Effects of polarization charge and structural optimization of Blue InGaN/GaN MQW LEDs

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- **Physical Models.**
- **Effects of polarization charge on properties of blue InGaN/GaN MQW LEDs.**
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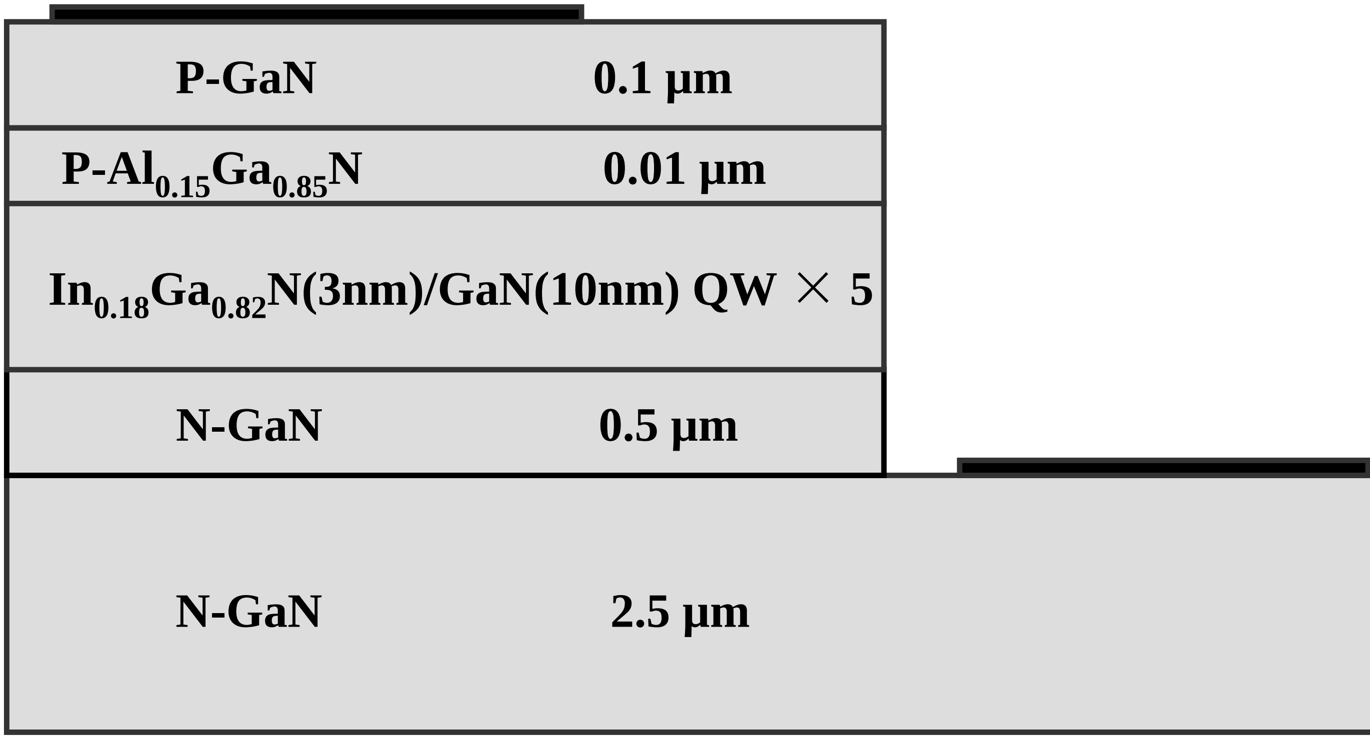
- **Conclusions.**
- **Appendix(comparison of two quantum transport models in polarized InGaN/GaN LEDS)**

Physical Models

- **K.p theory based MQW model for wurtzite material system.**
- **Polarization surface charge/self-consistent model.**
- **Manybody gain/spontaneous theory for quantum wells or dots.**
- **Non-equilibrium quantum transport model.**

Effects of polarization charge on properties of Blue InGaN/GaN MQW LEDs

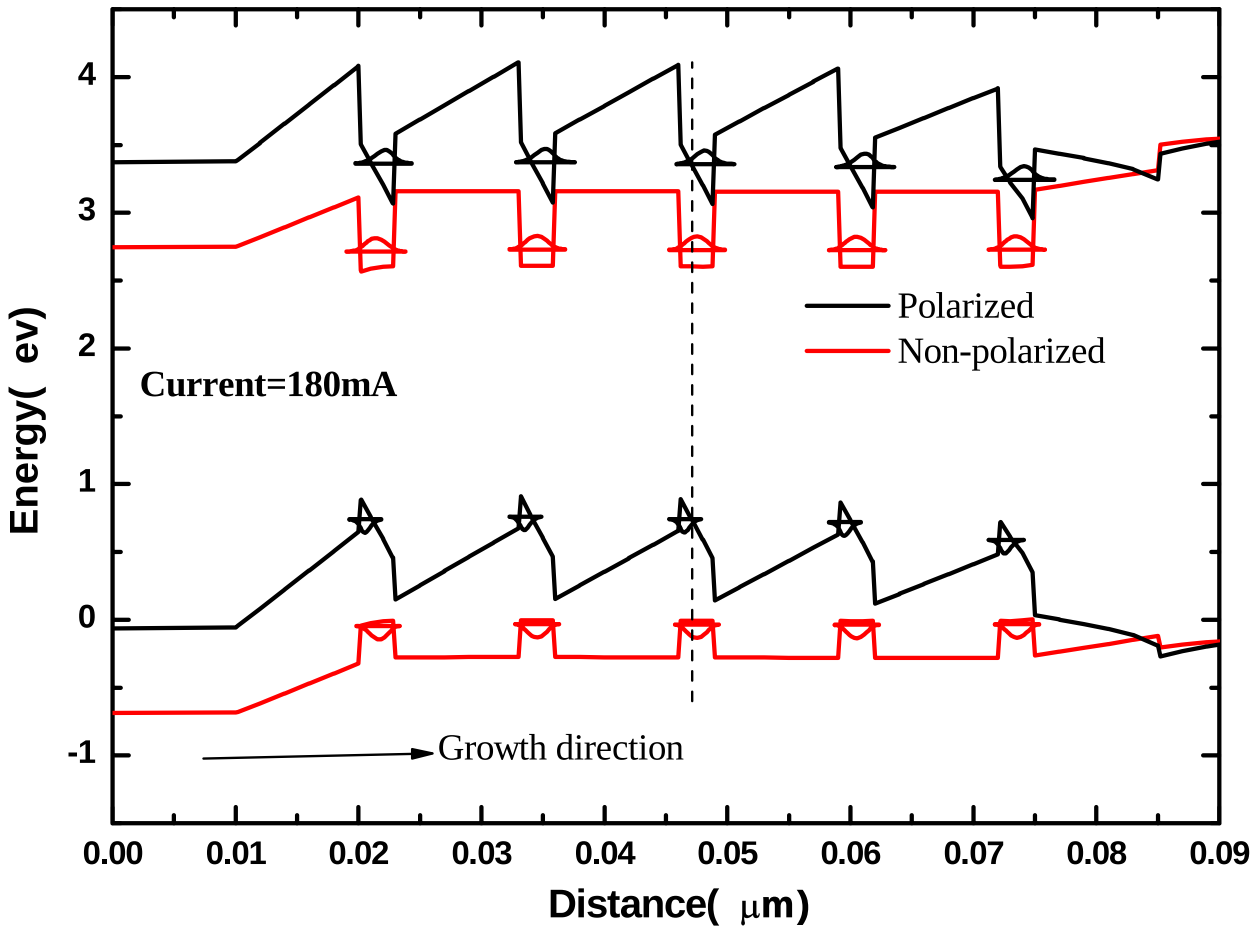
Reference Structure



Size: 300 µm × 300 µm

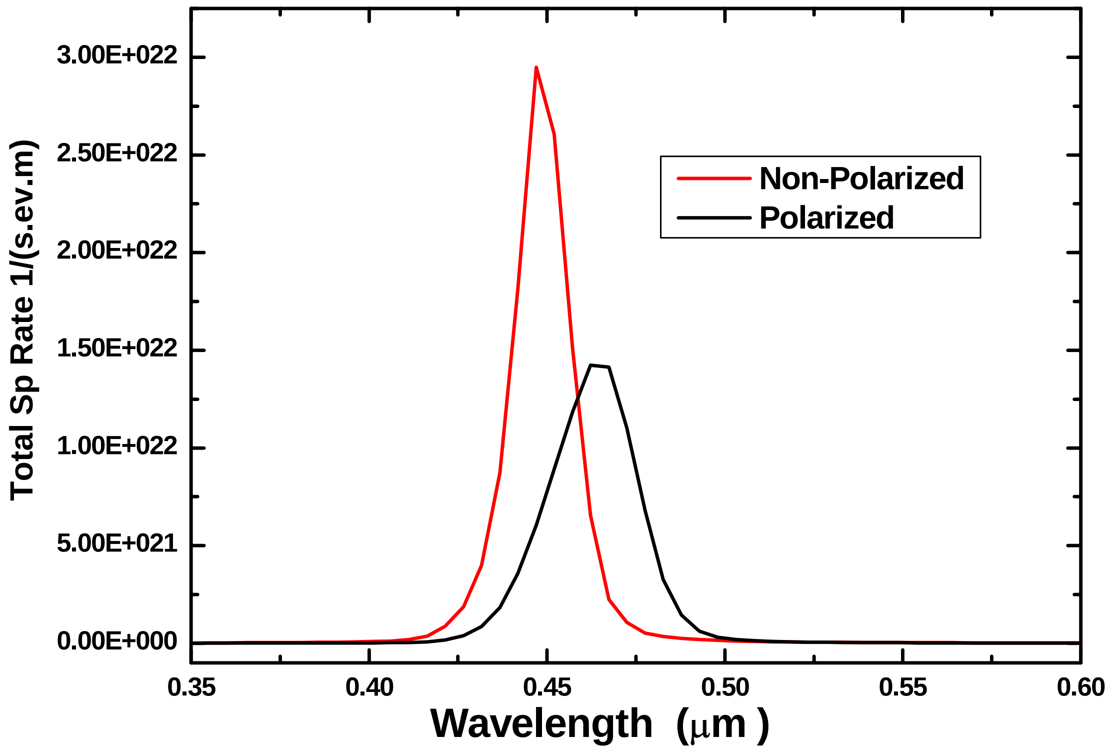
The polarization charge set on the interface of QWs is 80% of the theoretical value calculated based on the Ref. Appl. Phys. Letts, 80, 1204(2002).

Band Diagram



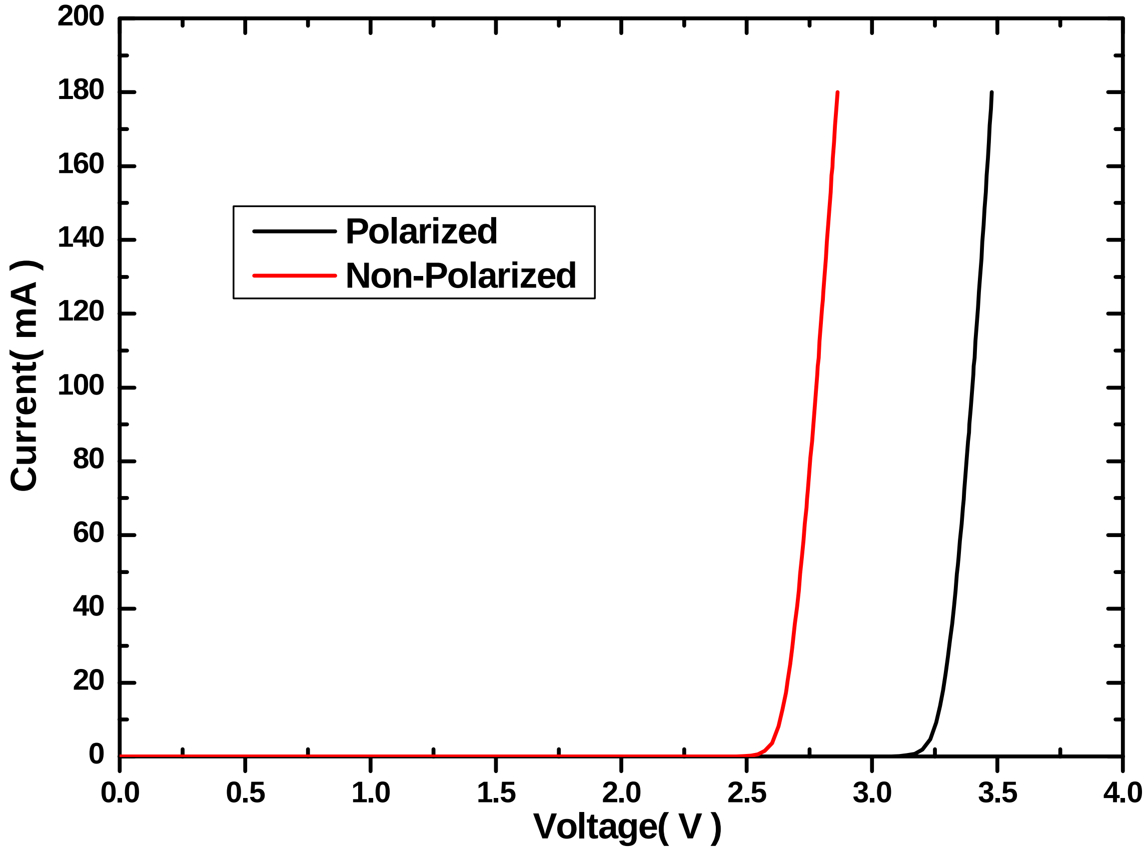
Polarization field tilts the energy band and induces the spatial separation of the electron and hole wave functions.

EL Spectrum



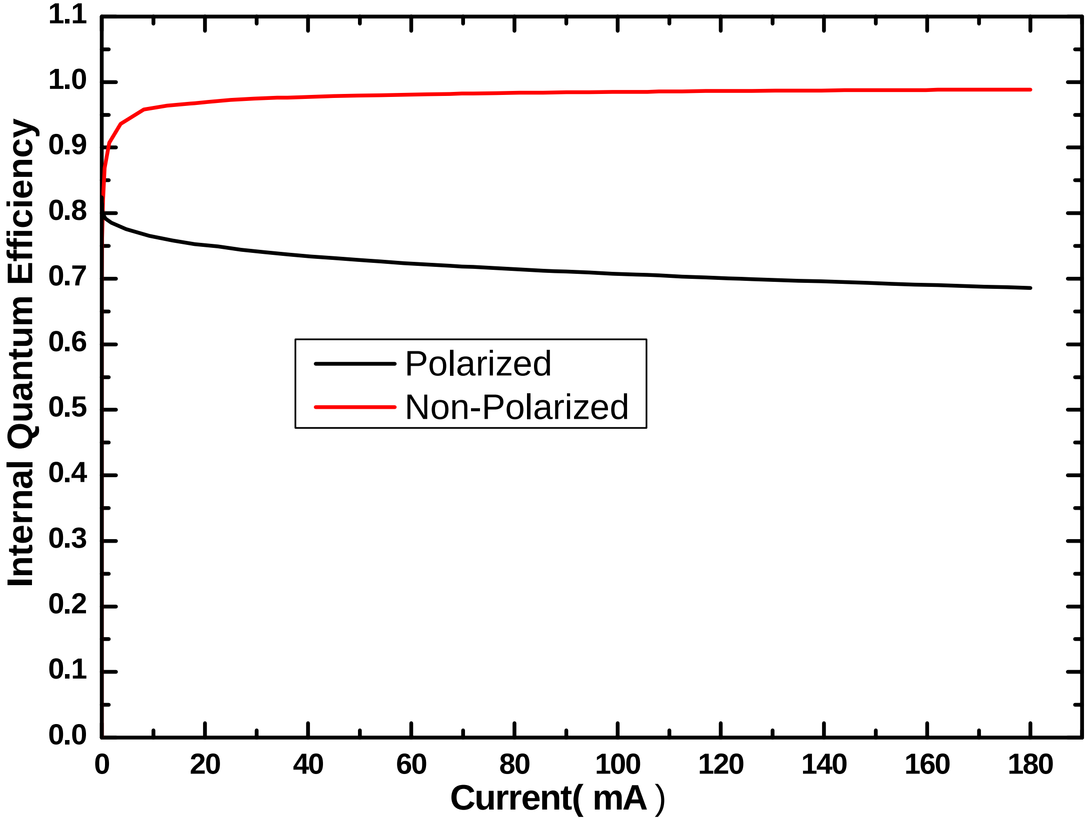
Polarization field decreases the interband recombination rate and results in the red shift of luminous energy .

I-V Curve



Polarization field increases the threshold voltage of LED.

IQE Curve



Polarization charge in the MQW structure plays an important role leading to the low luminous efficiency of InGaN/GaN MQW LEDs.

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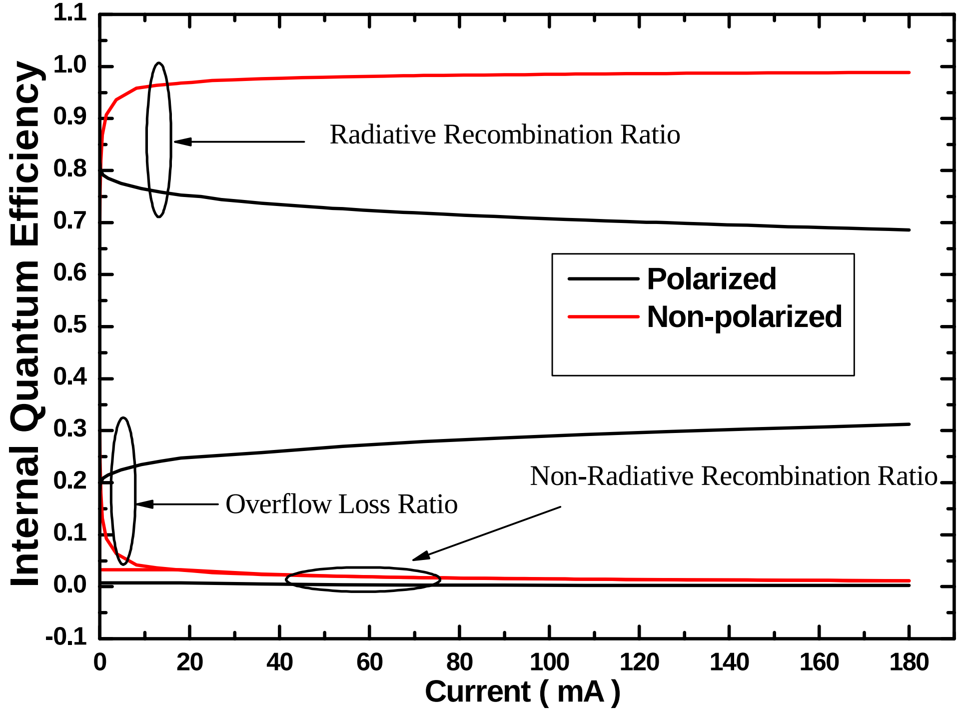
IQE Analyzed



More overflow loss of current is generated by Polarization charge leading to the drop of efficiency at high current, which is in good agreement with the results as shown in Ref. Appl.Phys.Lett. 91,183507.

Characteristics of MQW structure of Blue InGaN/GaN MQW LEDs with polarization effects

Simulation is performed on the reference LED structure with polarization charge as shown on page 5.

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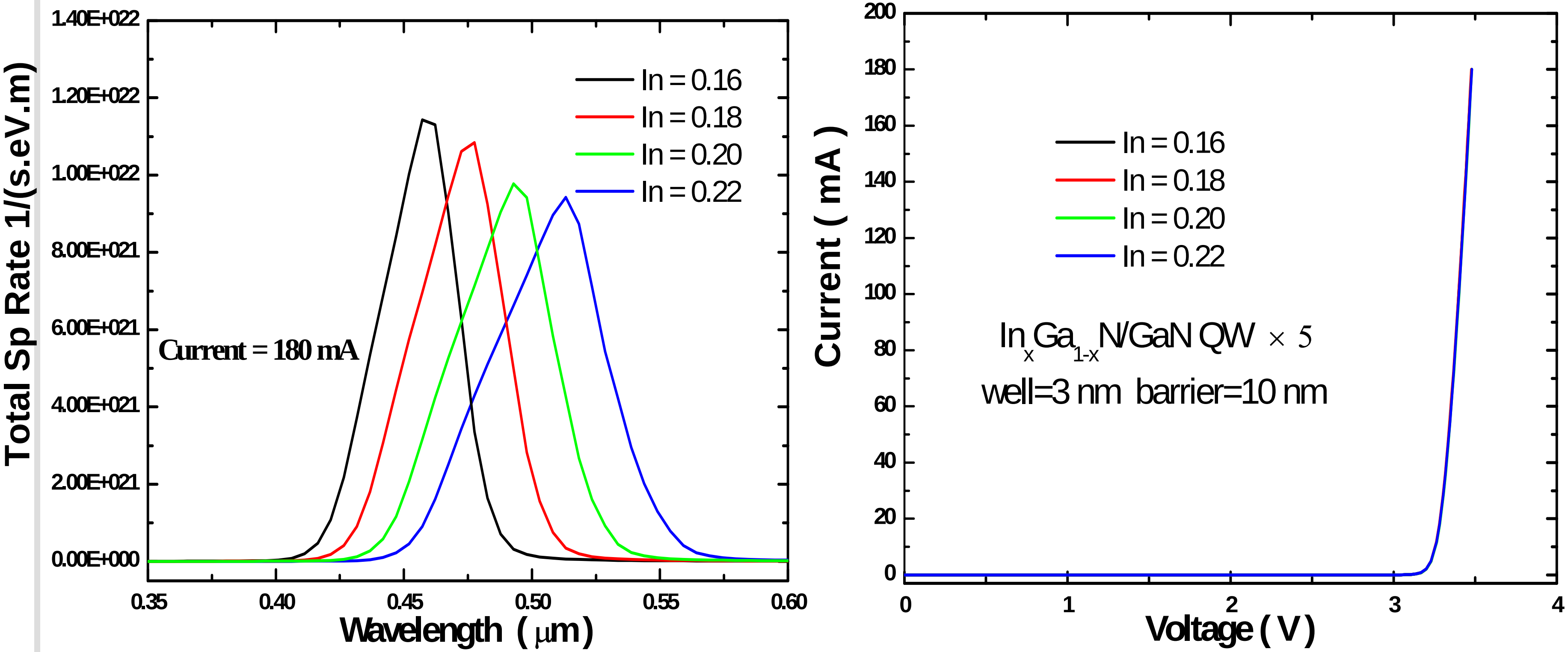
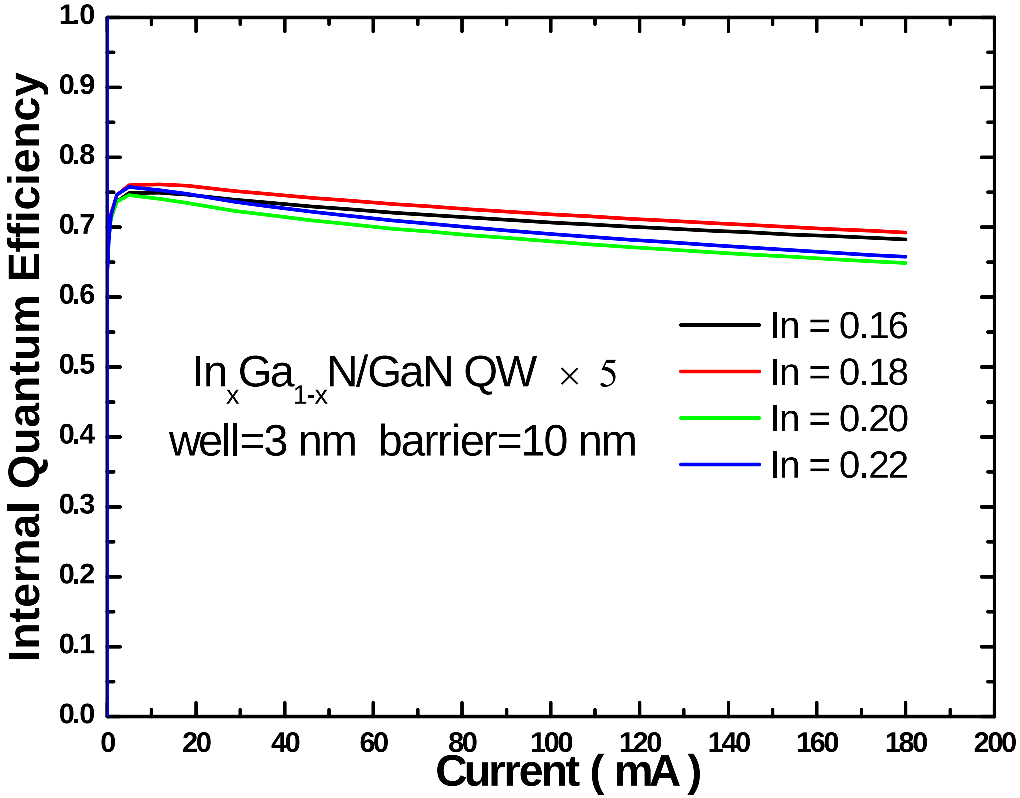
Indium Dependence



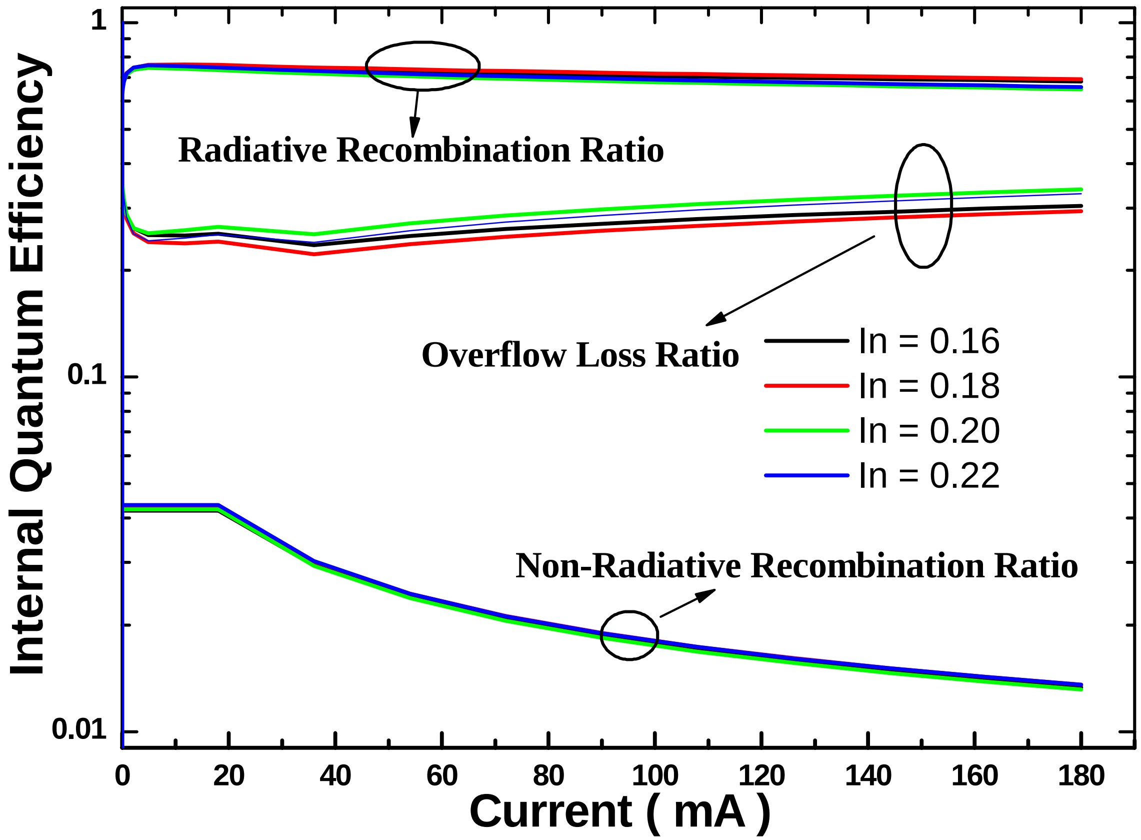
Different indium composition makes different spectrum peak and almost same I-V curve.

Indium Dependence

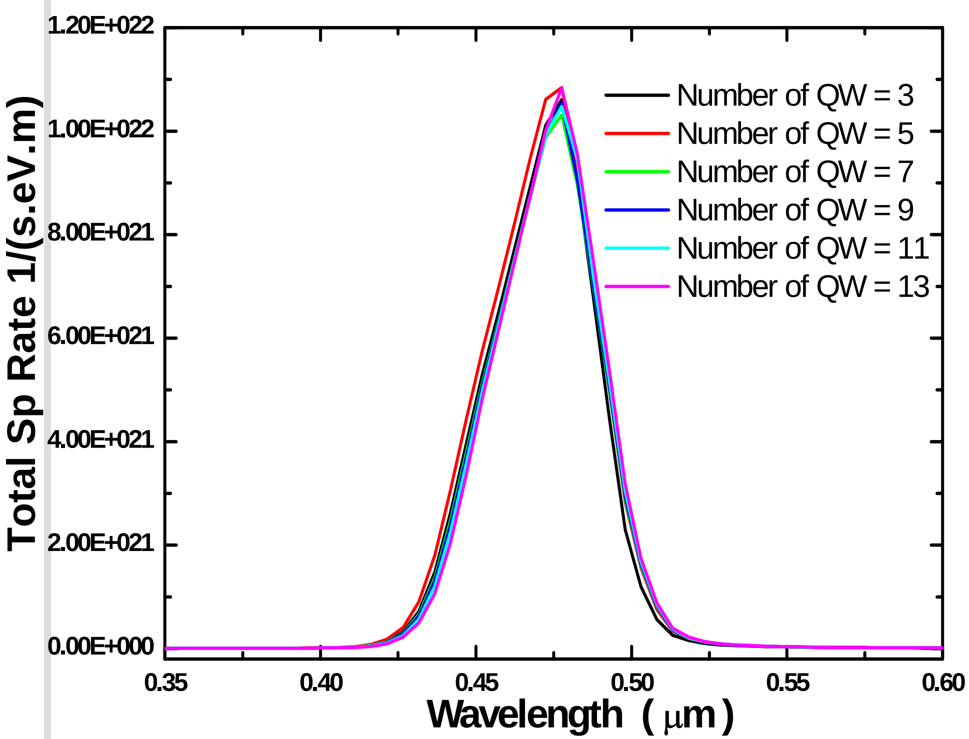


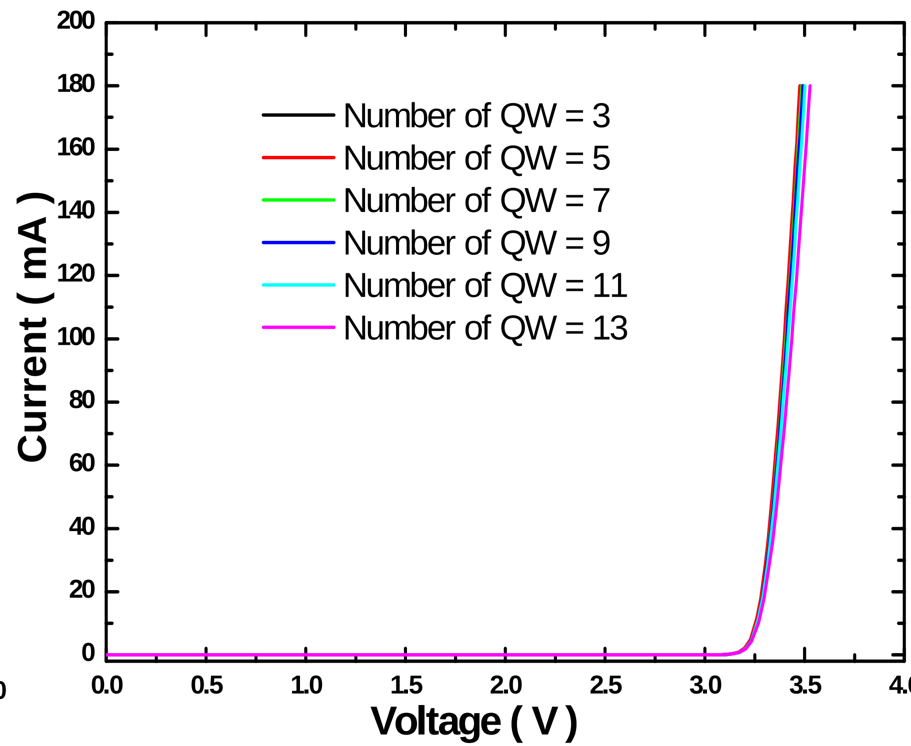
Also, IQEs are almost same for LEDs with different indium composition

IQE Analyzed

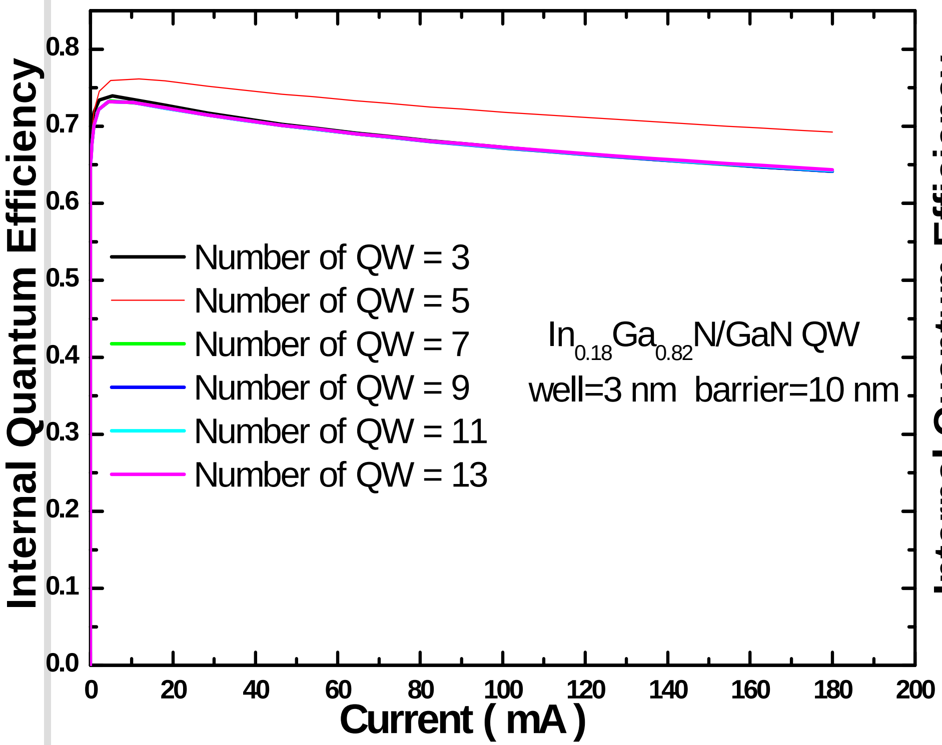


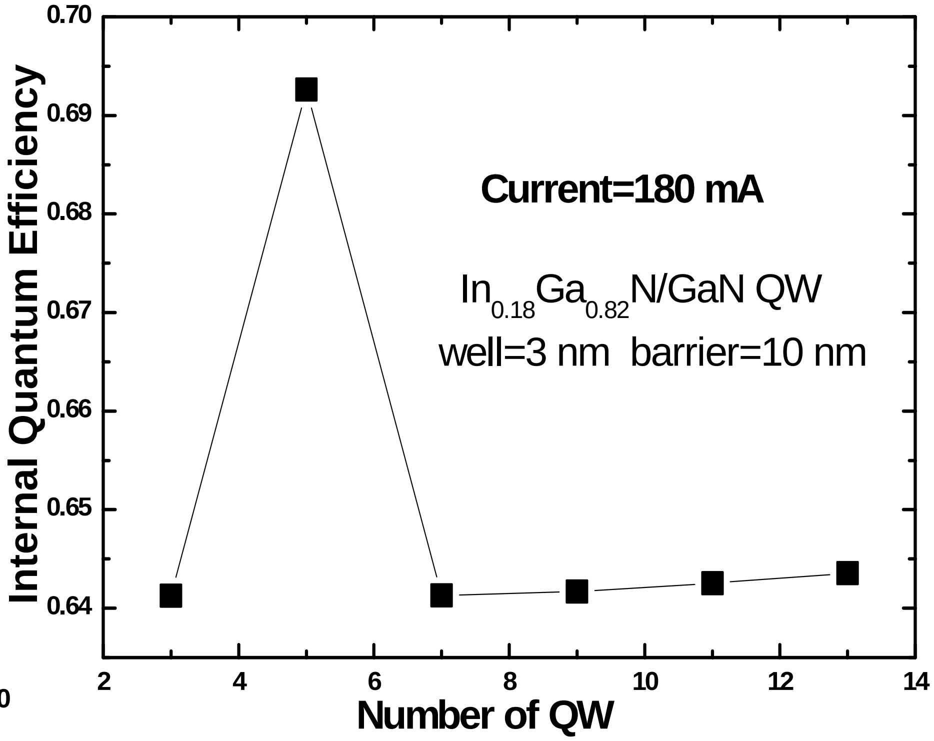
QW Number Dependence





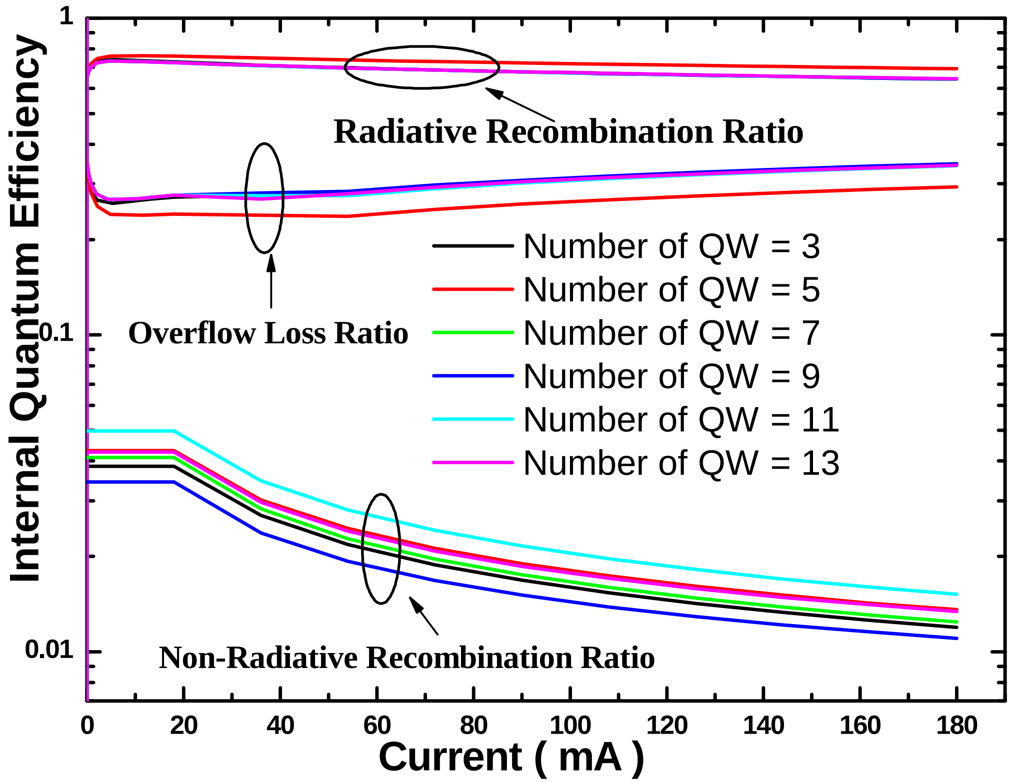
QW Number Dependence





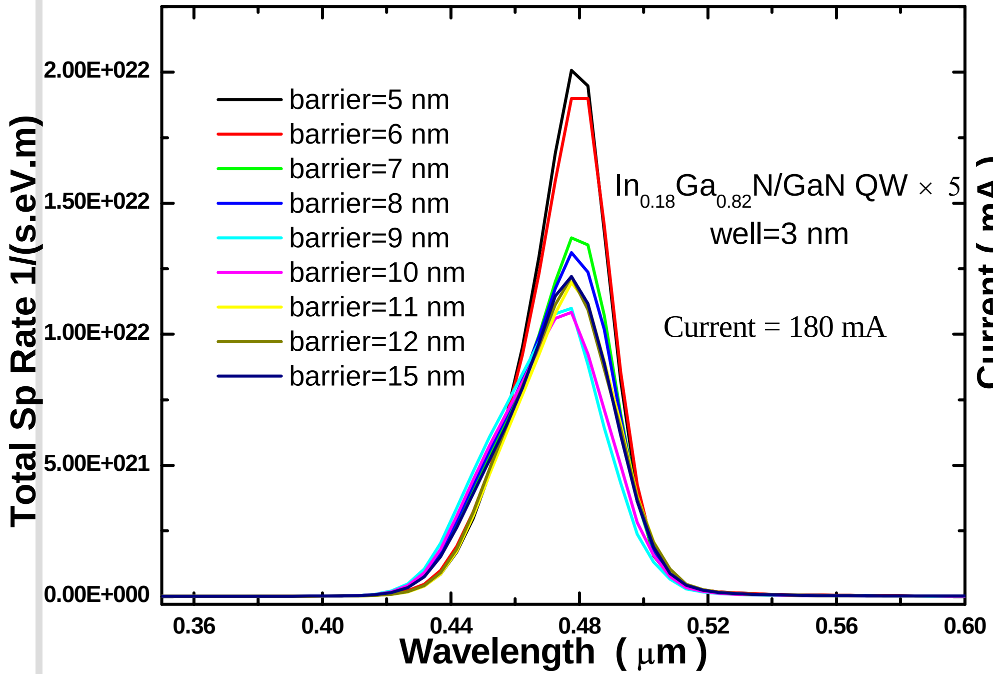
For integrated effect on LED IQE, QW number = 5 shows an optimal situatior

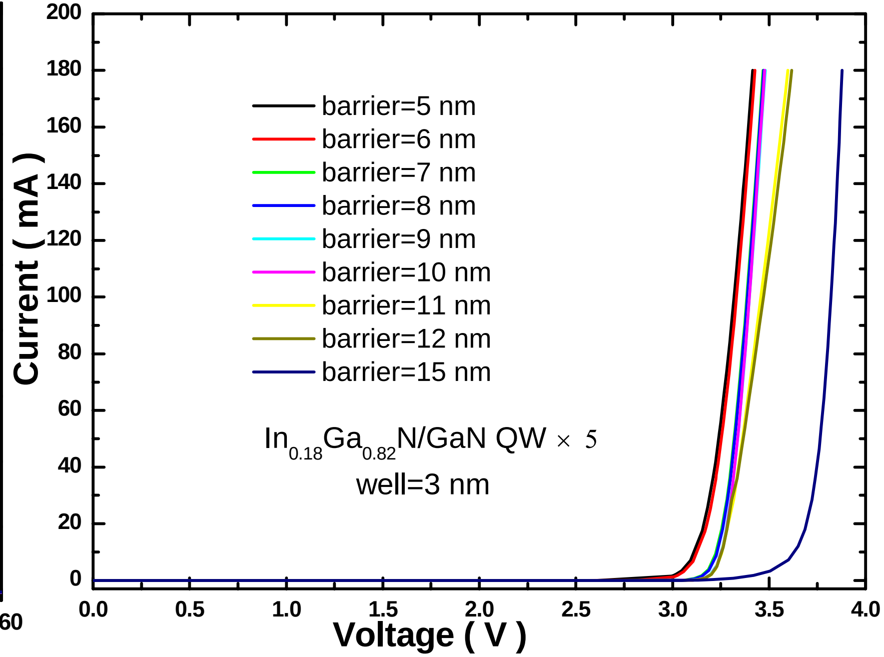
IQE Analyzed



Overflow loss plays an important role on polarized-LED IQE, which proves the conclusion in the former page.

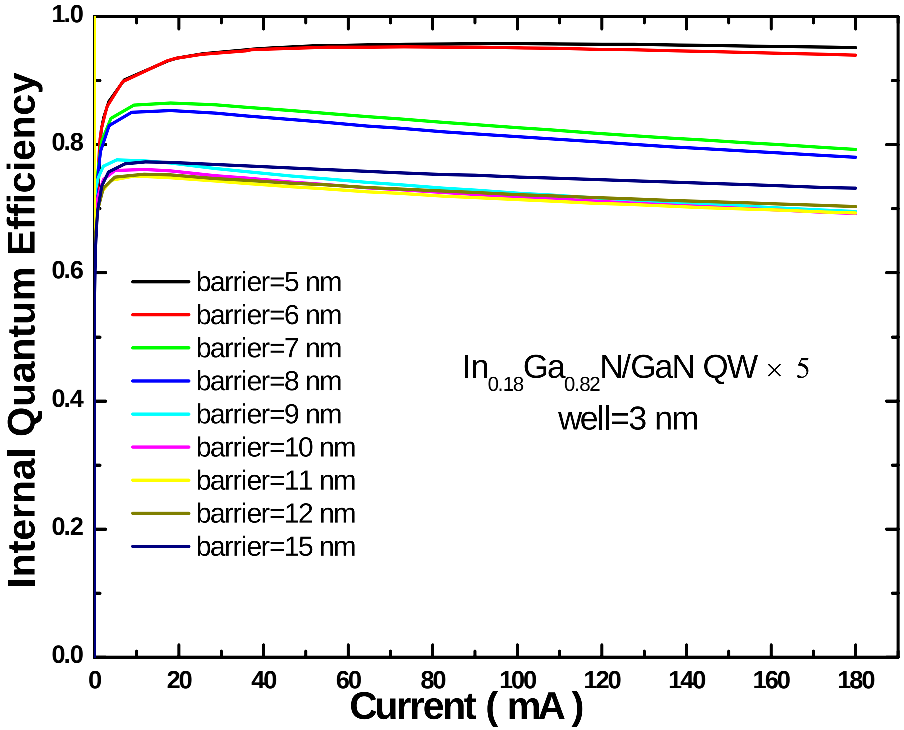
Barrier Width Dependence

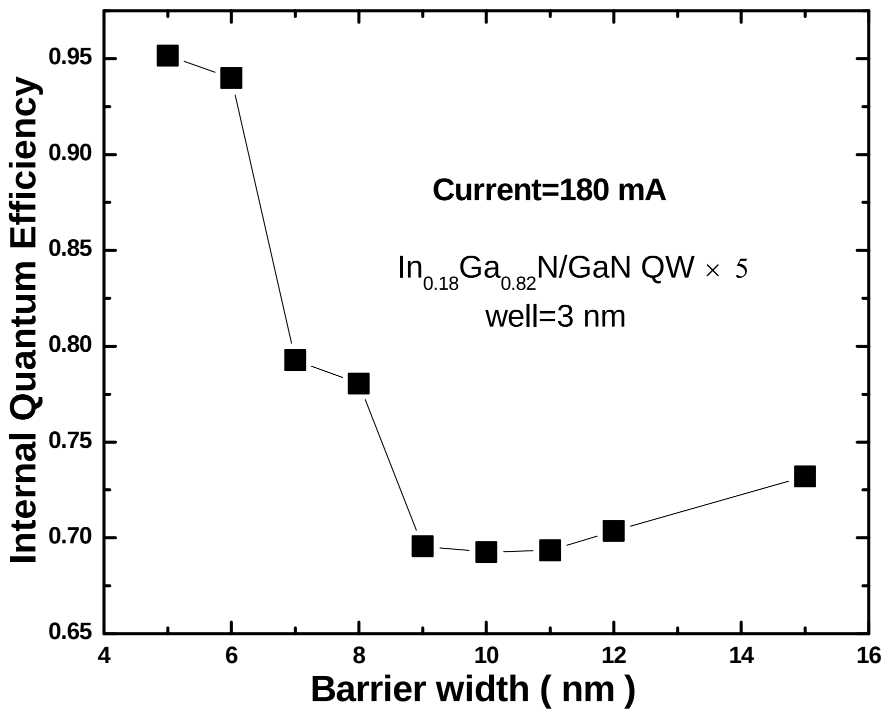




The thicker barrier is, the higher threshold voltage is.

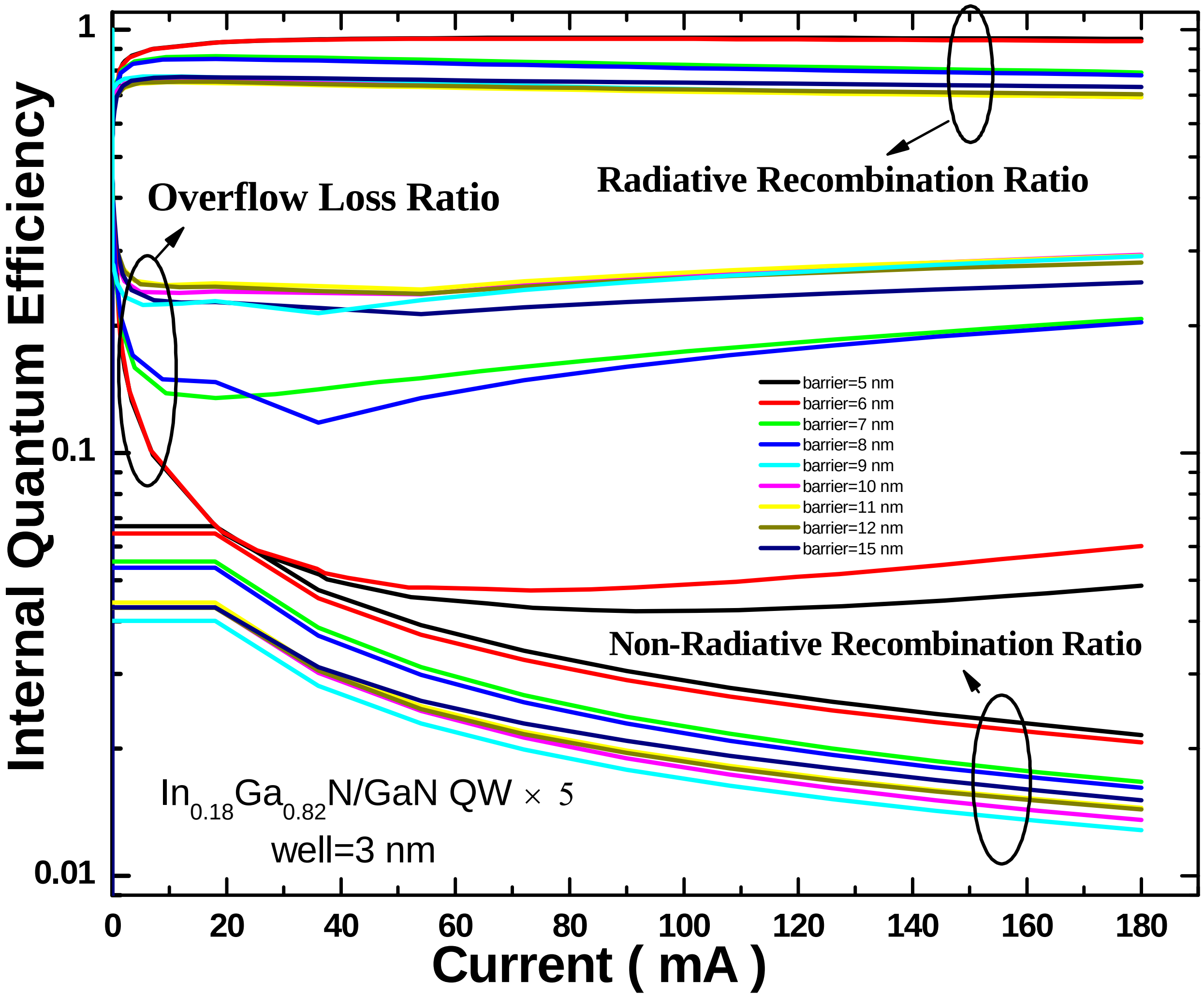
Barrier Width Dependence





Width of barrier has important effect on the efficiency of LEDs.

IQE Analyzed



Overflow loss is responsible for the dependence of efficiency on the width of barrier.

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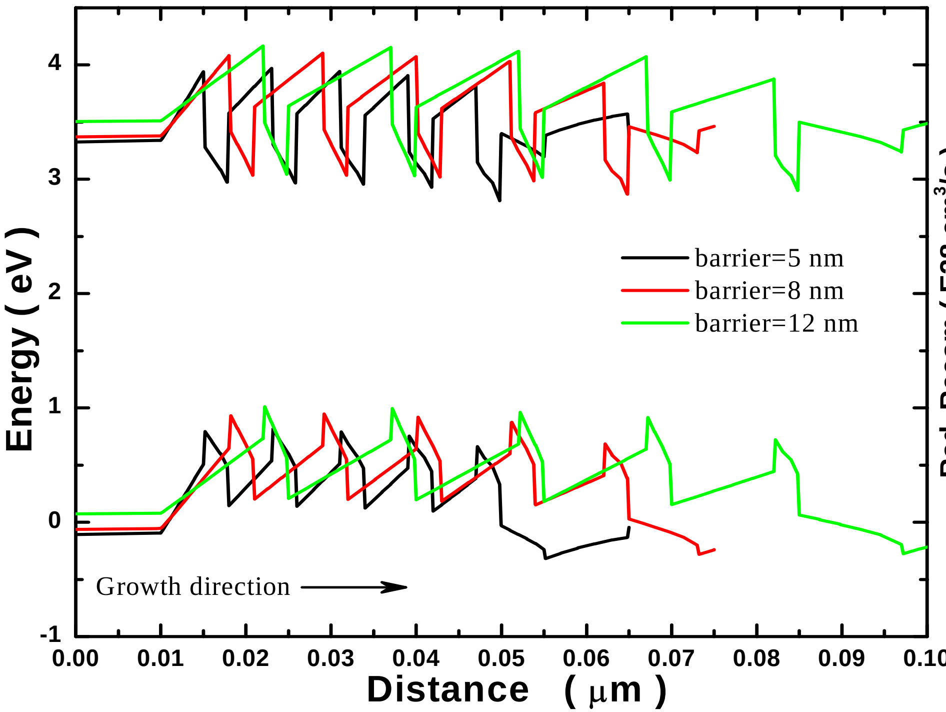
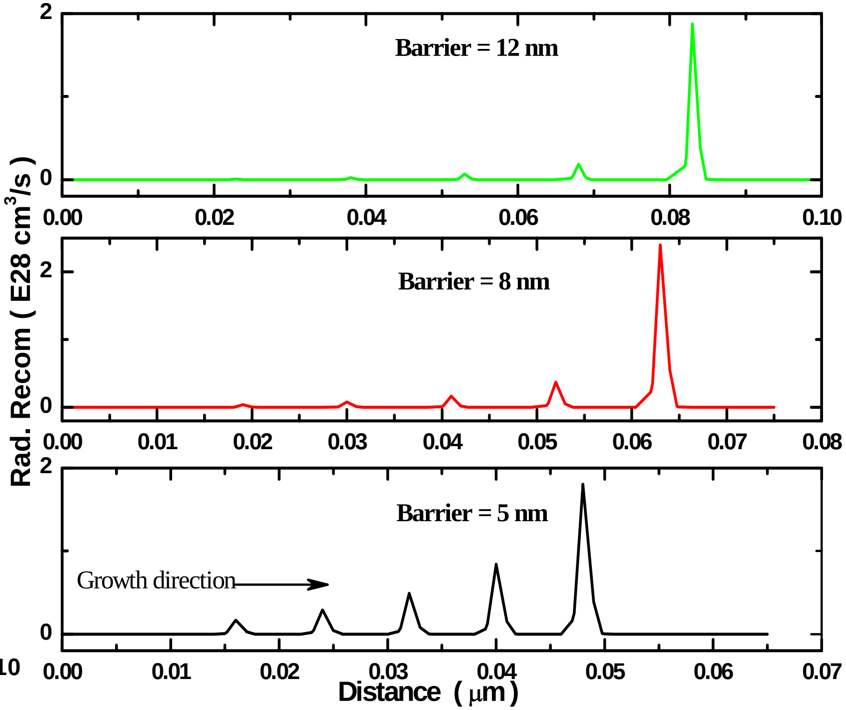
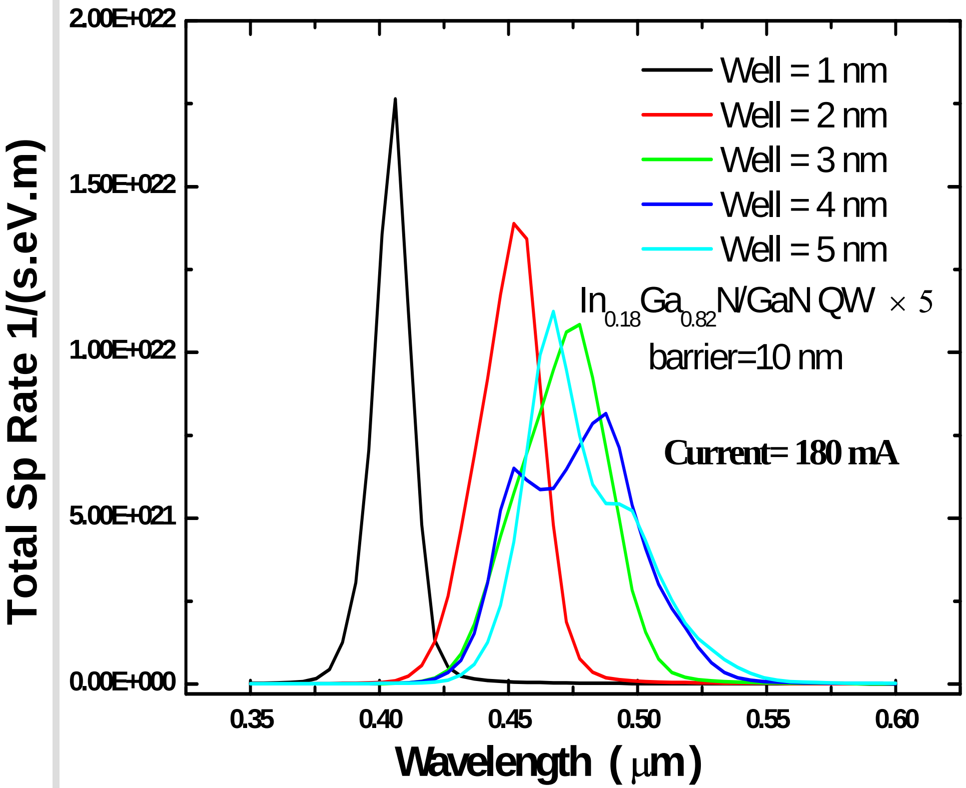
IQE Analyzed

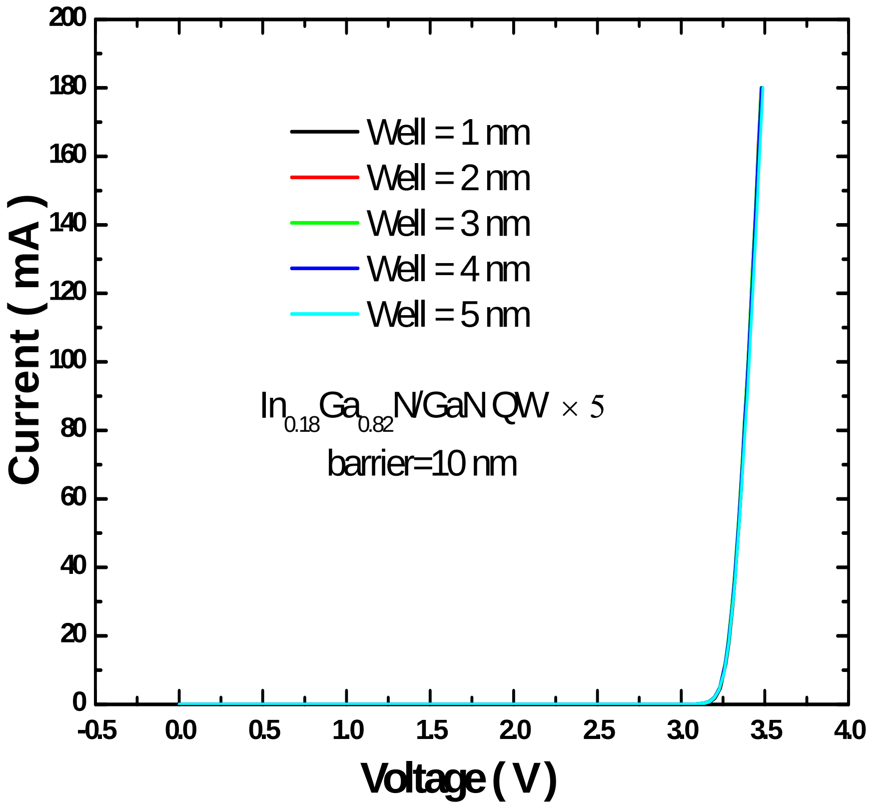




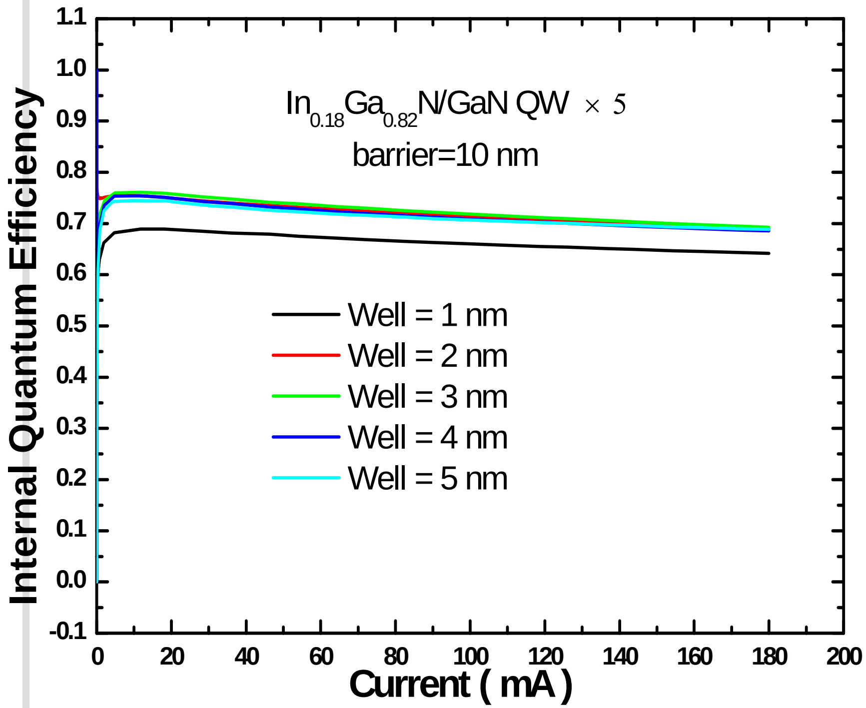
Thinner barrier makes holes easier to diffuse from p-region to MQW region, which totally increases radiative recombination rate

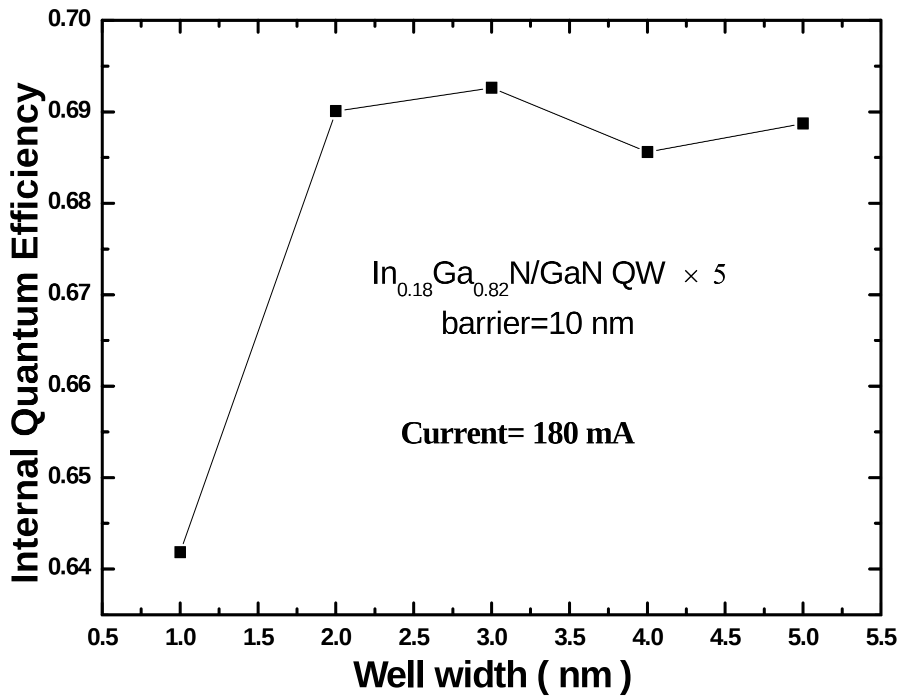
Well Width Dependence





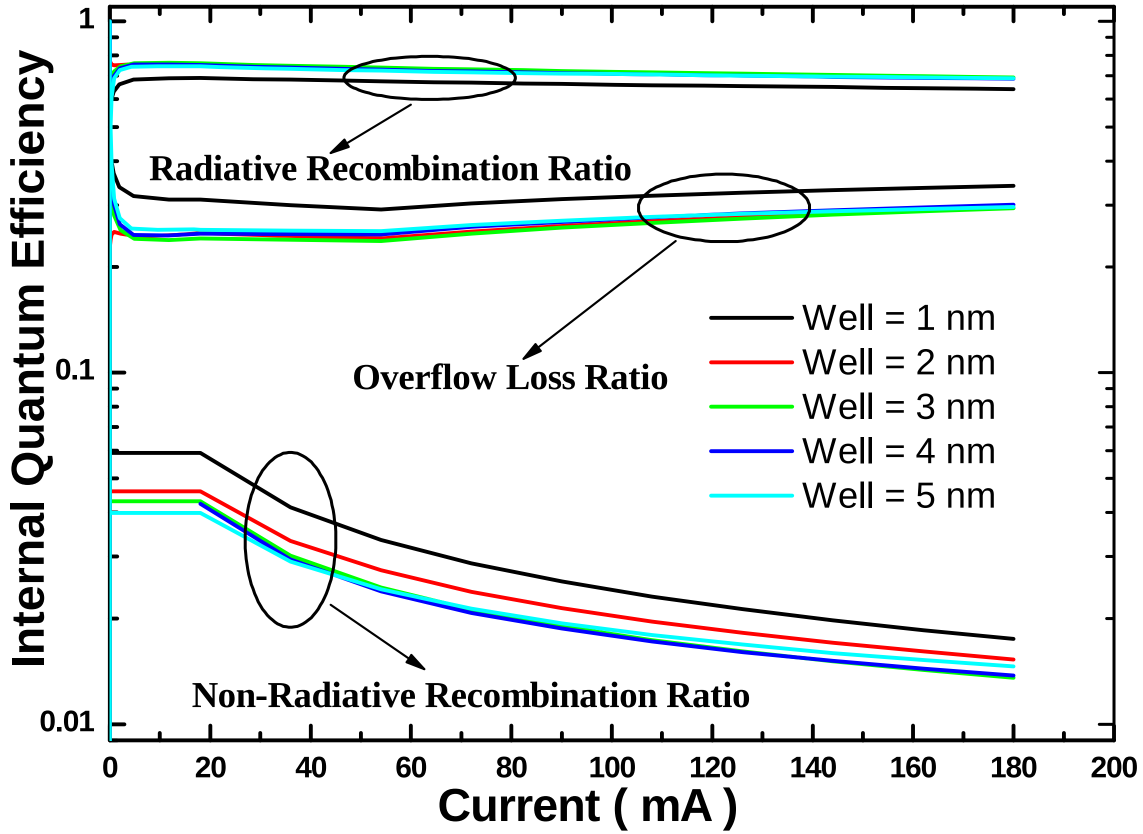
Well Width Dependence





For the well with 1nm thickness, polarization charges make larger effects than the other four cases.

IQE Analyzed



With increase of well width, the overflow loss decreases because the quantized levels are closer to the well bottom, making overflow less likely.

Characteristics of MQW structure of Blue InGaN/GaN MQW LEDs without polarization effects

Simulation is performed on the reference LED structure with no polarization charge as shown on page 5.

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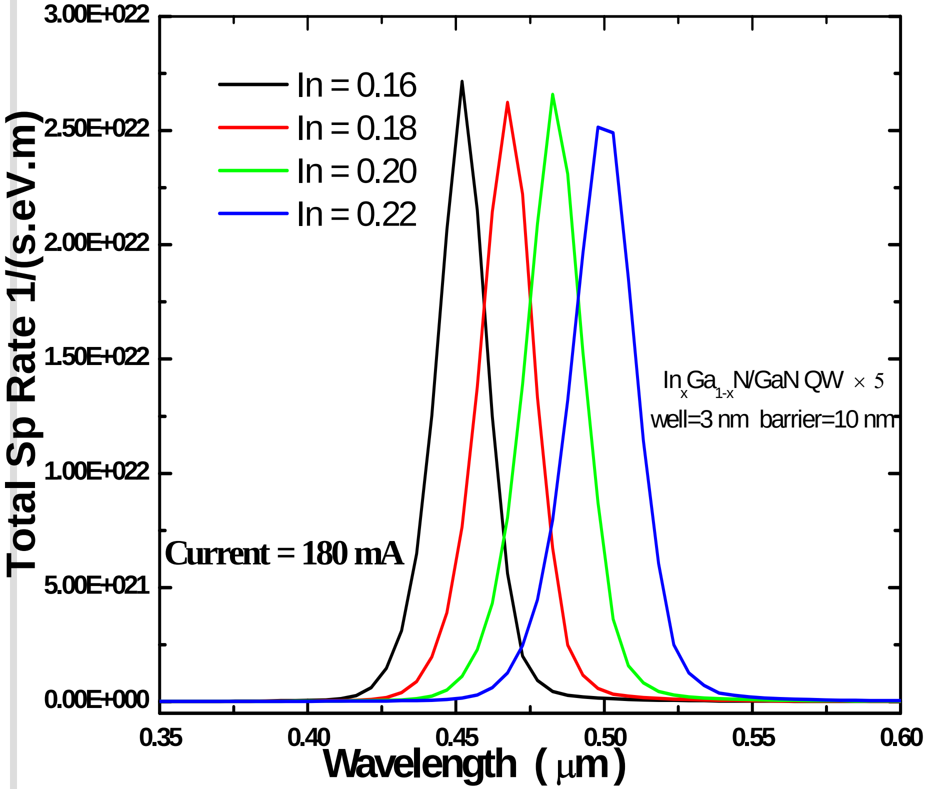
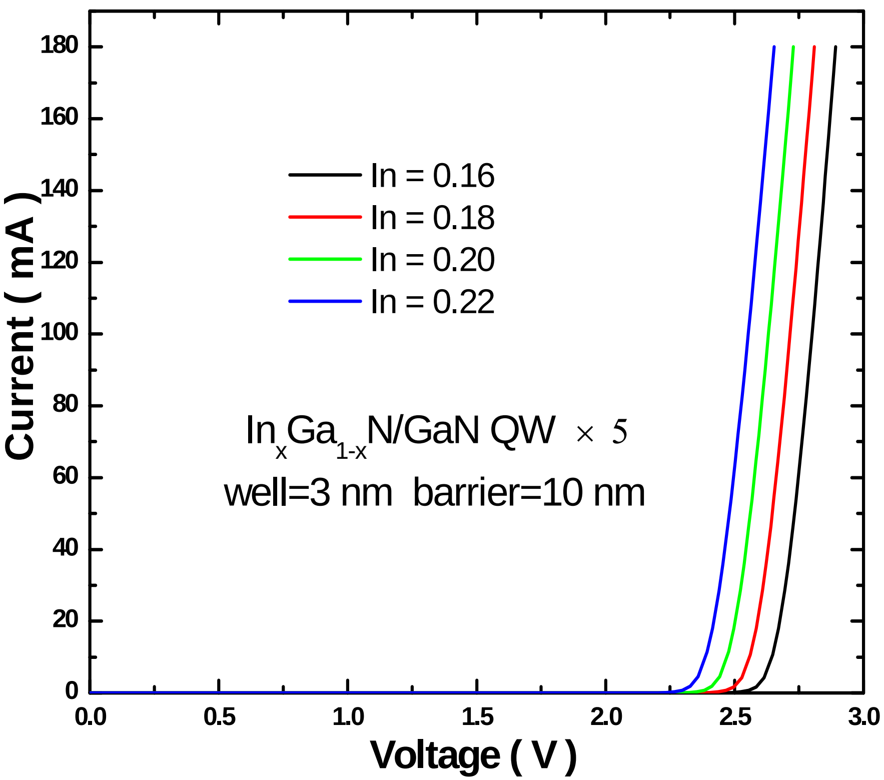
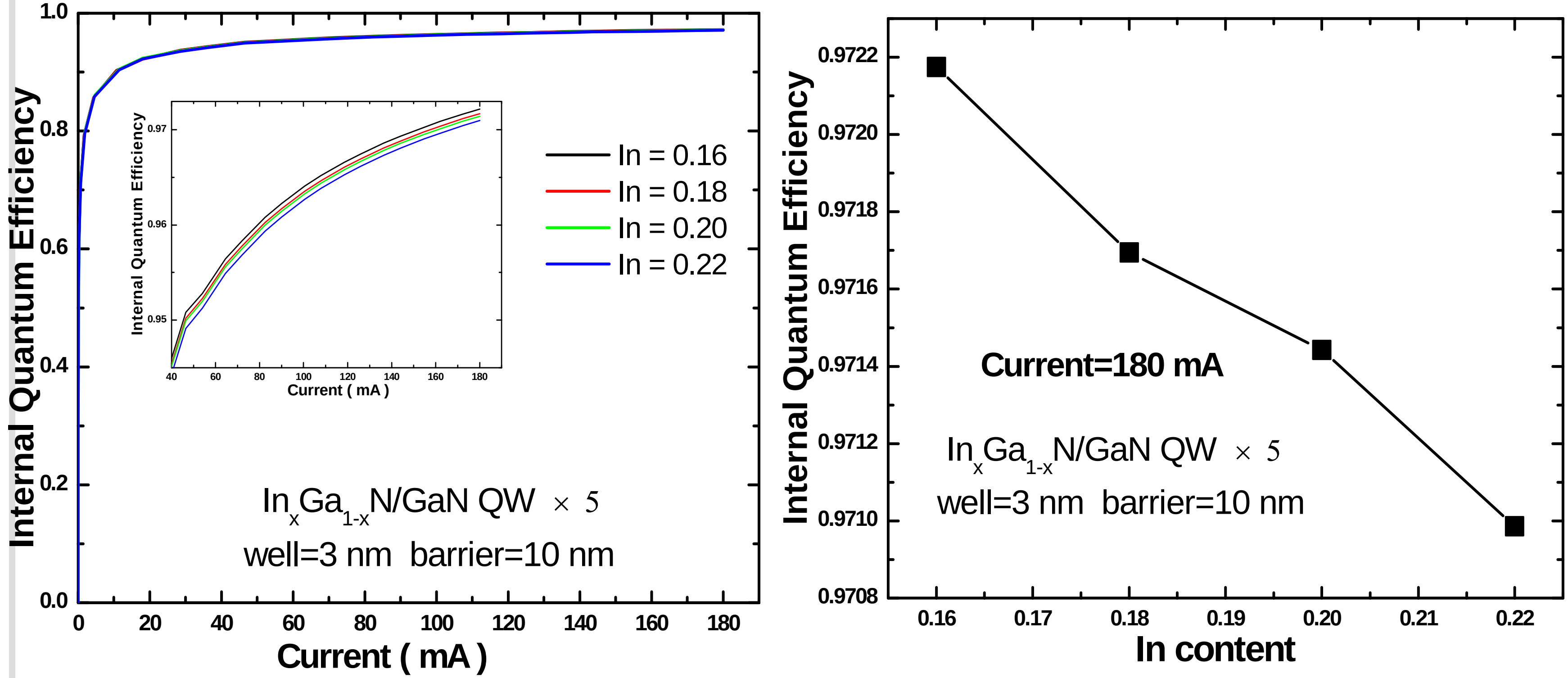
Indium Dependence



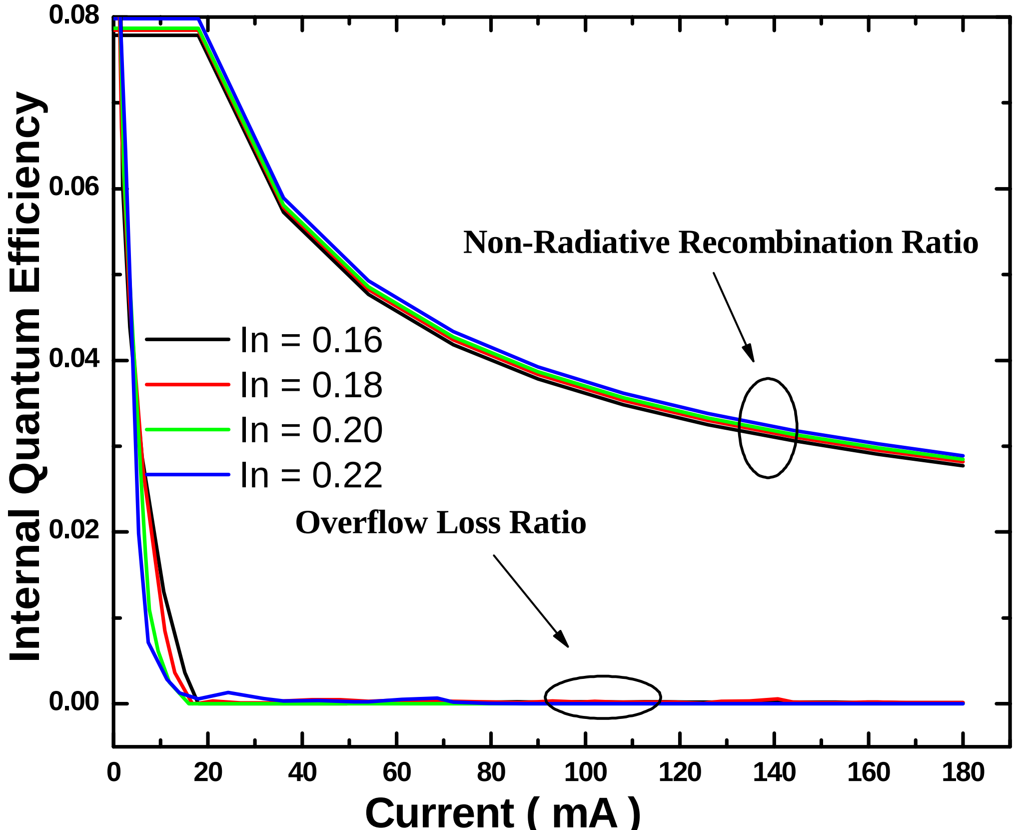


Indium Dependence



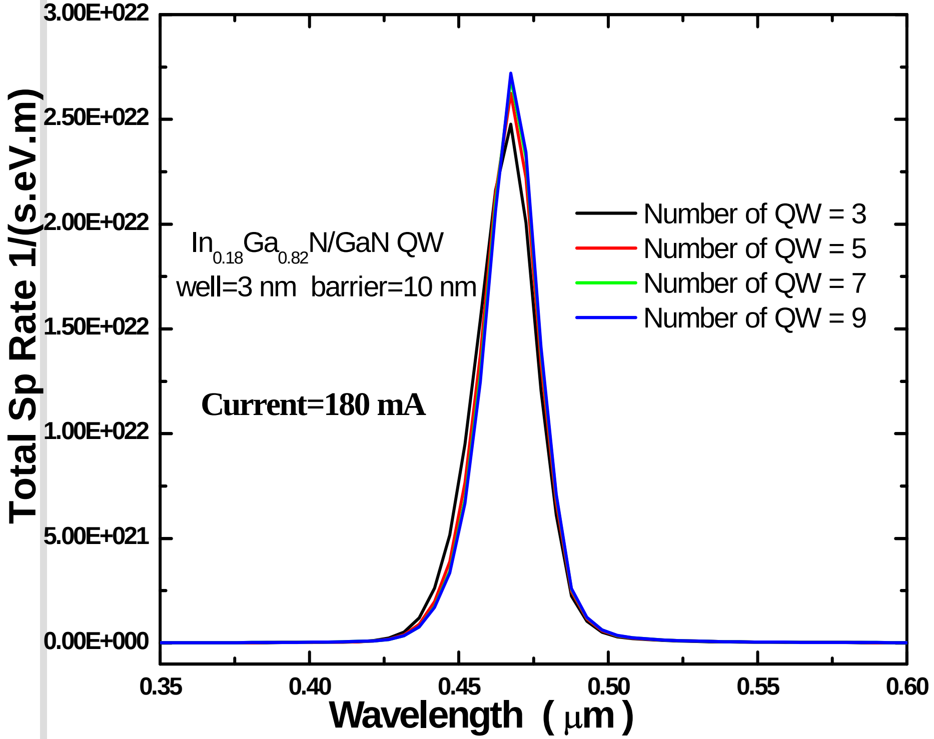
The InGaN/GaN MQW LEDs have similar properties with the polarized counterpart, but the IQE is less sensitive to the indium composition.

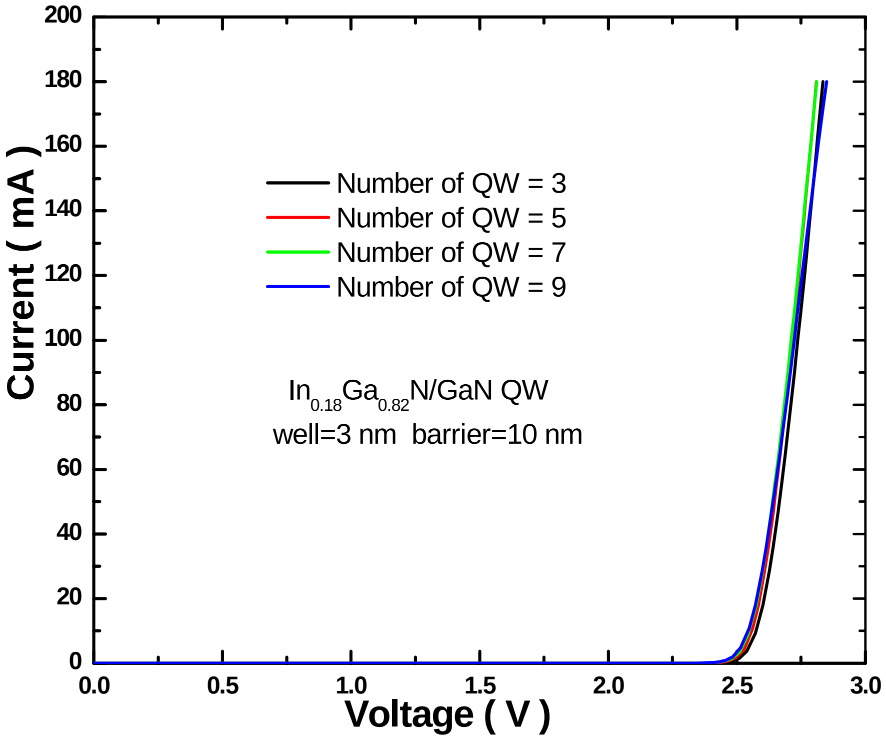
Indium Dependence



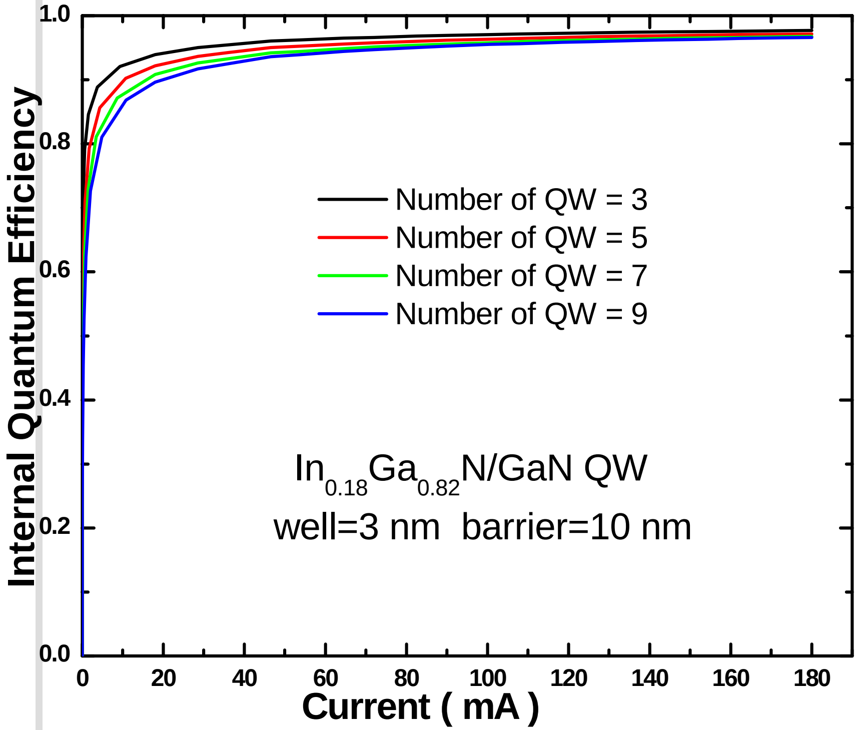
IQE in InGaN/GaN MQW LEDs without polarization effects is affected heavily by non-radiative recombination instead of overflow loss.

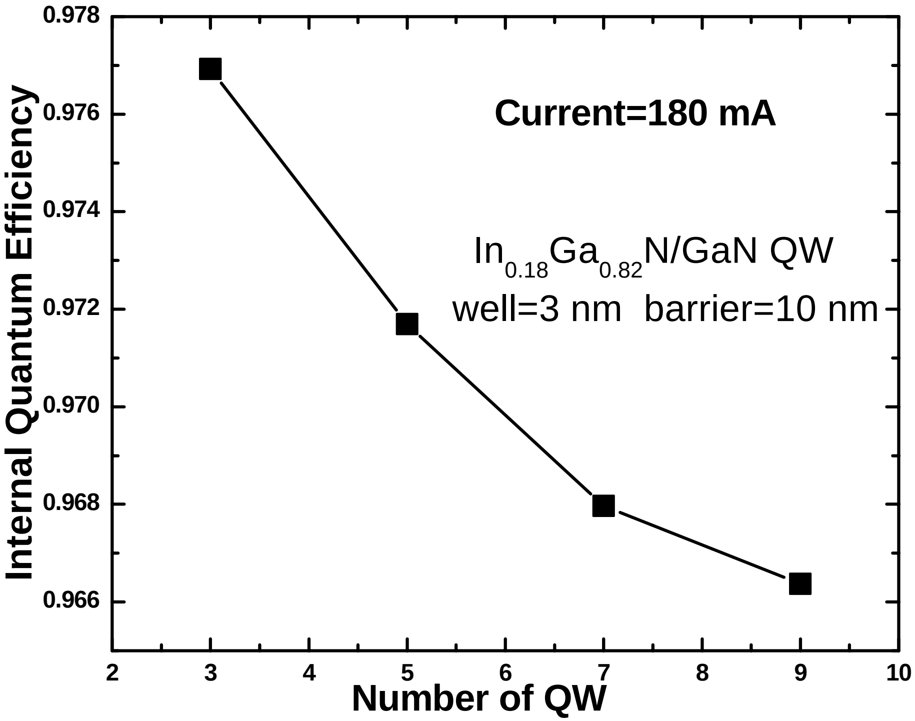
QW Number Dependence





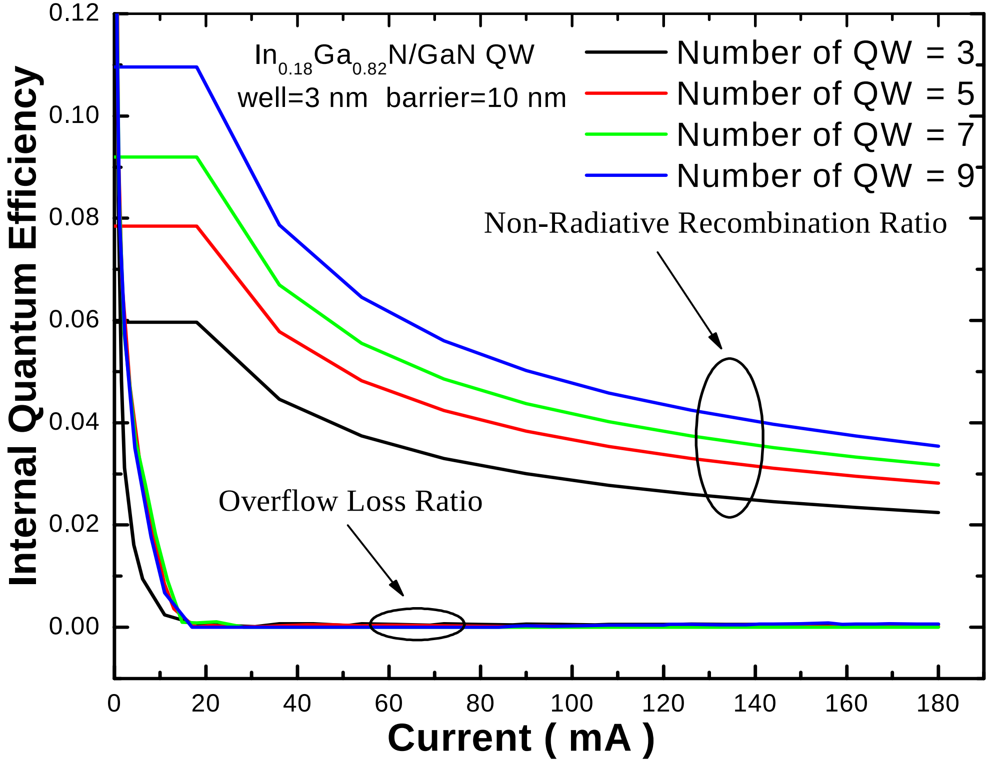
QW Number Dependence





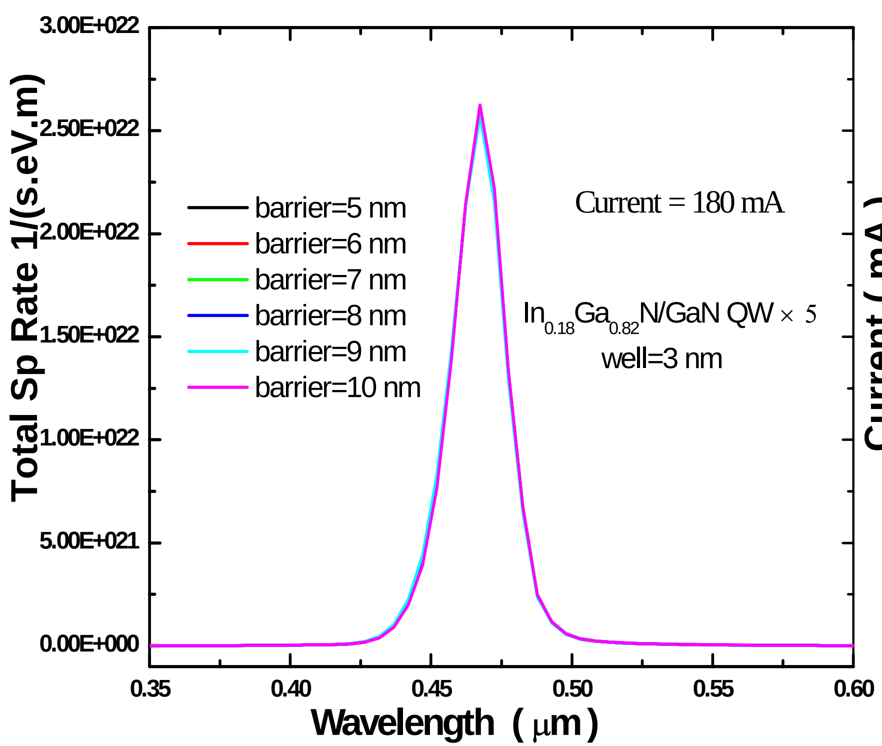
IQE decreases with number of QWs

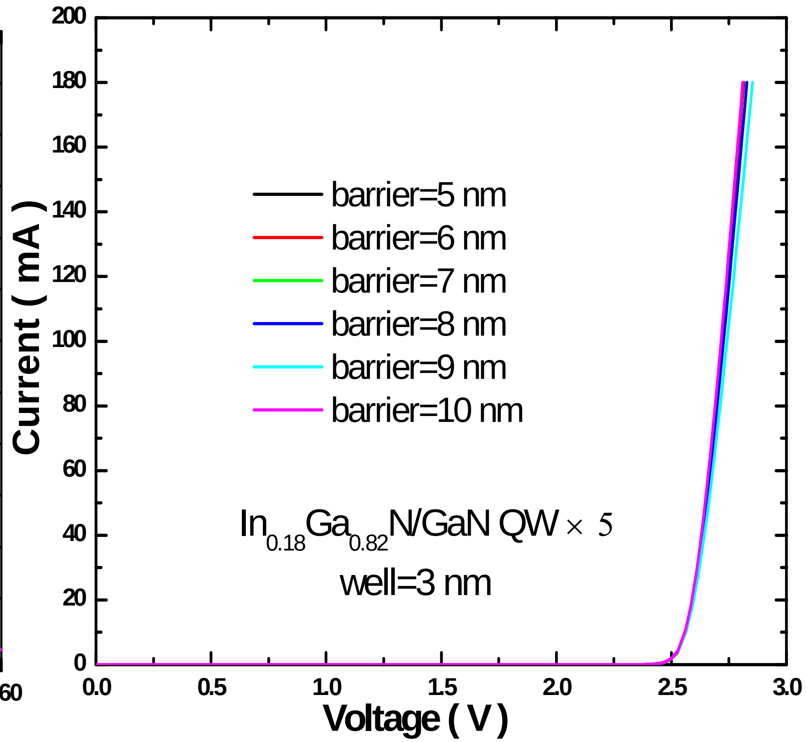
IQE Analyzed



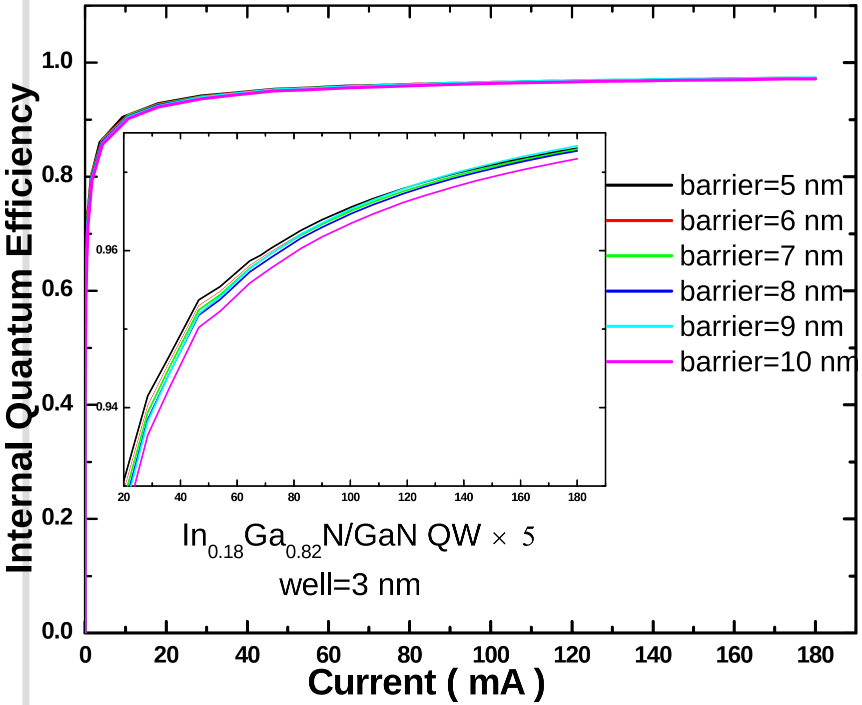
Increase of non-radiative recombination are responsible for the slight decrease of IQE with increase of QWs in InGaN/GaN MQW LEDs with no polarization charges where overflow loss is very small.

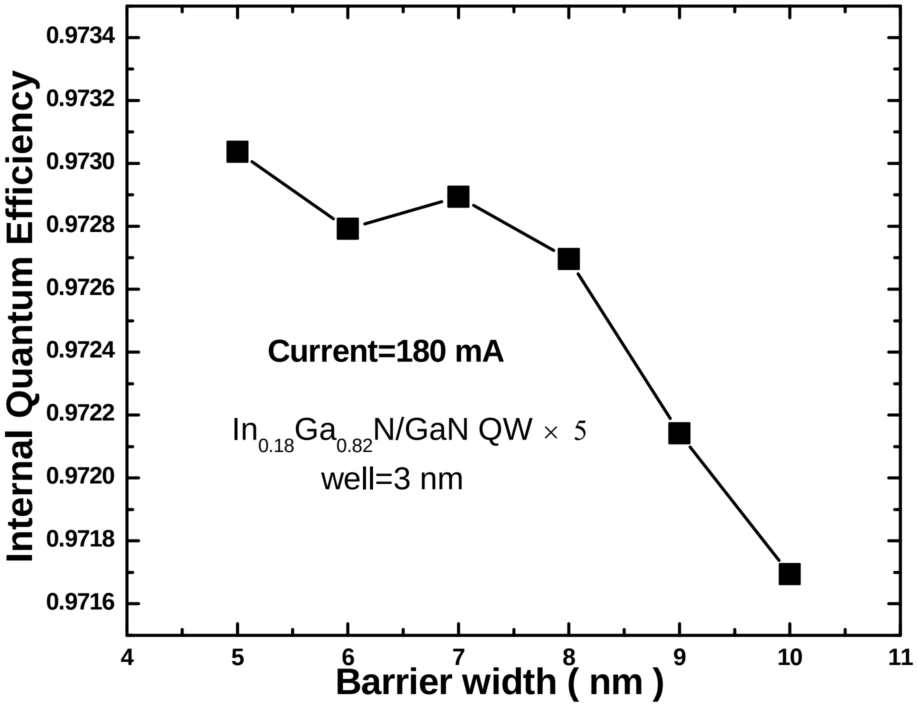
Barrier Width Dependence





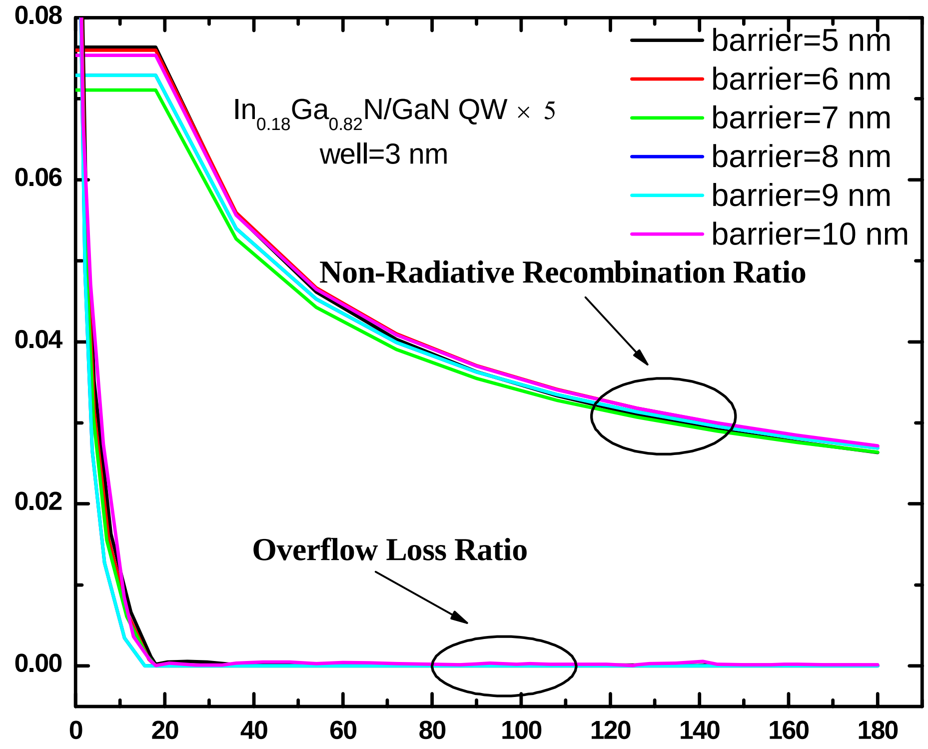
Barrier Width Dependence





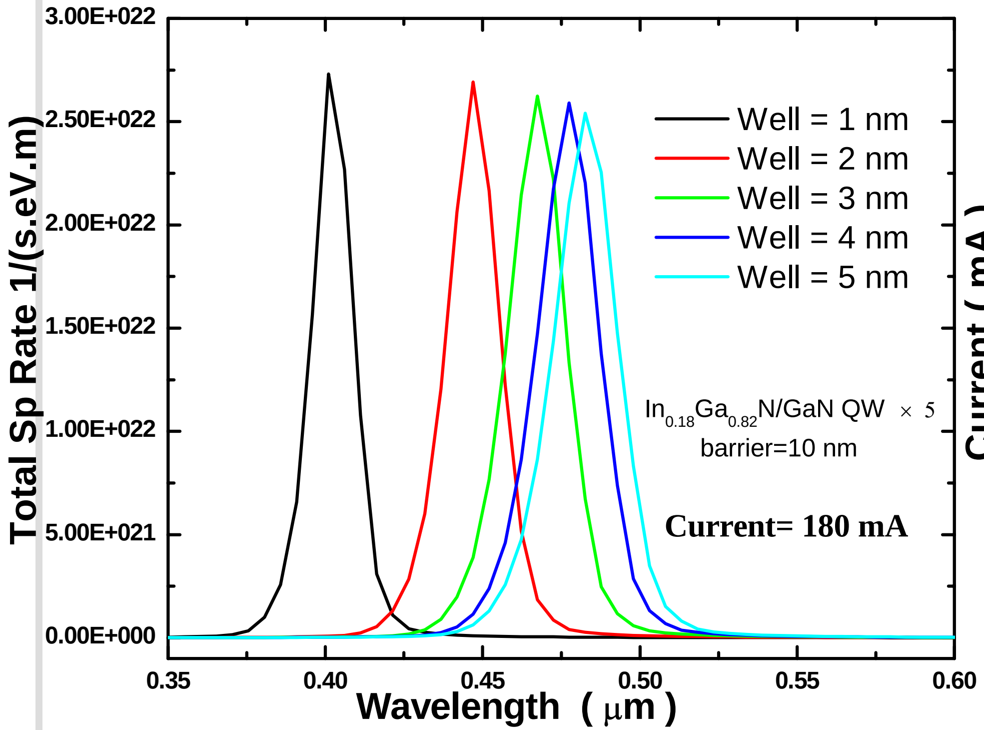
Narrow barrier are beneficial to get higher efficiency for InGaN/GaN MQW LEDs when there are no polarization charges.

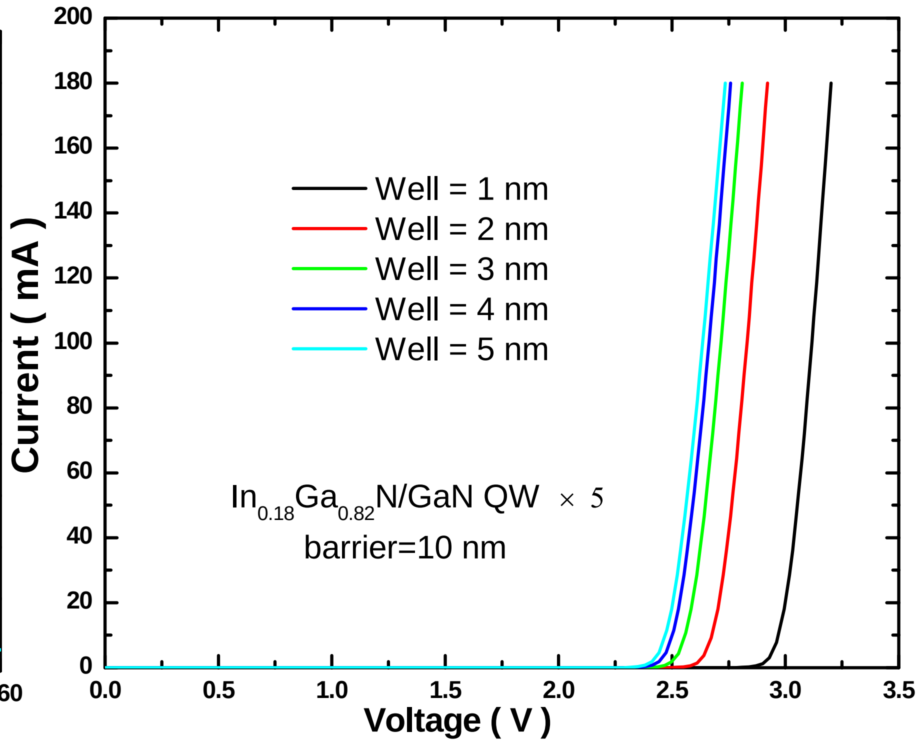
IQE Analyzed



Non-radiative recombination loss play a dominant role in InGaN/GaN MQW with no polarization charge.

Well Width Dependence





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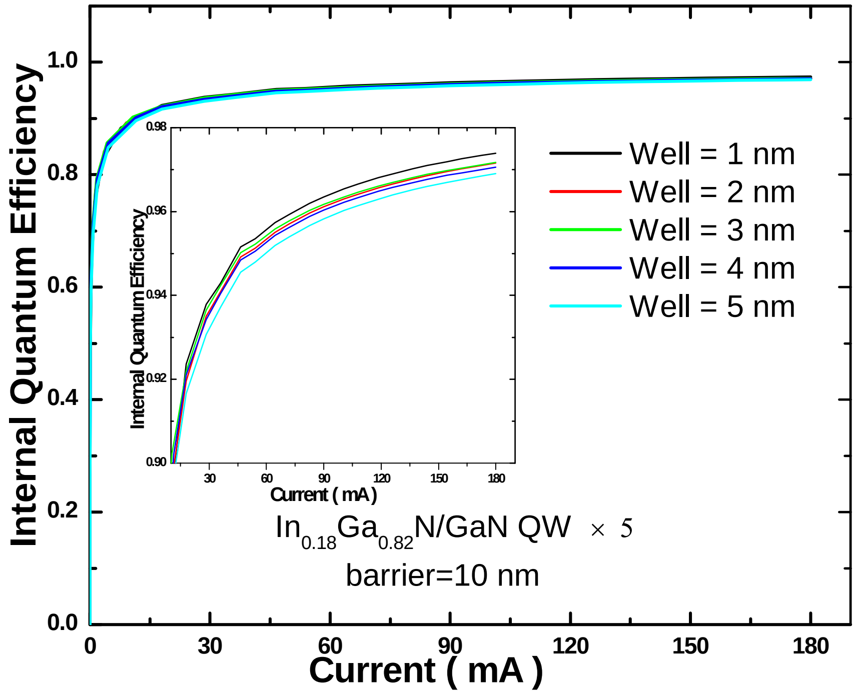
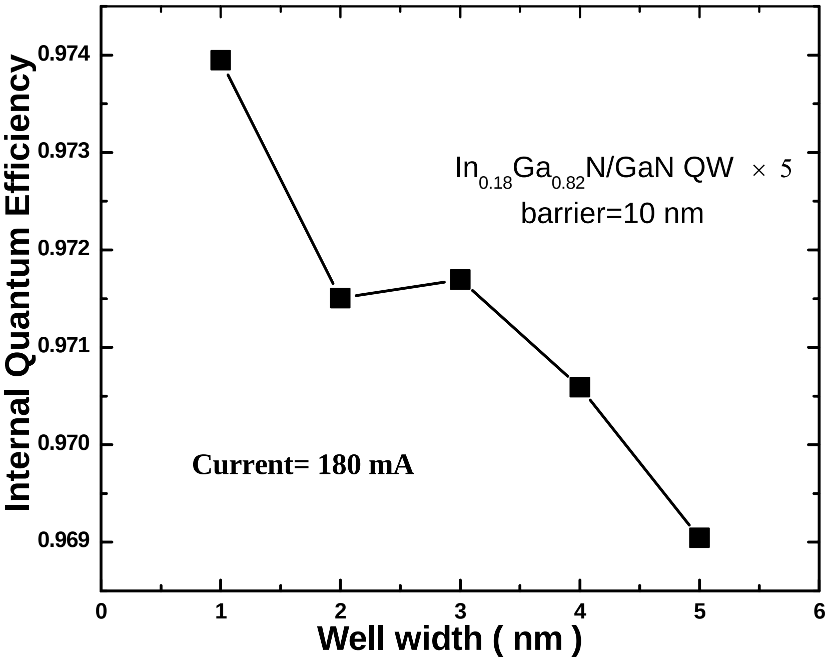
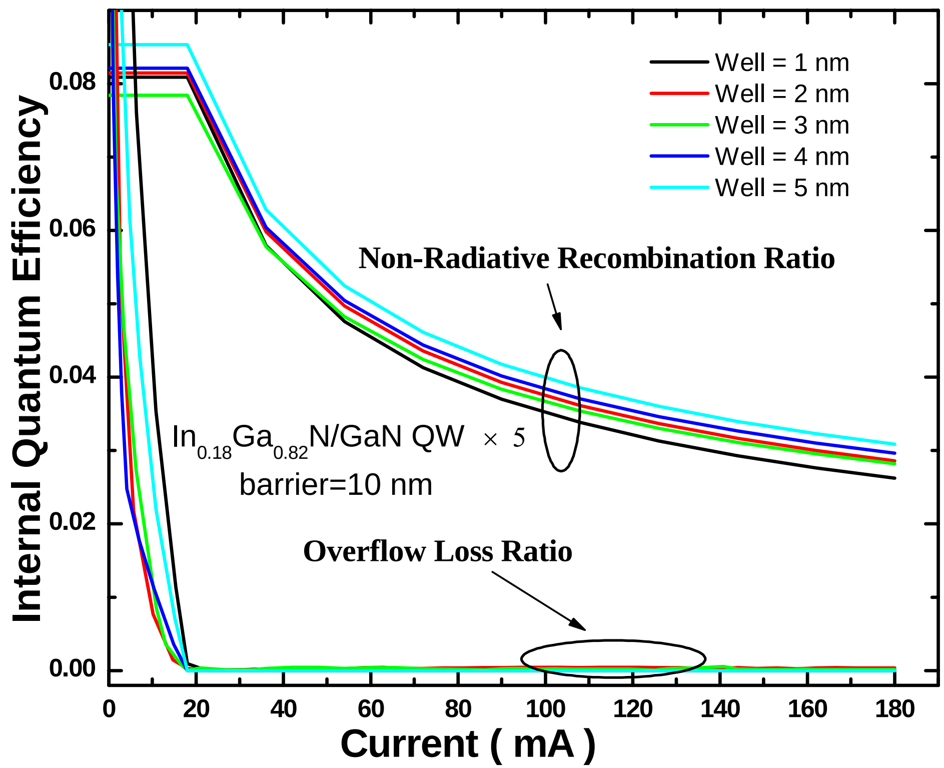
Well Width Dependence





IQE has weak dependence on the well width with the polarized counterpart

IQE Analyzed



Non-radiative recombination decreases with increase of well width and overflow loss is almost zero.

Conclusions

- **Polarization charge resulting from the lattice mismatch deteriorates the properties of InGaN/GaN MQW LEDs.**
- **Eliminating the polarization charges improves optical and electrical properties of the LEDs.**
- **The optimal parameters of MQW structure for InGaN/GaN MQW LEDs are different with or without polarization effects.**
- **Existing of overflow current is the crucial reason for performance decreasing in InGaN/GaN MQW LEDs.**

Appendix

Comparison of two quantum transport models in polarized InGaN/GaN MQW LEDs

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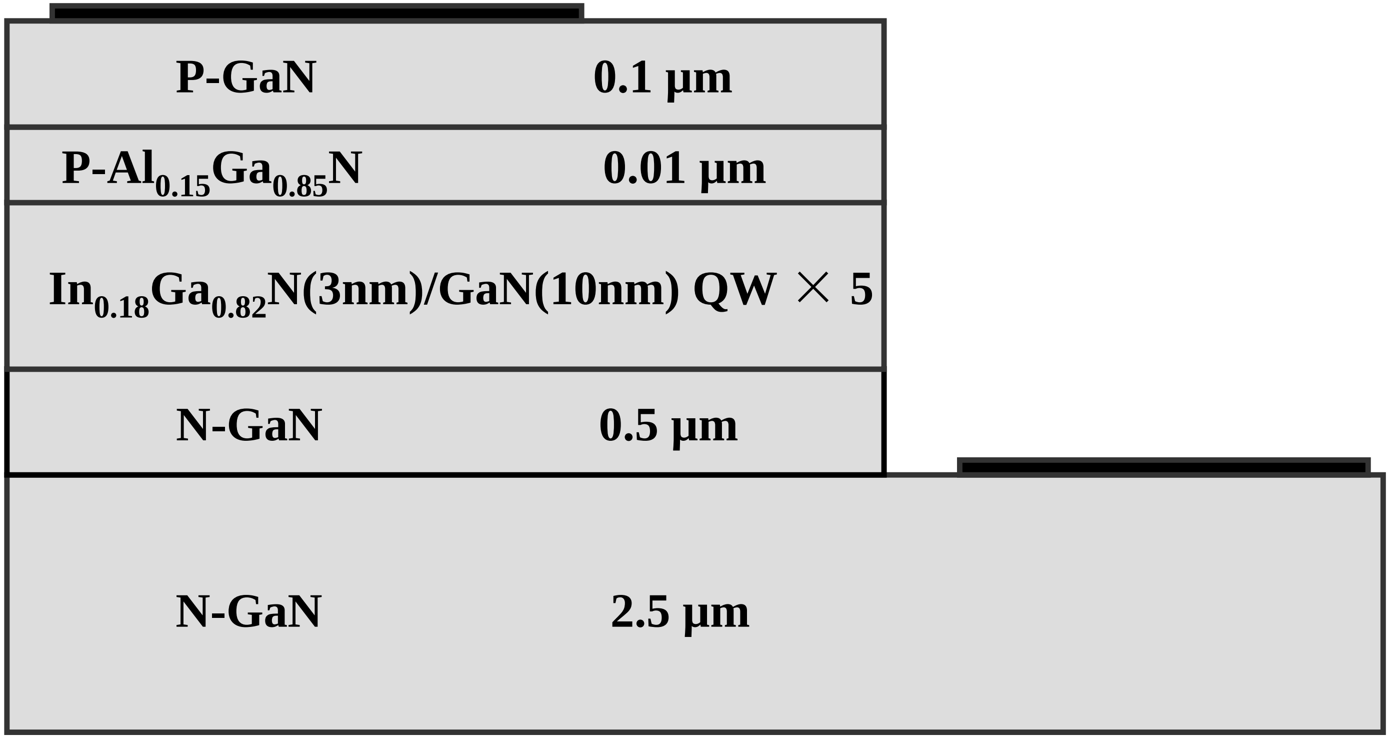
Contents

Physical Models

- **Default drift-diffusion transport model may become inaccurate at a microscopic scale.**
- **Difficulties with current injection means simulations show unrealistically high turn-on voltage**
- **Two-Fermi-level quantum well trapping model (Trapping model)**
- **Mean free path-controlled non-local transport model (MFP model)**

Reference Structure



Size: 300 µm × 300 µm

The polarization charge set on the interface of QWs is 80% of the theoretical value calculated based on the Ref. Appl. Phys. Letts, 80, 1204(2002).

Comparing the models

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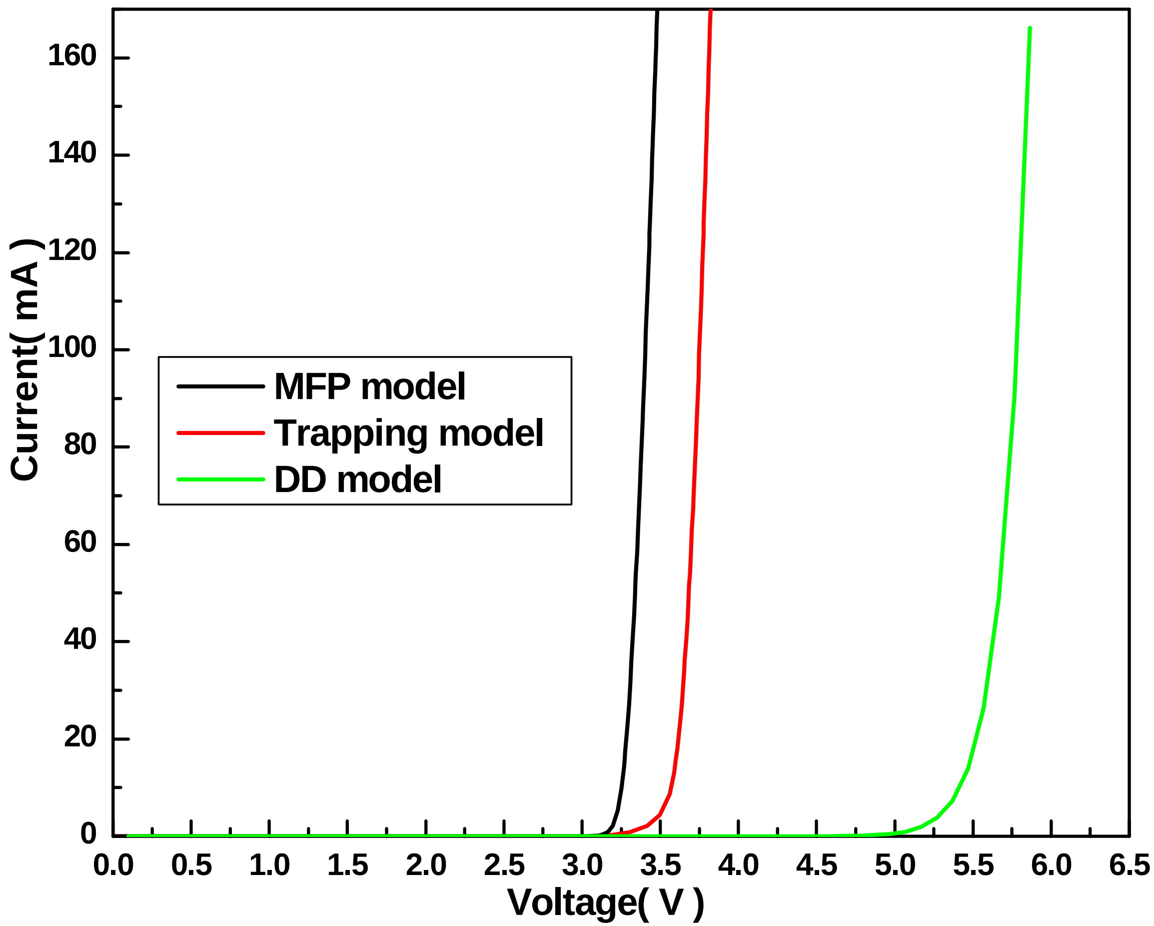
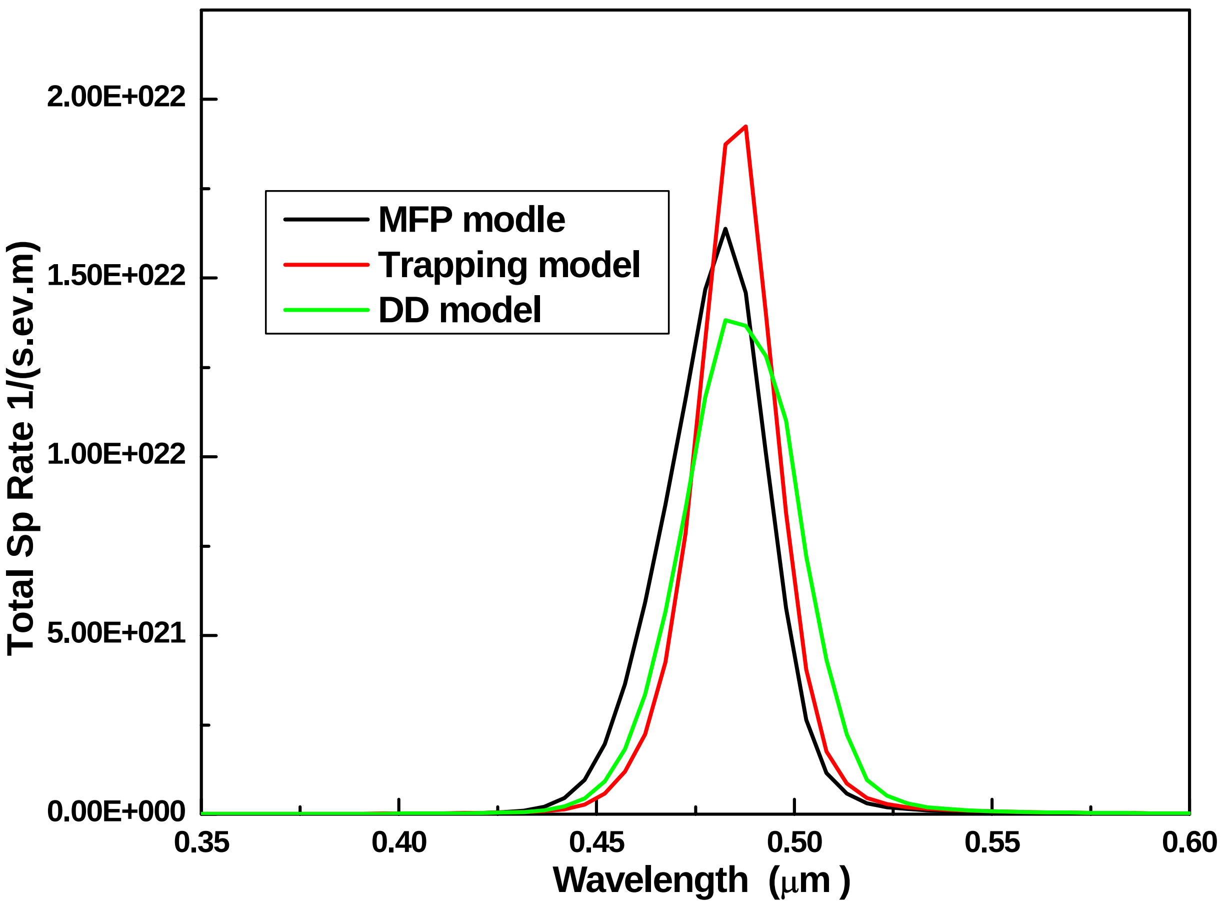
I-V Curve



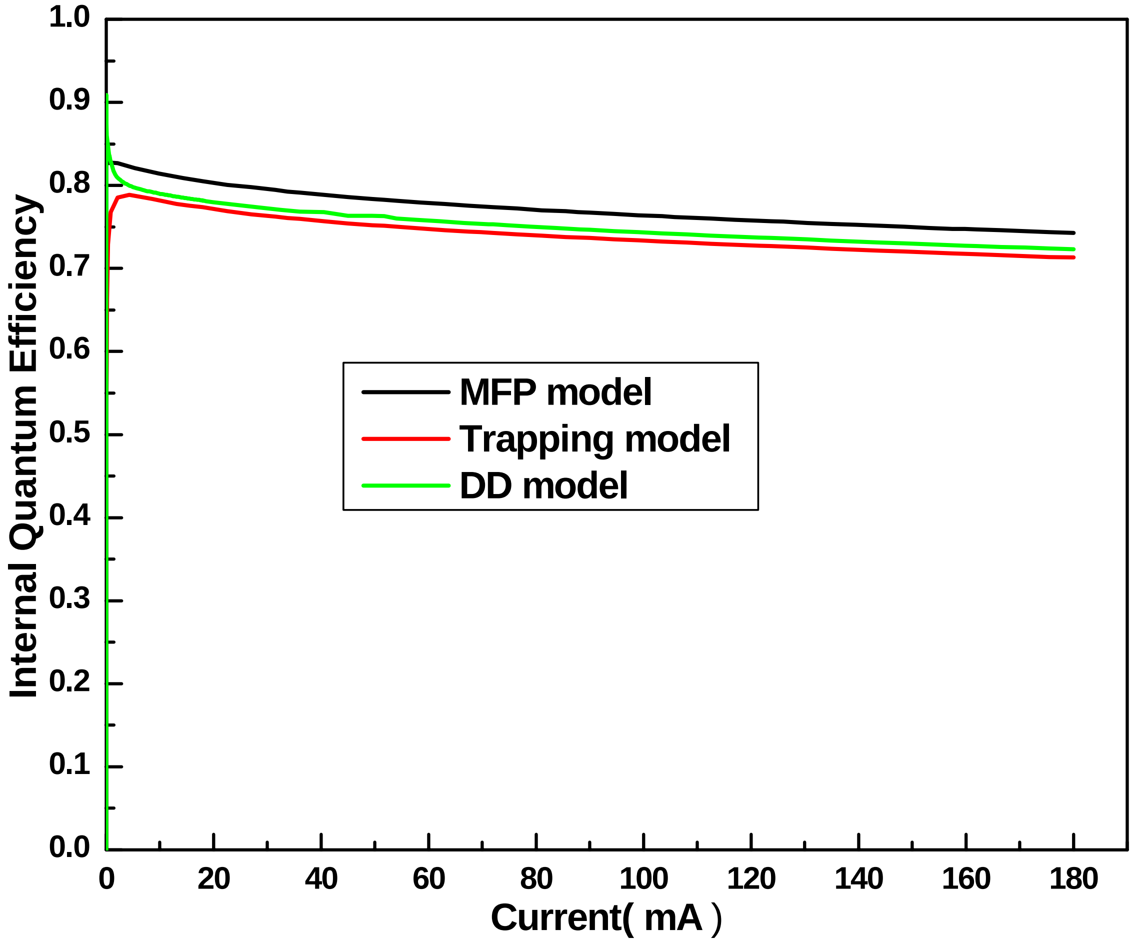
Drift-diffusion model shows unrealistically high turn-on voltage

EL Spectrum



Total Sp Rate 1/(s.ev.m)
2.00E+022
1.50E+022
1.00E+022
5.00E+021
0.00E+000
0.35
0.40
0.45
0.50
0.55
0.60
Wavelength (μm)
MFP modle
Trapping model
DD model

IQE Curve



Internal Quantum Efficiency
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
120
140
160
180
Current(mA)
MFP model
Trapping model
DD model

The impact of lifetime parameter in Trapping model

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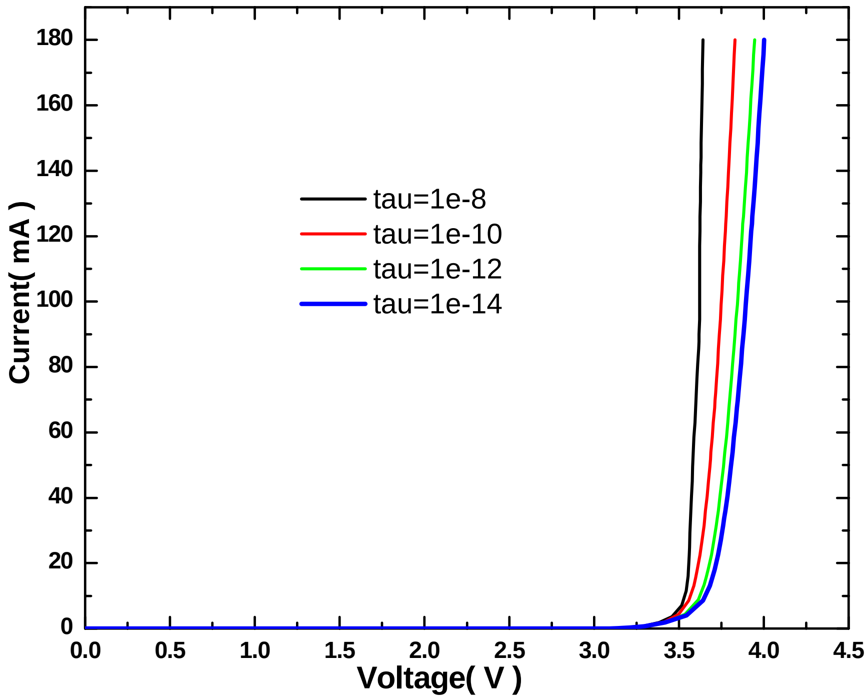
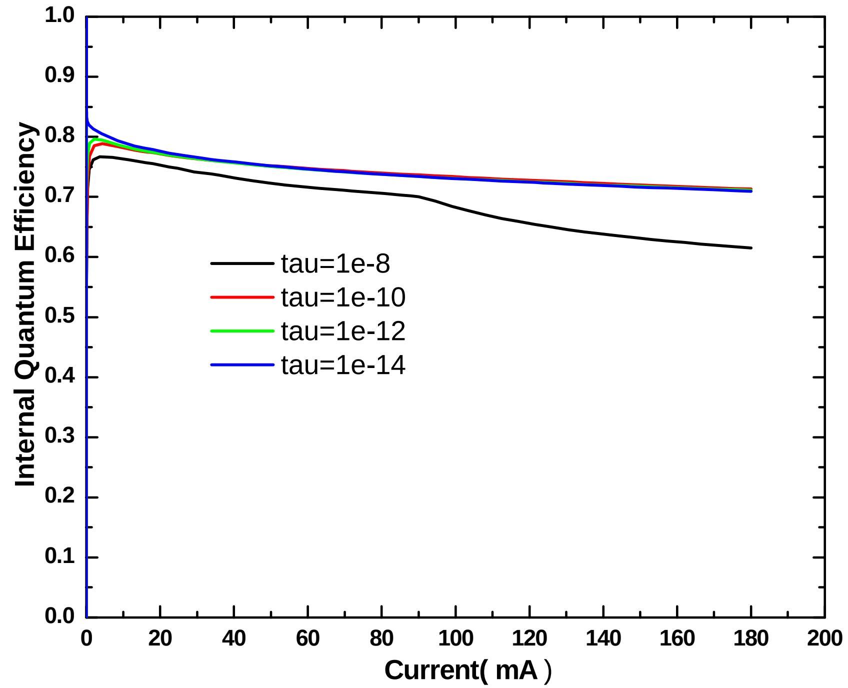
Comparison





q_trap_tau is the time constant for the 2-Fermi level trapping model.
In Crosslight, the default value is 1 ps.

The impact of the mean free path parameter in Trapping model

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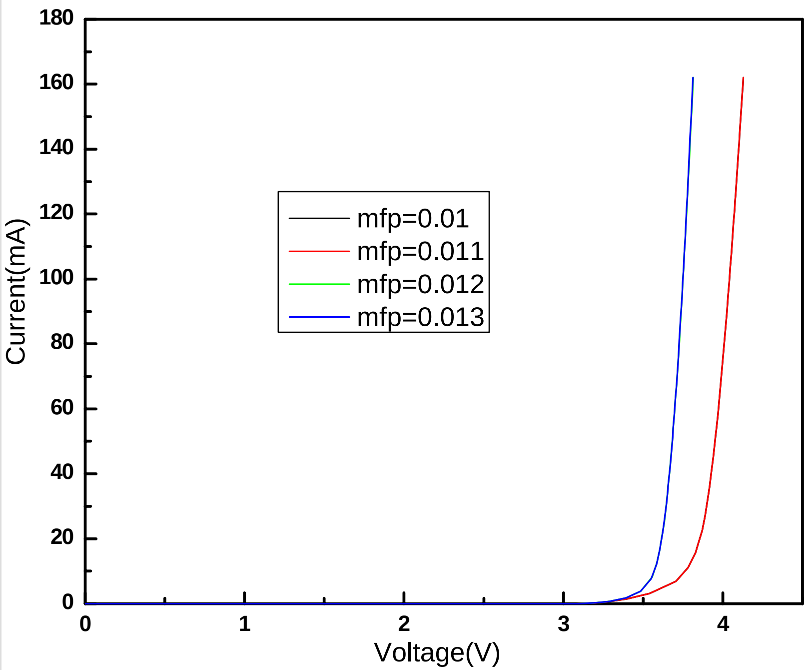
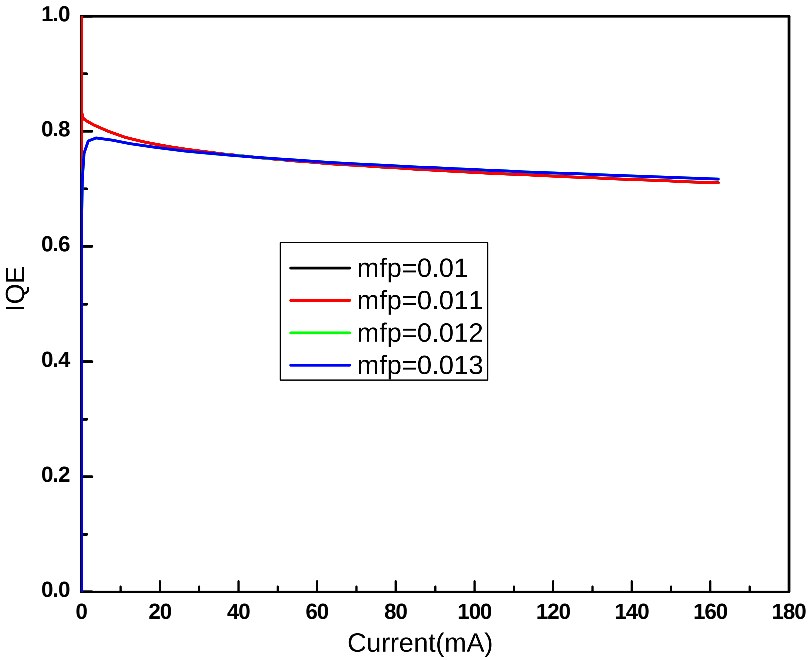
Comparison

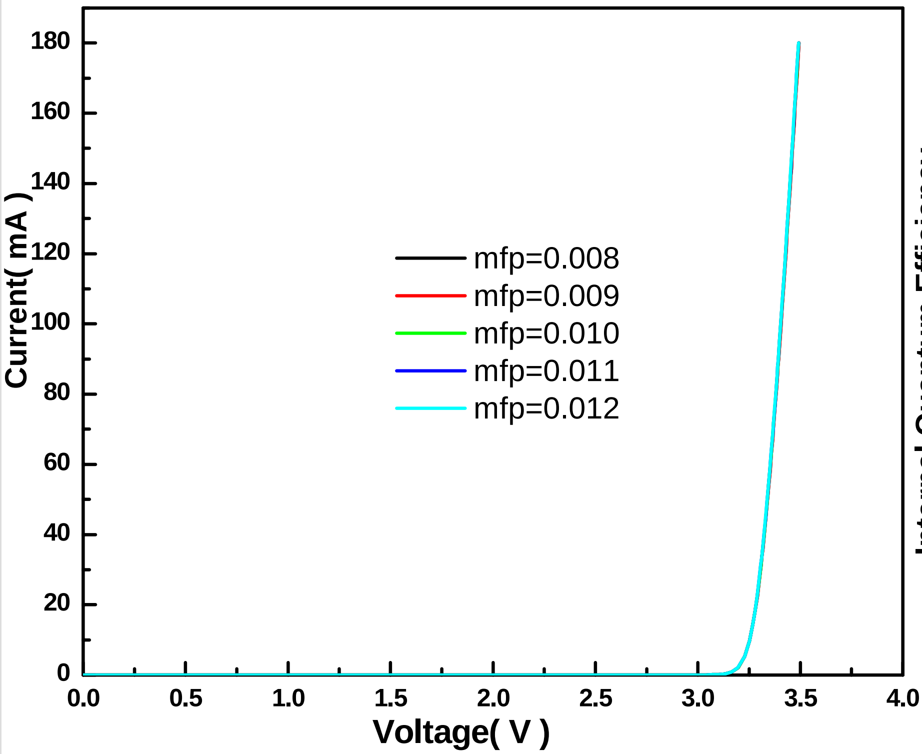


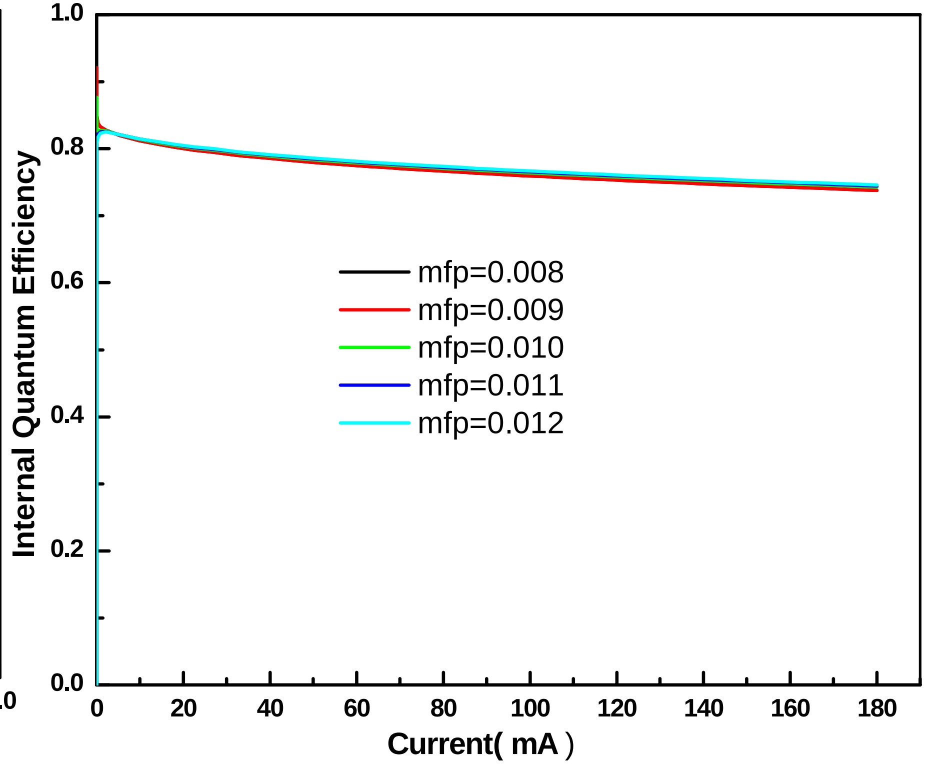


mfp is the electron or hole mean free path. In the trapping model, it controls the transport of carriers that fly-over and are not trapped. In Crosslight, the default value is 0.01 (um).

The impact of the mean free path parameter in MFP model

Comparison





In MFP model, **mfp** is used for the exponential factor to control the non-local current flow intensity. In Crosslight, the default value is 0.01 (um).

Conclusions

- **Both quantum transport models correct the problems associated with drift-diffusion.**
- **Realistic I-V and IQE curves of polarized InGaN/GaN MQWs LED for most values of model parameters.**
- **The Trapping model is more computationally intensive than the MFP model.**