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Hydrogen Etching of InGaN/GaN Quantum Wells and Epilayers

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Introduction

InGaN/GaN quantum wells (QWs) grown by a 2-temperature (2T) process can achieve high radiative efficiencies but with relatively large emission linewidths. This is originated by gross well width fluctuations (GWWFs) of the InGaN layers [1]. Alternative one could use Quasi-2-temperature (Q2T) growth method, resulting in QW structures with narrow linewidths but a reduced radiative efficiency.

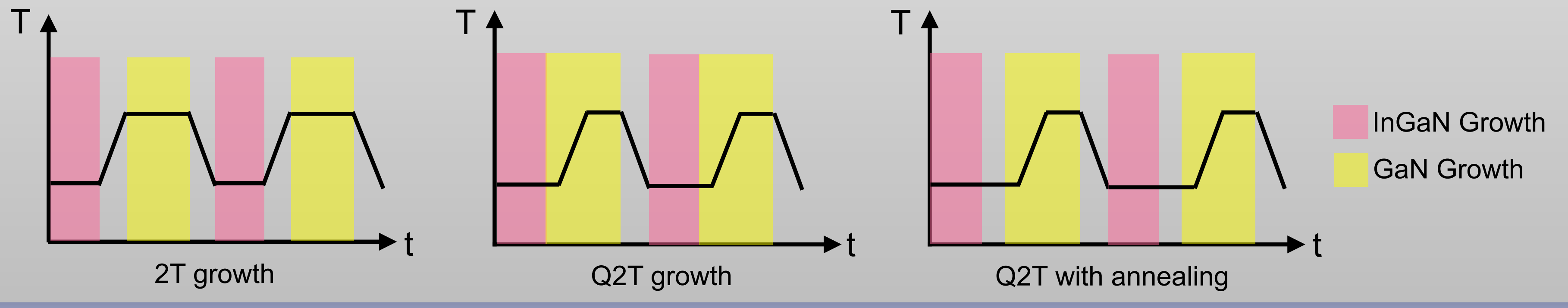
The aim of this study is to obtain high-efficiency quantum wells with a narrow emission line, which is desirable for laser applications. The growth process follows the Q2T method but includes a growth interruption of 30s after InGaN QW growth. The influence of hydrogen etching during the interruption on the morphology and luminescence behaviour were investigated.

Methods

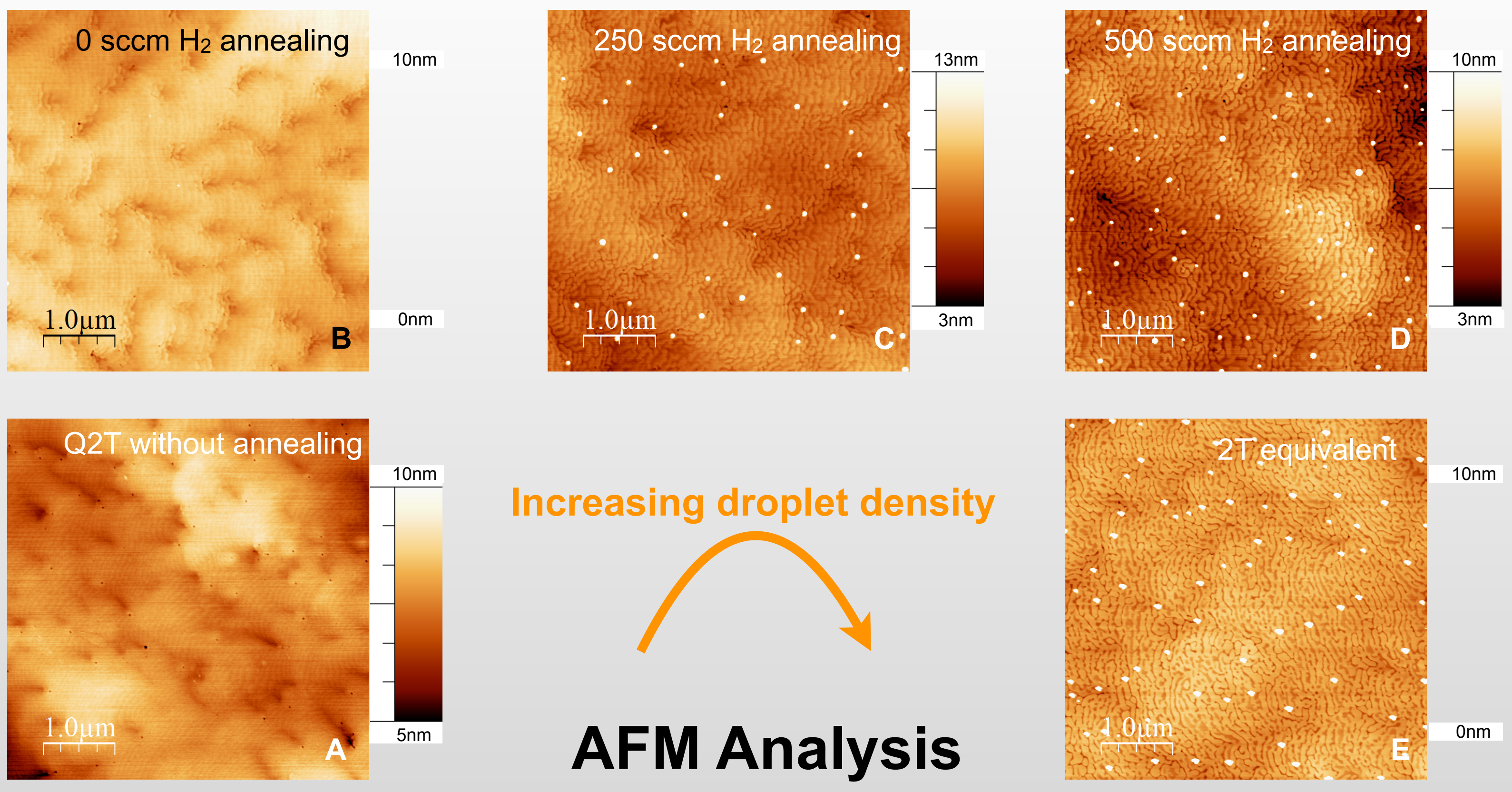
- A 5-QW sample series were grown using 2T method, Q2T method, and Q2T with annealing under varying H_2 flow.
- The QW samples were characterised by photoluminescence (PL) and high resolution X-ray (HRXRD).
- A series of InGaN epilayers without a GaN cap were grown under the same condition as the multi quantum well (MQW) samples with the temperature quenched after the growth interruption/etching step.
- The InGaN epilayer is analogous with the InGaN layers within the QW structures, and the tomography were studied by atomic force microscopy (AFM).

Epilayer sample	H_2 flow (sccm)	Growth time (s)
A	Q2T equivalent	349
B	0	305
C	250	315
D	500	326
E	2T equivalent	302

Table 1. Epilayer sample series, where the epilayer growth time and H2 flow while annealing are presented



AFM Analysis



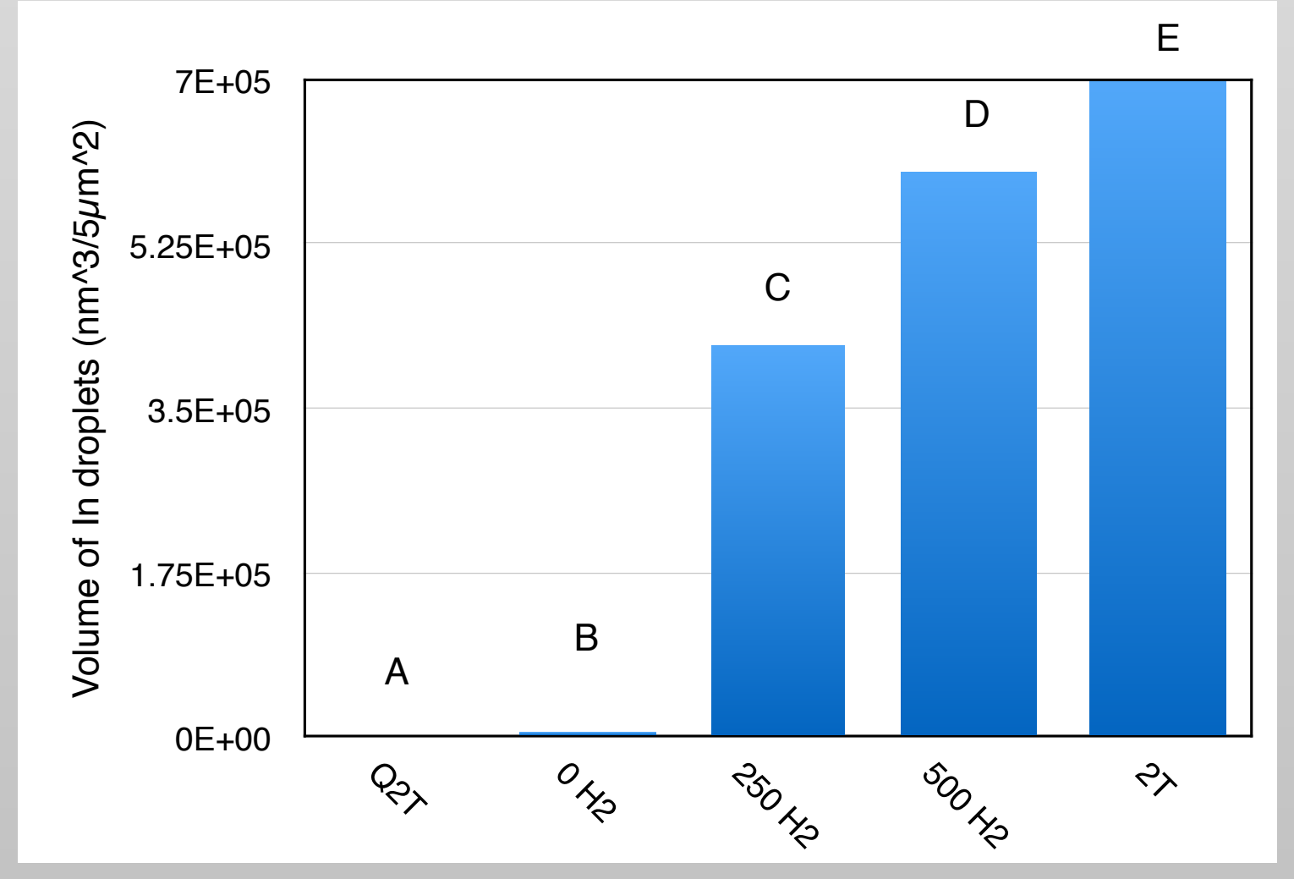
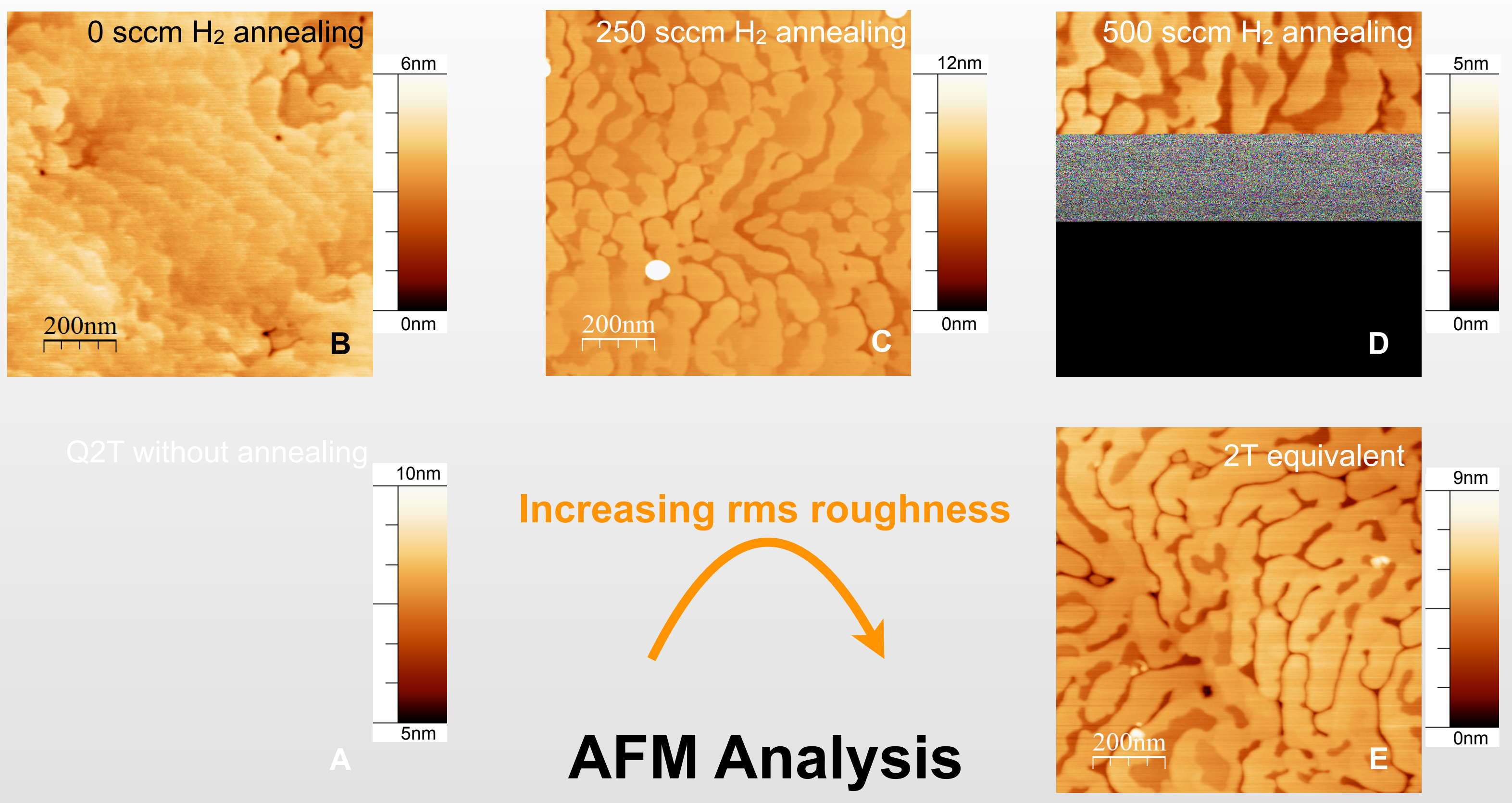


Fig 1. The volume of In droplets on the surface was affected by the annealing step.

- Droplets are remaining indium (white dots) due to temperature quench.
- Increased H_2 flow when annealing led to an increased volume of In metallic droplets on the surface.
- This is likely to reflect an increase in the amount of In loss from the InGaN epilayer during the growth interruption.

AFM Analysis



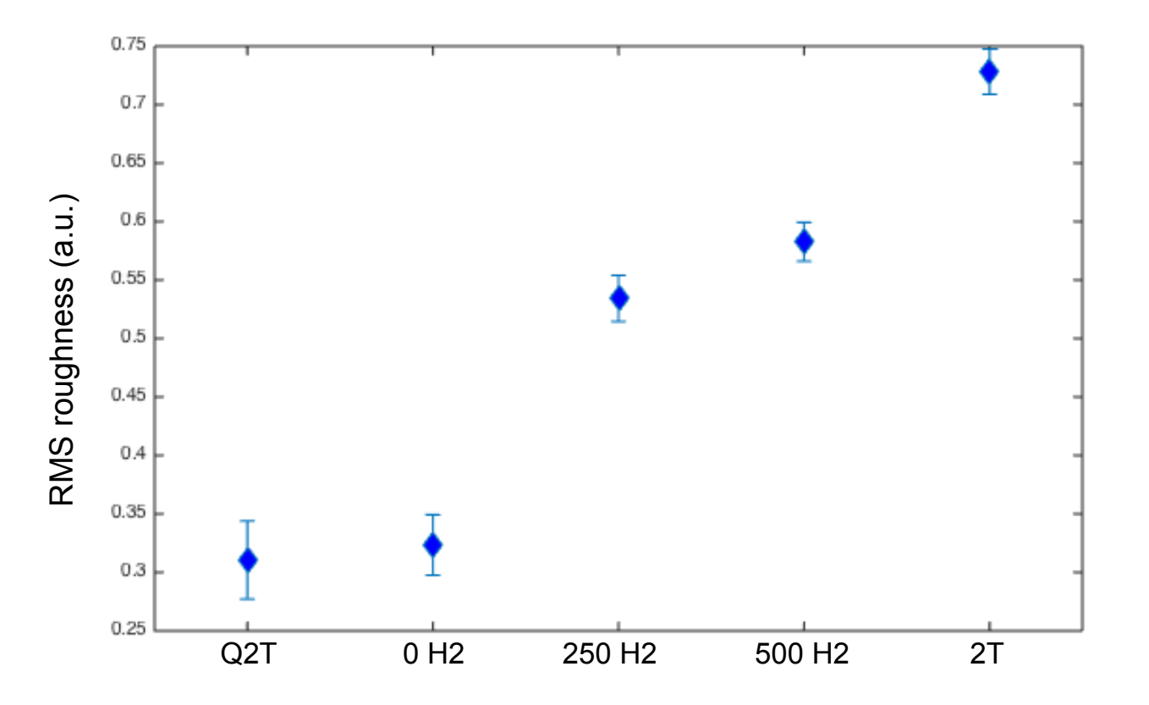


Fig 2. Surface rms roughness of the epilayer samples (i.e. QW uniformity). Several 500×500nm² areas without droplets were used to calculate rms roughness.

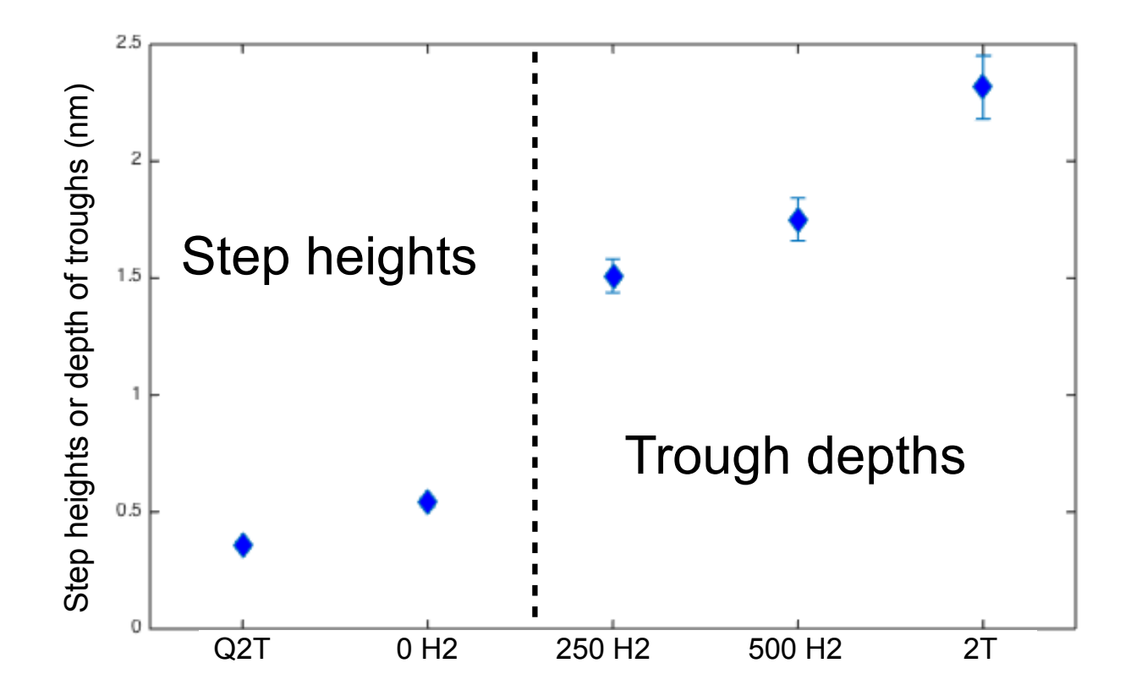


Fig 3. The measurements of step heights (of Sample A and B), and depth of troughs (of Sample C, D, and E)

- The Q2T without annealing sample (A) and the sample annealed without H_2 (B) have flat surfaces with single/two monolayer steps.
- All H_2 annealed samples (C and D) and the 2T equivalent sample (E) showed a morphology consisting of interlinking strips.
- The surface roughness of the epilayer samples reflects the uniformity of the InGaN layers in QWs. Increased H_2 flow when annealing resulted in an decrease of the QW uniformity.
- The step heights of Sample A (Q2T equivalent) and Sample B (annealed without H_2), and the depth of troughs of the other epilayer samples were also studied. The increased surface toughness was probably due to increasing depth of troughs/step heights.

PL Analysis

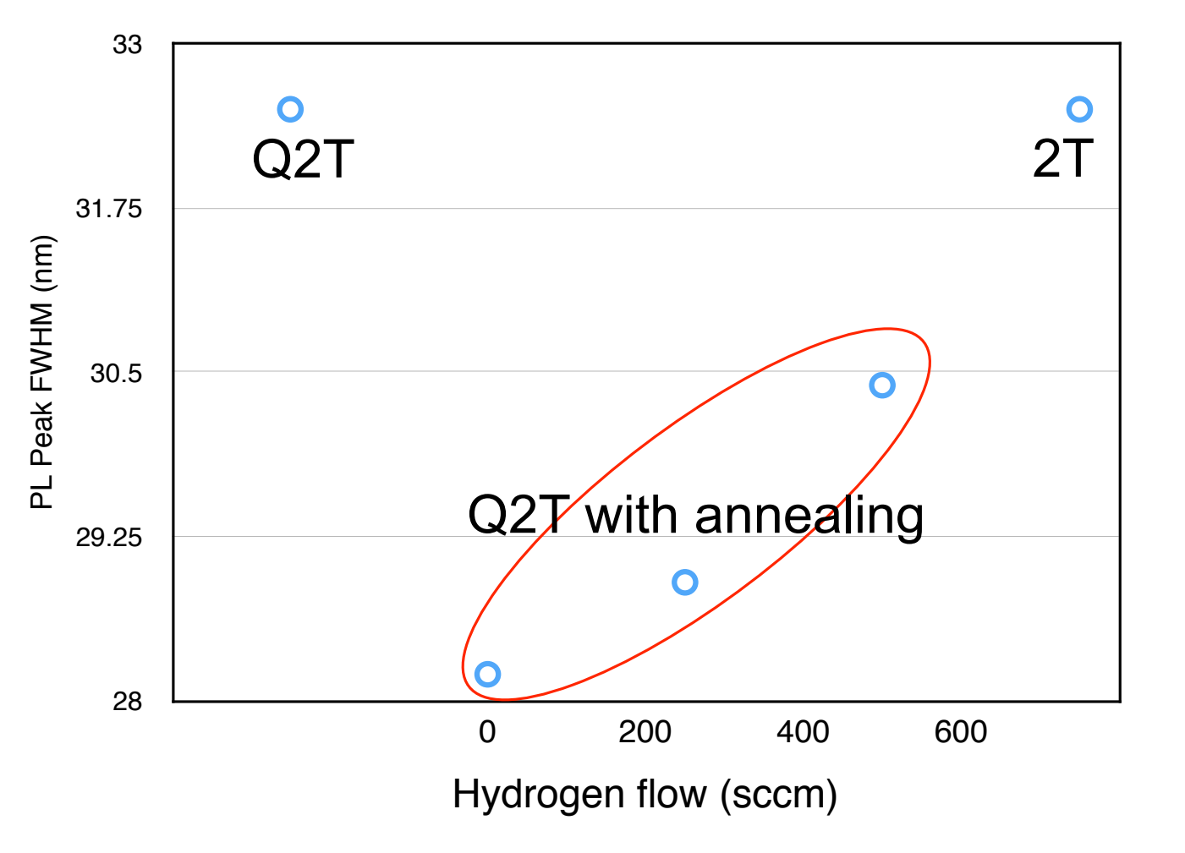


Fig 4. FWHM comparison of MQW samples grown by 2T, Q2T and Q2T with annealing

- The emission wavelengths were engineered to be the same (450-451nm) in order to compare PL peak full width at half maximum (FWHM).
- Samples with the annealing step were found to have narrower linewidths, and the sample annealed without H_2 flow had the narrowest linewidth (see Fig 4).

XRD Analysis

5QW sample	H_2 flow (sccm)	Average In content (%)	Period thickness (nm)	InGaN growth time (s)
A*	Q2T	3.7	10.70 ± 0.1	302
B*	0	4.1	10.65 ± 0.1	305
C*	250	4.0	10.85 ± 0.1	315
D*	500	3.9	10.95 ± 0.1	349
E*	2T	3.5	9.90 ± 0.2	302

Table 2. 5-QW sample series

- The average In content and period thickness (thickness of a QW plus a barrier) were investigated by HRXRD (see Table 2).
- Samples annealed with higher H_2 flow have lower In incorporation, which is consistent with the study of In loss during the growth interruption (see Fig 1).
- The change of period thickness does not have a trend because samples do not have the same growth time. The growth time was used to tune the emission wavelengths.

Summary

- The unannealed InGaN epilayer (analogous with Q2T QWs) showed a flat surface with mainly single monolayer steps. The growth interruption without hydrogen also led to a flat InGaN layer with mainly two monolayer steps.
- InGaN layers etched in small flows of H2 showed a morphology consisting of interlinking strips of InGaN as well as small metallic droplets on the surface.
- The rms roughness, the depth of the troughs between the strips and the volume of the metallic droplets increased with increasing H_2 flow.
- The annealing step can help to achieve narrower linewidths, but the linewidths increase with increased H_2 flow.

References

1. R.A. Oliver, F.C.-P. Massabuau, M.J. Kappers, W.A. Phillips, E.J. Thrush, C.C. Tartan, W.E. Blenkhorn, T.J. Badcock, P. Dawson, M.A. Hopkins, D.W.E. Allsopp, and C.J. Humphreys. Appl. Phys. Lett. 103, 141114 (2013).

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