Lighting the Future

Effect of QW growth temperature on optical properties of blue and green InGaN/GaN structures

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Green gap

- Green QWs typically show lower IQEs than blue QWs (50 v 70%)

- “Green gap” explained by presence of polarization-related electric fields: Large electric fields can spatially separate the electron and hole wavefunctions in QW, reducing the oscillator strength of radiative transitions

Growth temperature and low IQE in green QWs

- One key difference between the growth of blue and green QWs is the lower growth temperature used to achieve increased indium contents in the green

- Growth at lower temperature might significantly increase *point defect* or *impurity incorporation*, and thus reduce the IQE

- We aim to investigate how, for a constant emission wavelength, lowering the growth temperature affects the QW performance

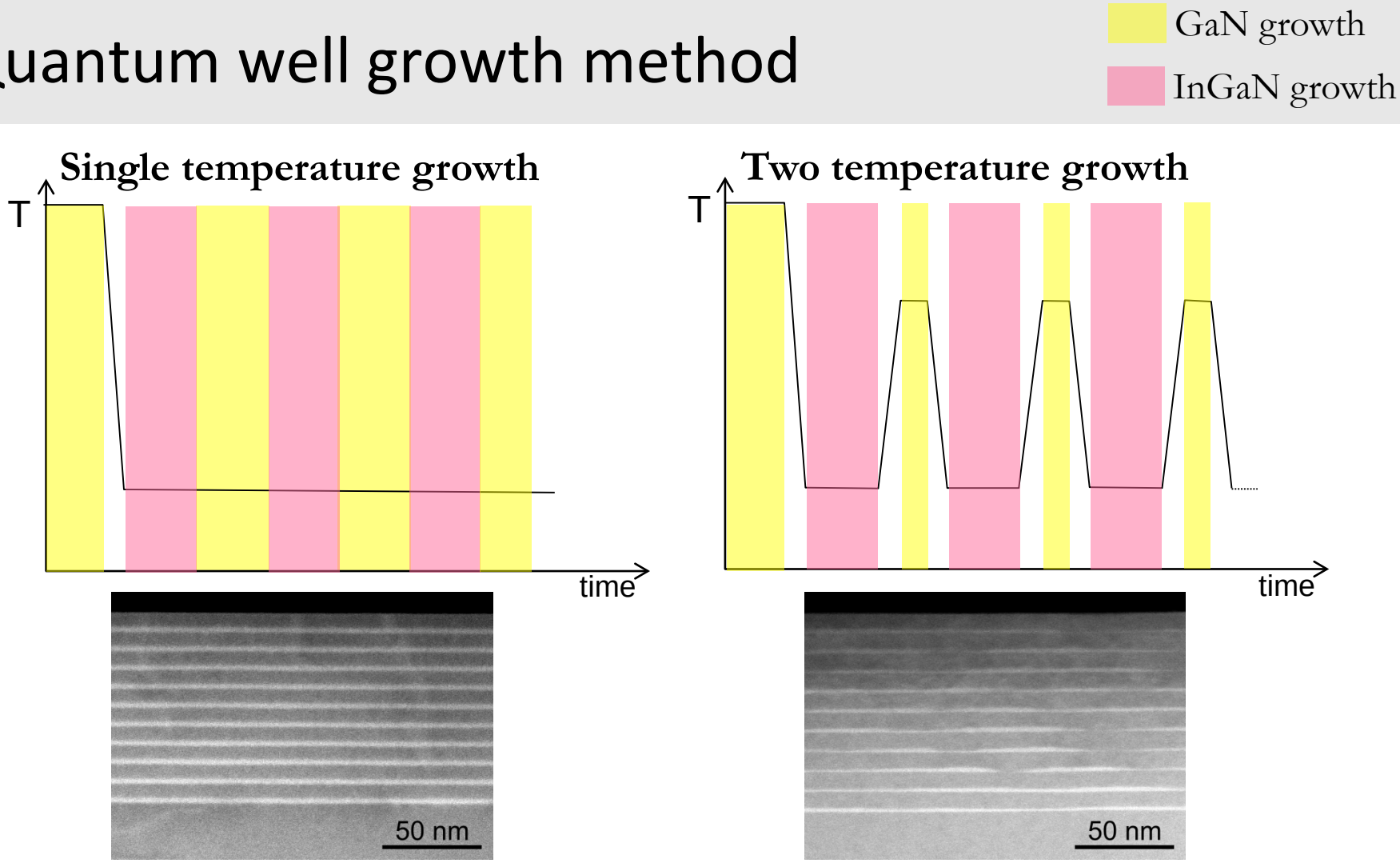
Samples

- Three blue 2T 10QW samples and three green 2T 5QW samples were grown.
- For each set of samples, three different QW growth temperatures were chosen.
- To compensate for the increased indium incorporation at reduced temperatures, the TMI flow was reduced to keep the variation of PL peak emission wavelength within each sample set within ~10 nm.
- InGaN QWs ~3nm thick and GaN barriers ~7nm grown on LDD GaN templates.

Sample number	Growth T/ °C	TMI flow / sccm
Blue1	748	120
Blue2	730	25
Blue3	716	16

Sample number	Growth T/ °C	TMI flow / sccm
Green1	716	120
Green2	706	60
Green3	698	43

Quantum well growth method



- Changes to the InGaN morphology (gaps and gross well width fluctuation)
- For samples emitting *at the same wavelength* 2T QWs typically gives significantly higher PL IQE.

XRD characterisation

Sample	QW Temp (ºC)	TMI flow (sccm)	$t_{QW}+t_{QB}$ (nm)	Av. In (%)
Blue1	748	120	9.7 ± 0.2	3.15
Blue2	730	25	9.8 ± 0.2	3.14
Blue3	716	16	9.7 ± 0.2	3.15
Green1	716	120	9.9 ± 0.2	5.07
Green2	706	60	9.9 ± 0.2	5.24
Green3	698	43	10 ± 0.2	5.1

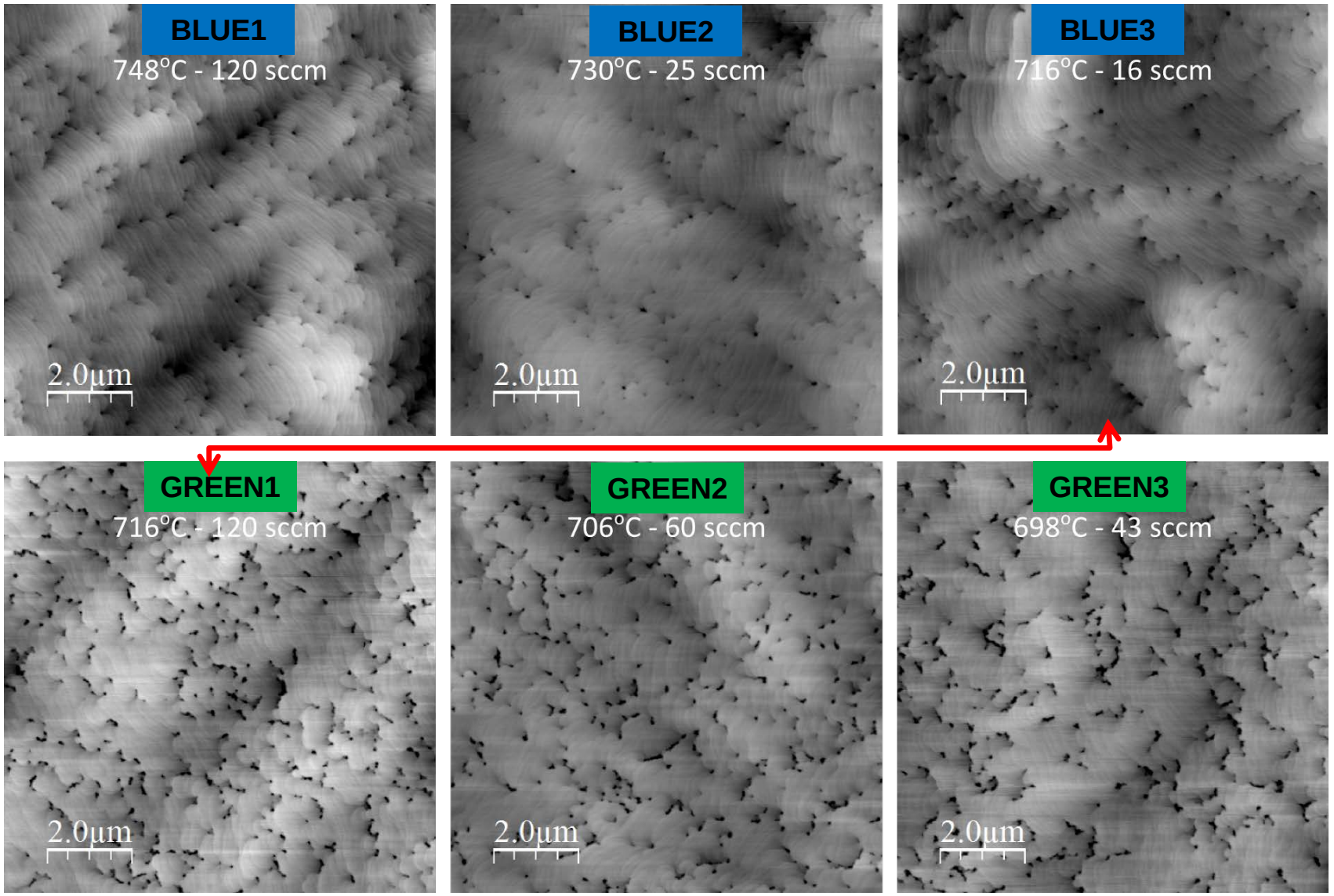
Two samples grown at same temperature, with same dimensions, but different indium contents. Allows direct green/blue comparison

All blue samples have very similar QW parameters

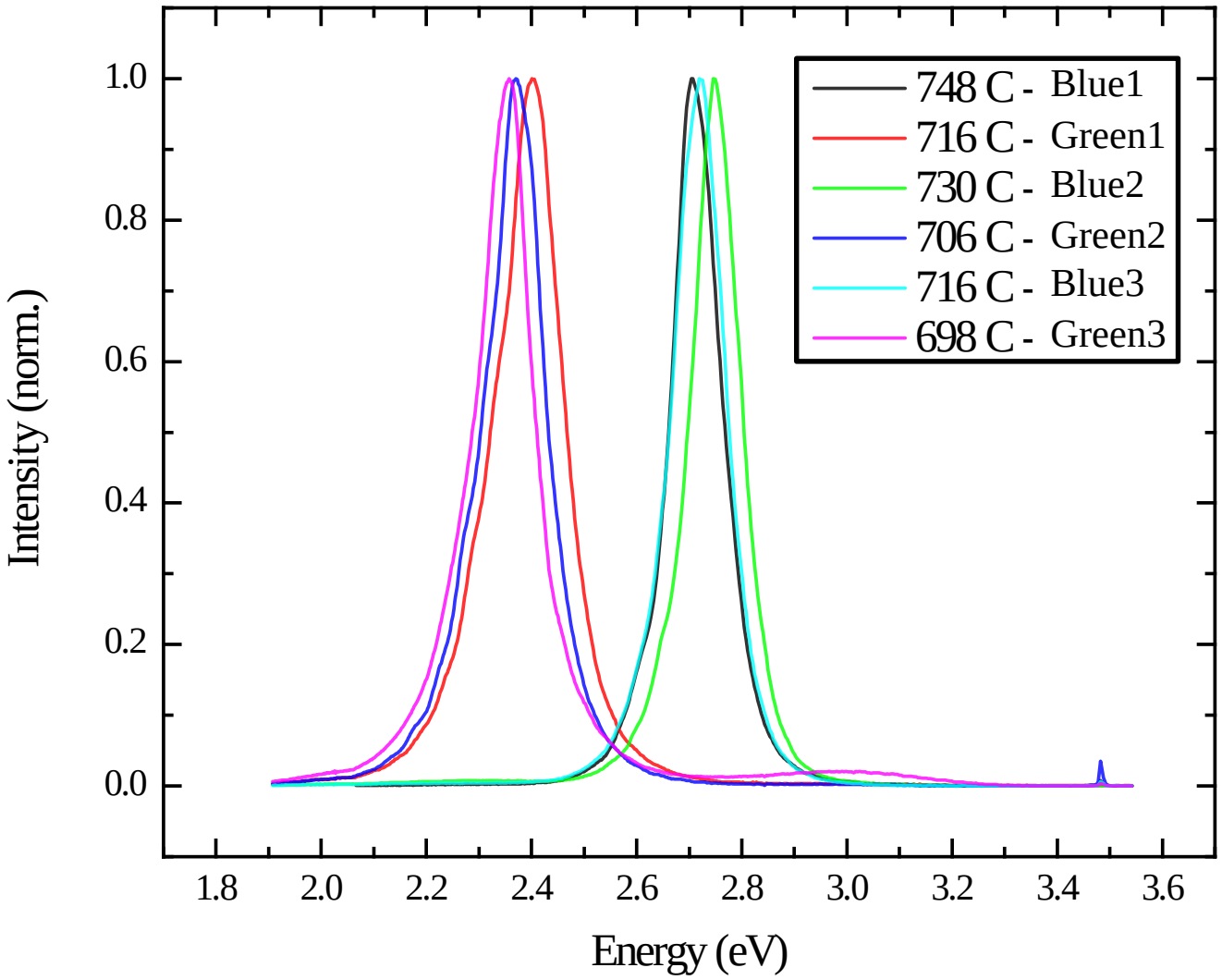
All green samples have very similar QW parameters

No QW thicknesses or compositions can be extracted from XRD data as QWs have gaps

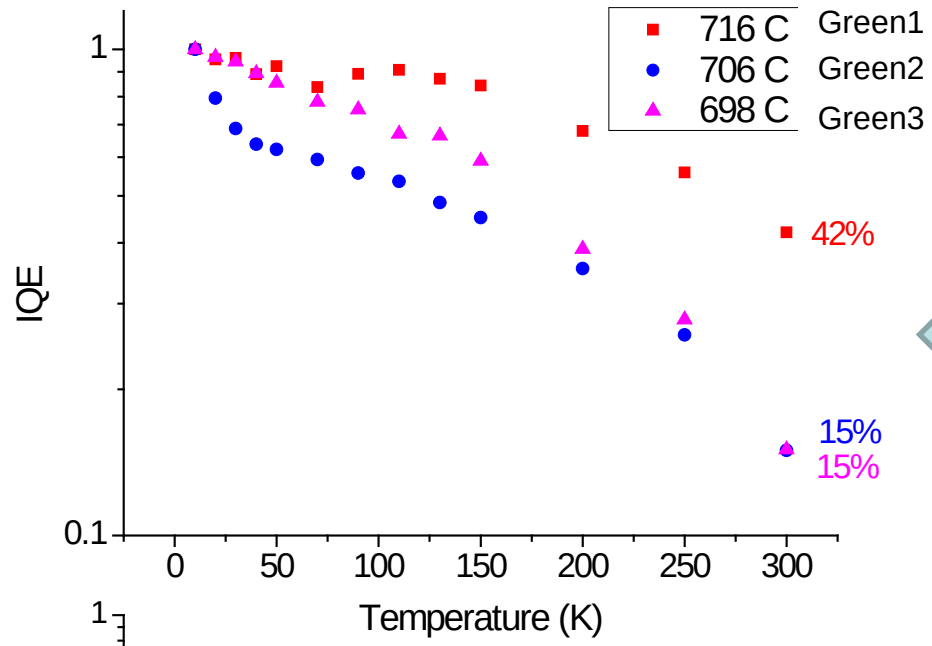
AFM


BLUE1
748°C - 120 sccm
2.0µm
BLUE2
730°C - 25 sccm
2.0µm
BLUE3
716°C - 16 sccm
2.0µm
GREEN1
716°C - 120 sccm
2.0µm
GREEN2
706°C - 60 sccm
2.0µm
GREEN3
698°C - 43 sccm
2.0µm

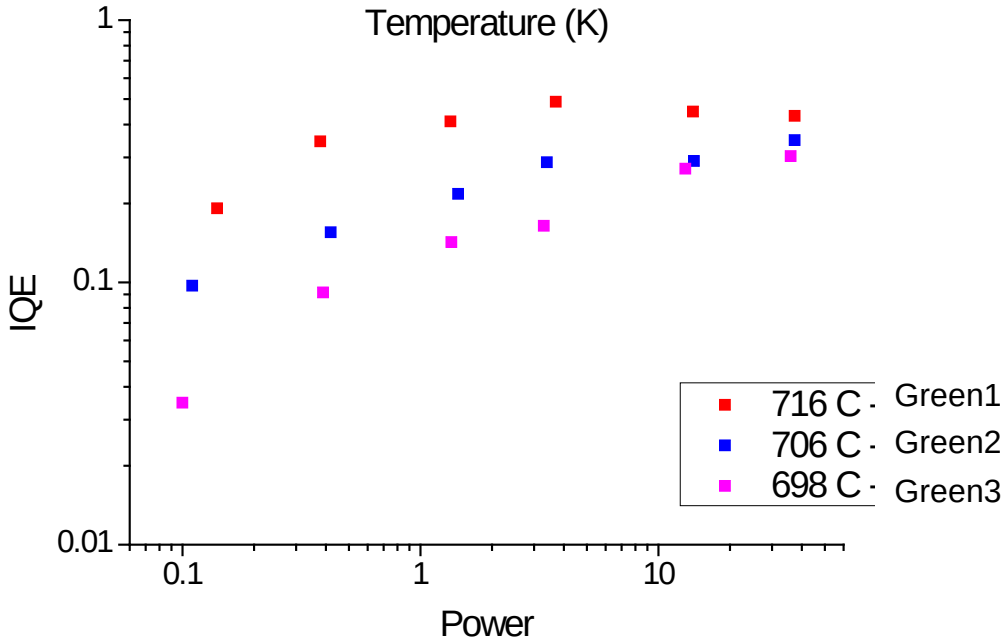
Photoluminescence spectrum T = 10K



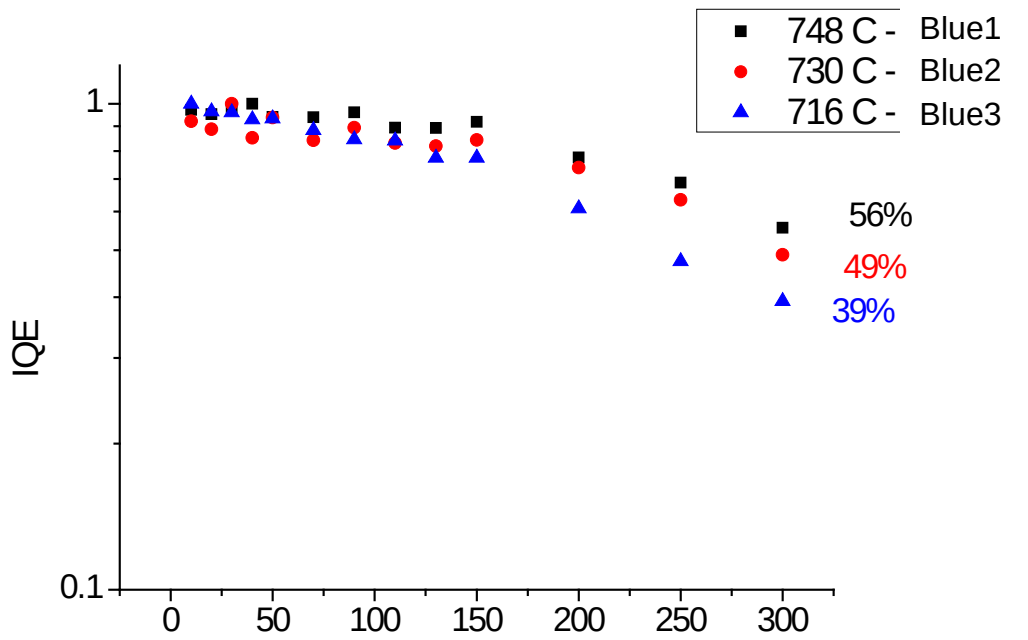
Measurement of IQE: Green



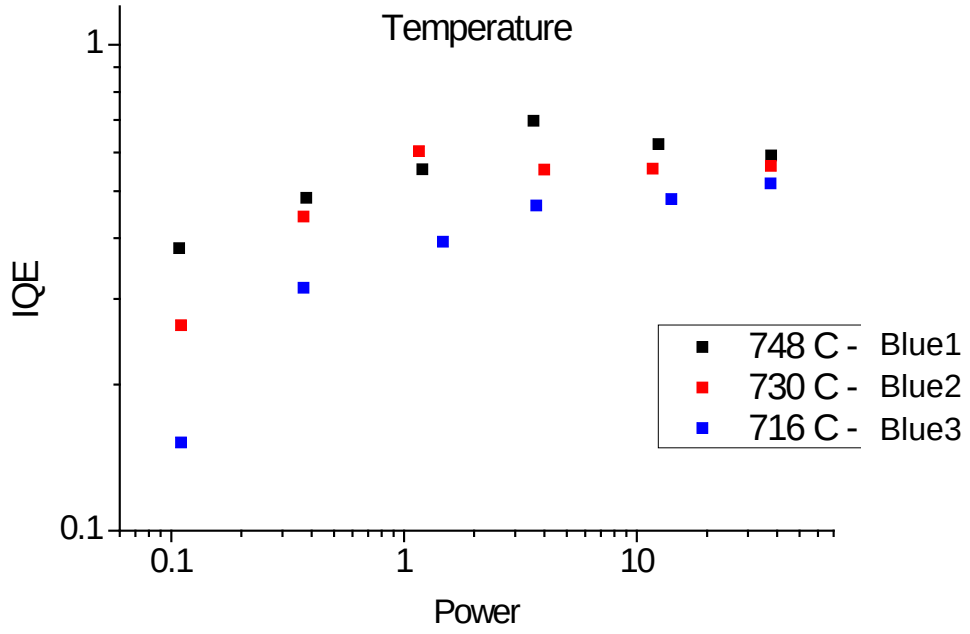
Low power density



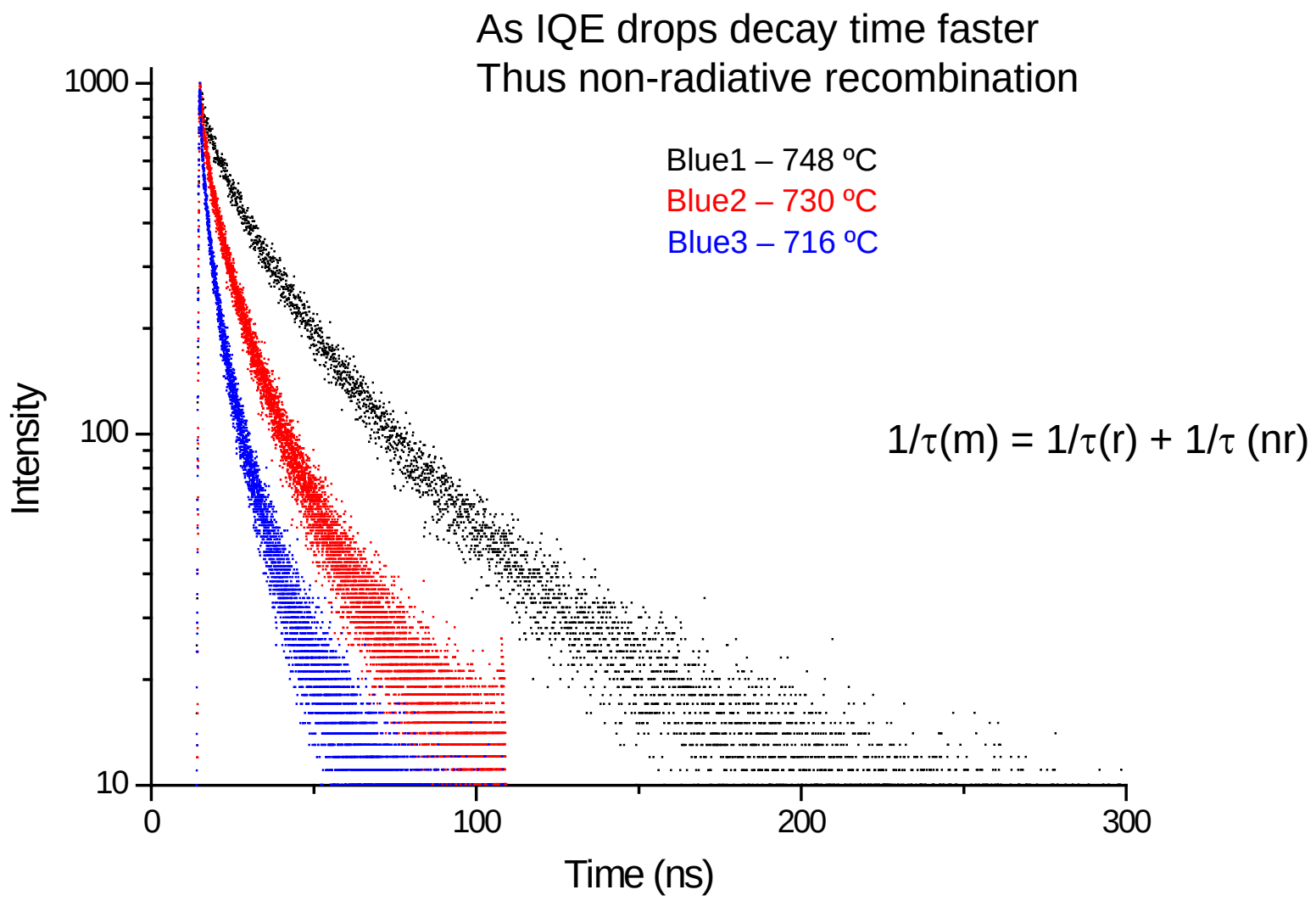
Measurement of IQE: Blue



Low power density



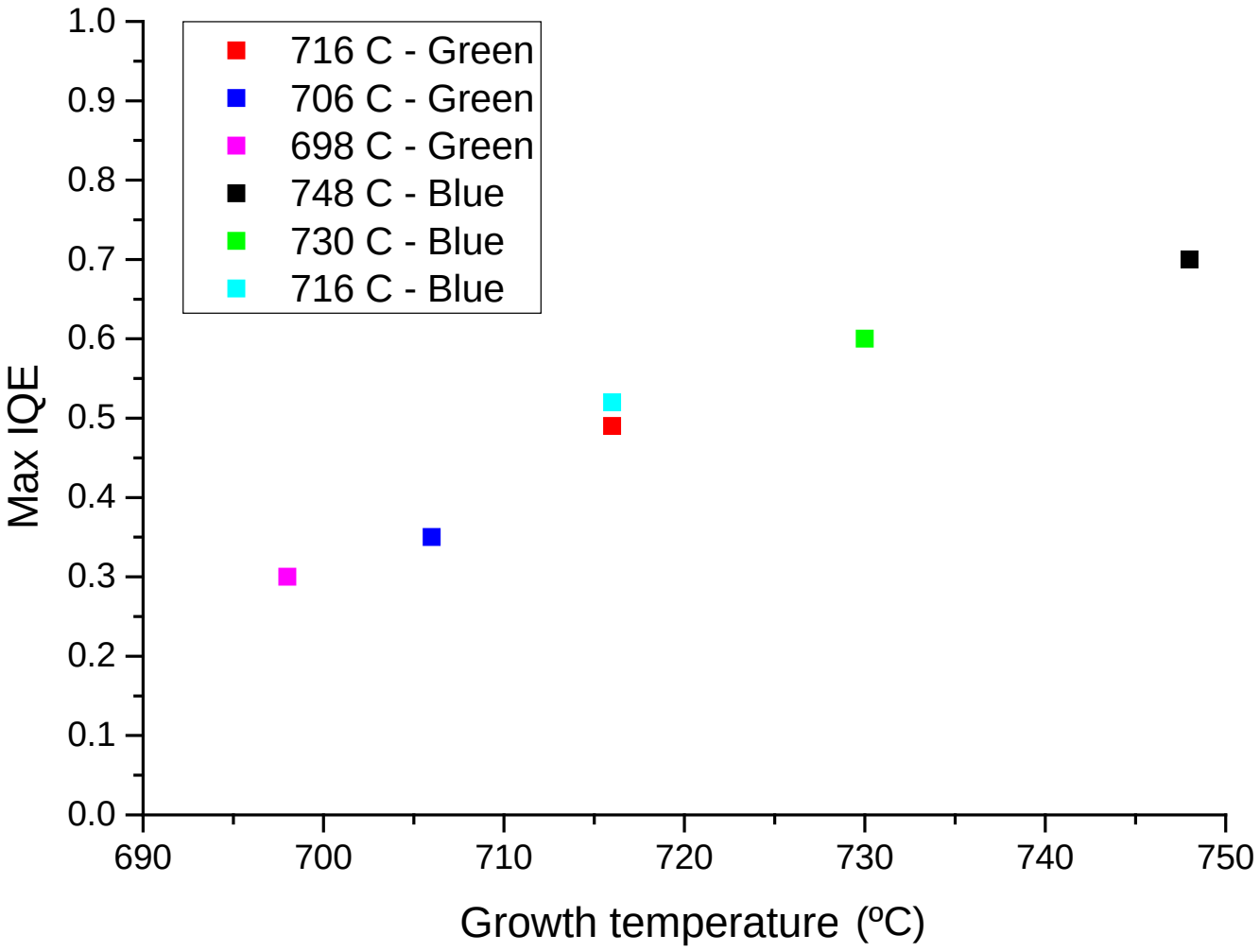
Decay time at peak of emission for blue emitters



Comments on optical measurements

- Notable improvement in blue and green samples with growth temperature
- More rapid reduction in IQE as power drops reflecting changes to the non-radiative recombination processes
- Is this systematic change universal across both blue and green samples?

Maximum IQE vs Growth Temperature



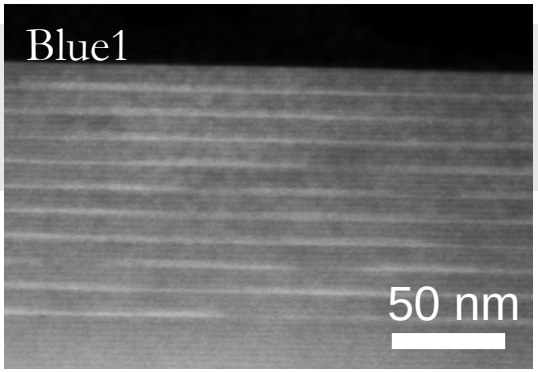
Comments

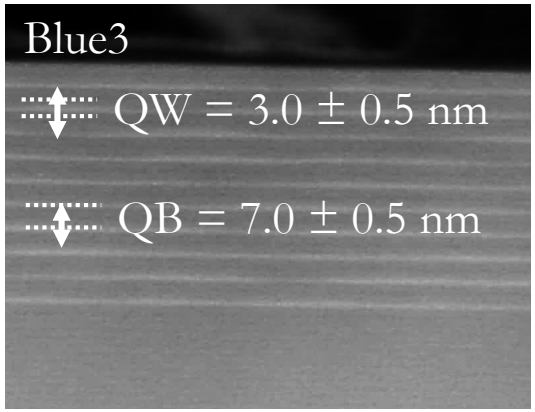
- Blue and green samples grown at the same temperature (716 °C) have very similar peak IQE (roughly 50%) despite significant difference in observed V-pit density.
  - Tentatively suggests limited impact of TDs on green samples.

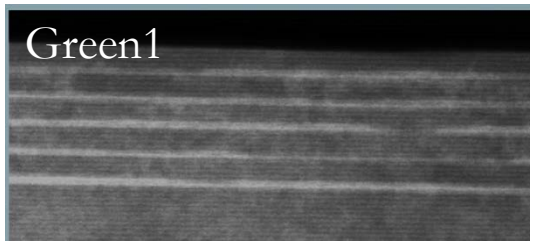
- Overall, IQE seems to increase with growth temperature, and time-decay data suggests non-radiative recombination decreases.
  - Could be linked to decreasing point defect density
  - Need TEM to check for other structural differences

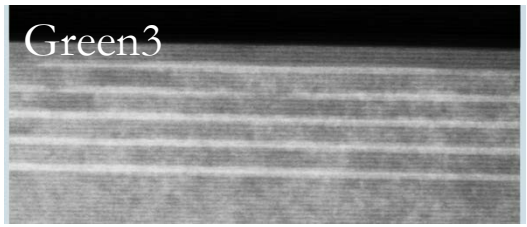
TEM of blue and green samples

Sample	TT Temp (ºC)	GWWFs (μm^{-1})	Gaps (μm^{-1})
Blue1	748	6.9 ± 0.5	1.1 ± 0.4
Blue2			
Blue3	716	3.6 ± 0.3	0.6 ± 0.3
Green1	716	6.0 ± 0.8	1.0 ± 0.7
Green2			
Green3	698	3.0 ± 0.4	0.6 ± 0.4



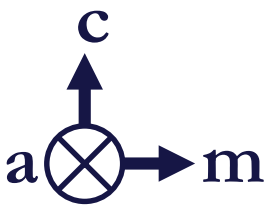






GWWF (gross well width fluctuation): region where the QW thickness drops to less than half the maximum value.

Gap:
Region where the QW thickness drops to zero.



Comments on TEM

For both blue and green sample sets:

- Samples grown at higher temperature exhibit more GWWFs and gaps in the QW
- Previous work has shown that increasing the density of GWWFs lead to increased IQE

It may be invalid to attribute optical improvements here solely to changes in point defect density

Summary

- Both blue and green samples show a systematic increase in IQE with growth temperature for low power excitation conditions
- Systematic increase in maximum IQE with increasing temperature
- Non-radiative recombination processes become more important as the growth temperature is reduced
  - Both an increase in the point defect density (increase in number of non-radiative centres) and a change in the QW morphology (fewer gaps = fewer barriers to carrier diffusion to non-radiative sites) may be relevant to this change

Acknowledgement:

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