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# Effect of growth conditions on defect incorporation and optical efficiency of AlGaN/GaN multi-quantum wells

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Sandia National Labs

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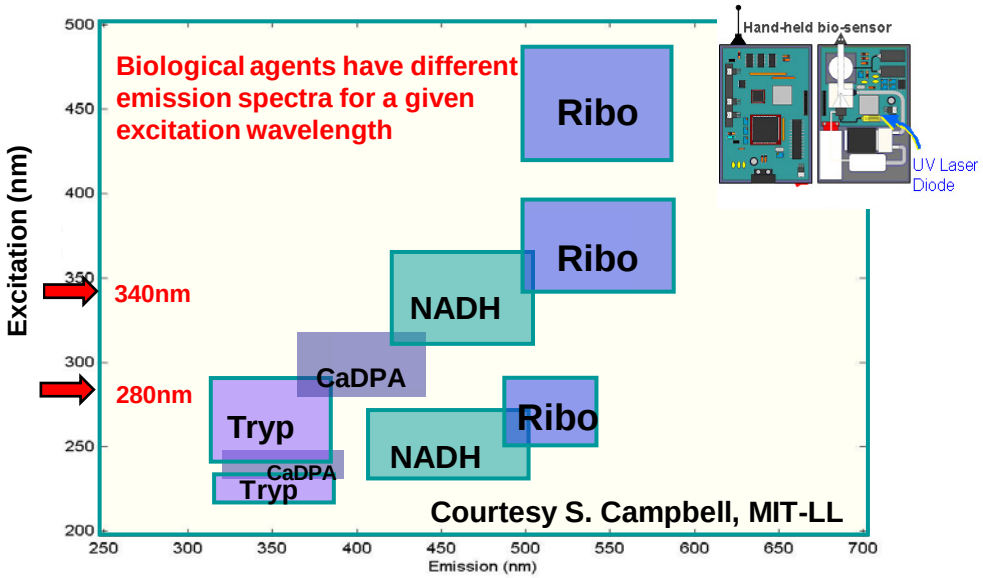
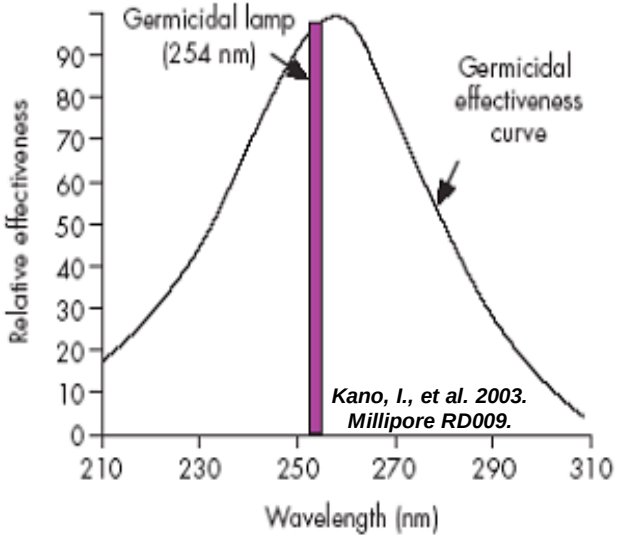
# Motivation for compact UV emitters

**Development of miniaturized UV optical sources for:**

- **Biological agent detection systems via UV-L(ED)IF**
- **Decontamination and water purification**




**Decontamination by UV radiation**

- **AlGaN-based UV emitters for portable biosensing**
  - **Laser- or LED-induced fluorescent bioagent detection**
- **Ongoing challenges:**
  - **Improve output power**
  - **Minimize DL for efficient detection**

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# AlGaN/GaN MQW growth conditions

**Temp ($T_g$):** 1010 – 1065 °C

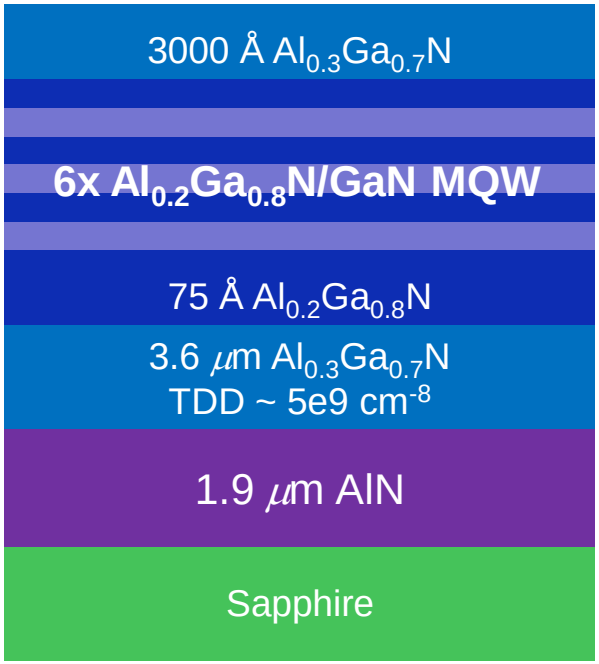
**Pressure:** 75 torr

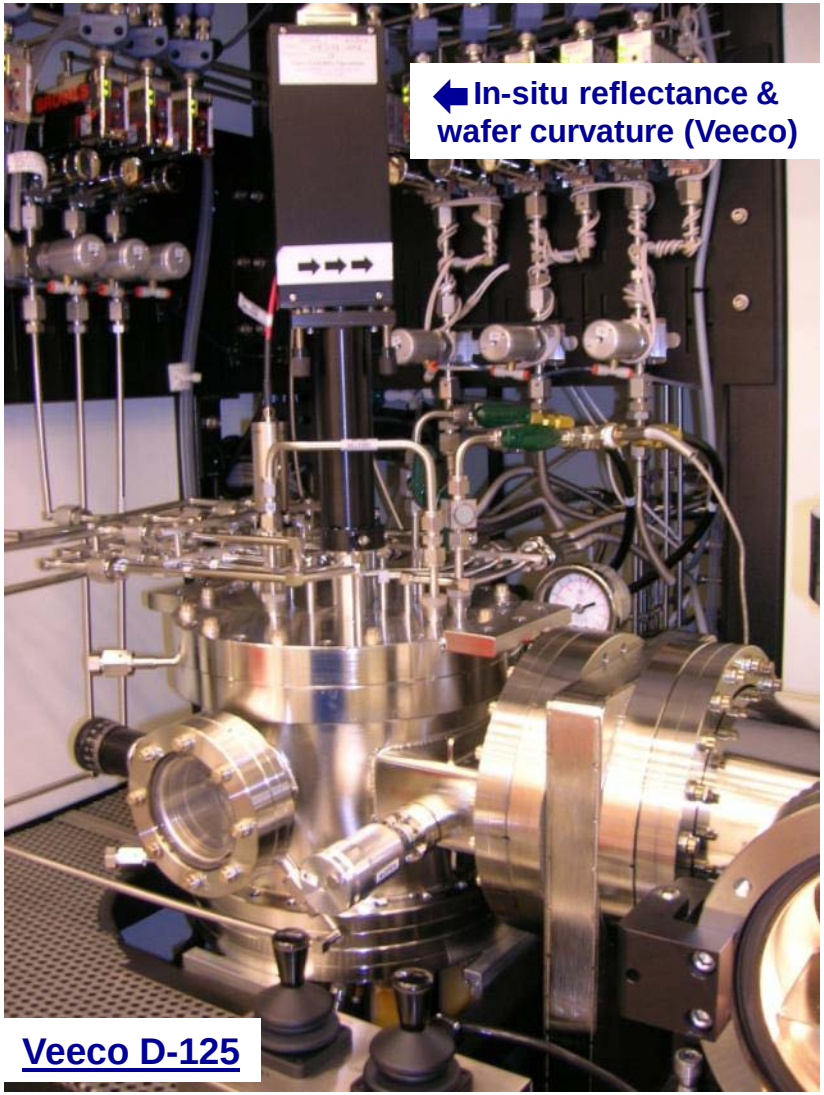
**Sources:** TMAl, TMGa, $NH_3$, $H_2$

**V/III Ratio:** 1000 < V/III < 4000

**Sapphire:** 0.2° off toward m-plane

## 340 nm MQW




Veeco D-125

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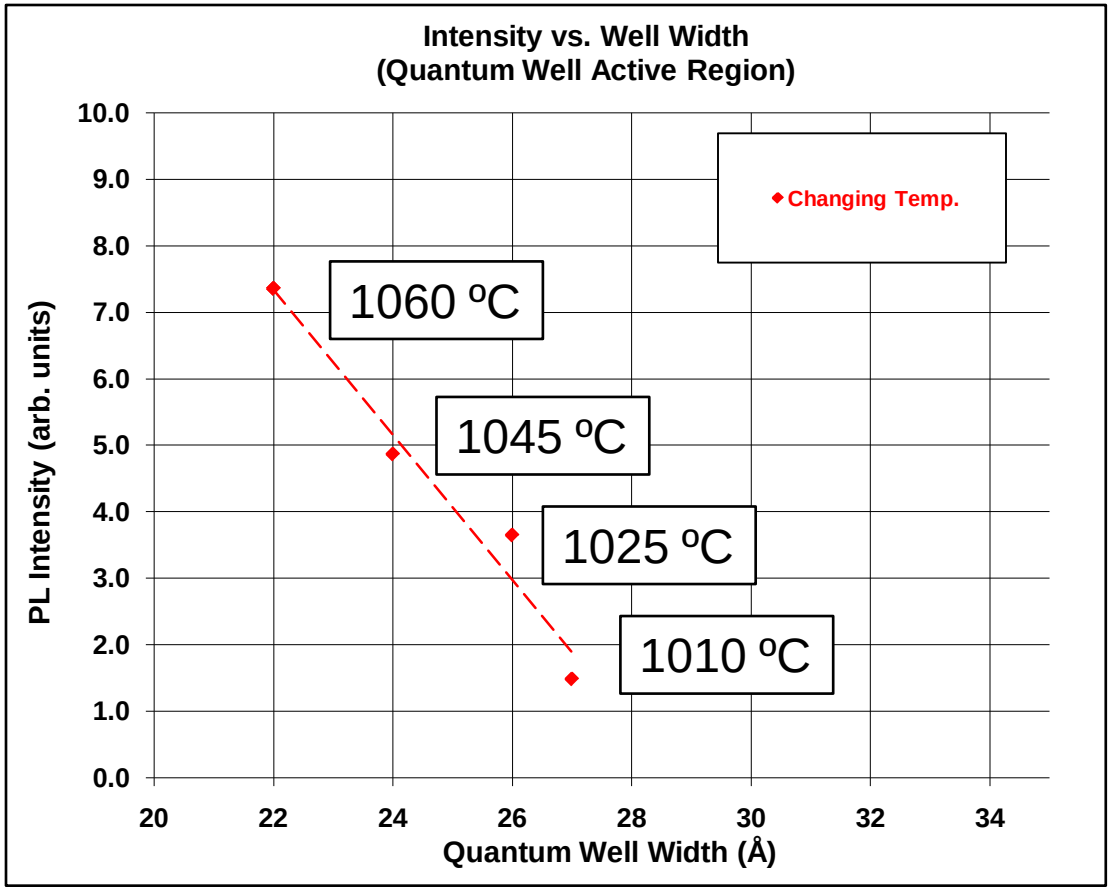
# Impact of well growth temperature ($T_g$)

## 340 nm MQW




- 5X PL intensity for greater QW $T_g$

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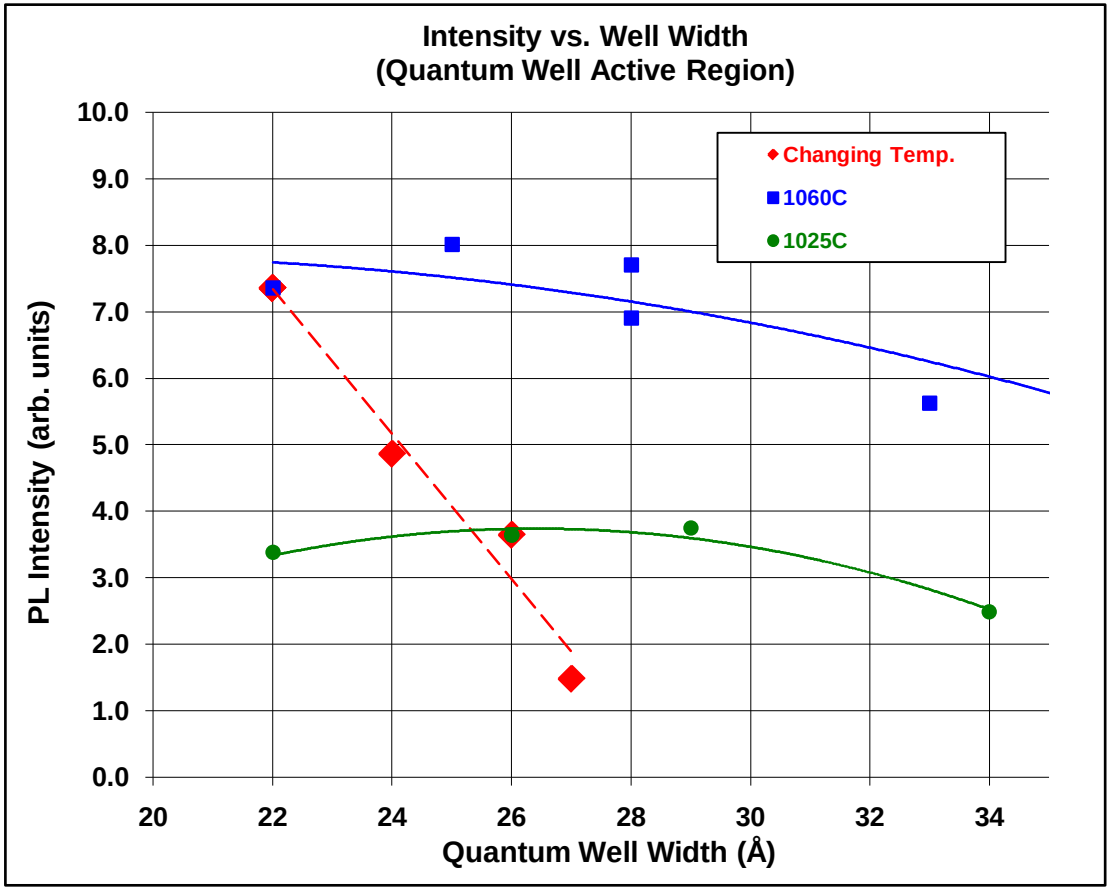
# Impact of well growth temperature ($T_g$)

## 340 nm MQW

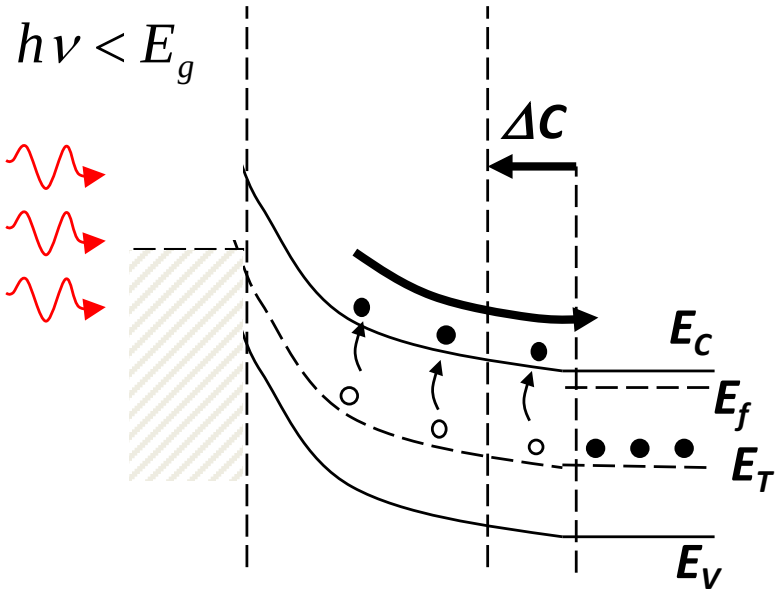


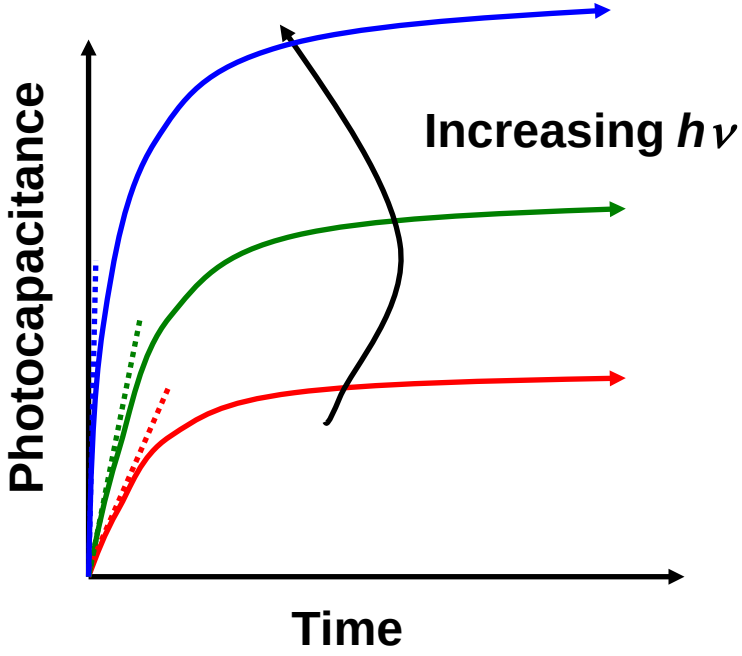

- PL improvement with greater $T_g$ not QCSE
- Reduced PL for lower $T_g$ due to excess point defects?

# DLOS background

**Deep Level Optical Spectroscopy (DLOS)[1]**

- Photocapacitance technique
- ***Sub-band gap optical stimulation*** to photoionize defect levels (reverse of PL)
- ***Quantify non-radiative*** defect level energy and density (difficult for PL)



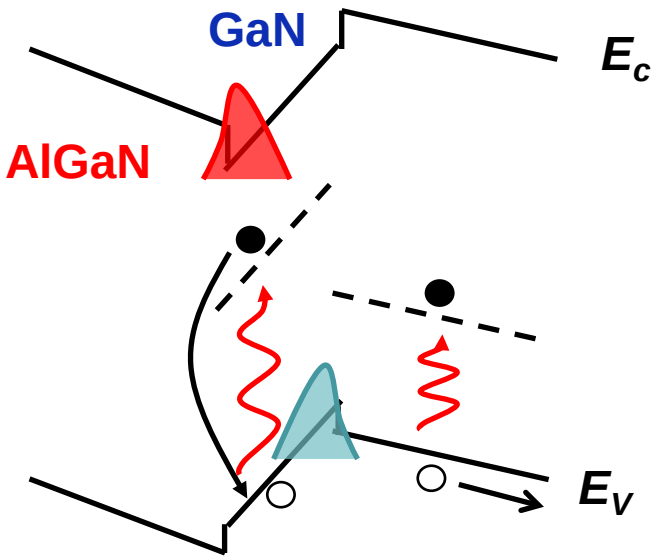

- DLOS only sensitive to depleted regions
- Enables nano-scale depth resolution

- Optical cross-section $\sigma^o = e^o / \Phi(h\nu)$
  - $dC(t)/dt|_{t=0} \propto \sigma^o(h\nu)$
- Optical ionization energy $E^O$
- Defect density $D_t$ from light-on C-V

1. Chantre *et al.* PRB 23, 5335 (1981).

# Depth-resolved DLOS

**AlGaN/GaN QW**

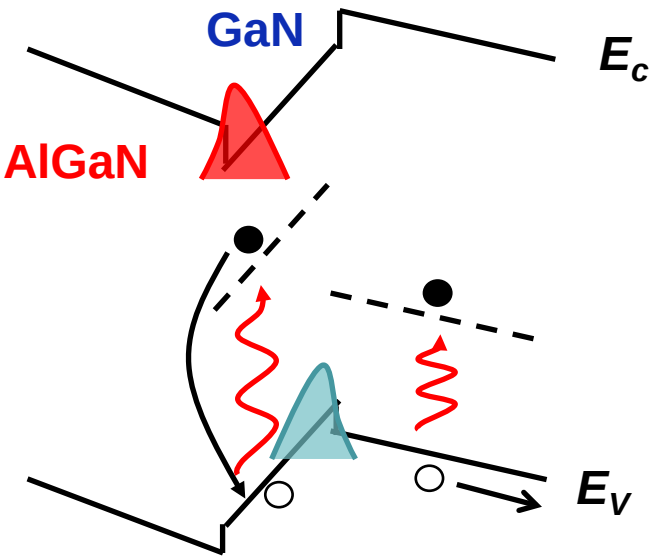



***Not sensitive*** **to well defects**

- Slow growth rates and strain prohibit extending well region into thin film

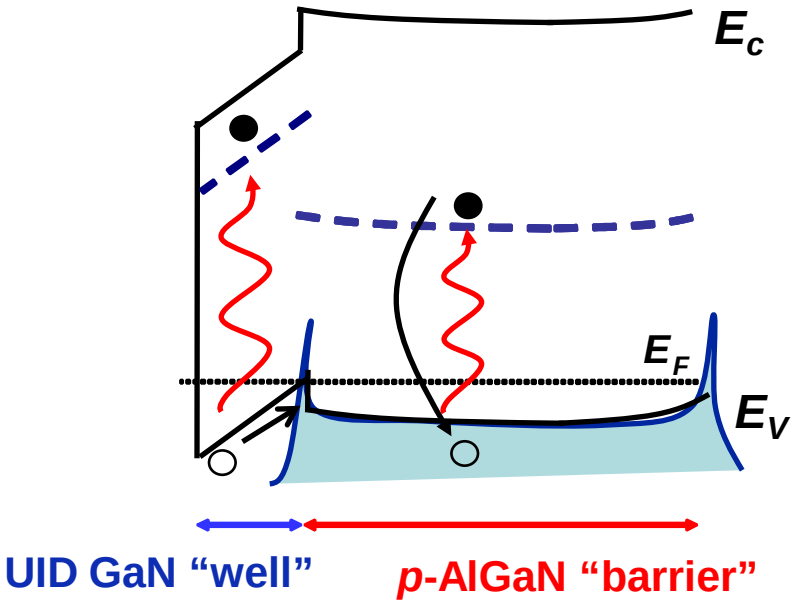
# Depth-resolved DLOS

## AlGaN/GaN QW




***Not sensitive*** **to well defects**

## "half QW"




***Mainly sensitive*** **to "well" defects**

**Difficult to implement:**

- **Polarization requires *p*-type AlGaN template for "half QW"**

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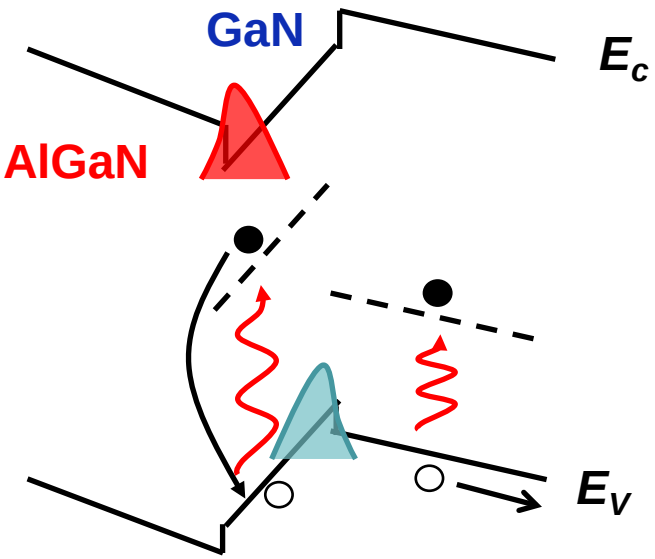
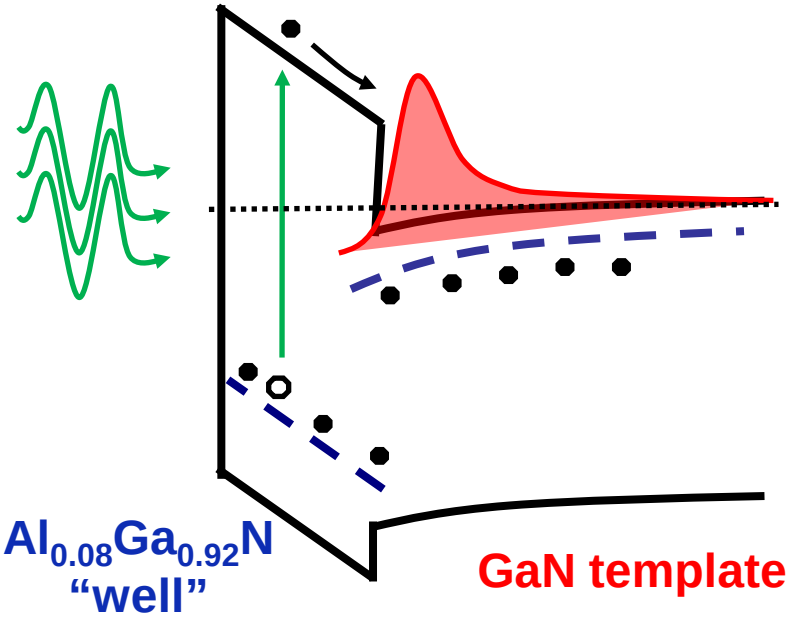
# Depth-resolved DLOS

## AlGaN/GaN QW




**_Not sensitive_ to well defects**

## "half QW"




**_Mainly sensitive_ to "well" defects**

- Nominal QW growth conditions for dilute AlGaN cap
- Expect defect incorporation similar to MQW active region

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# DLOS sample structure

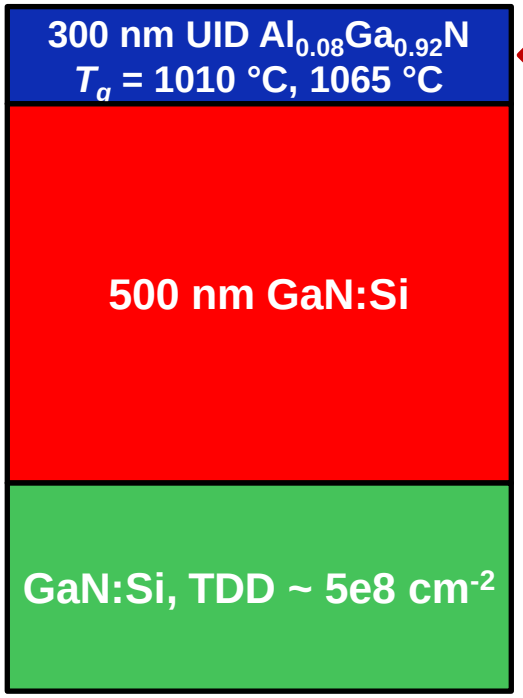
**Temp ($T_g$):** 1010 – 1065 °C

**Pressure:** 75 torr

**Sources:** TMAl, TMGa, $NH_3$, $H_2$

**V/III Ratio:** 1000 < V/III < 4000

**Sapphire:** 0.2° off toward m-plane




- QW growth conditions
- Coherently-strained

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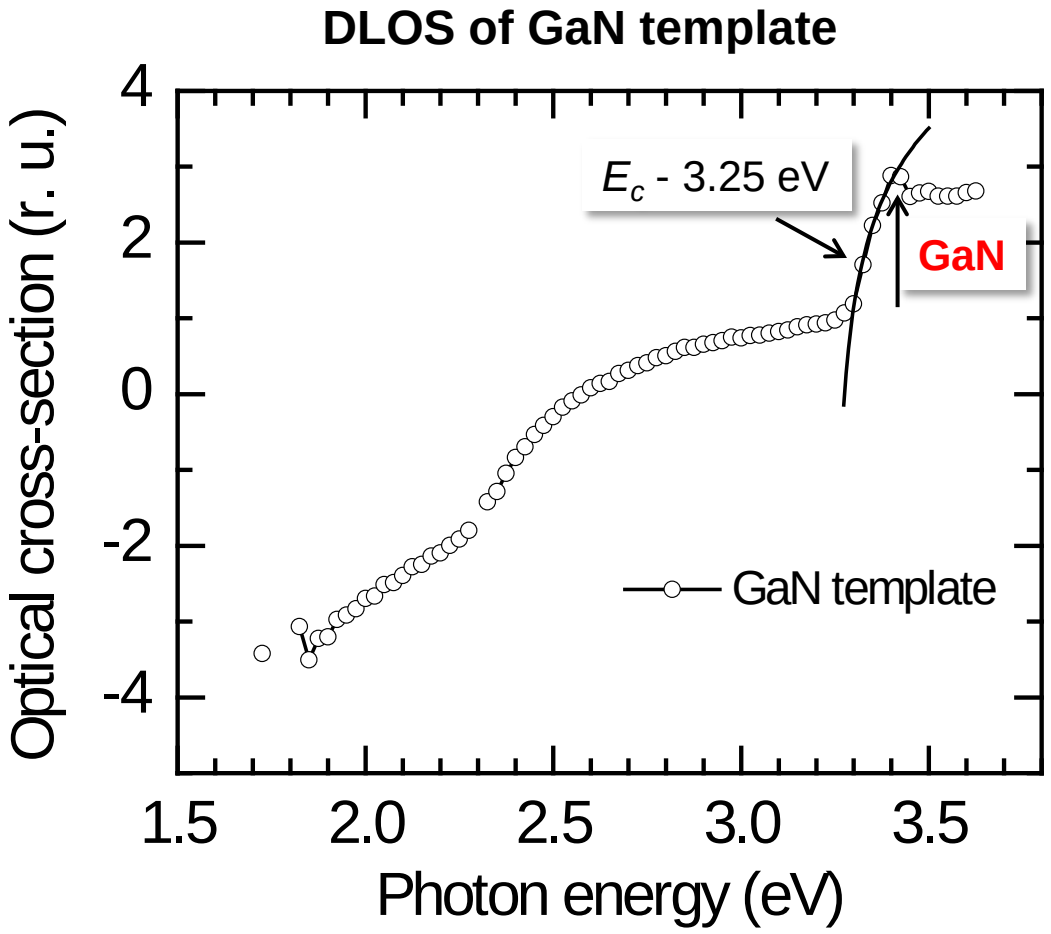
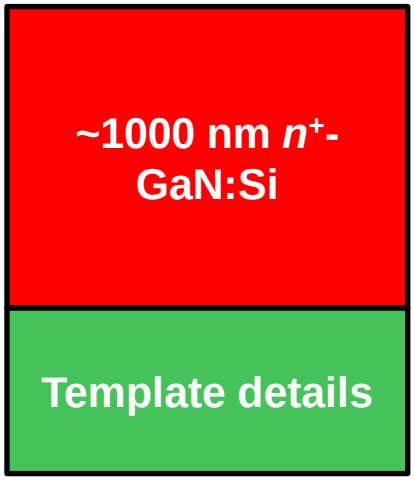
# DLOS for QW growth conditions




GaN template *not* associated with AlGaN/GaN QWs

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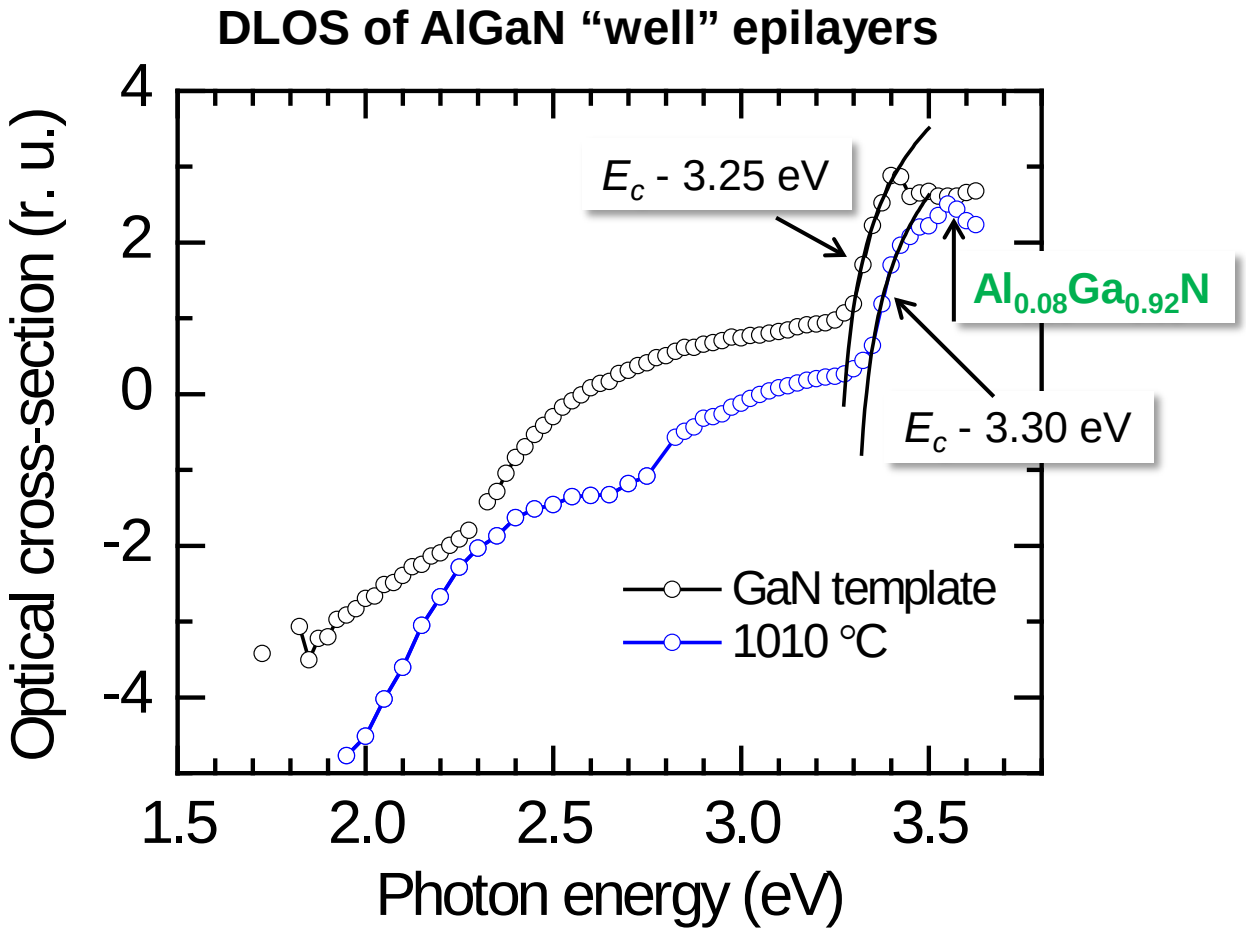
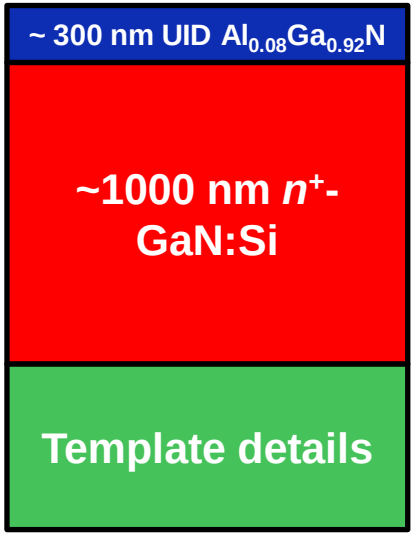
# DLOS for QW growth conditions




Different deep level spectra with "well" epilayer

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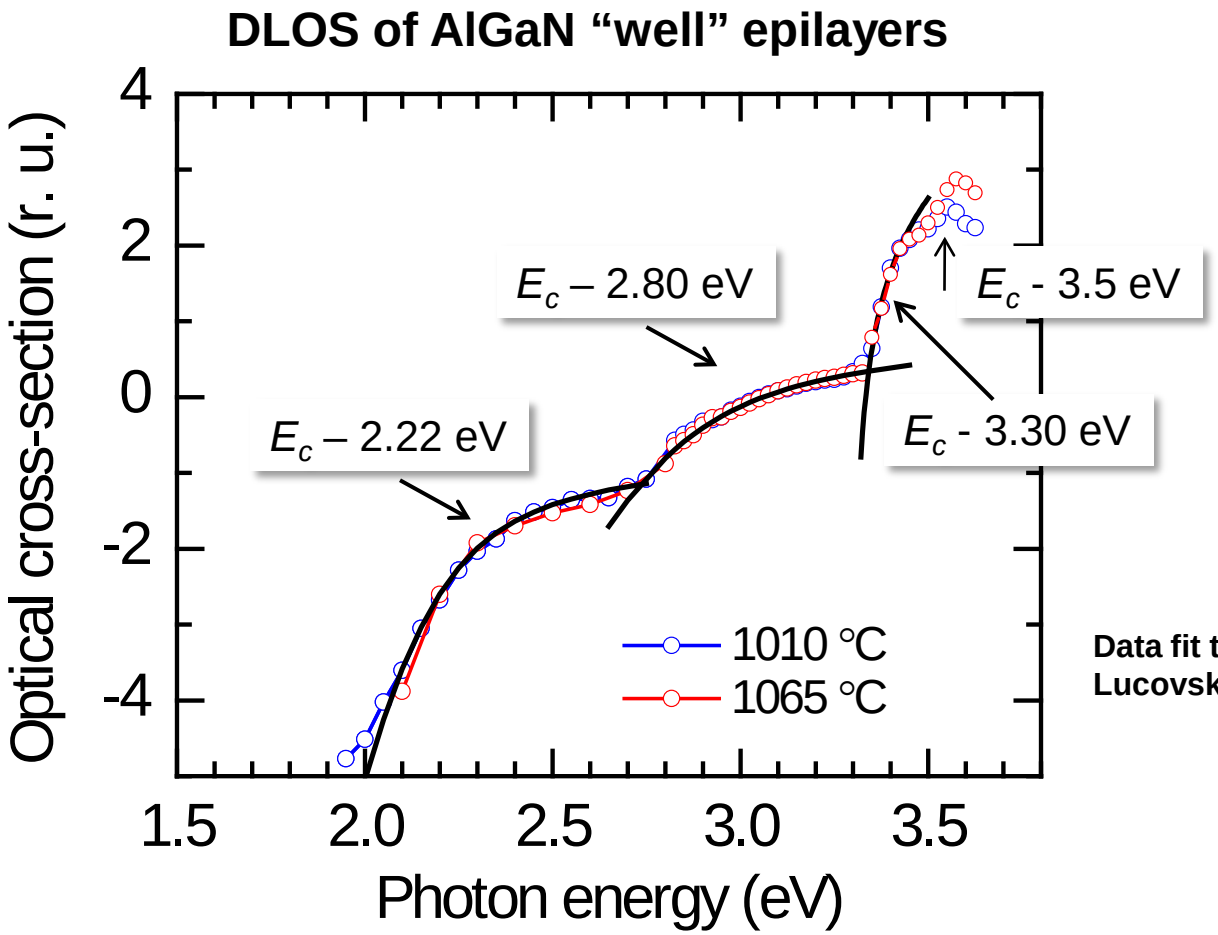
# DLOS for QW growth conditions




**Data fit to model of Lucovsky[1] or Pässler[2]**

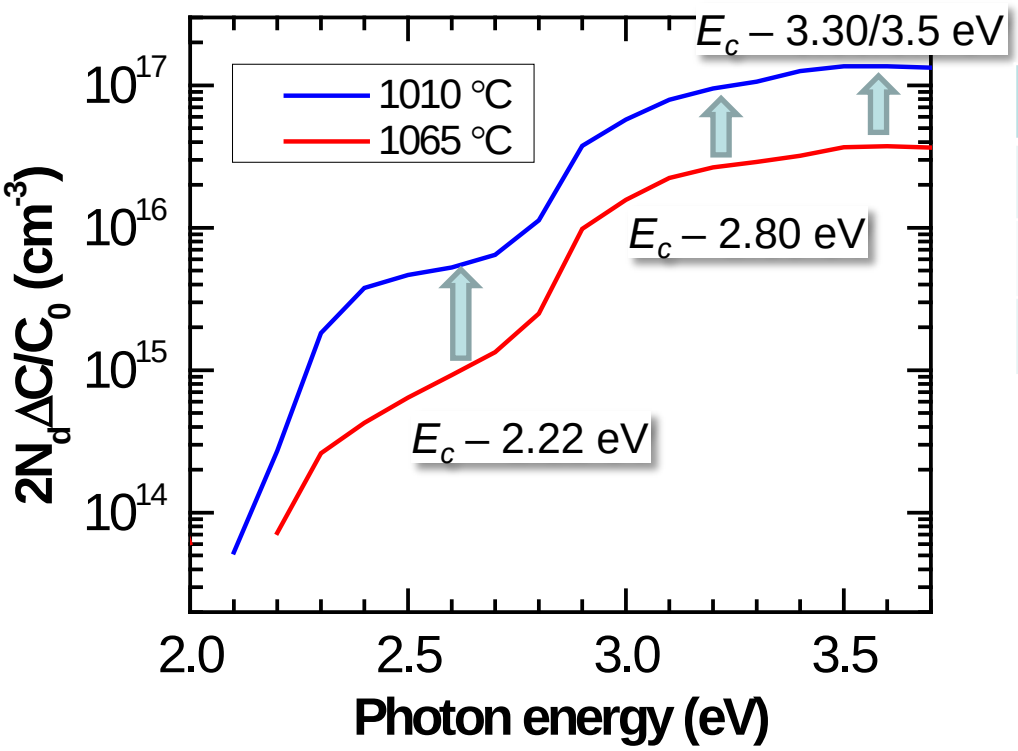
- Same QW deep levels for both $T_g$
- Changing $T_g$ by 55 C did not introduce new defect levels


1. G. Lucovsky, Solid State Commun.. 3 299–302 (1965).

2. R. Pässler, J. Appl. Phys. 96, 715 (2004).

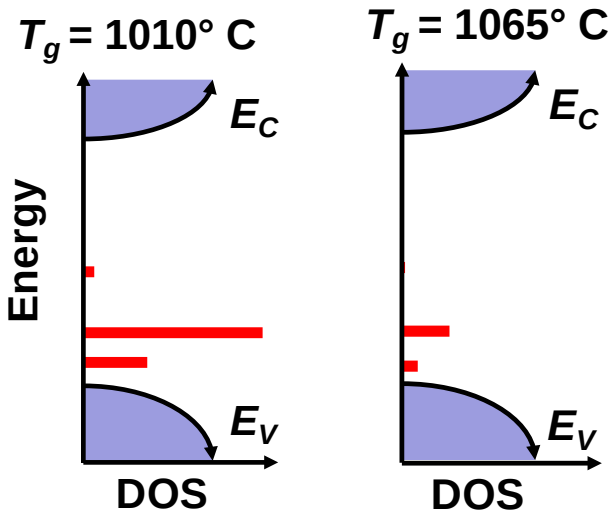
# Defect density vs. QW $T_g$

**Steady-state Photocap.**




**Defect density ($cm^{-3}$) vs. $T_g$**

| Level (eV) | $T_g$ = 1010 C | $T_g$ = 1065 C | Δ |
|---|---|---|---|
| 2.20 | 6.5e15 | 1.3e15 | 5X |
| 2.80 | 10e16 | 2.8e16 | 3.6X |
| 3.30/3.50 | 3.6e16 | 8.3e15 | 4.3X |




- **>3x increase in defect density for lower $T_g$**
- **[$E_c$ – 2.80 eV] least sensitive to $T_g$**
  - **Still likely dominate non-radiative recombination center**

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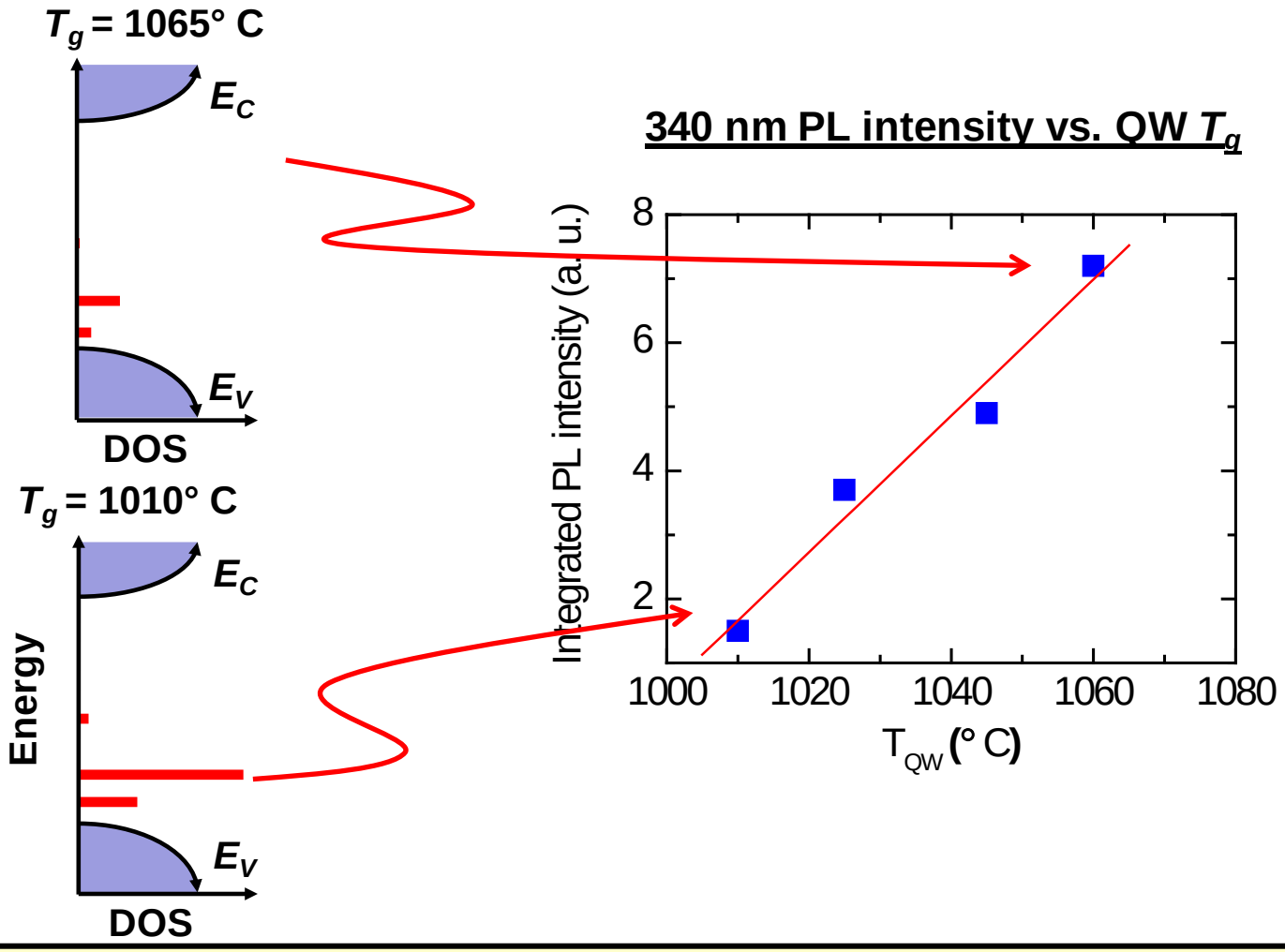
# Summary and Conclusions




- Used DLOS and PL to study impact of QW defects on AlGaN/GaN MQW efficiency
- Increasing QW $T_g$ improves PL intensity and reduces point defect density
- Controlling deep level defect incorporation critical for highly efficient UV emittiners

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