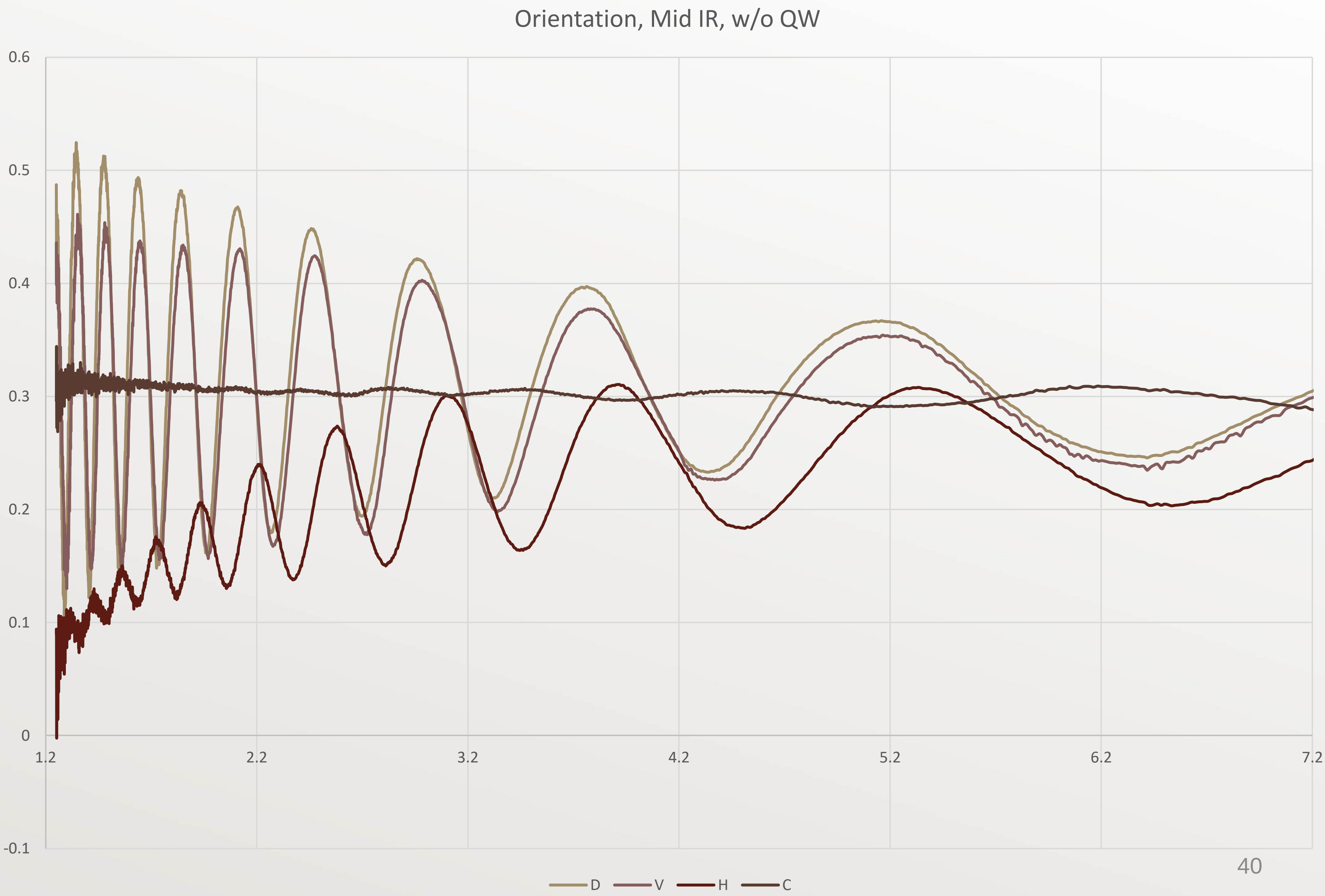

Photoluminescence Edge Emission (EB)
Intensity (a. u.)
1.00E-03
9.00E-04
8.00E-04
7.00E-04
6.00E-04
5.00E-04
4.00E-04
3.00E-04
2.00E-04
1.00E-04
0.00E+00
840
860
880
900
920
940
960
980
1000
1020
Wavelength (nm)
1.4D_E
1.4D_E2
1.4D_M
1.4D_M2
Control_E
Control_E2
Control_M
Control_M2

Functionality of Dielectric Metastructures

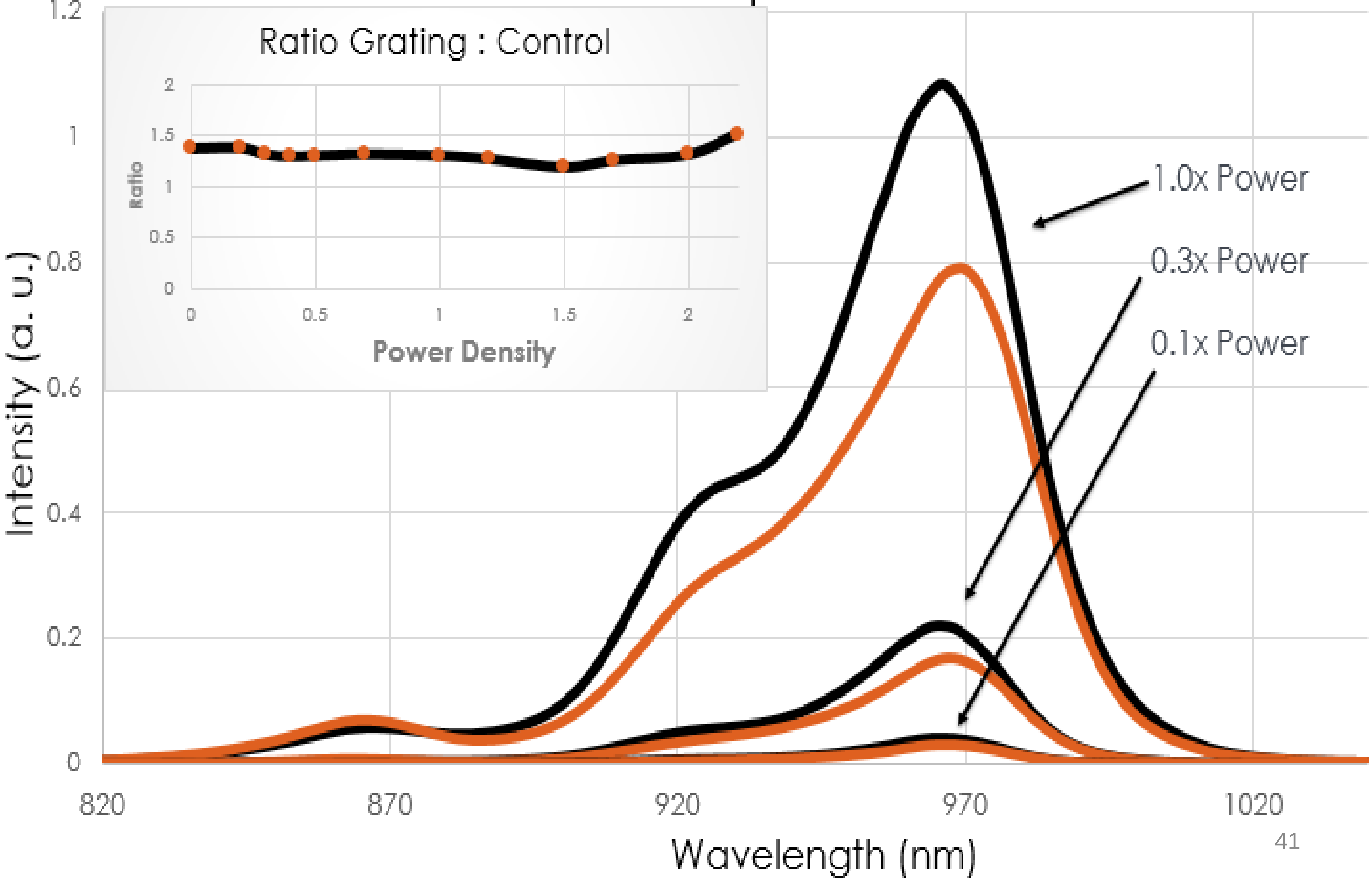


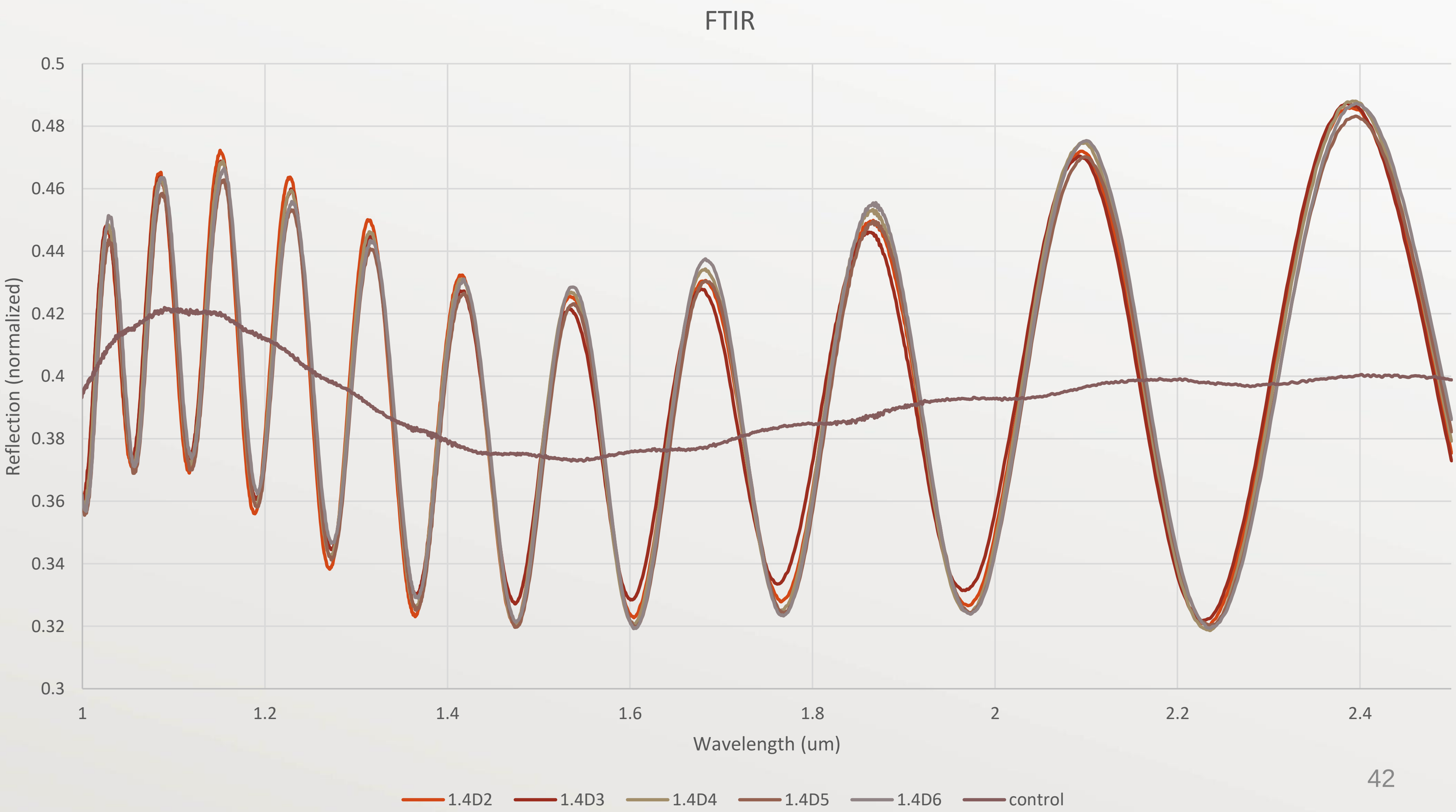
Defect Density



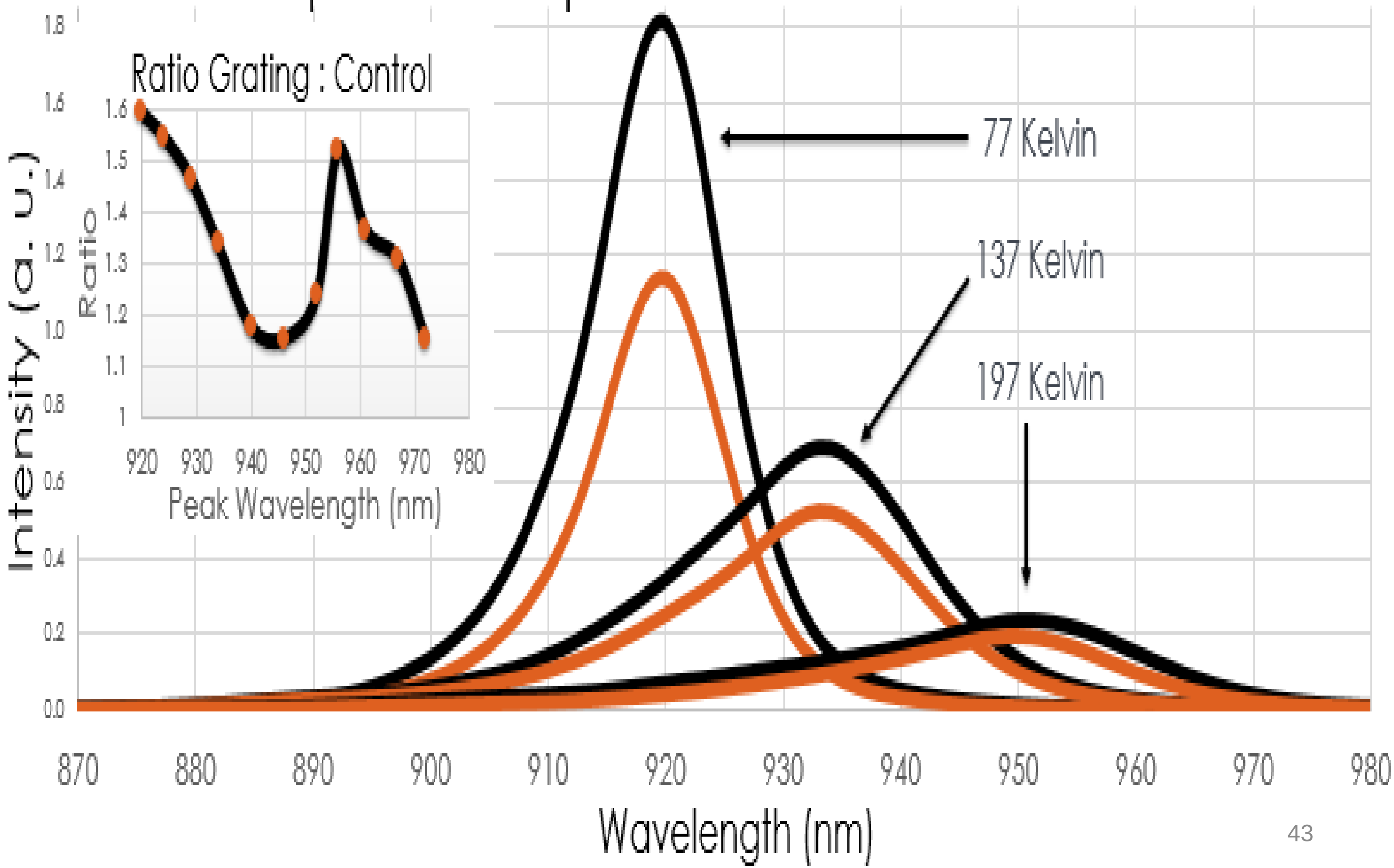

Orientation, Mid IR, w/o QW
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
1.2
2.2
3.2
4.2
5.2
6.2
7.2
D
V
H
C

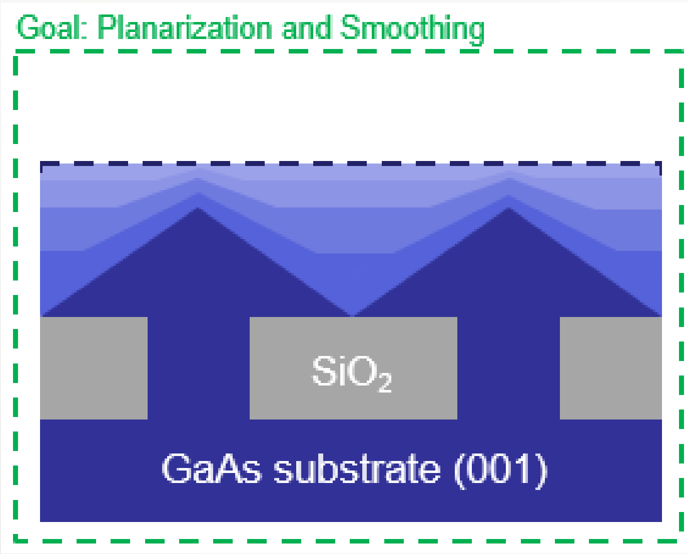
Excitation Dependent PL

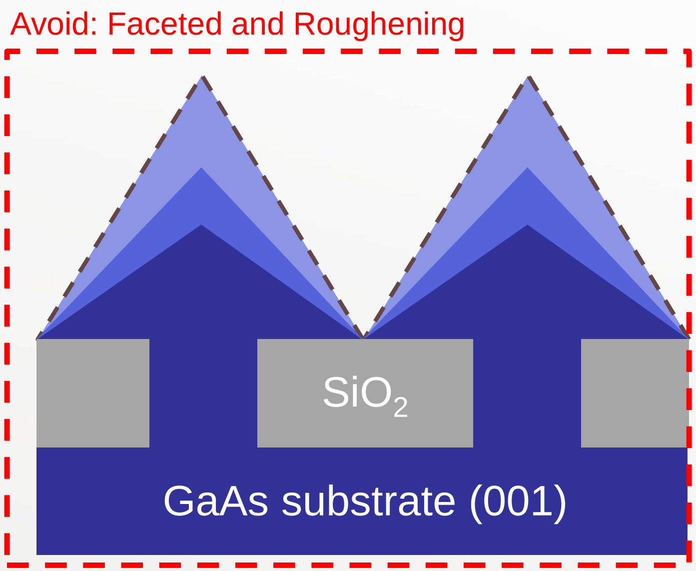


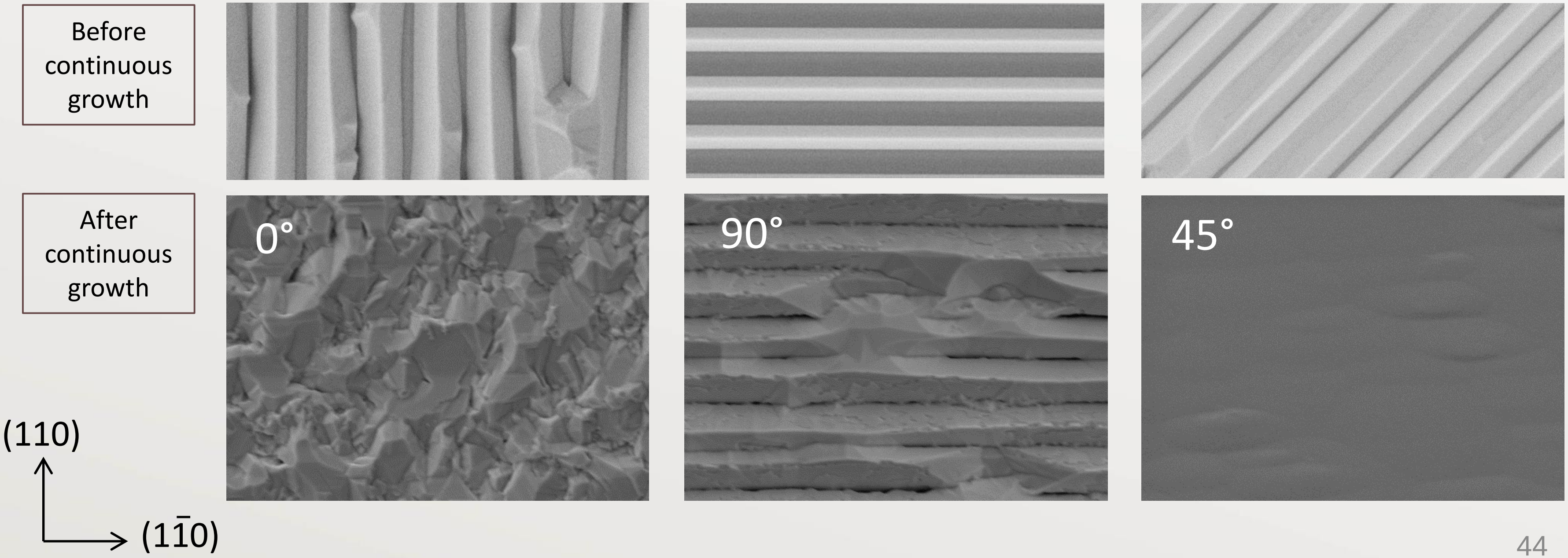

FTIR
0.5
0.48
0.46
0.44
0.42
0.4
0.38
0.36
0.34
0.32
0.3
Reflection (normalized)
1
1.2
1.4
1.6
1.8
2
2.2
2.4
Wavelength (um)
1.4D2
1.4D3
1.4D4
1.4D5
1.4D6
control

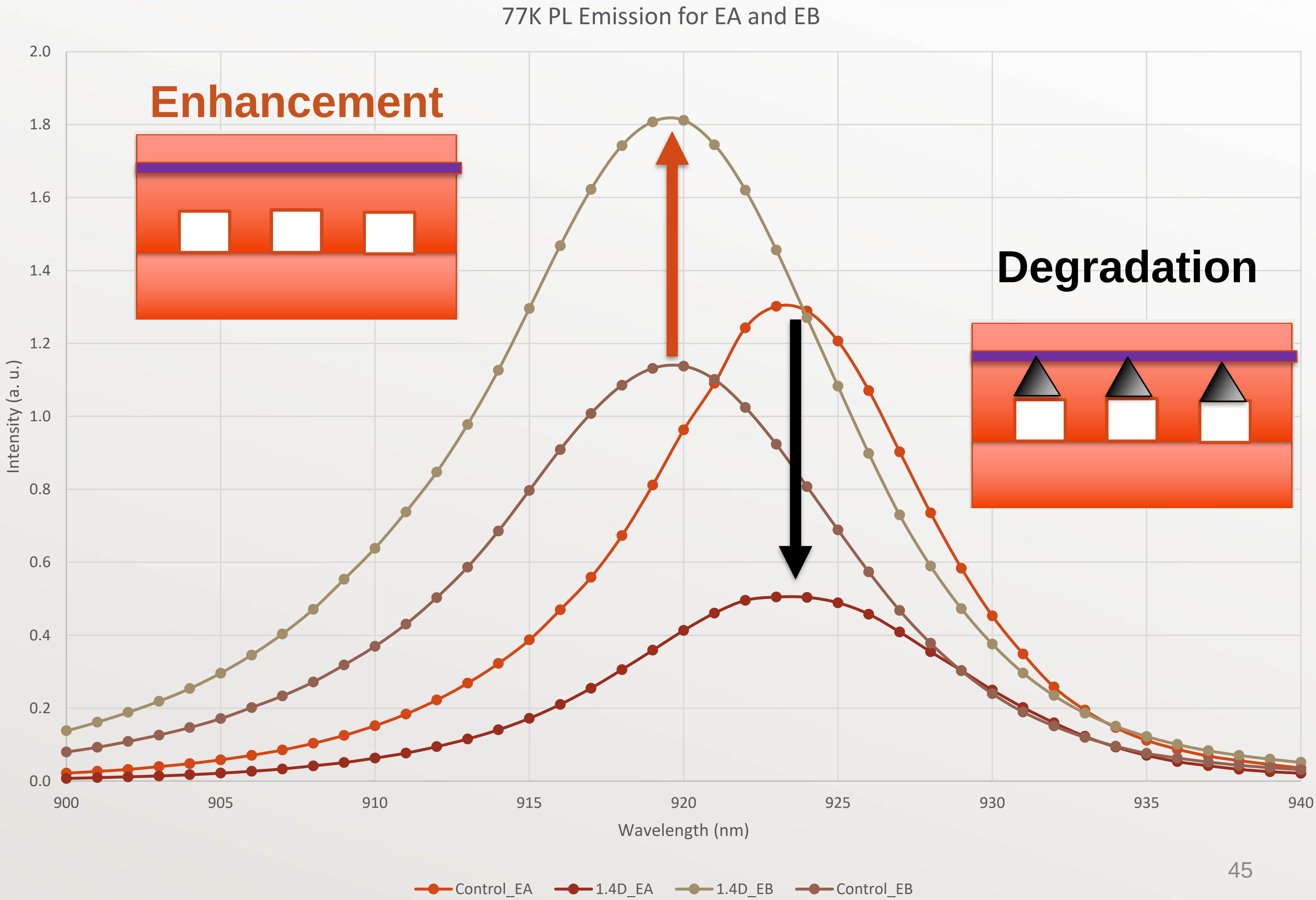
Temperature Dependent Photoluminescence




Goal: Planarization and Smoothing
SiO_2
GaAs substrate (001)

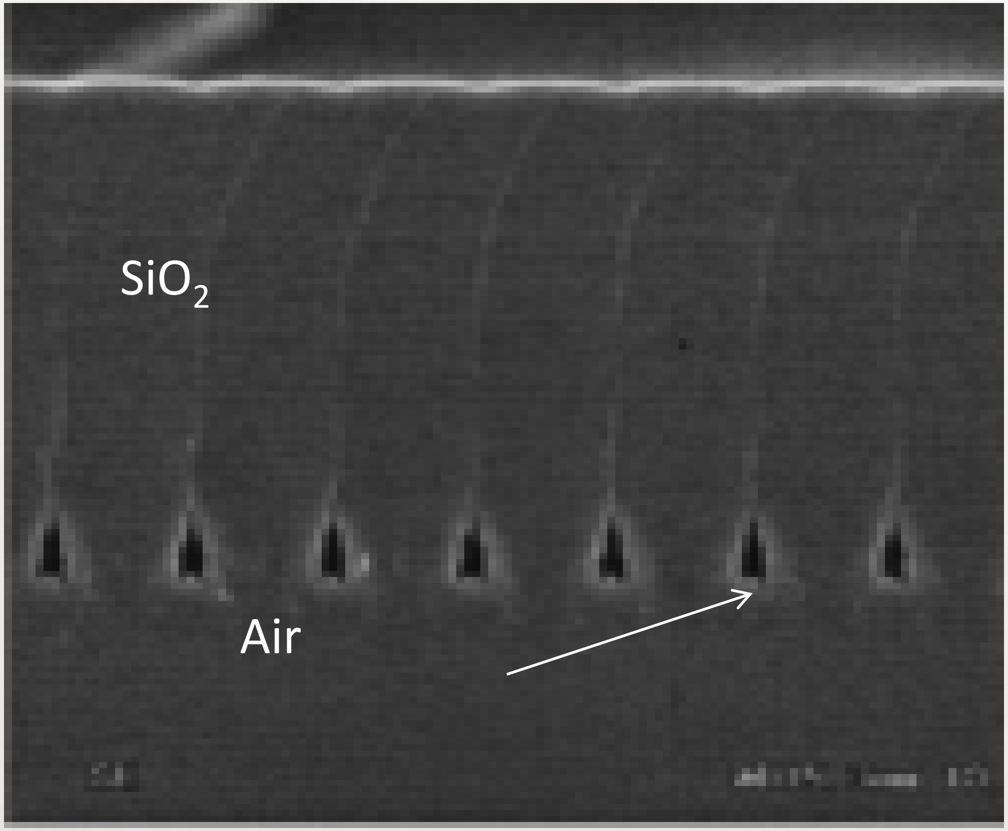

Avoid: Faceted and Roughening
SiO_2
GaAs substrate (001)


Before continuous growth
After continuous growth
0°
90°
45°
(110)
$(1\bar{1}0)$


77K PL Emission for EA and EB
Enhancement
Degradation
Intensity (a. u.)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
900
905
910
915
920
925
930
935
940
Wavelength (nm)
Control_EA
1.4D_EA
1.4D_EB
Control_EB

Motivation

- Single Crystal vs. Amorphous (QW)



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