Cascaded Emission in a Dual-Wavelength Quantum Cascade Laser

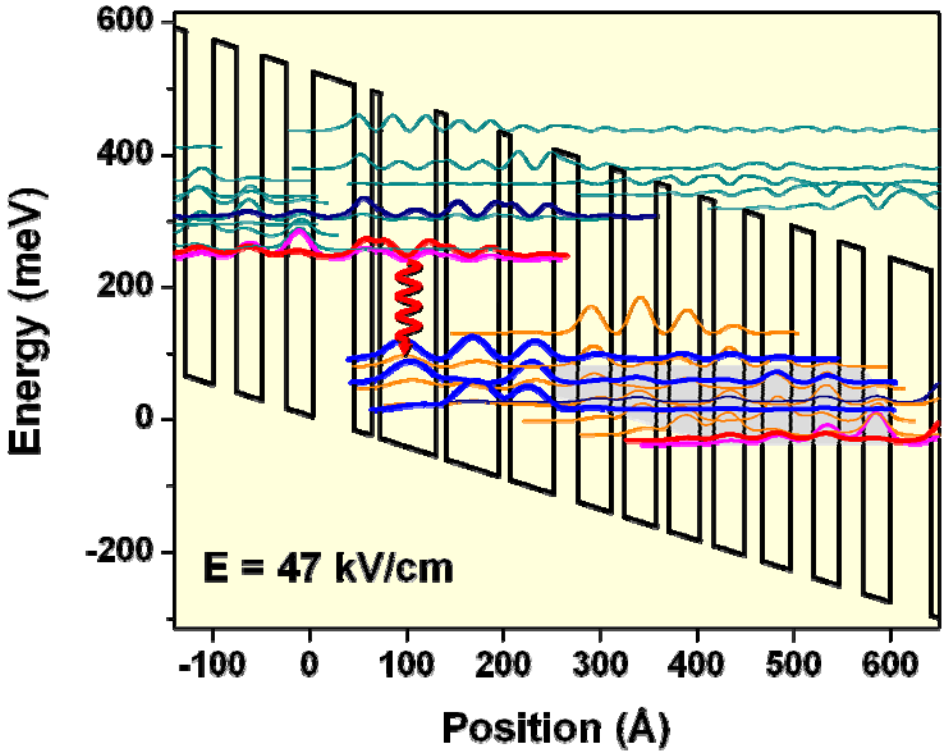
Kale J. Franz, Daniel Wasserman, Anthony J. Hoffman, Kuen-Ting Shiu*, Stephen R. Forrest*, and Claire Gmachl

Department of Electrical Engineering
Princeton Institute for the Science and Technology of Materials
Princeton University, Princeton, NJ 08544

* Current address: Department of Electrical Engineering and Computer Science
University of Michigan, Ann Arbor, MI 48109

Designing a Better QC Laser

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



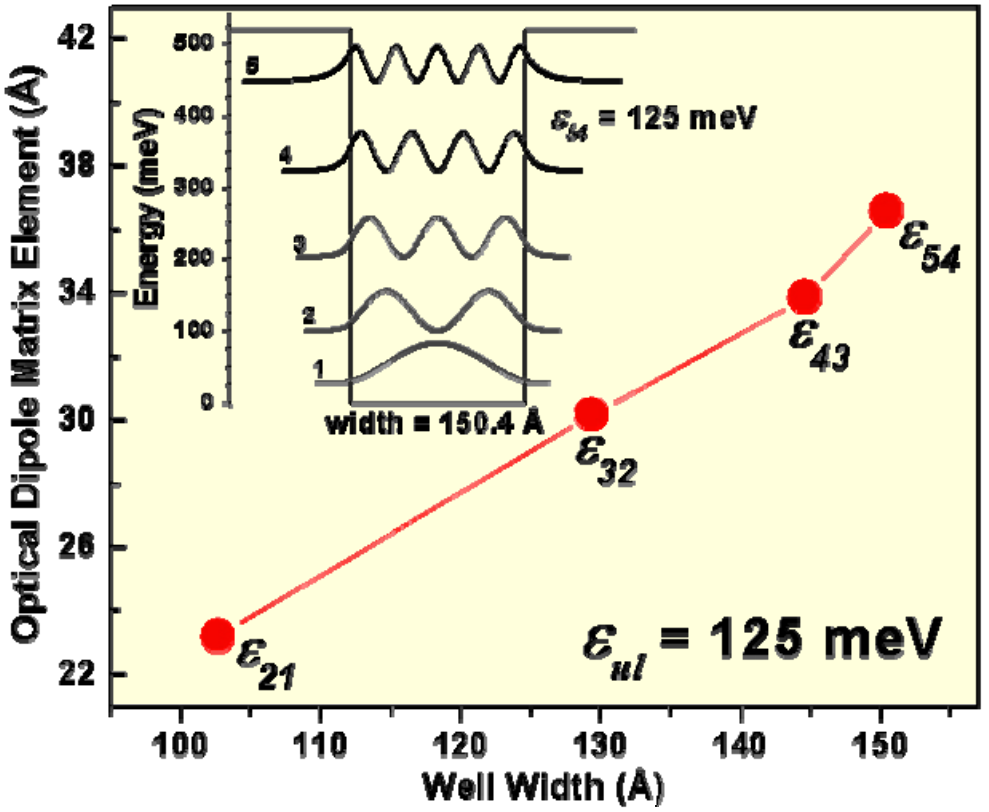
$$J_{th} = \frac{\alpha_m + \alpha_w}{g\Gamma}$$

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

Improving Laser Gain

optical dipole matrix element

$$g \propto z_{ul}^2 = \left| \left\langle \phi_u(z) \middle| z \middle| \phi_l(z) \right\rangle \right|^2$$

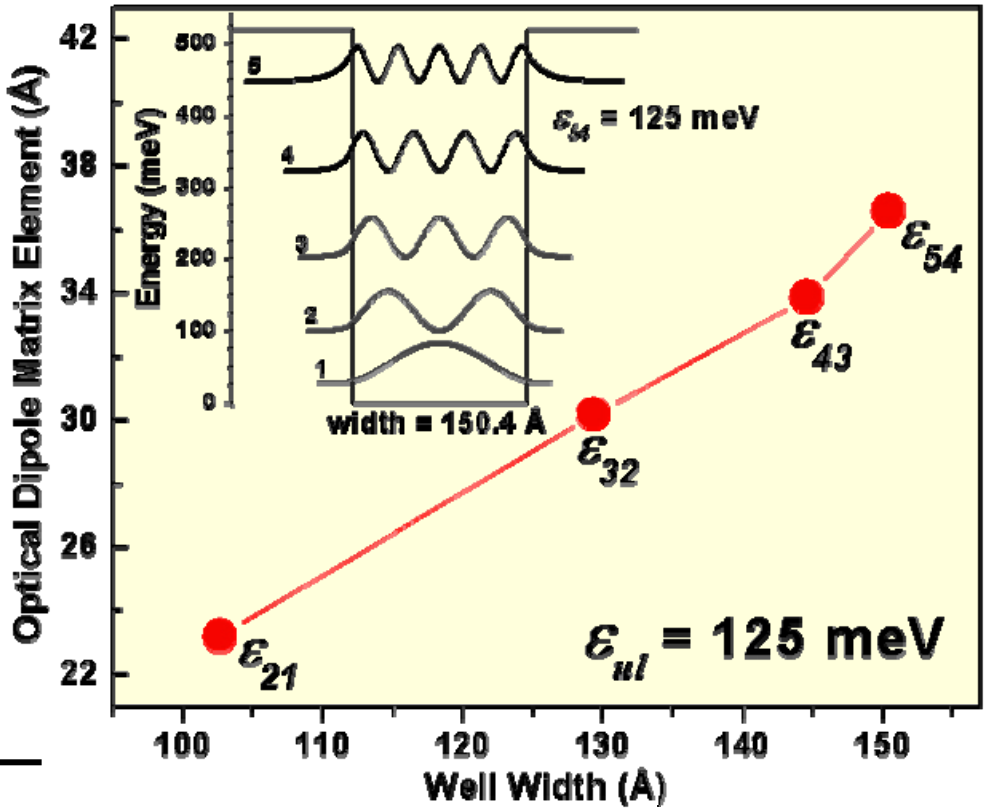


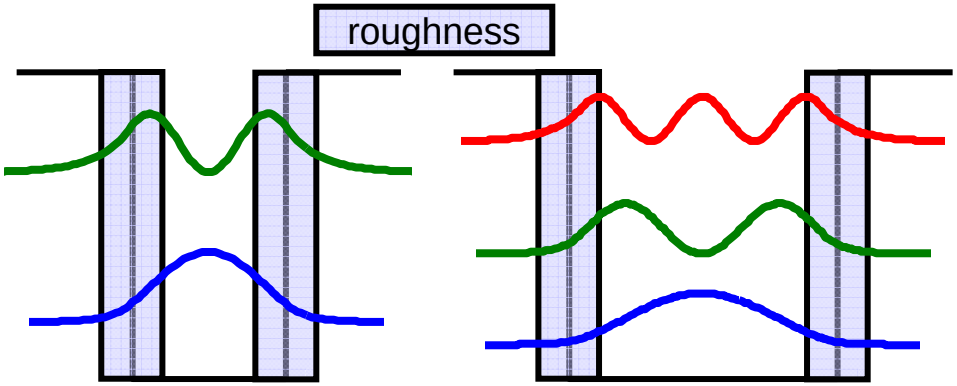
Improving Laser Gain

optical dipole matrix element

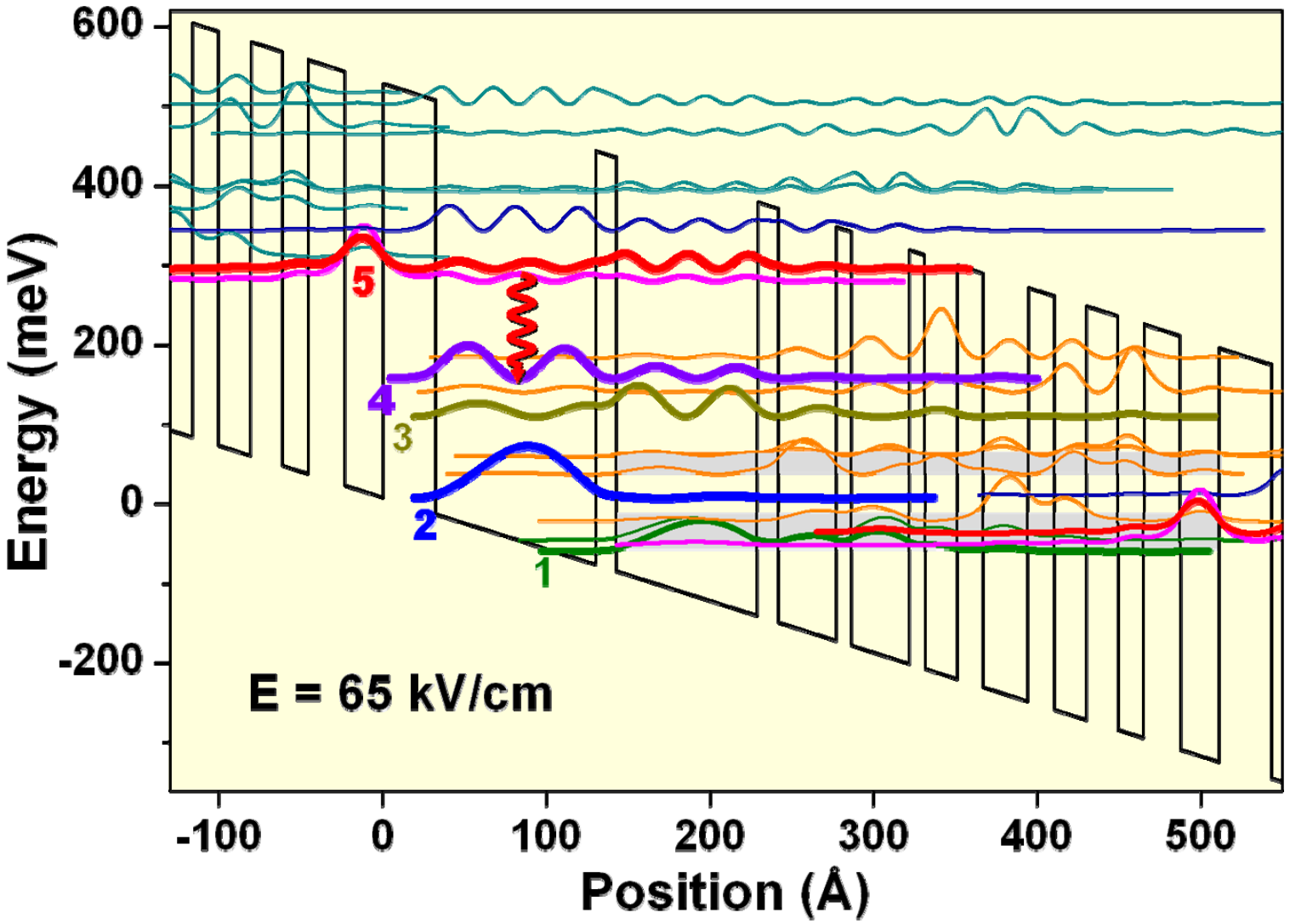
$$g \propto z_{ul}^2 = \left| \left\langle \phi_u(z) \middle| z \middle| \phi_l(z) \right\rangle \right|^2$$

$$g \propto \frac{1}{2\gamma_{ul}}$$

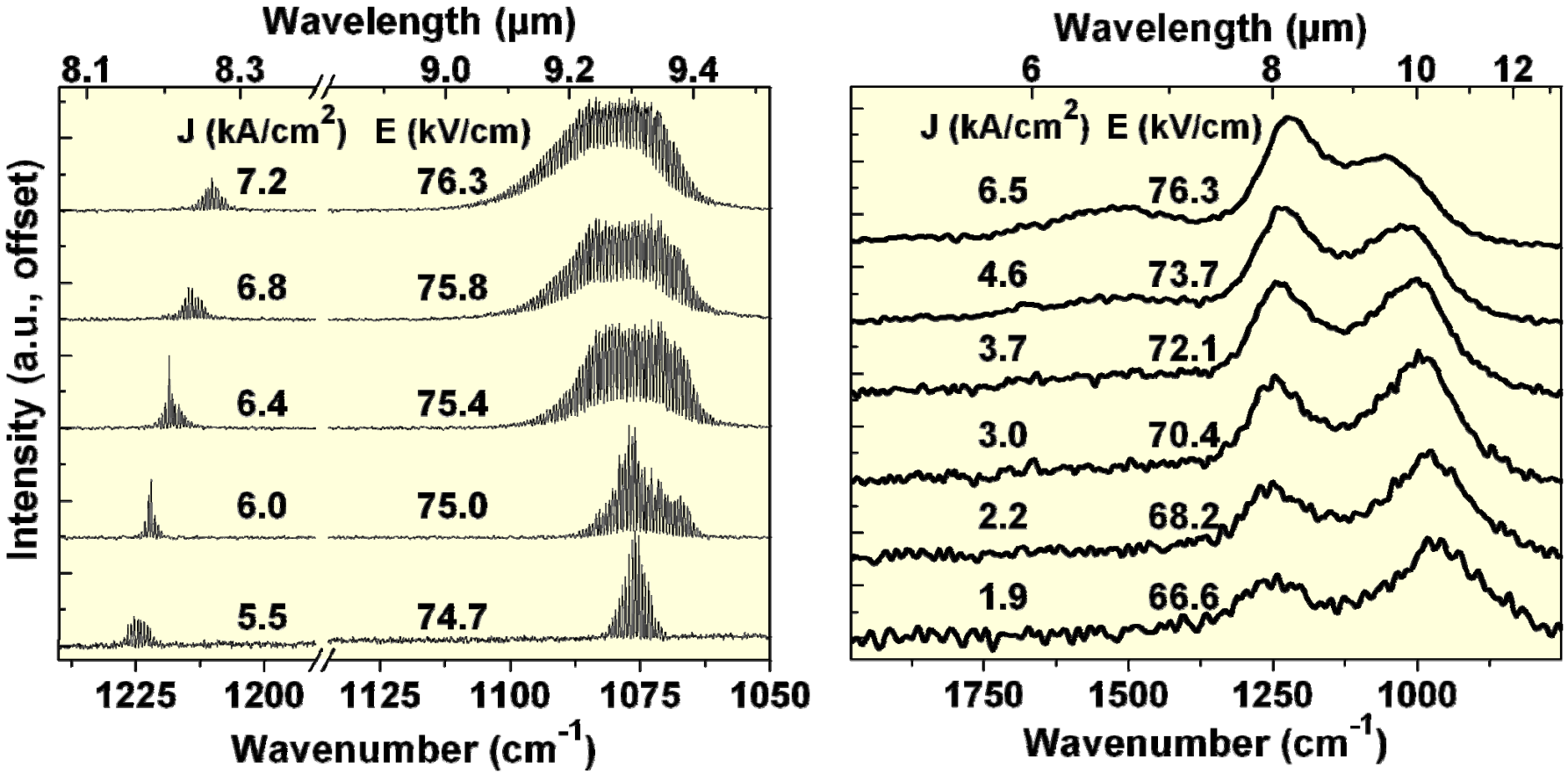




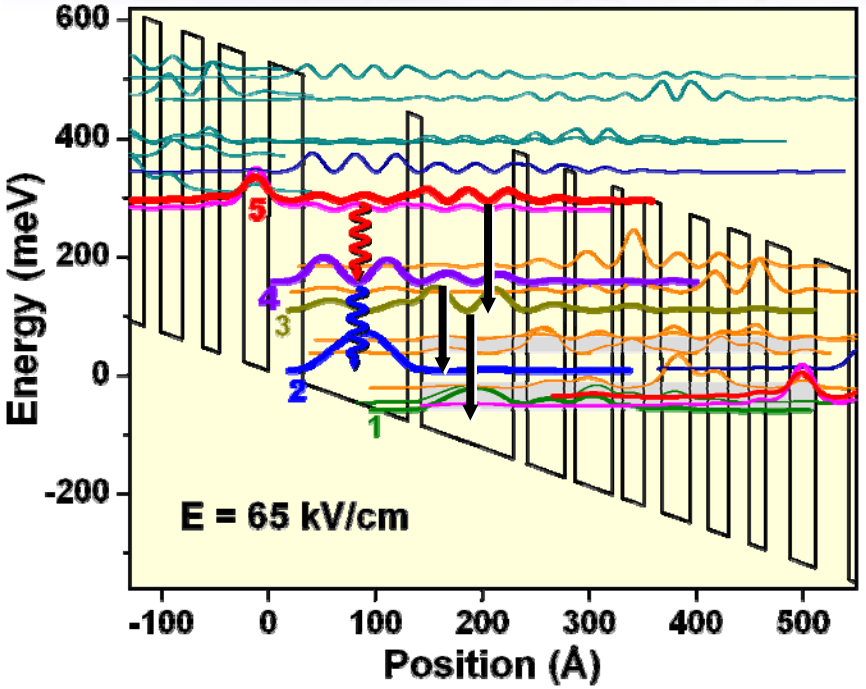
Cascaded QC Laser

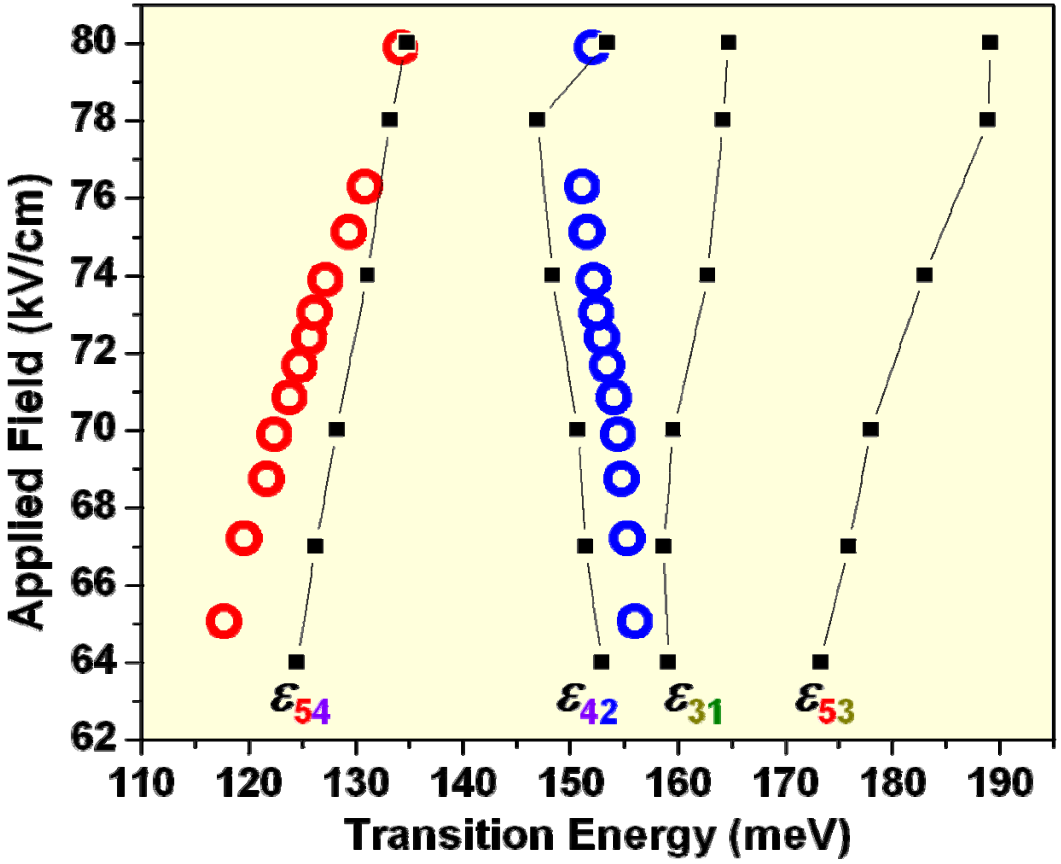


Lasing and EL Spectra

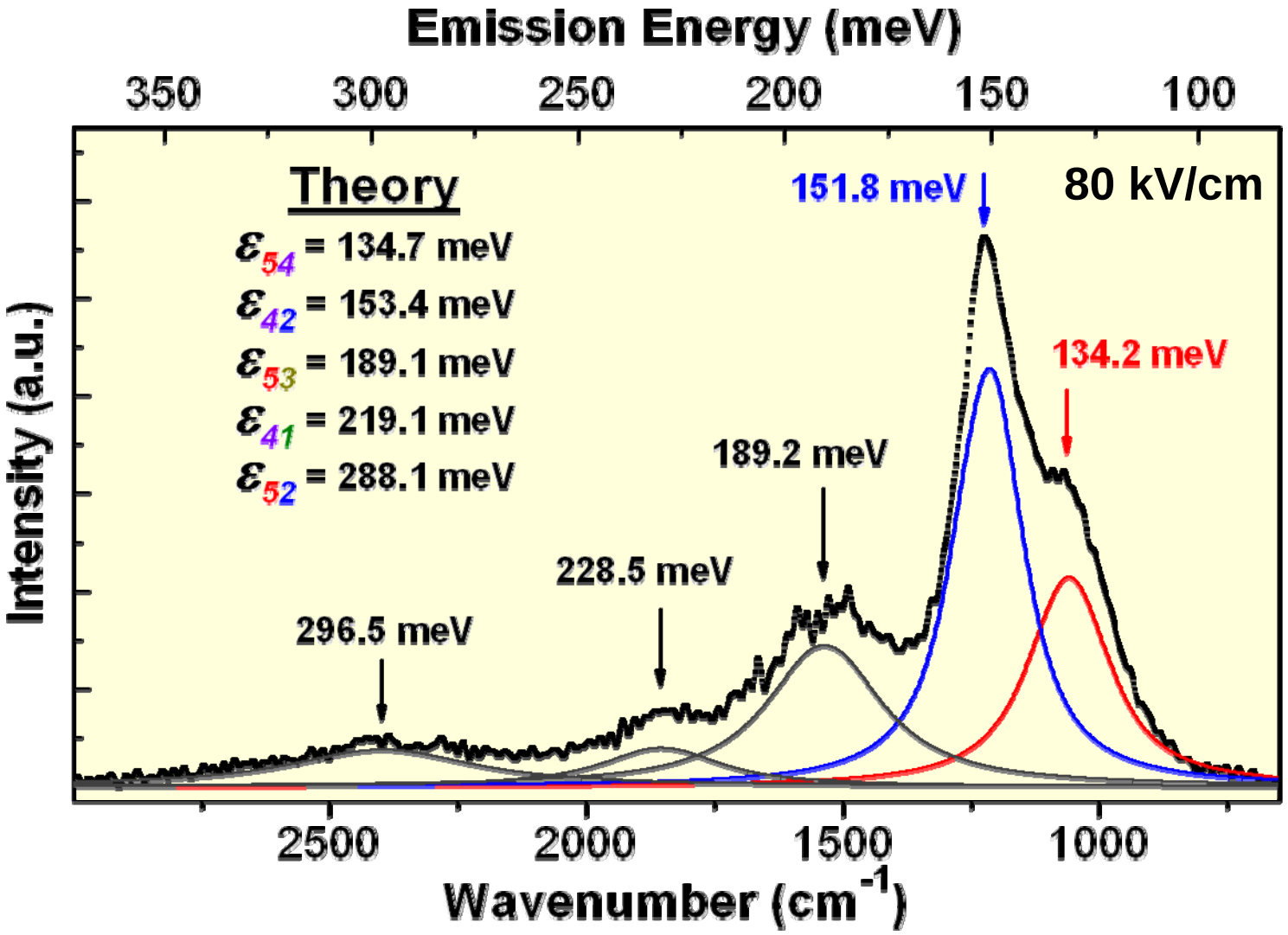


Emission Behavior with Field

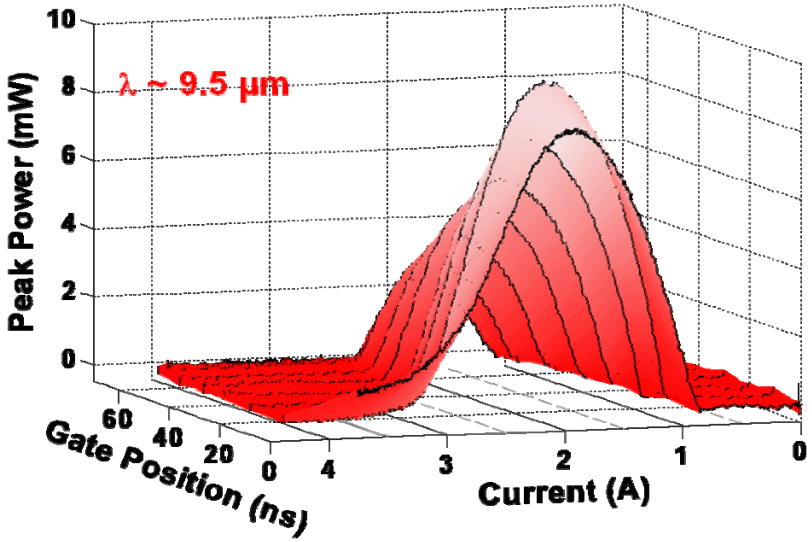


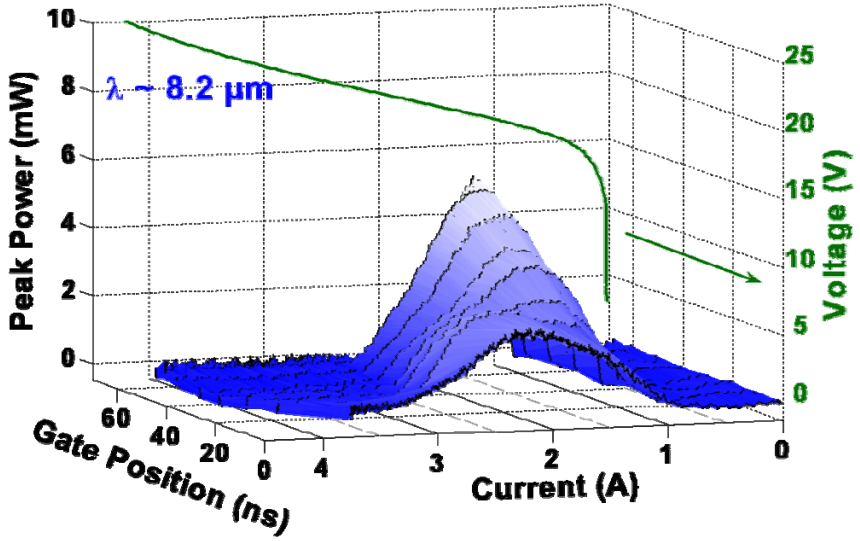


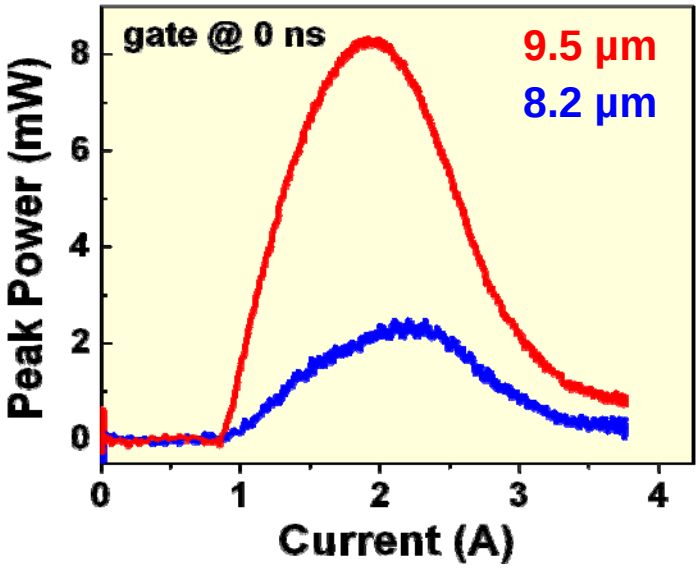
High Current EL

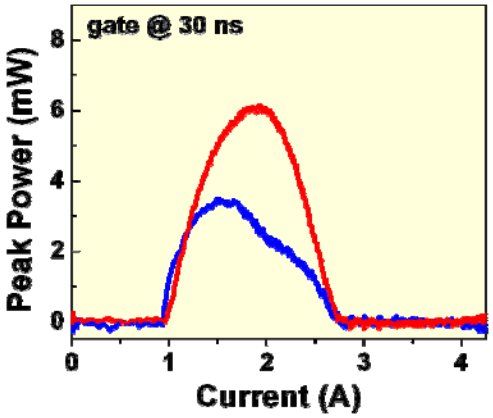


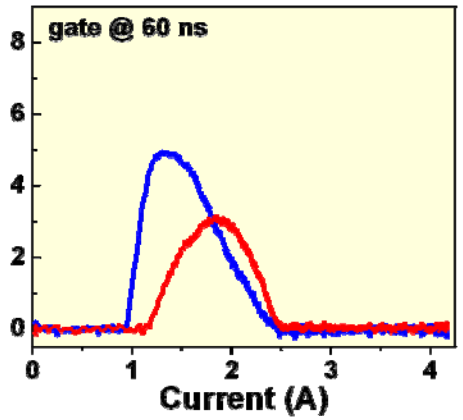
Light – Current – Voltage



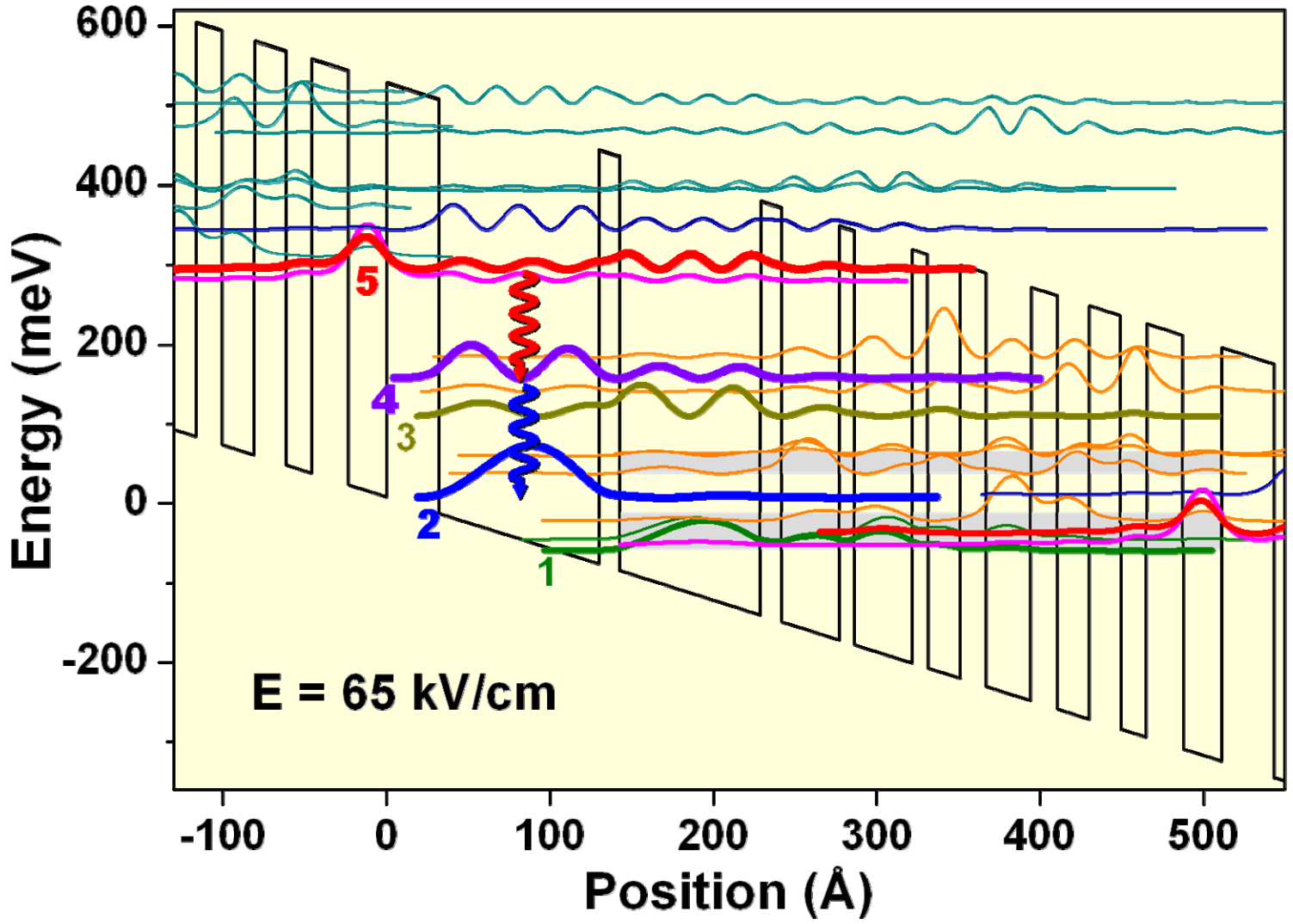




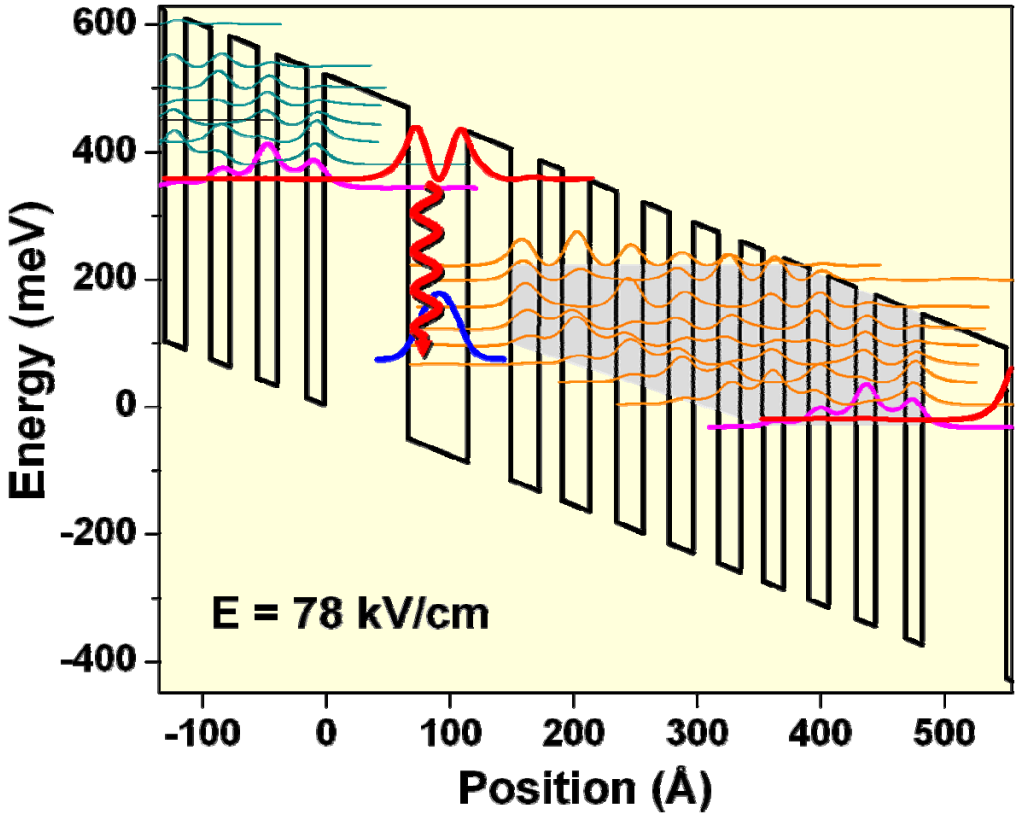


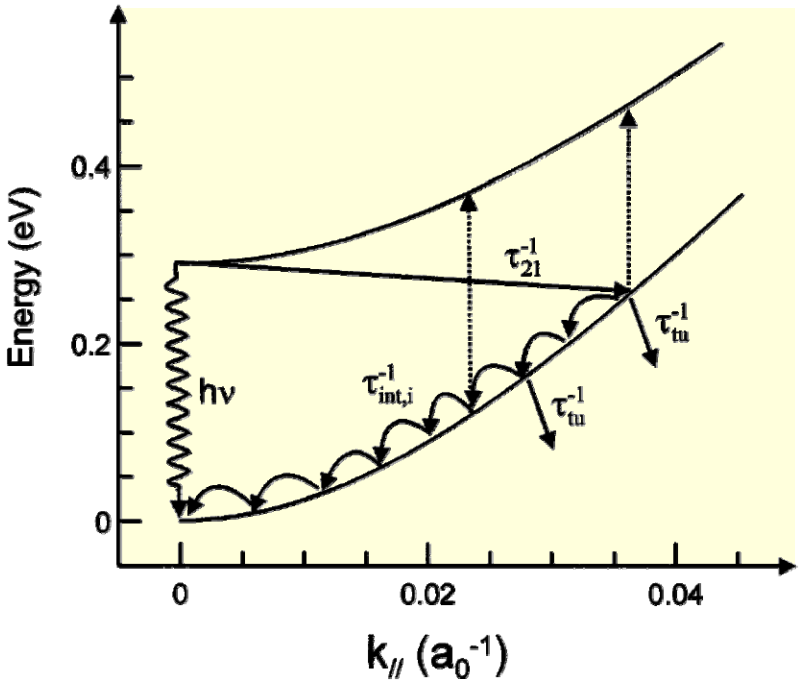


Cascaded QC Laser



Tunneling



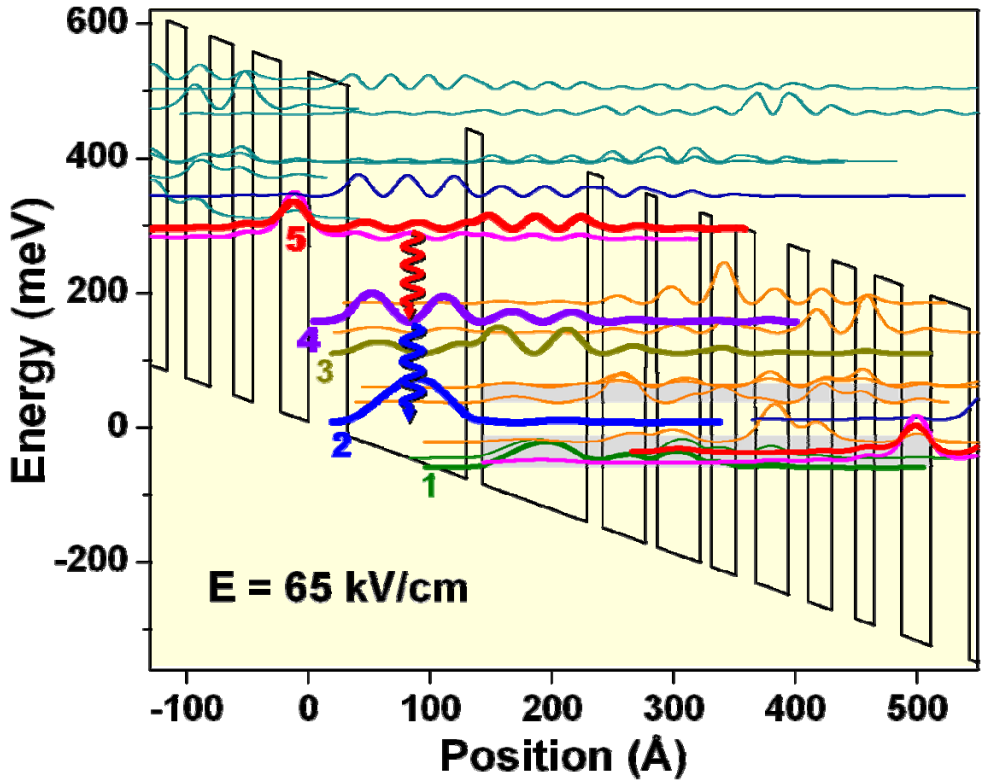


J. Faist, F. Capasso, C. Sirtori, D.L. Sivco, A.L. Hutchinson, M.S. Hybertsen, and A.Y. Cho "Quantum cascade lasers without intersubband population inversion," *Phys. Rev. Lett.* **76** 411 (1996).

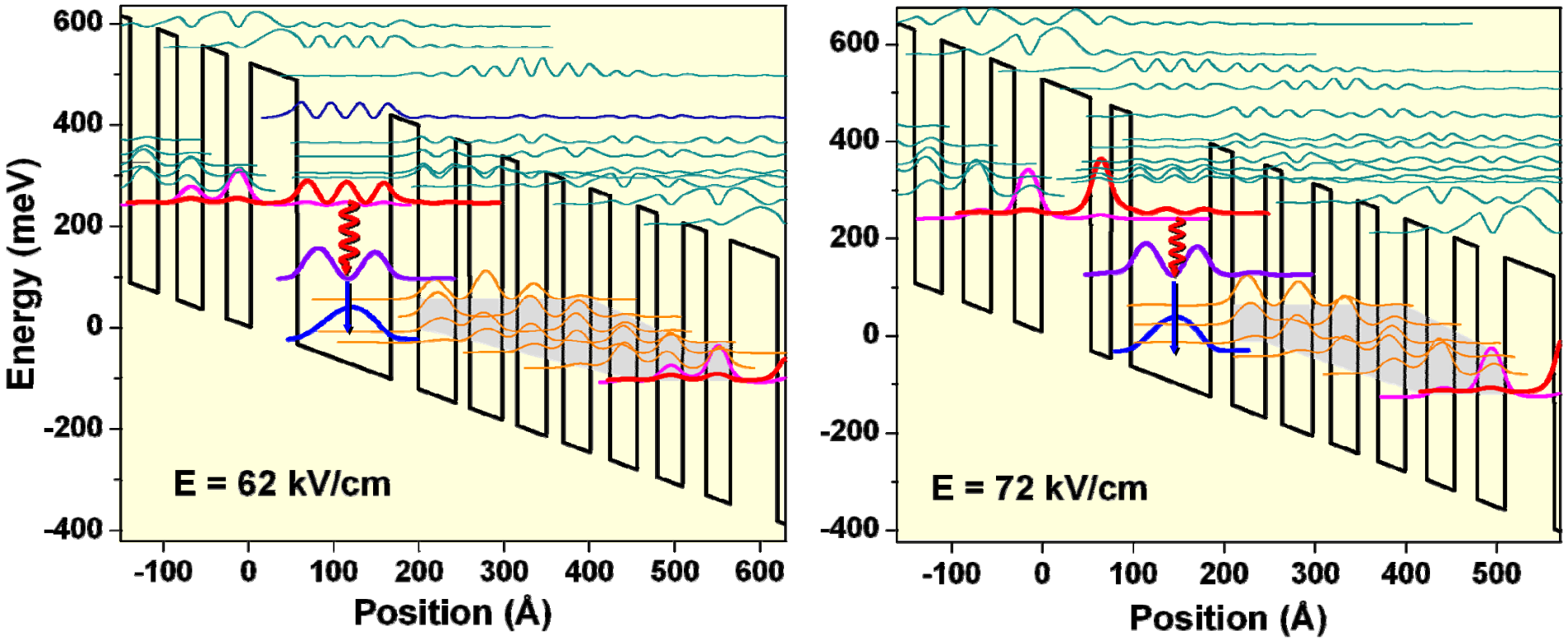
Summary

Appl. Phys. Lett. **90** 091104 (2007)

- Excited state transitions: a strategy to lower threshold currents
- Cascaded emission in semiconductor lasers
  - Injector design important
  - Cannot always neglect other scattering mechanisms
- Acknowledgements
  - MIRTHE (NSF-ERC)
  - DARPA L-PAS
  - PCCM (NSF-MRSEC)
  - NSF Graduate Research Fellowship Program



Cascaded Emission



C. Sirtori, A. Tredicucci, F. Capasso, J. Faist, D.L. Sivco, A.L. Hutchinson, and A.Y. Cho, "Dual-wavelength emission from optically cascaded intersubband transitions," *Opt. Lett.* **23** 463 (1998).