Excited State Optical Transitions in Quantum Cascade Lasers for Lower Thresholds and Multi-Wavelength Emission

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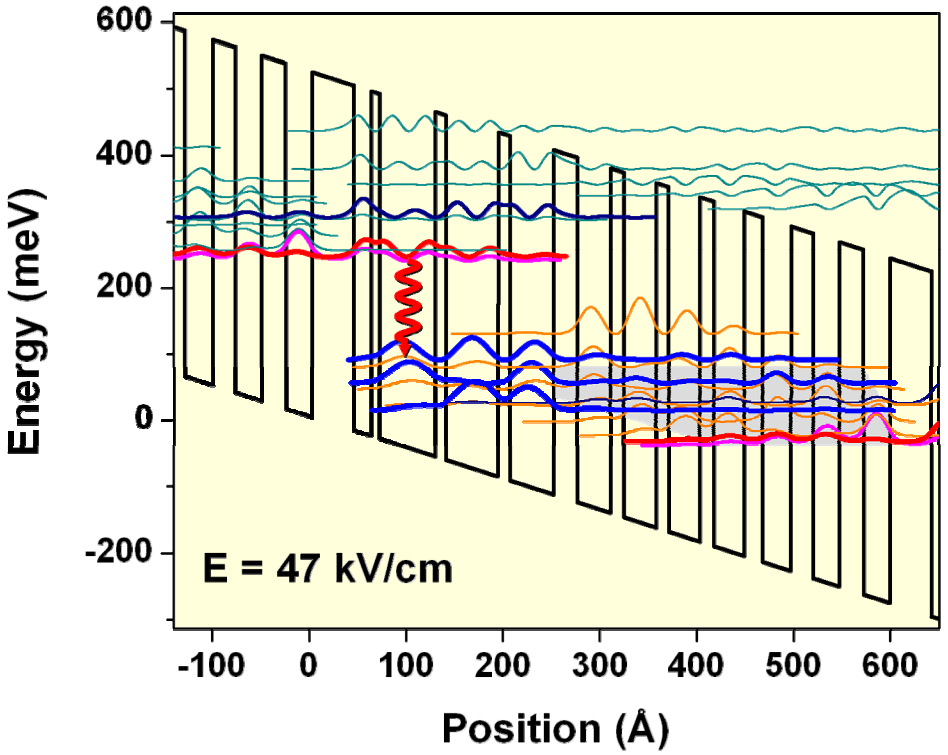
designing a better QC laser

- QC emitters: a "designer" material
- Limited by design space

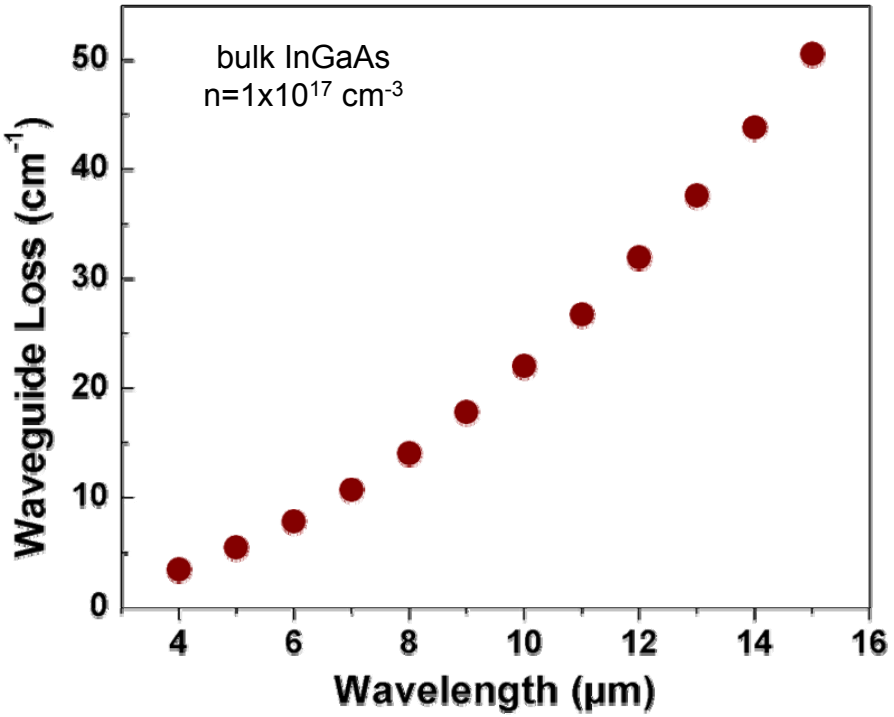


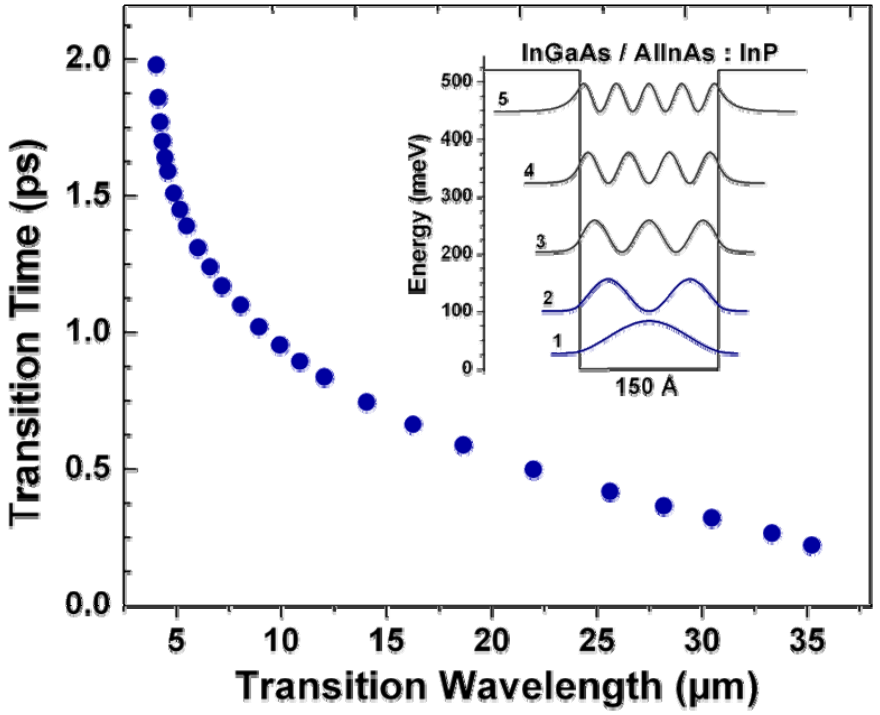
$$J_{th} = \frac{\alpha_m + \alpha_w}{g\Gamma}$$

$$g = \tau_u \left(1 - \frac{\tau_\ell}{\tau_{u\ell}}\right) \frac{4\pi q}{\varepsilon_0 \lambda_0 n_{eff} L_p} \frac{z_{u\ell}^2}{2\gamma_{u\ell}}$$

Why is long wavelength so hard?

- Optical absorption
- Upper laser level lifetime
- Coupling efficiency



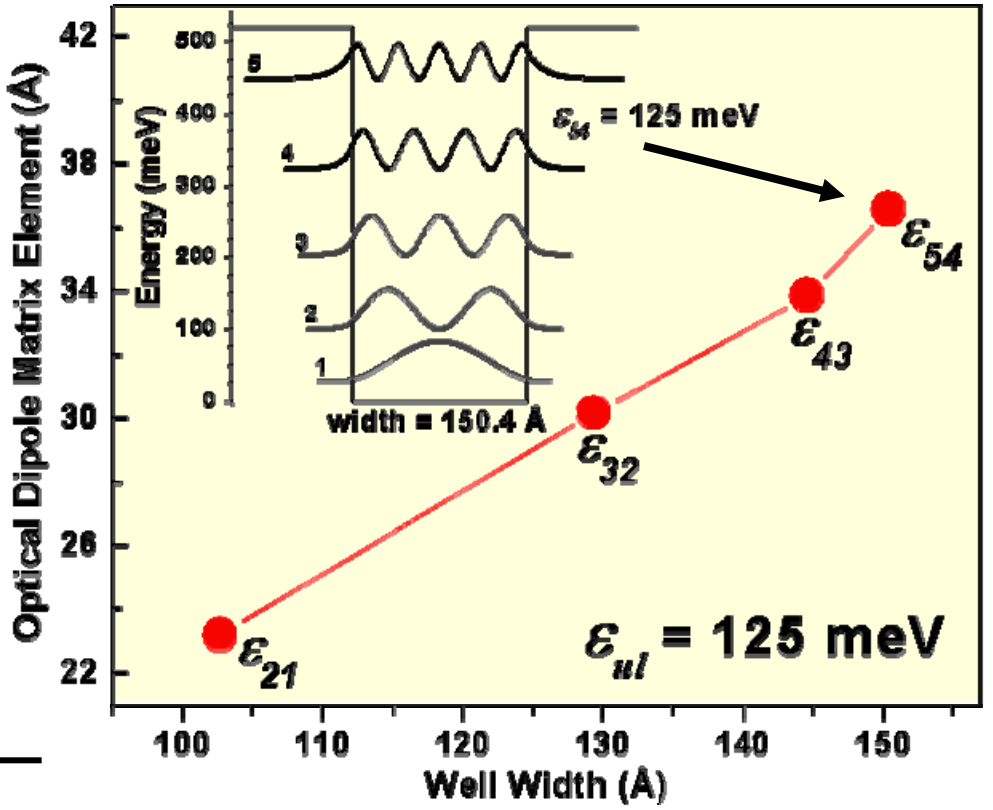


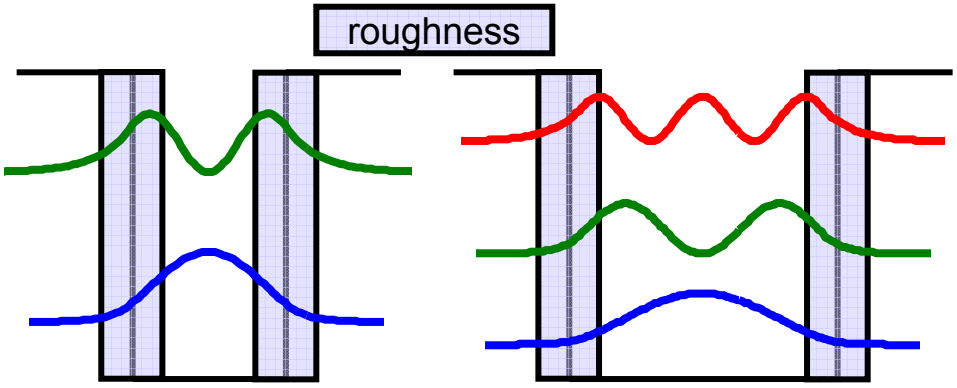
improving laser gain

optical dipole matrix element

$$g \propto z_{u\ell}^2 = \left| \langle \phi_u(z) | z | \phi_\ell(z) \rangle \right|^2$$

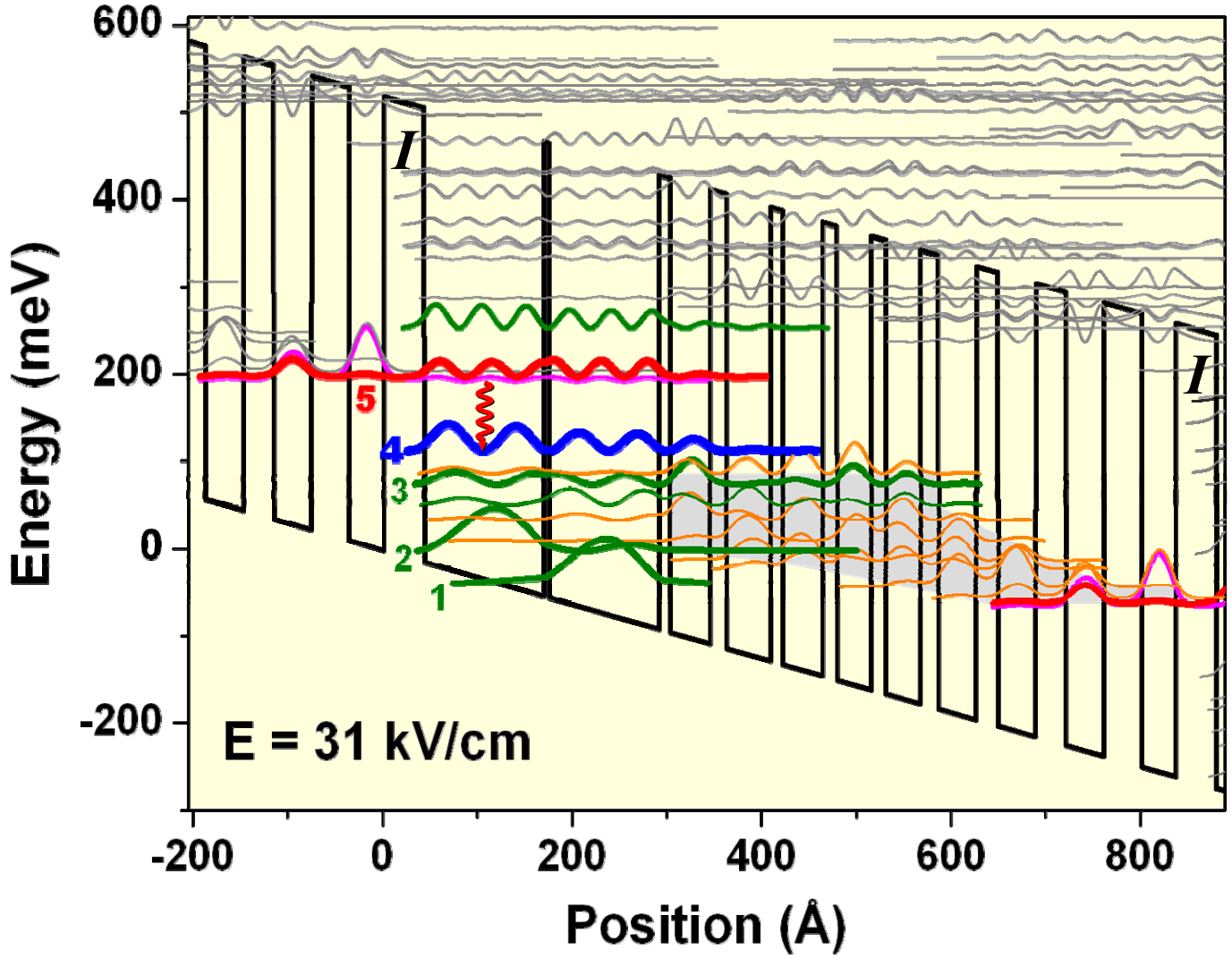
$$g \propto \frac{1}{2\gamma_{u\ell}}$$





especially useful for longer-wavelength optical transitions

15 μm excited state QC laser

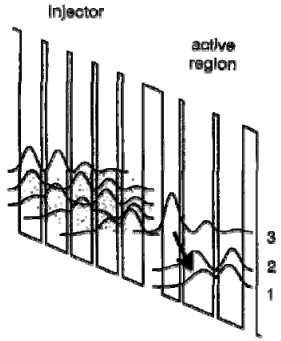


- E_{ul} = 83.6 meV
- z_{ul} = 50.3 Å
- τ_5 = 0.586 ps
- τ_4 = 0.215 ps
- τ_{54} = 1.9 ps
- FoM = 1313 ps Å^2
- $z^2\tau_5$ = 1483 ps Å^2
- $z^2\tau_5 E$ = **124** ps Å^2 eV

FoM comparison

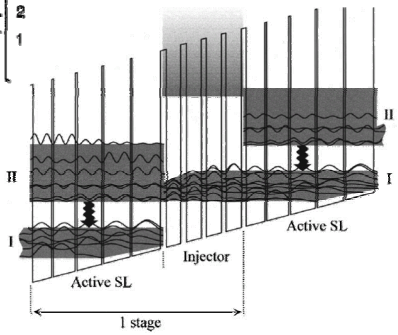
$\tau_3 z^2 E$ (ps Å^2 eV)

C. Gmachl et al. (1998)
13 μm Diagonal Transition



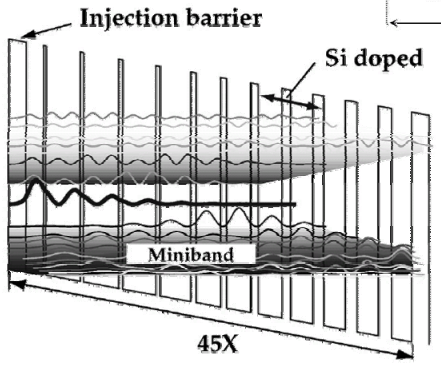
69.8

A. Tredicucci et al. (1999)
17 μm Superlattice



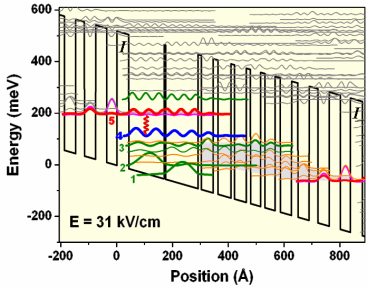
56.0

M. Rochat et al. (2001)
15.6 μm B-to-C



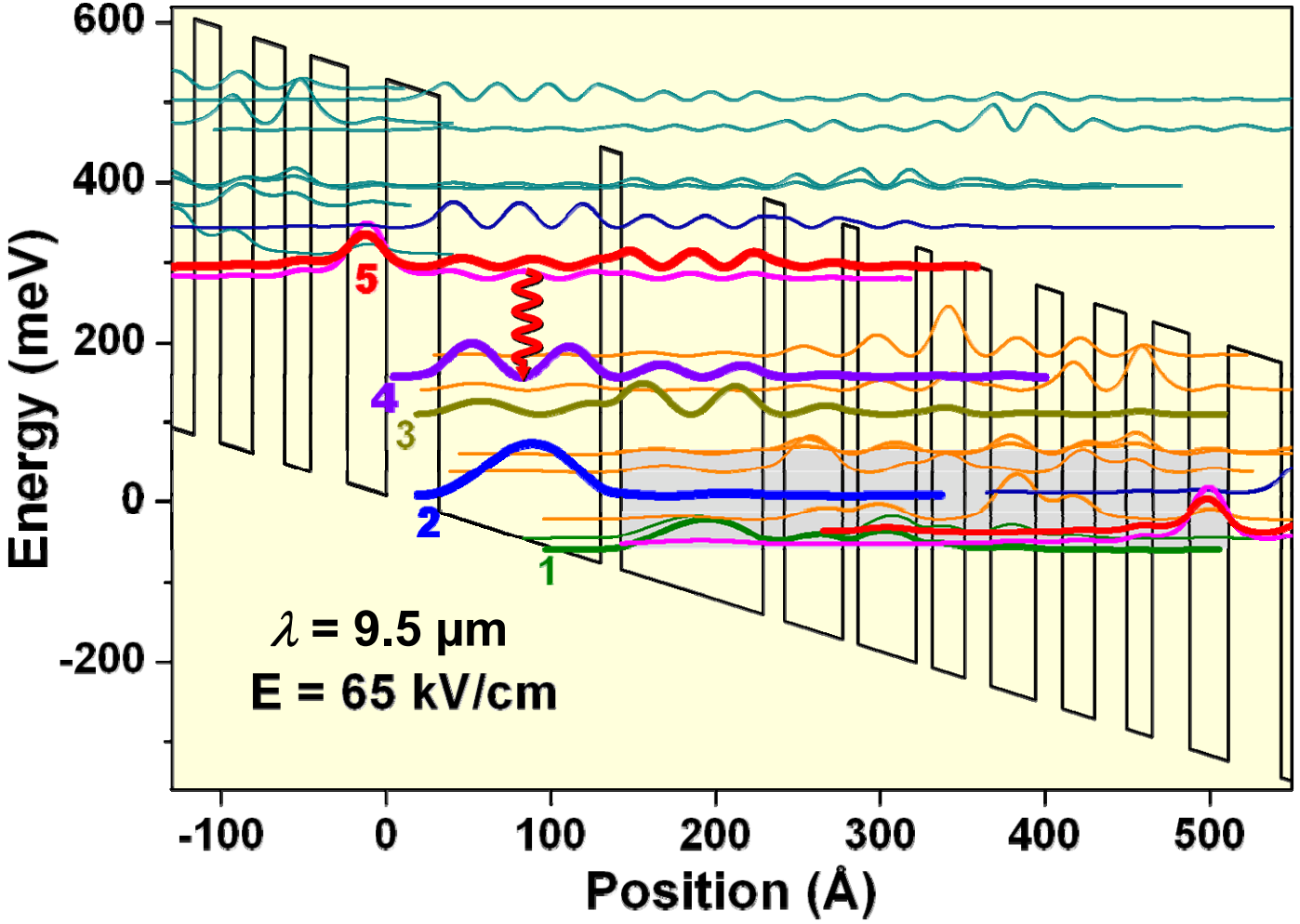
70.2

15 μm Excited State (2007)

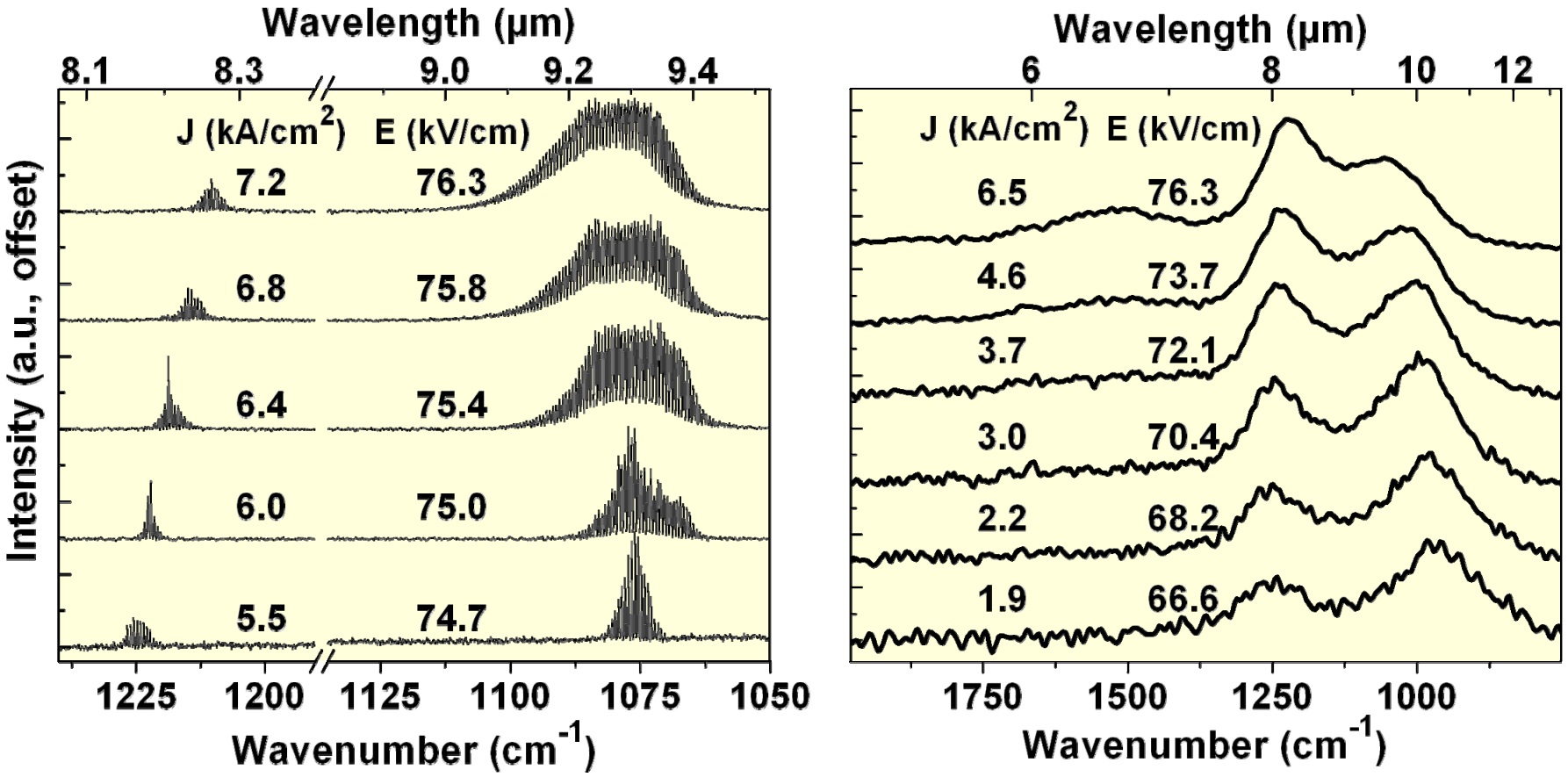


123.9

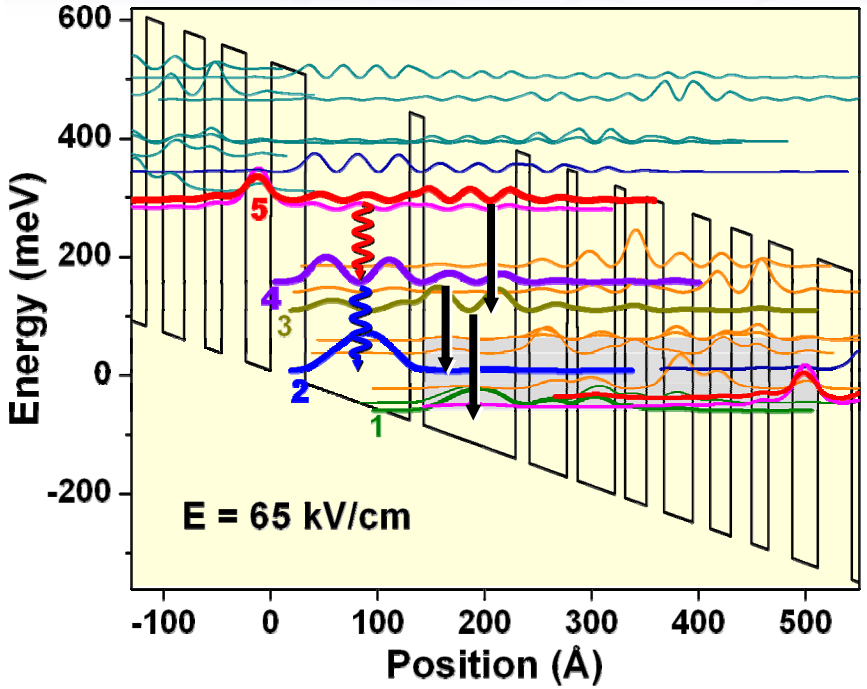
excited state QC laser
the first attempt

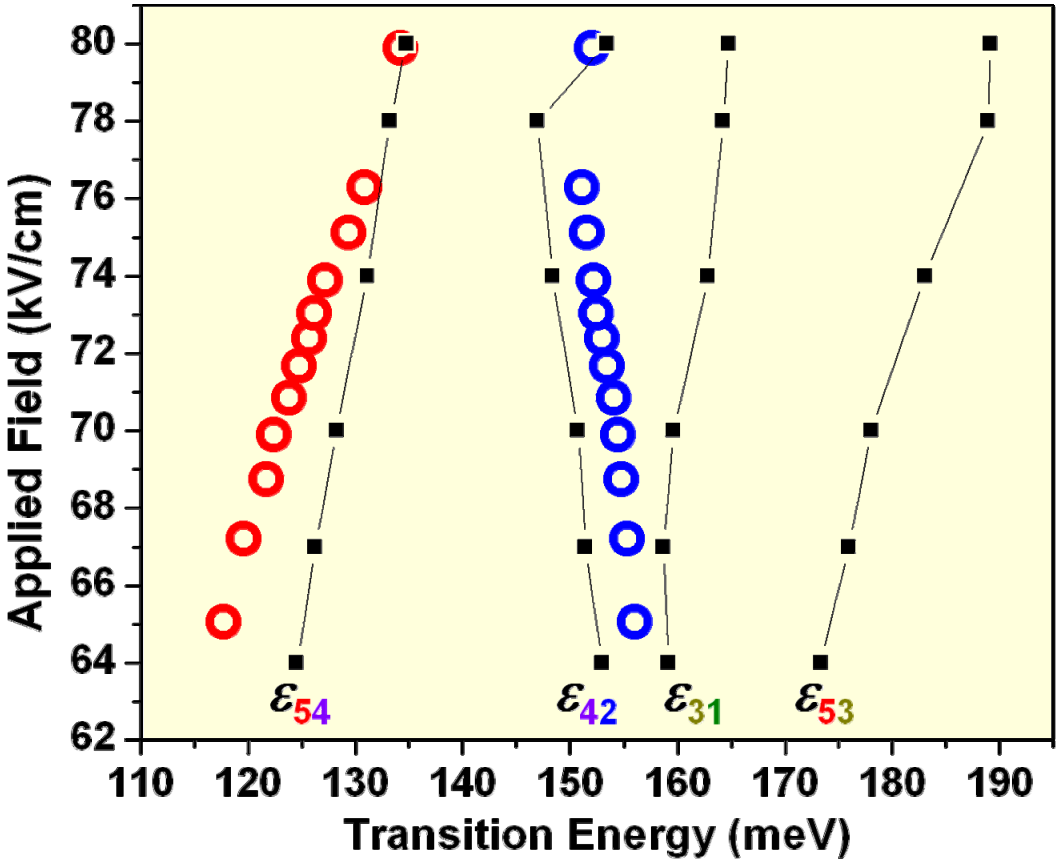


lasing and EL spectra

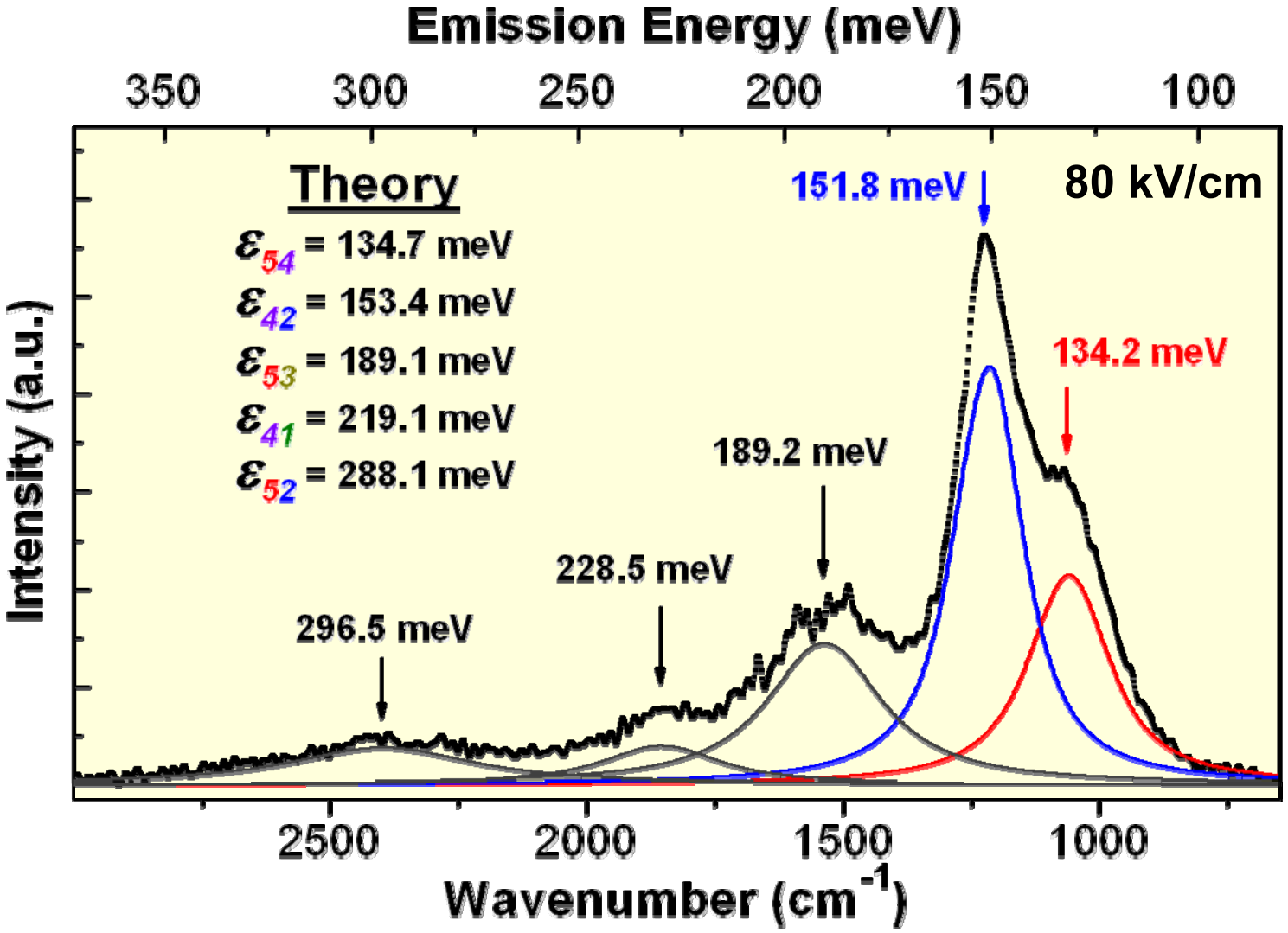


field-dependent emission

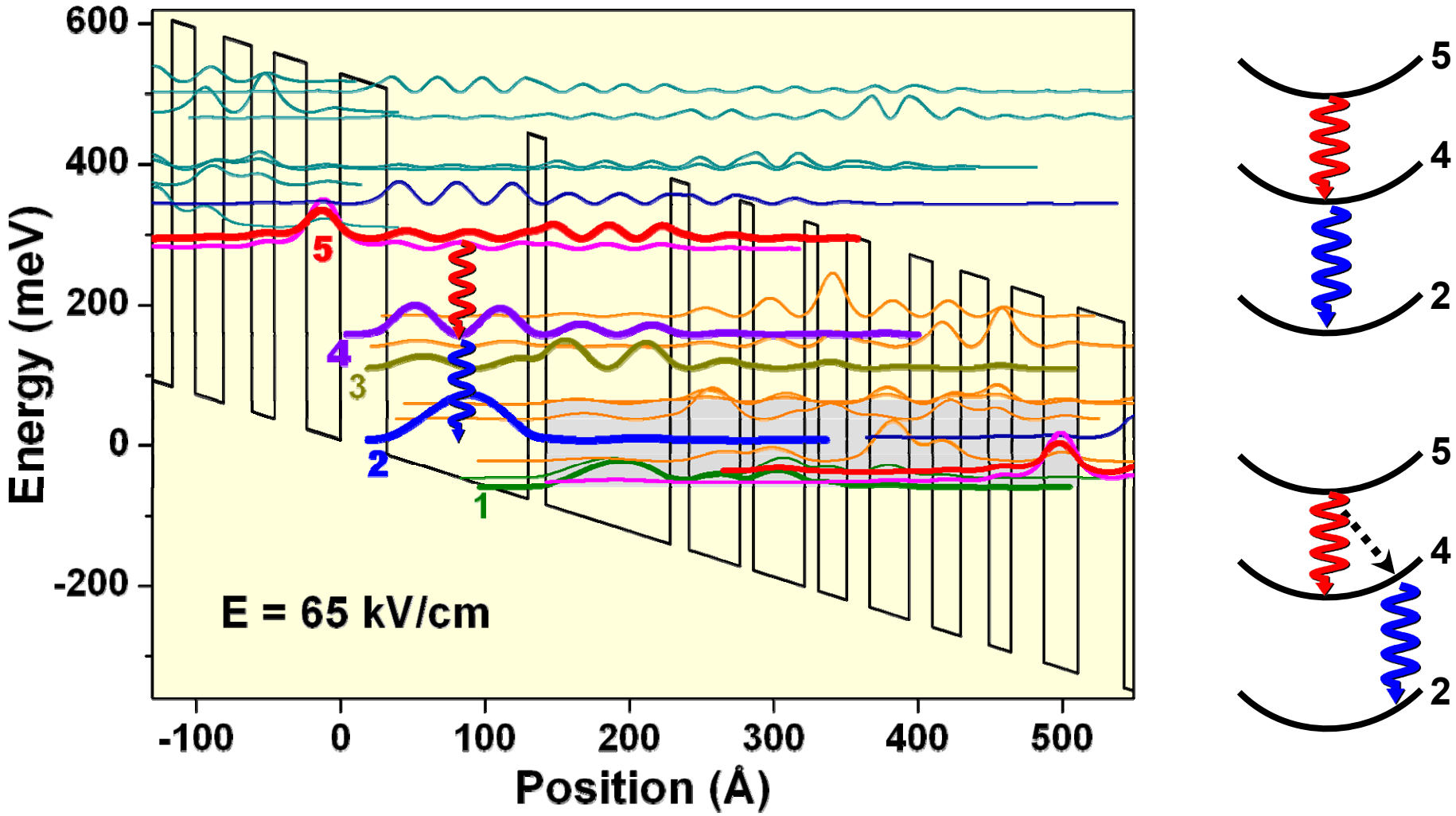




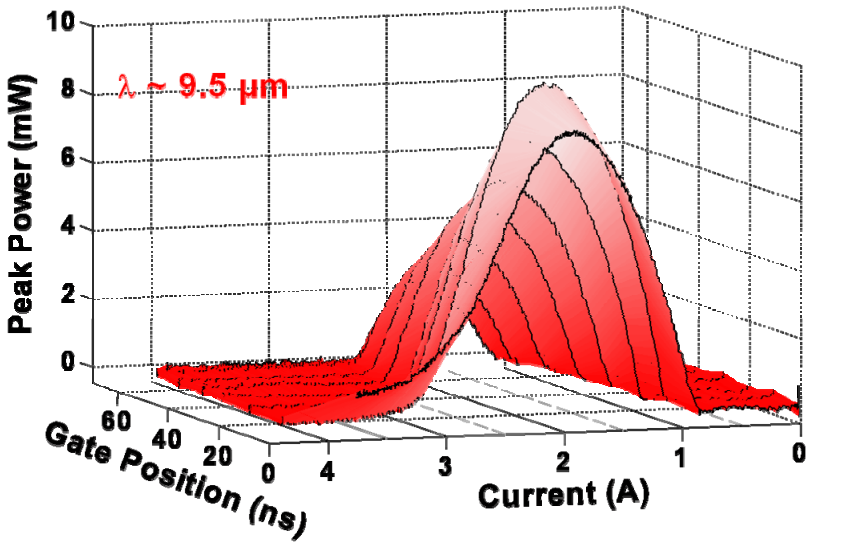
high current EL

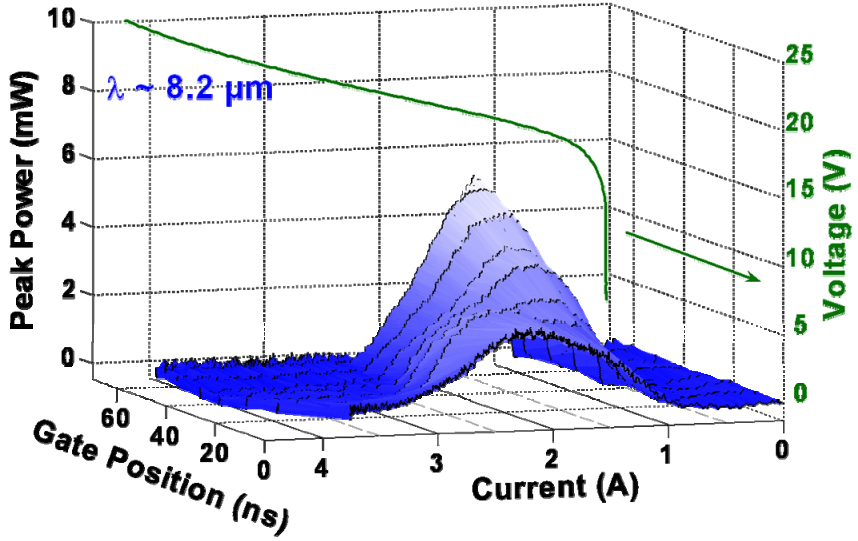


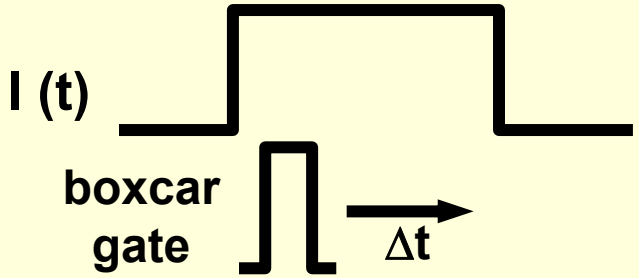
cascaded QC laser

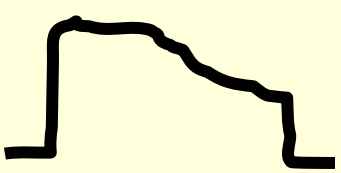


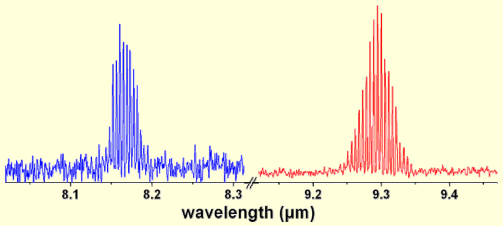
Light – Current – Voltage

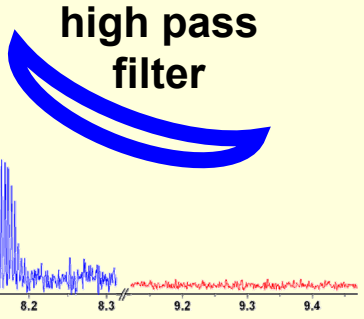


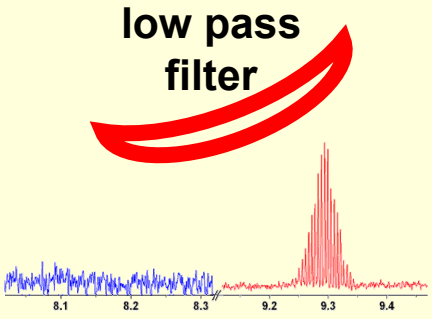




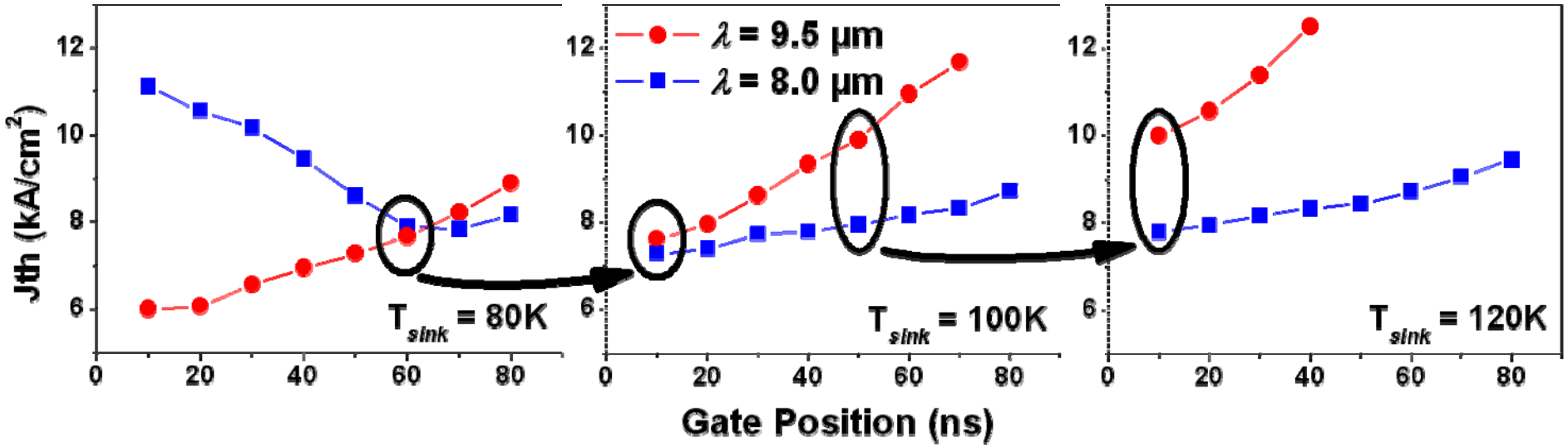


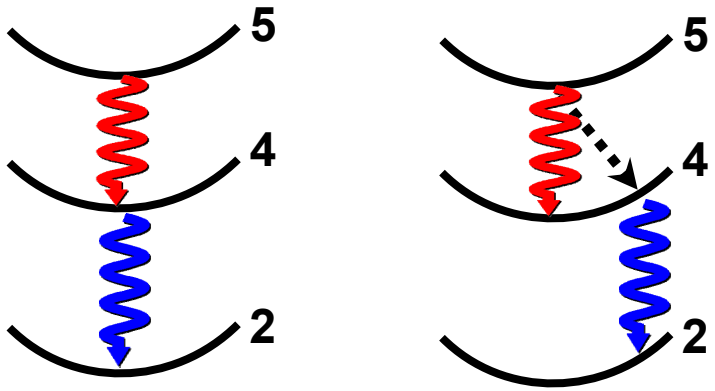






threshold behavior





summary

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- **Excited state transitions: a strategy to lower threshold currents**
- **Cascaded emission in semiconductor lasers**
- **Acknowledgements**
  - **MIRTHE (NSF-ERC)**
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