Characterization of III-V MQW LED

EEE 460 : Optoelectronics Laboratory

Group: 01

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Objective

- To investigate the characteristics of **III-V** MQW LED devices for near-infrared and visible wavelength emission.
- To analyze the effect of different parameters (temperature, quantum well width, and well number of the LED) on the tunable performance of **III-V** MQW LED
- To analyze spontaneous emission rate and optical extraction mechanism of a MQW structure using MATLAB and Lumerical software.

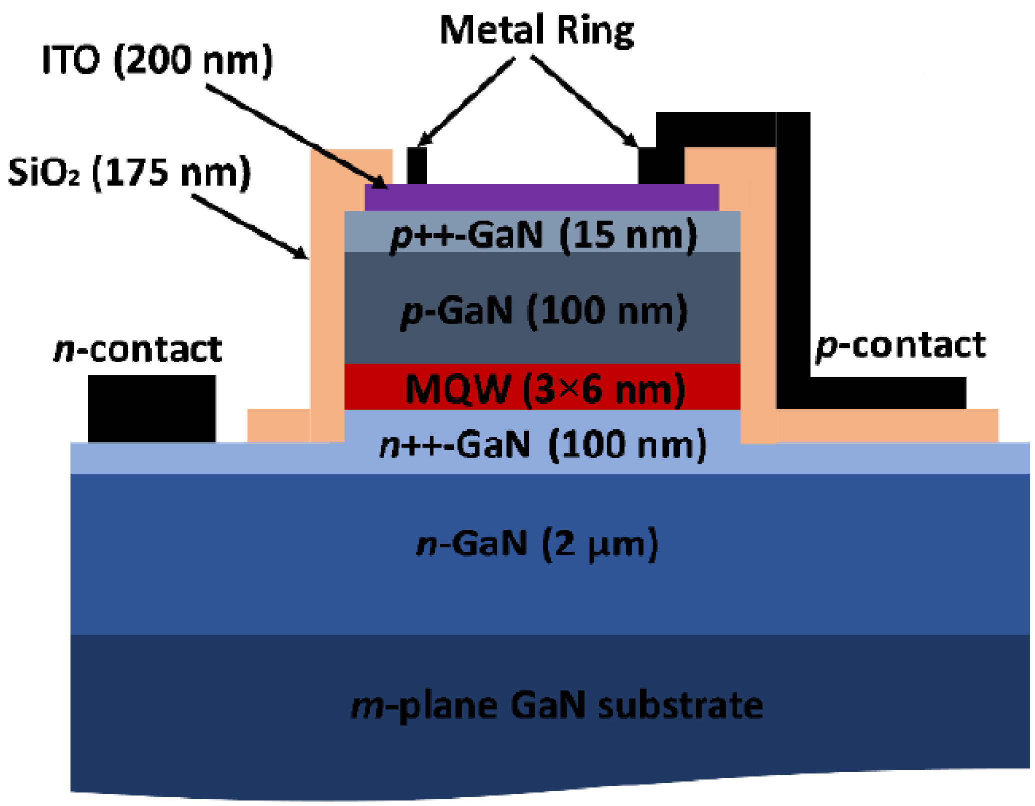
Why III-V based MQW?

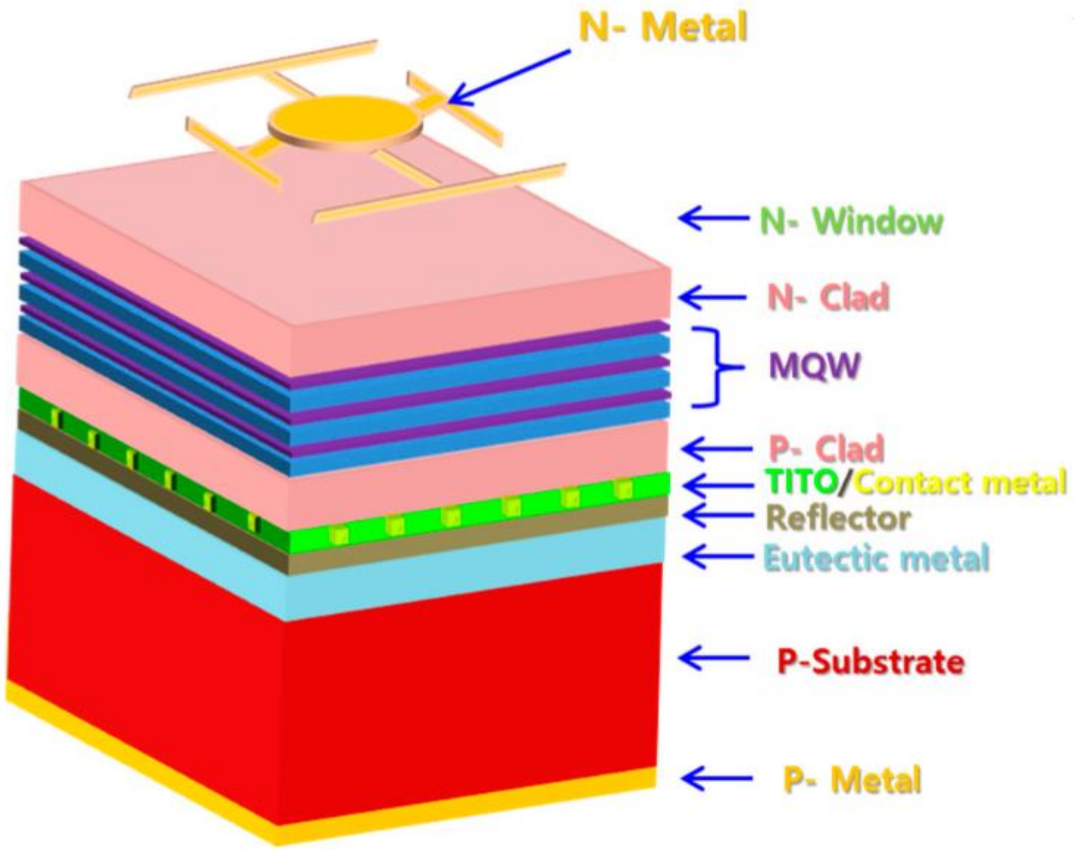
- III-V materials promising for visible LED applications due to their bandgap tunability and high electron mobility.
- Density of states g(E) is constant and does not depend on the electron energy, and huge value of g(E) at band edge.
- Enhanced radiative recombination probability and carrier confinement in the 2DEG region

Material Selection

Material	Wavelength	Typical number of layers (limited by fabrication process, found from literature)
GaAs-AlGaAs or AlAs-AlGaAs	600-800 nm	~55
GaN-InGaN or AlGaN-InGaN	300-400 nm	~12

Typical III-V MQW LED Structure





Spontaneous Emission Rate

$R_{sp}(E)$ for a MQW LED can be expressed in

$$P_{em} \; . \; N_j(E) \; . f_n(E_2) . \; [\; 1 - f_n(E_1)]$$

Here,

Emission Transition Probability, $P_{em} = 1/t_{rec}$

Joint density function, $N_j(E)$

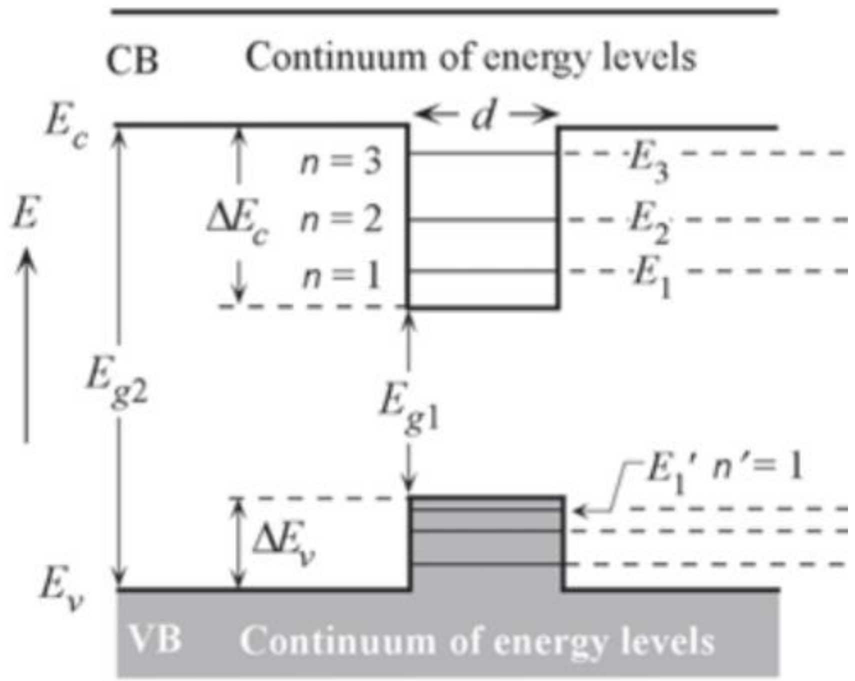
f_n is the Fermi-Dirac distribution of electron

Joint density function $N_j(E)$

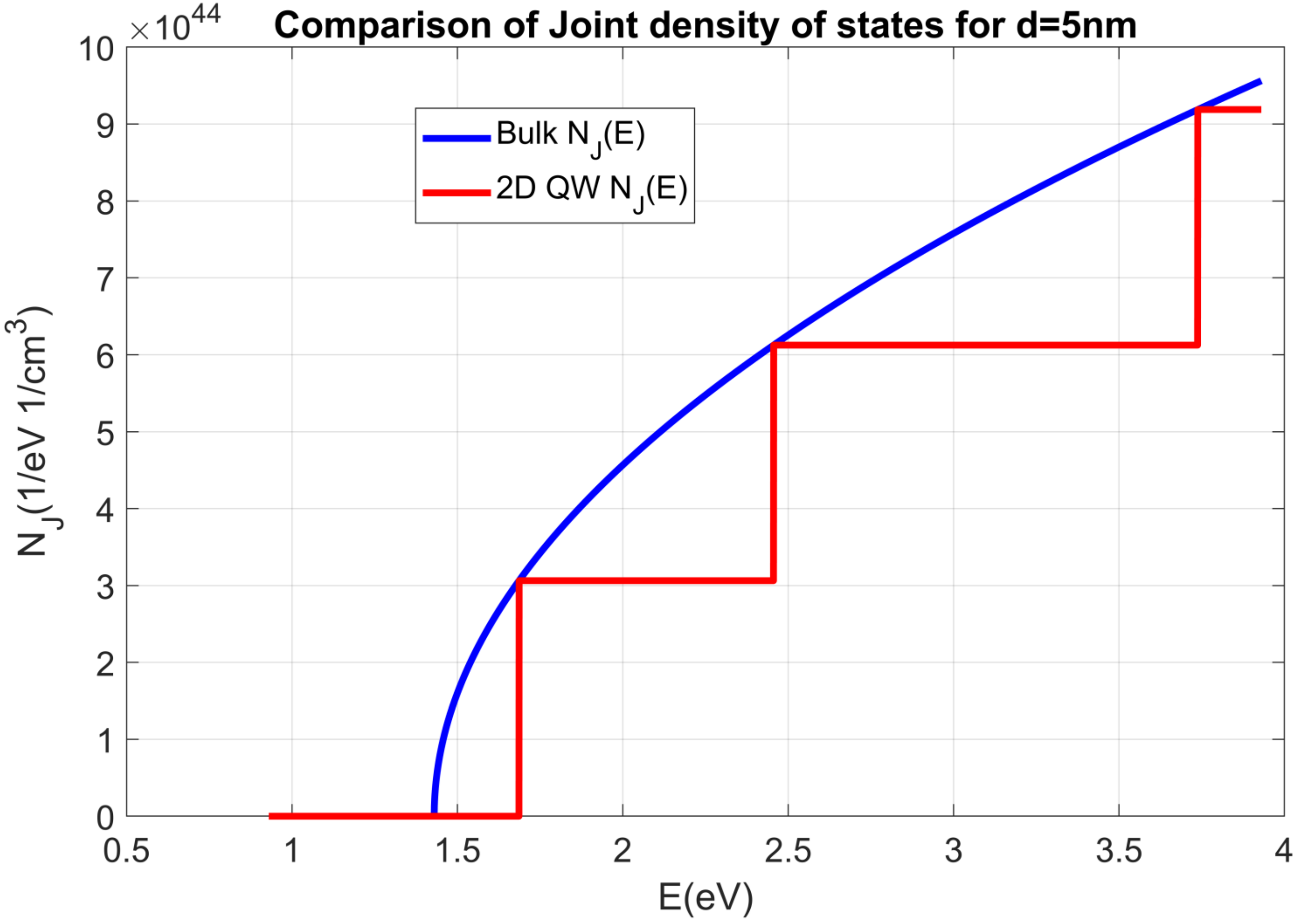
- Selection rules for infinite quantum well: $\Delta n = 0$
- The joint density of states of 2D quantum well is -

m_r =reduced electron mass, E^i_C and E^i_V are the i'th sub-bands for conduction and valence band, d= well width

$$N_J(E) = \frac{m_r}{\pi\hbar^2}\cdot\frac{1}{d}\cdot\sum_i u(E - E_g - E_c^{\,i} - E_V^{\,i}) \;\; eV^{-1}cm^{-3}$$



DOS for MQW Structure



GaAs, d= 5nm, N= 100 wells

Carrier Dynamics

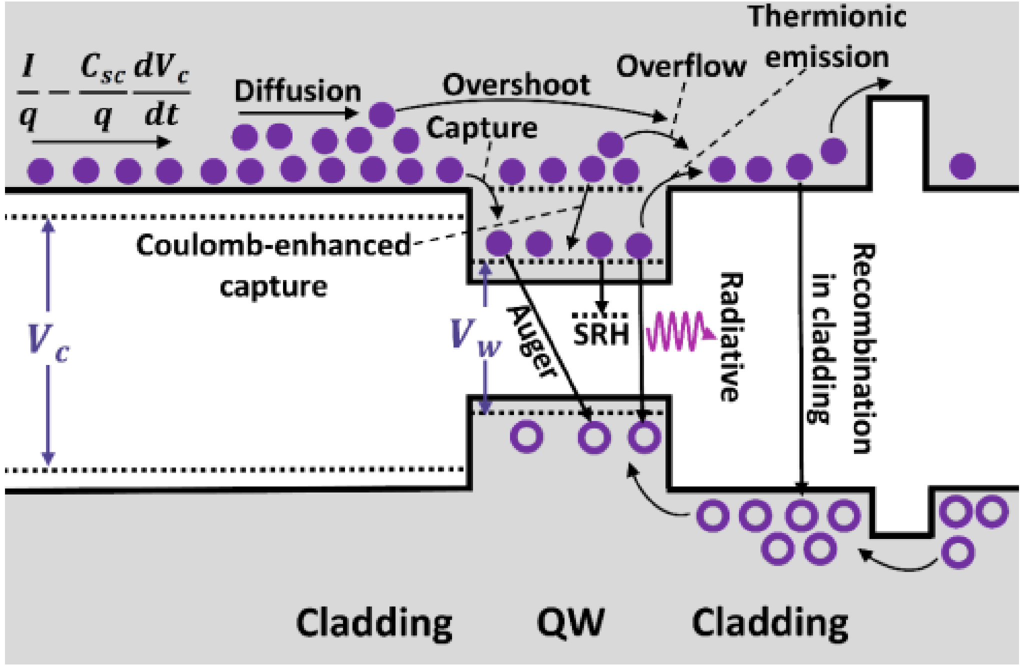
Rate equations governing carrier mechanisms in the QW and cladding layers are as follows

$$\frac{dN_w}{dt} = \frac{N_c}{\tau_c} - \frac{N_W}{\tau_{rec}} - \frac{N_W}{\tau_{esc}}$$

$$\frac{dN_c}{dt} = \frac{I}{q} - \frac{N_c}{\tau_c} + \frac{N_W}{\tau_{esc}} - \frac{N_c}{\tau_{rec,clad}}$$

At steady state,

$$N_w\left[\frac{\tau_c.\tau_{esc}}{(\tau_{rec}||\tau_{esc}).(\tau_c||\tau_{rec,clad})} - 1\right] = \frac{\tau_{esc}}{q} I$$

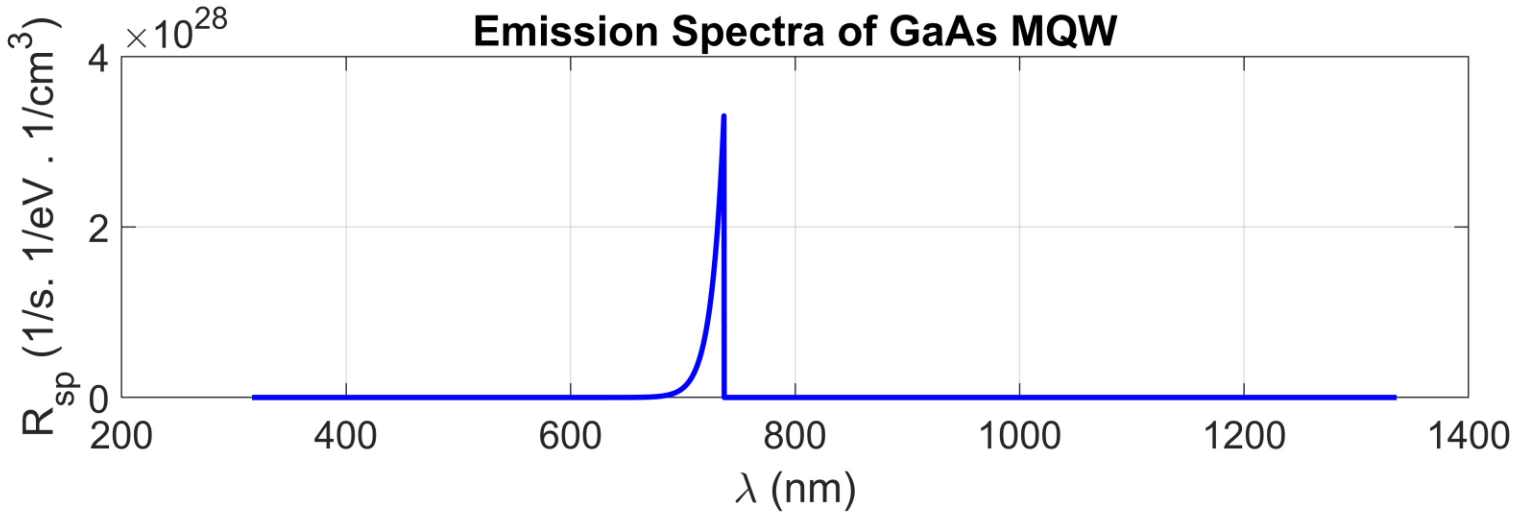


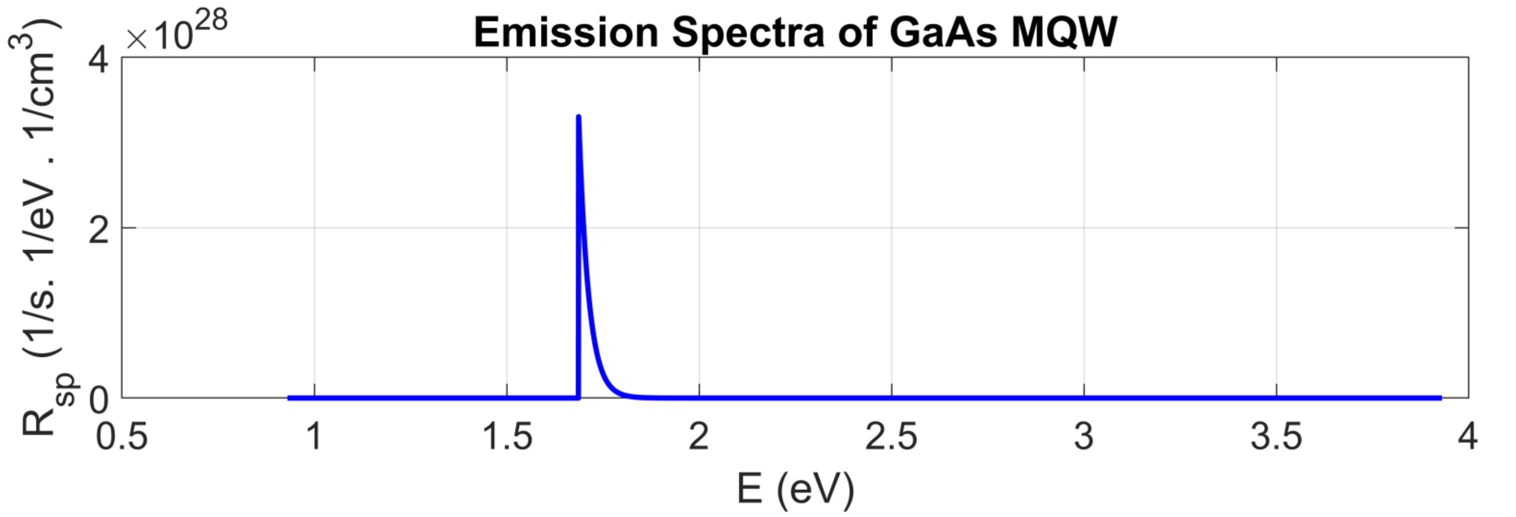
Nw = nw.A.d and I = J.A, final expression for τ_{rec} and n_w becomes in terms of current density J

$$\tau_{rec} = \left(\frac{B_r}{dq}\right)^{-1/2} J^{-1/2}$$

$$n_w = \left(\frac{1}{B_r qd}\right)^{1/2} J^{1/2}$$

Emission Spectra

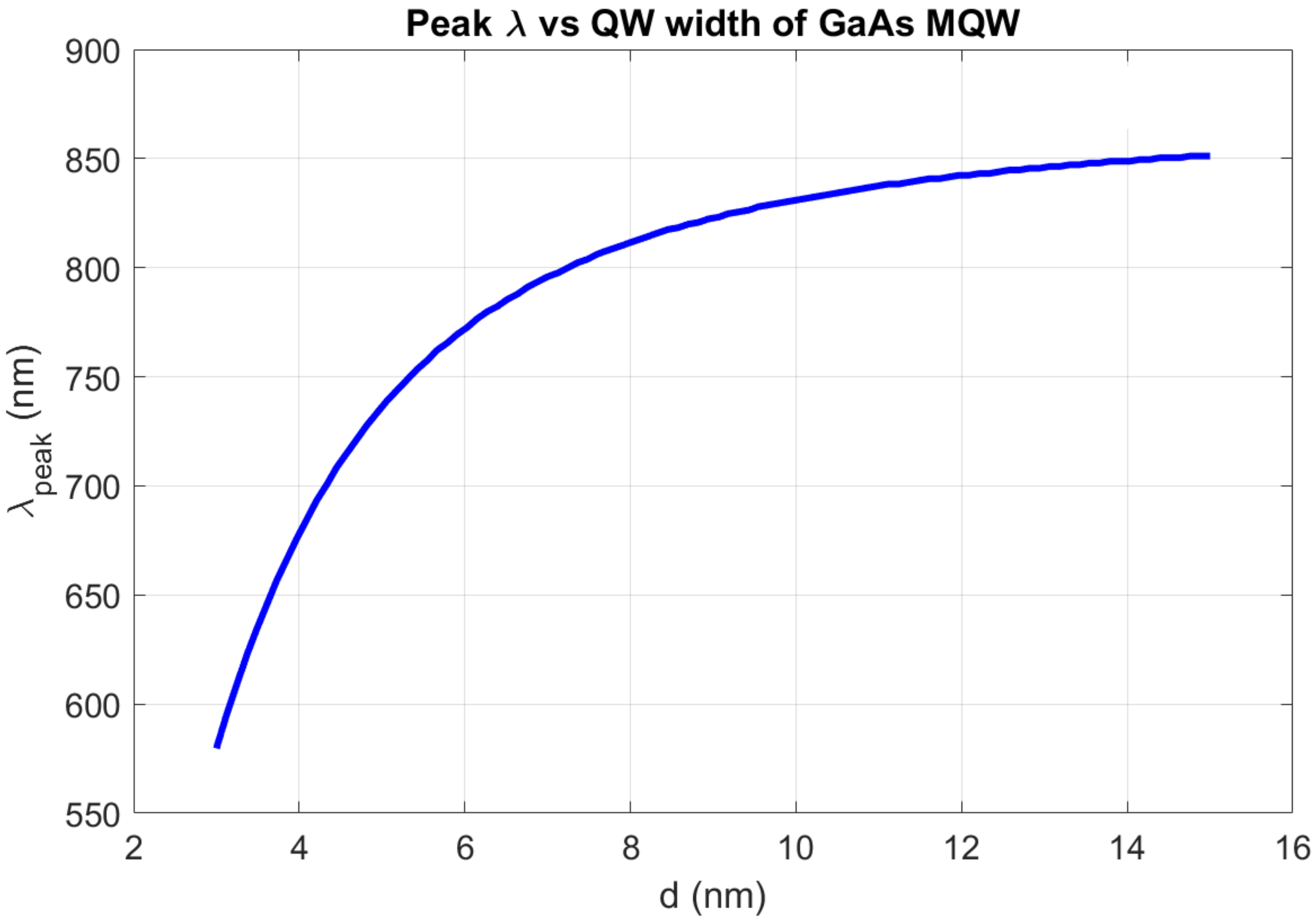




Spontaneous emission spectra provide important characteristics about LED:

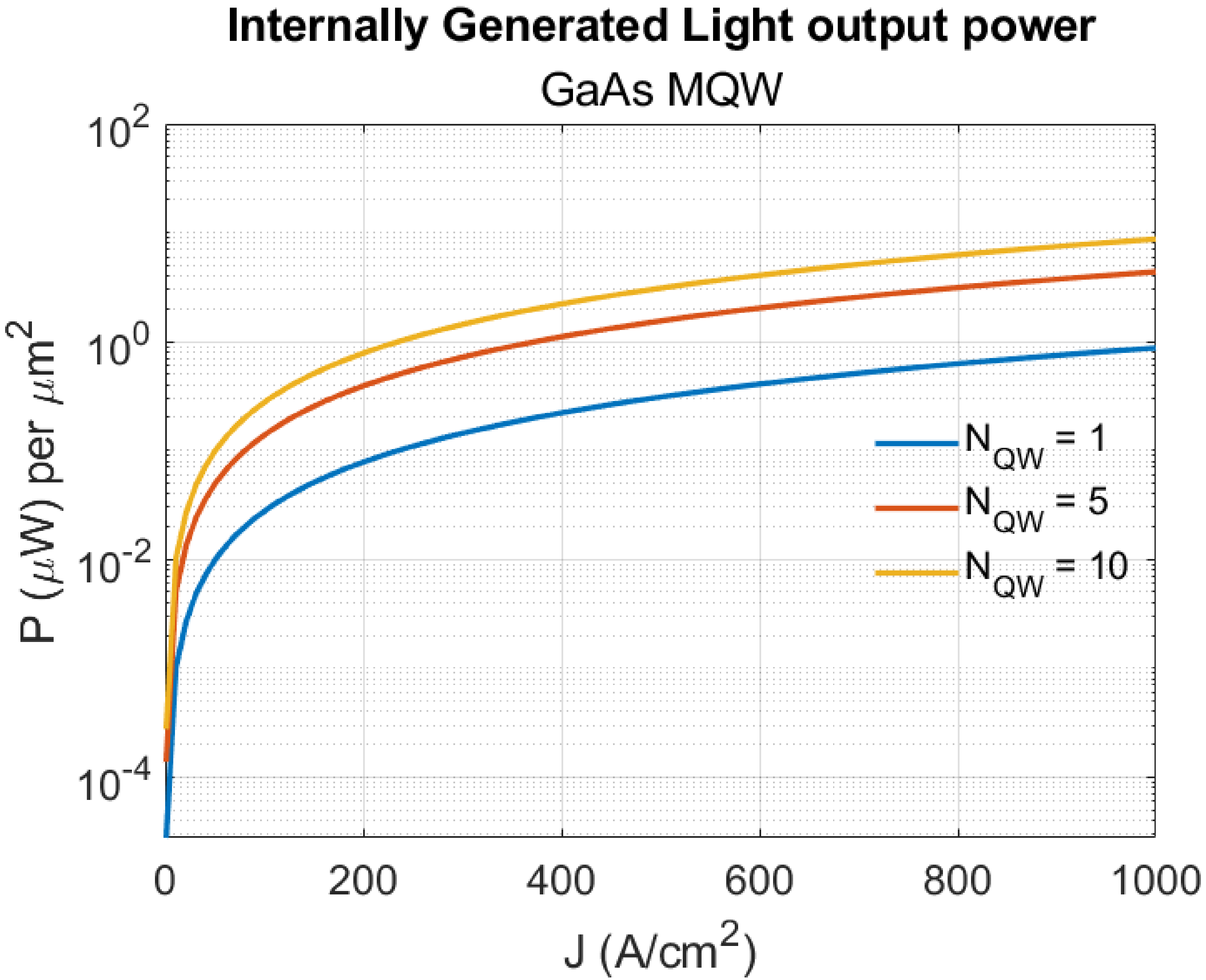
- Emission Peak (678.6 nm)
- Spectral linewidth(FWHM = 6.6 nm)
- Photon flux
- Internally generated optical power

Peak Wavelength vs well width



With increasing well width, ground state of well gets closer to E_c and the transition energy decreases to E_g and hence the emission peak saturates to λ_{Eg} eventually.

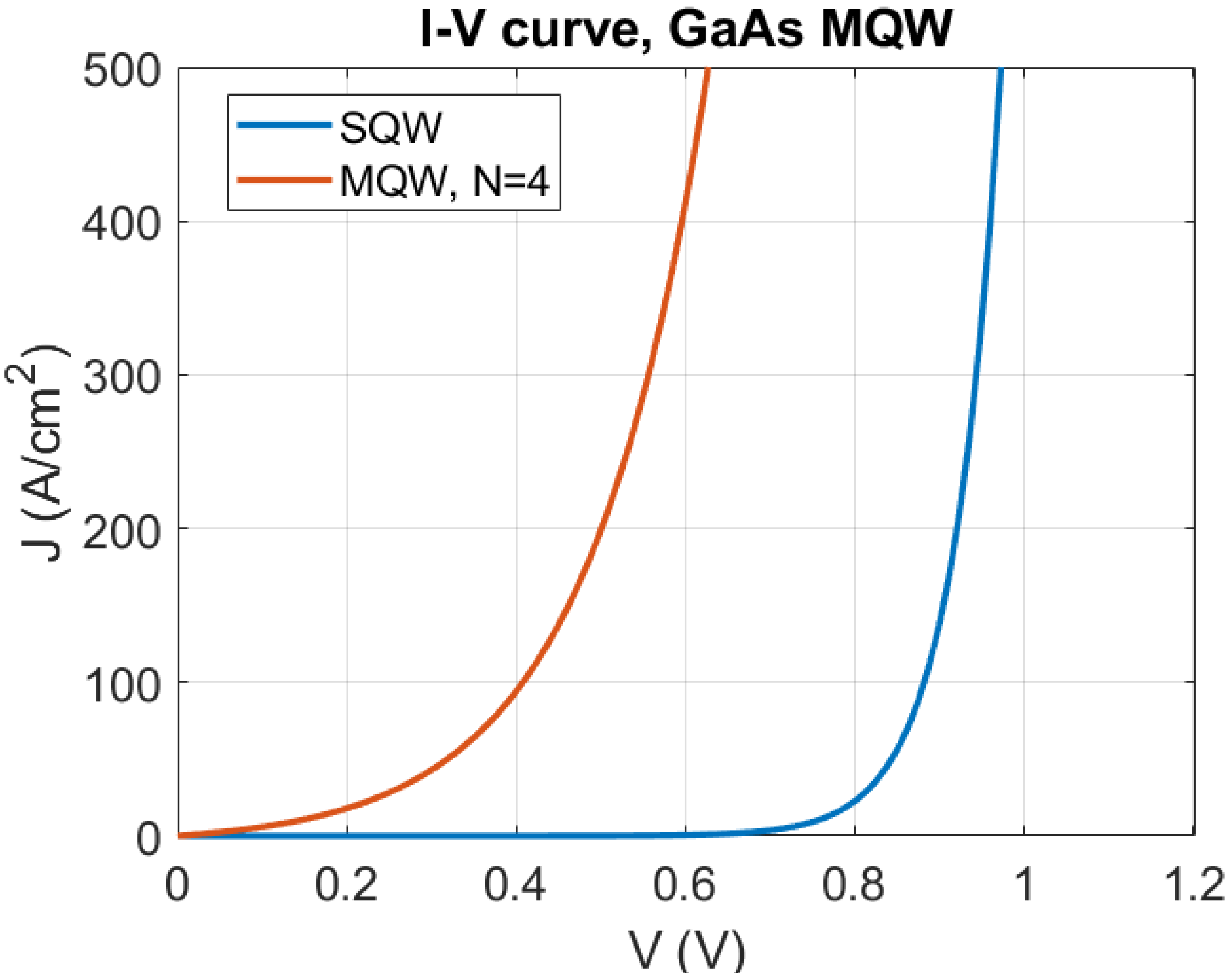
P-J curve for varying QW numbers

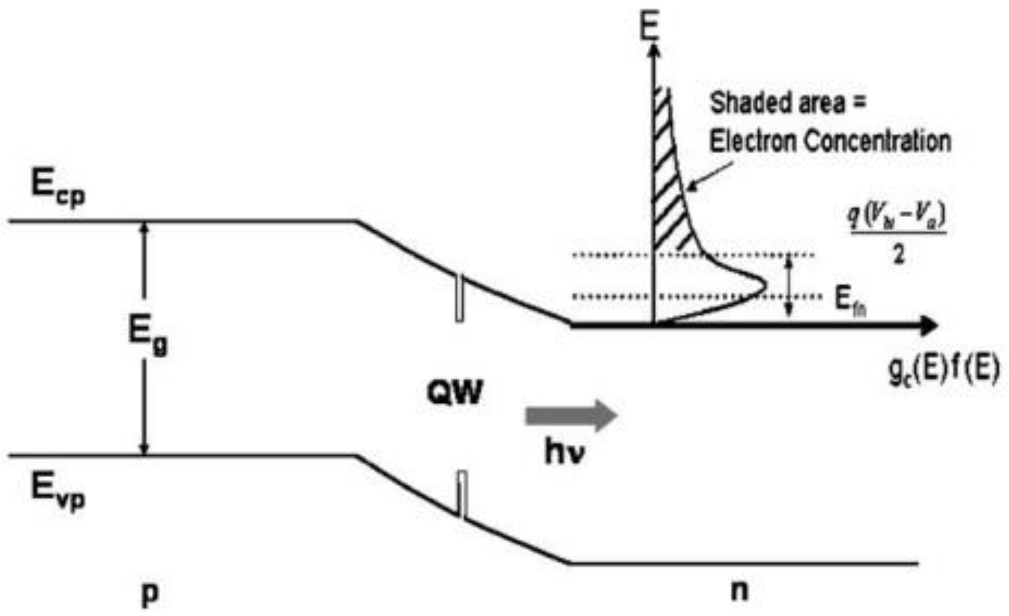


Multiple QW emission enhancement are governed by two main mechanisms:

- Multiple QWs can be thought of as independent QWs, so increasing QW number results in more electron and holes available for recombination.
- Active region volume increases linearly with QW number.

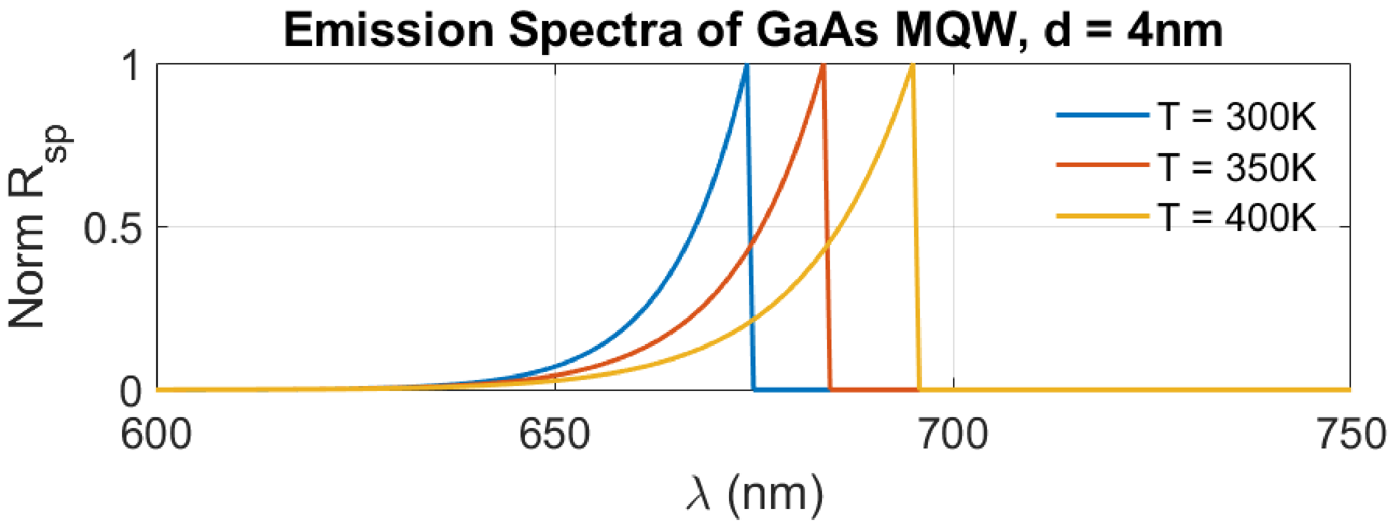
I-V curve

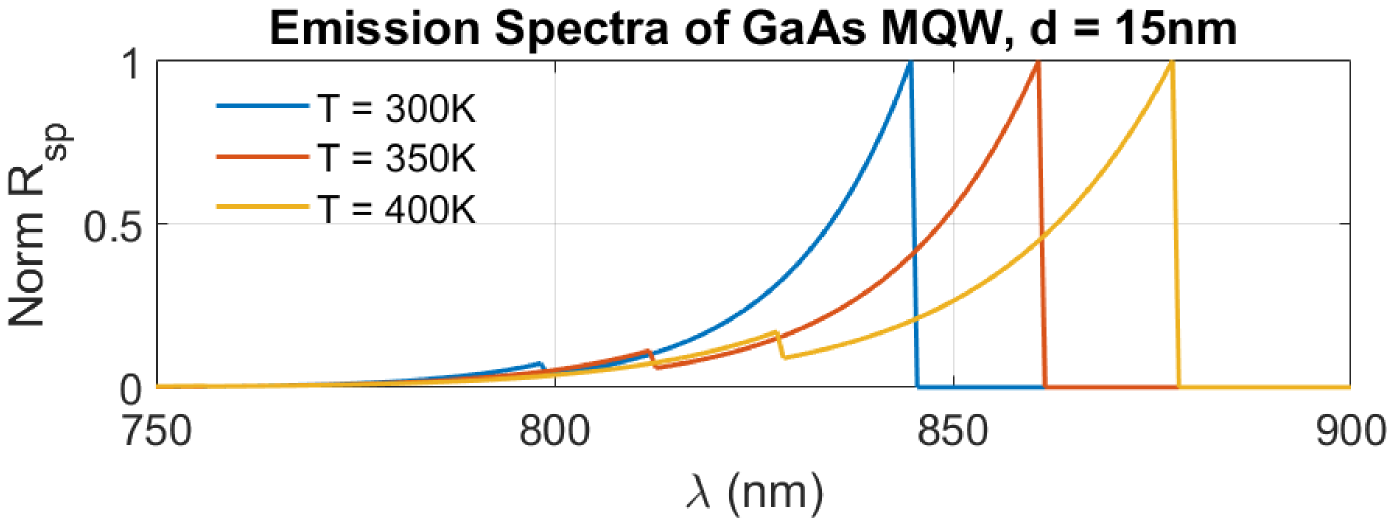




Multiple QW requires less build-in potential travelled by an electron along the depletion layer to reach the well. Thus, less potential required for photogeneration.

Temperature effect on R_{sp}



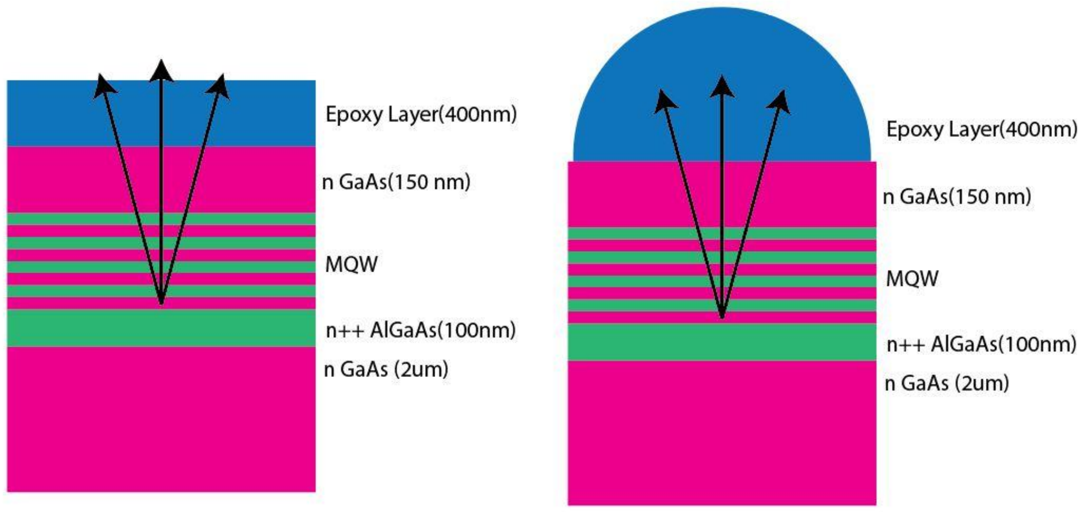


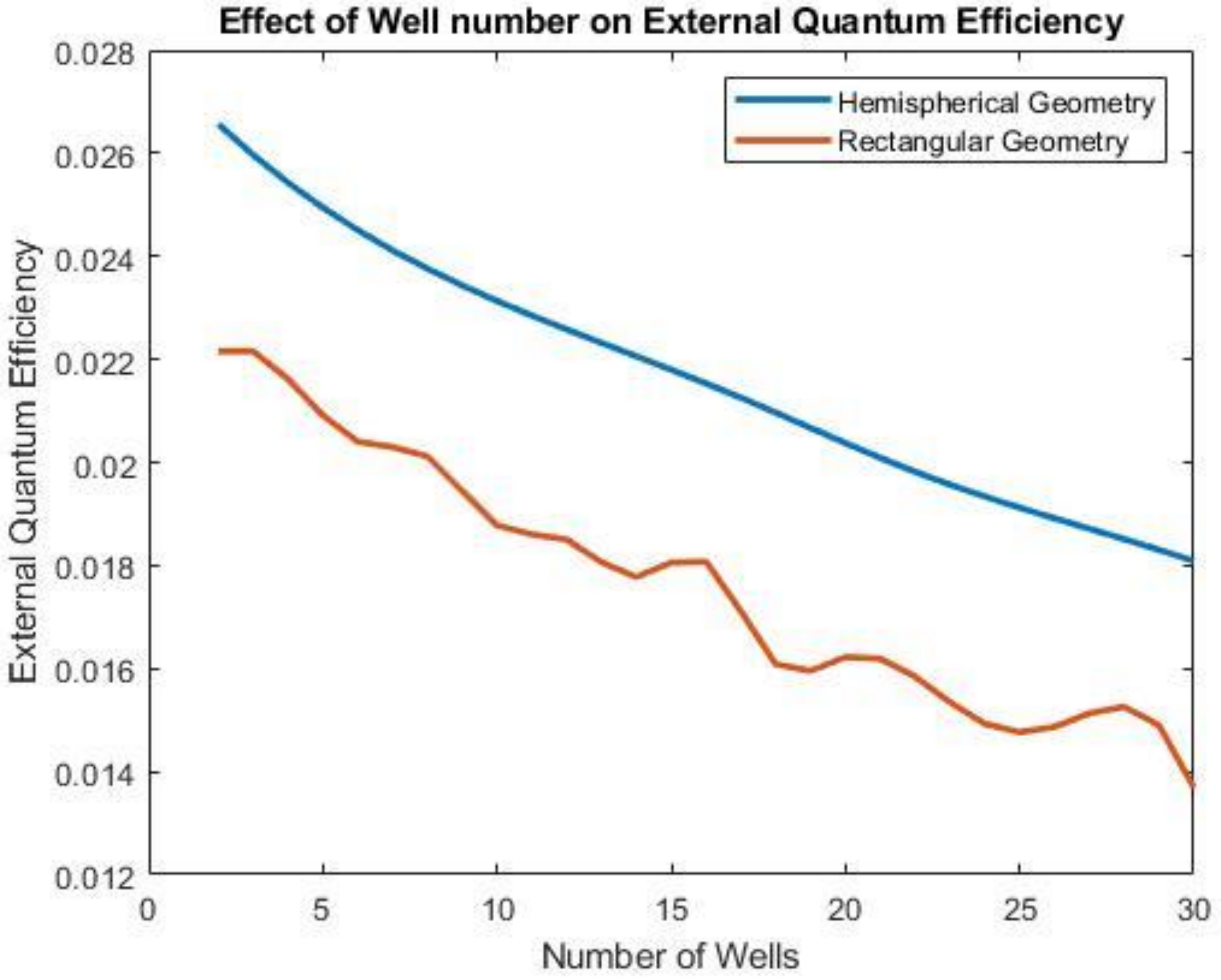
For temperature increase, Bandgap decreases. So emission occurs at lower energies and peak emission wavelength increases.

However, for wide well, multiple peaks are observed as closely spaced higher energy levels contribute to the emission.

Optical Extraction with FDTD simulation

For surface emission, effect of quantum well number and effect of geometry on external quantum efficiency of the LED is shown.



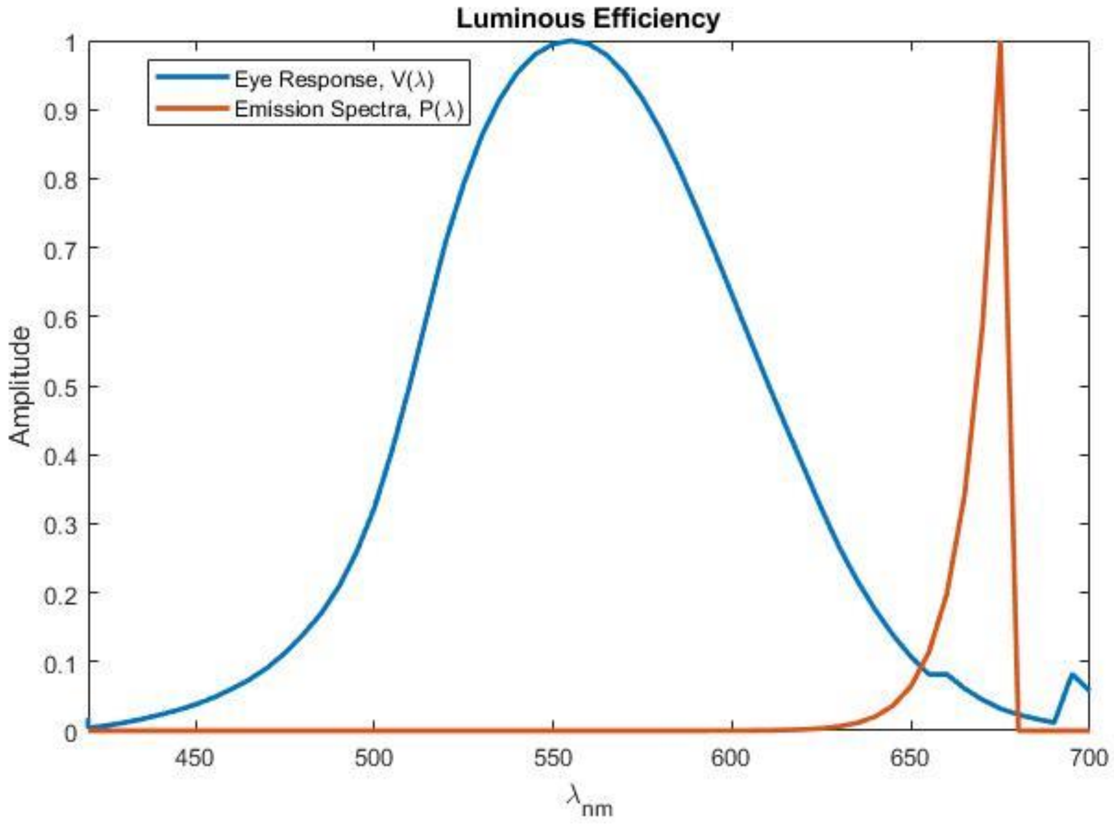


Luminous efficiency

- From eye sensitivity and emission spectrum, luminous efficiency can be calculated by

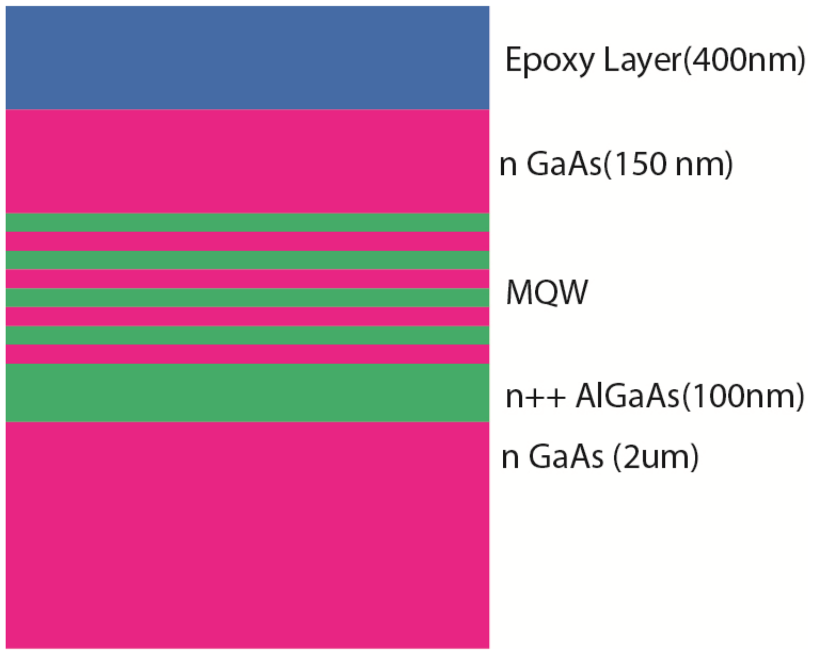
$$\eta_L = \frac{\int_\lambda V(\lambda)P(\lambda)d\lambda}{\int_\lambda P(\lambda)d\lambda}$$

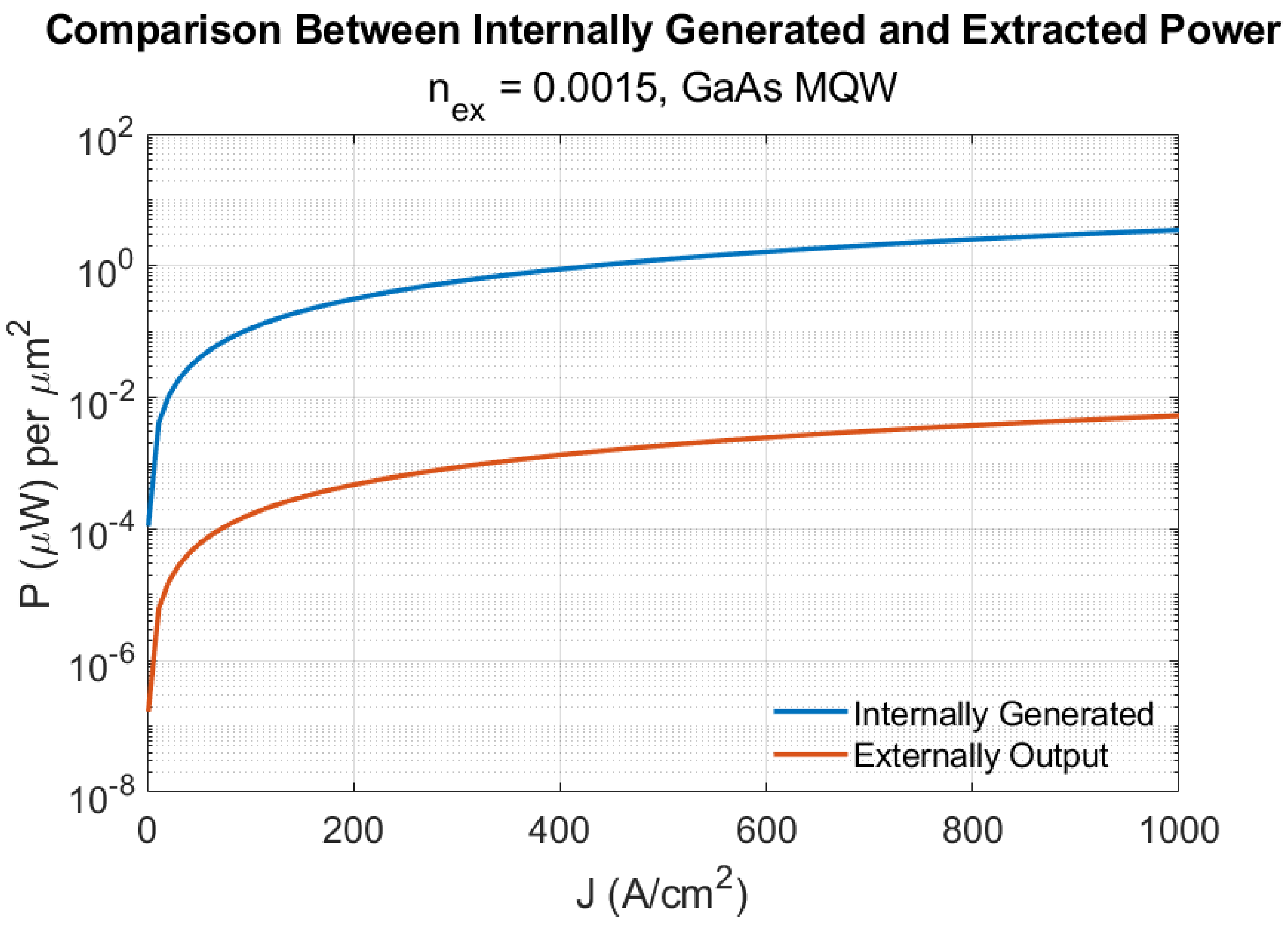
- Luminous efficiency = 0.0532



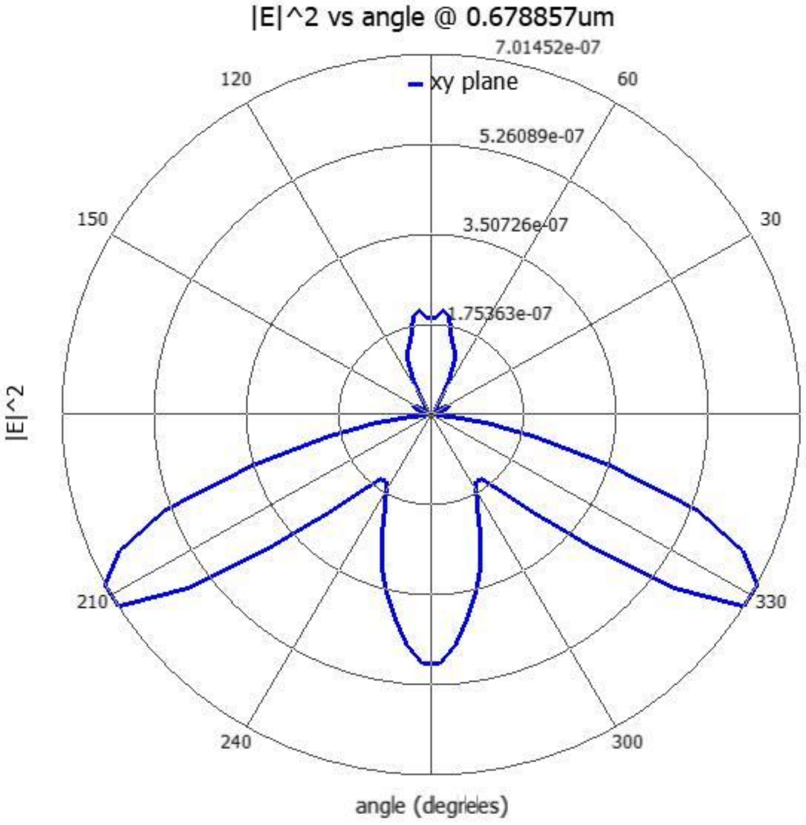
P-J Curve for complete structure

After calculating the extraction and luminous efficiency, extracted light power was reduced by a factor of ~1000.

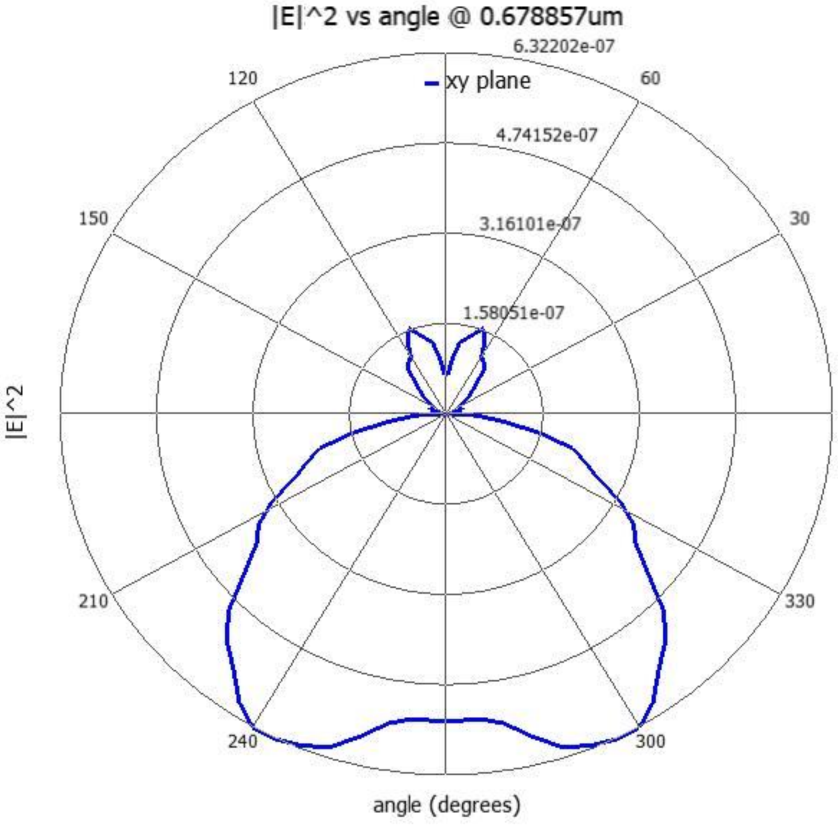




Lambertian Emission Pattern

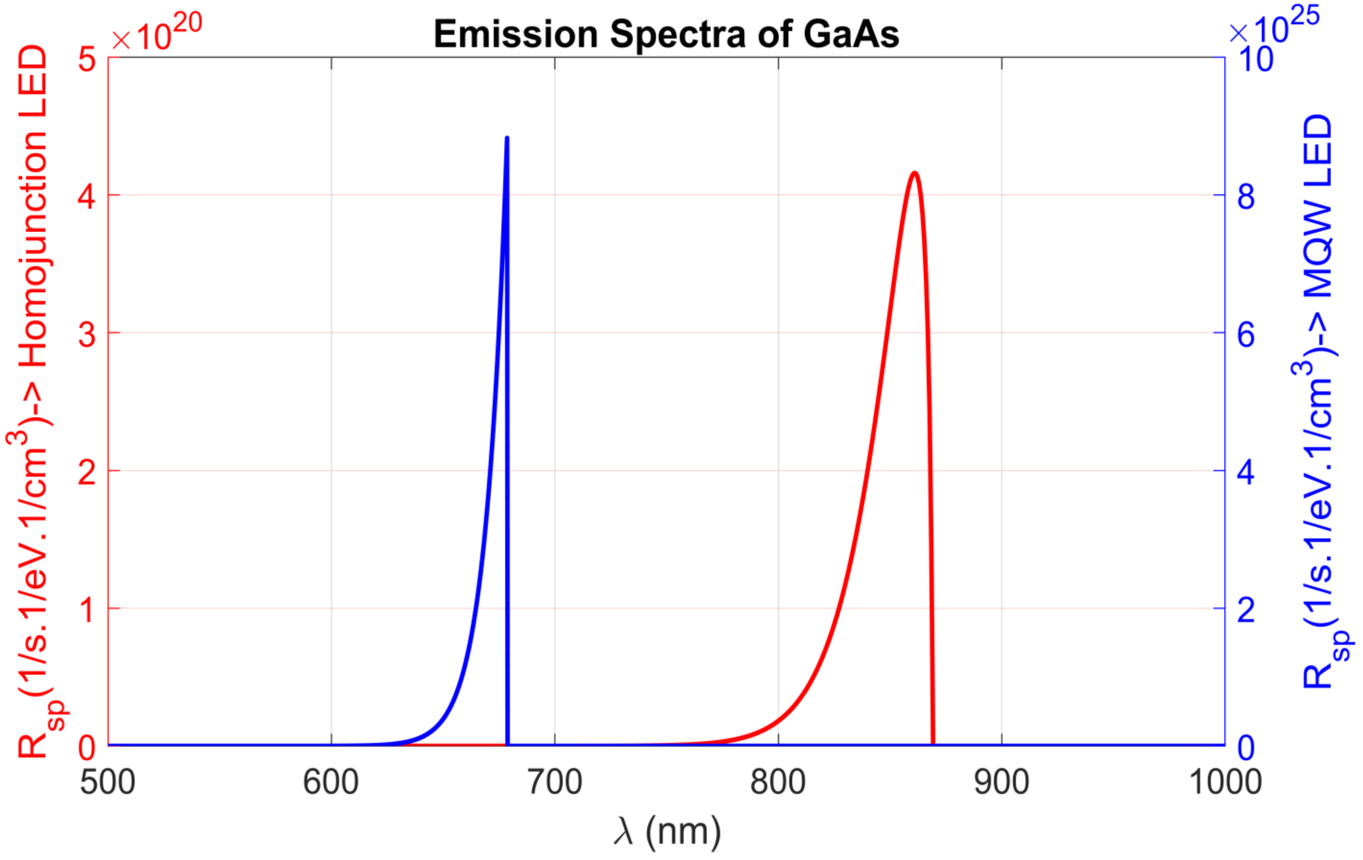


Emission Pattern For Rectangular geometry (n_{QW} = 4)



Emission Pattern For hemispherical geometry (n_{QW} = 4)

Comparison with Homojunction LED



Photon flux for

Homojunction LED= $4.45\times10^{15}\ s^{-1}$

MQW LED= $4.32\times10^{17}\ s^{-1}$

Thank You!