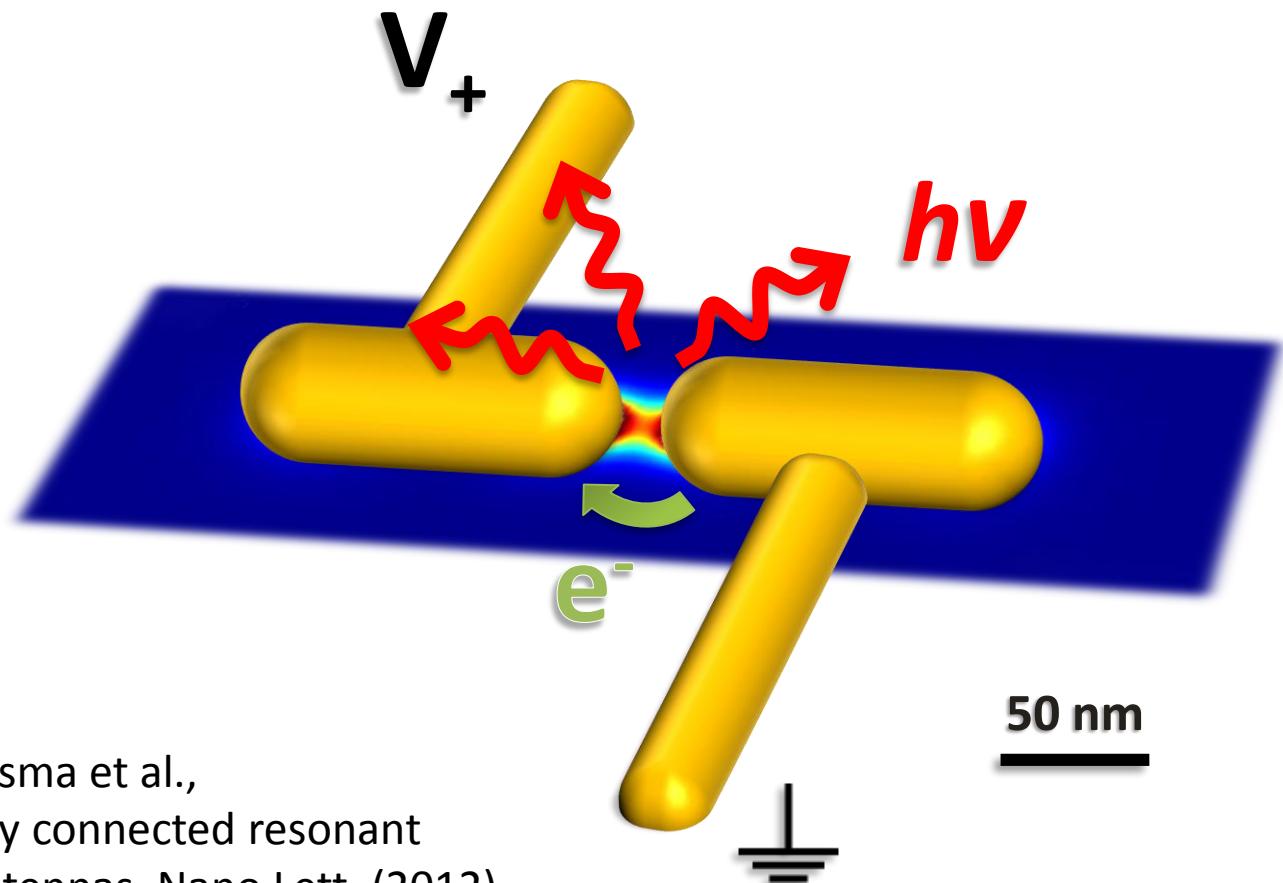


Electrically-Driven Optical Antennas



J.C. Prangsma et al.,
Electrically connected resonant
optical antennas, Nano Lett. (2012)

50 nm

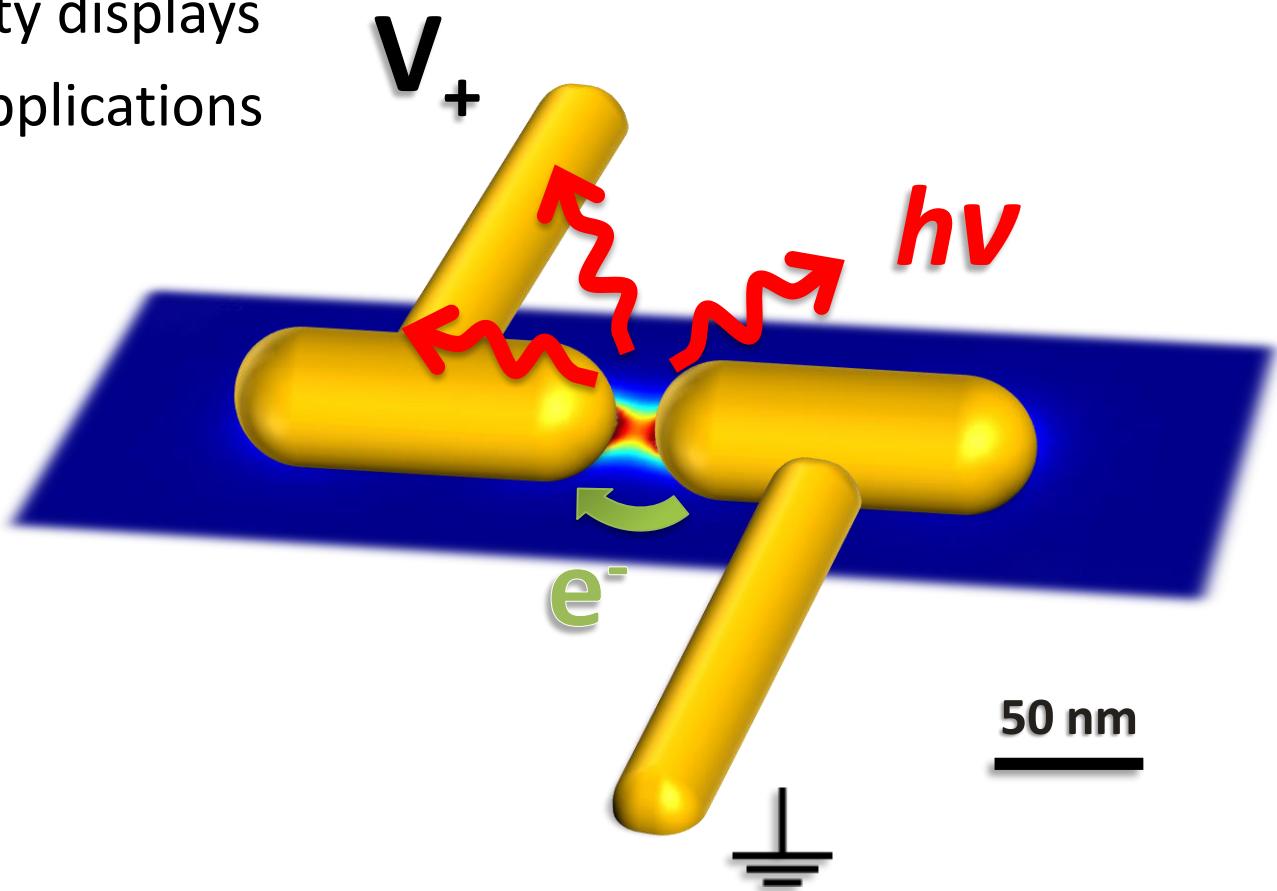
René Kullock, Johannes Kern, Jord Prangsma and Bert Hecht

Motivation

On-chip data communication

Ultra-high density displays

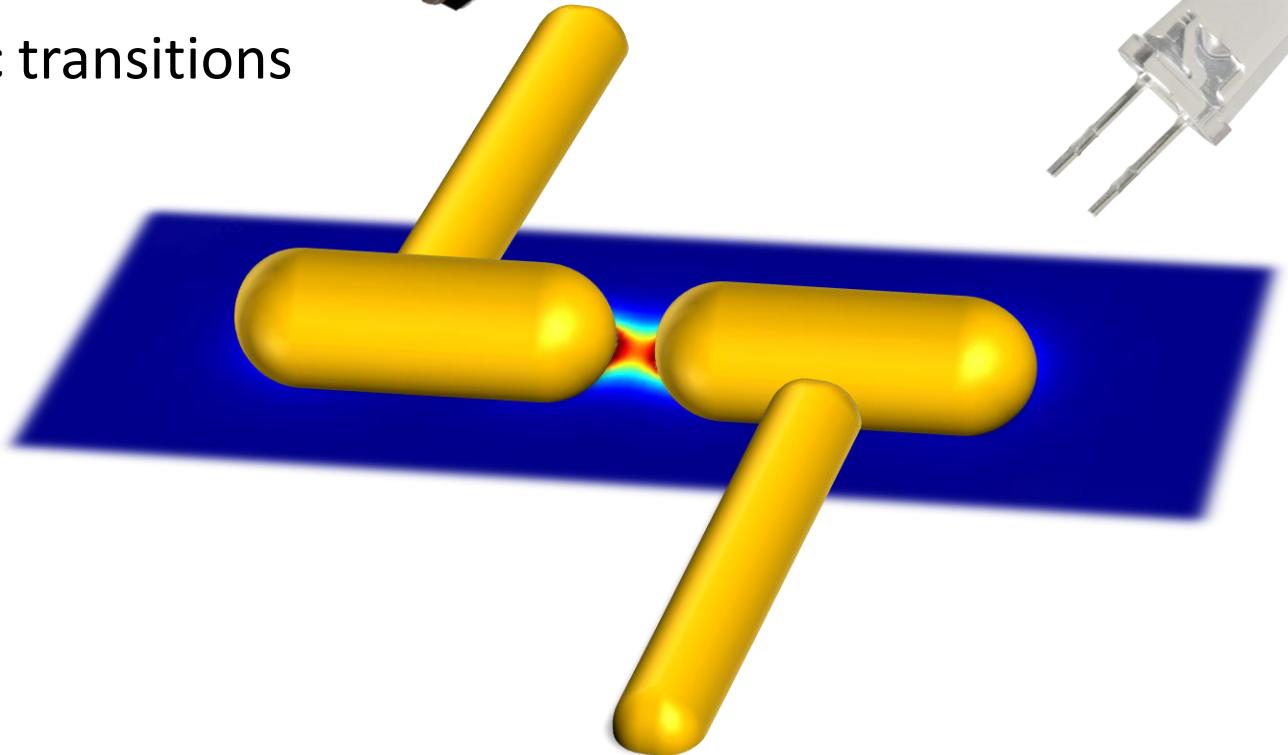
Spectroscopic applications



How to Generate Light?

Processes:

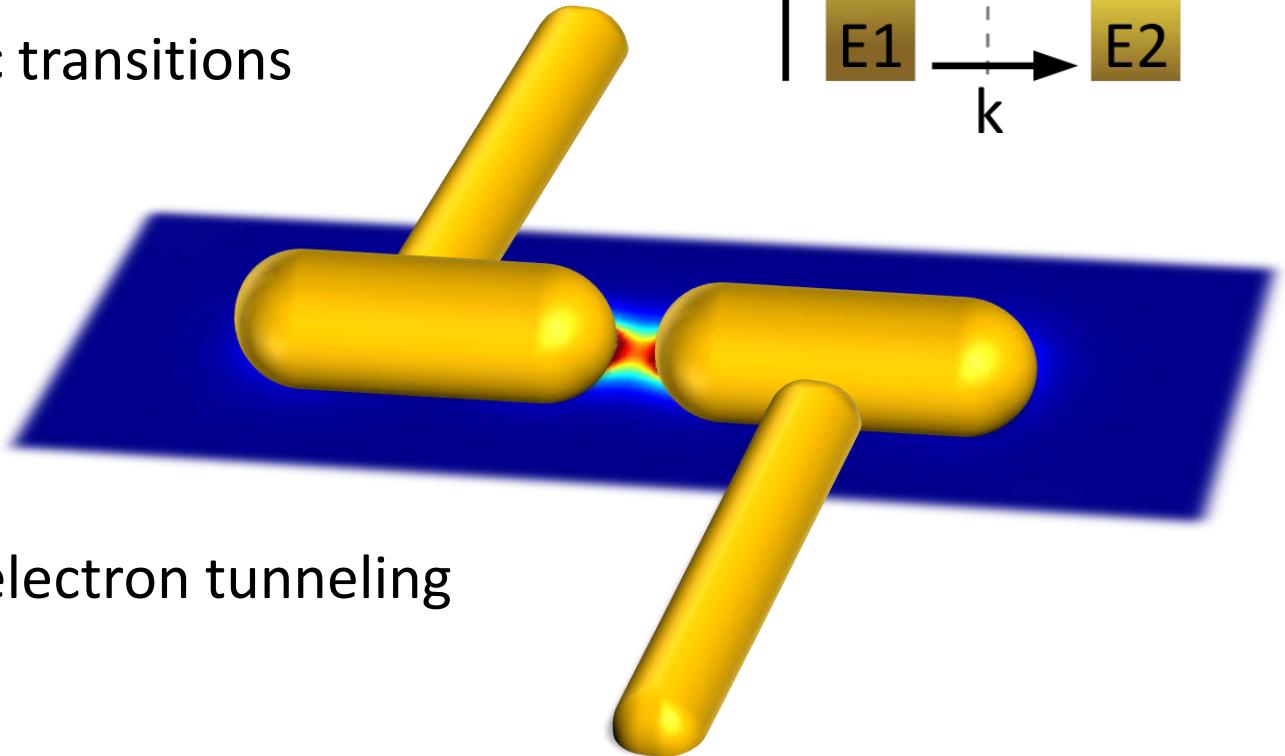
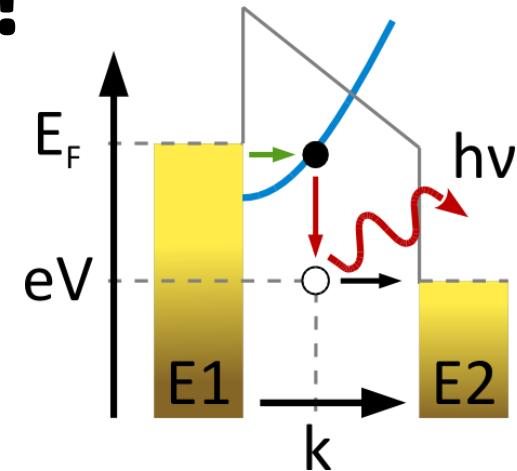
- thermal
- electronic transitions



How to Generate Light?

Processes:

- thermal
- electronic transitions



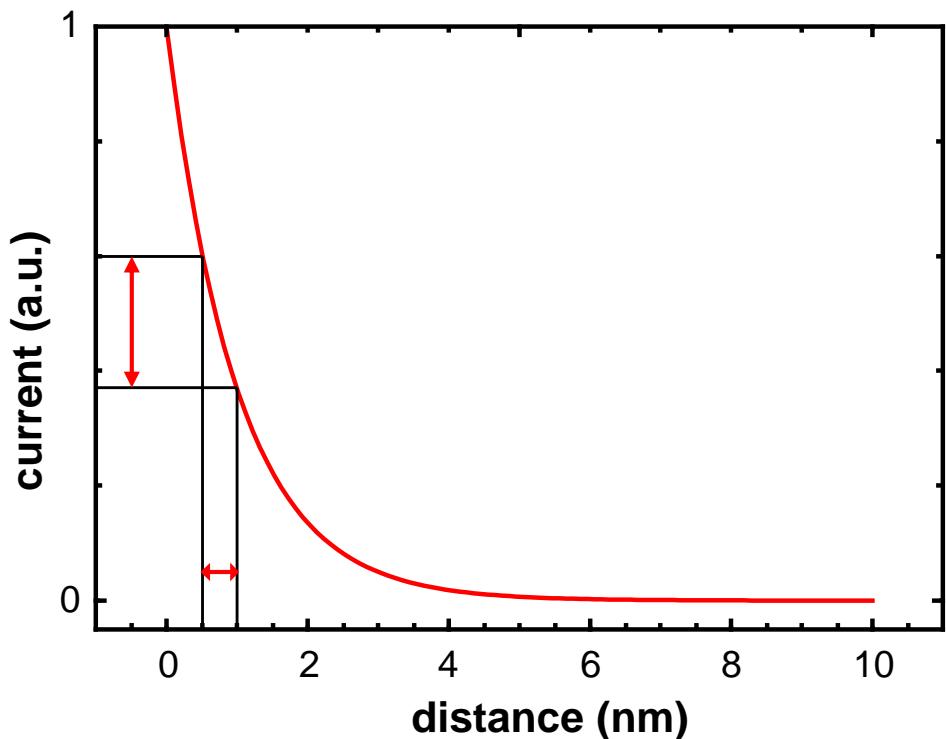
- Inelastic electron tunneling

-> “Just” a tunnel gap is needed

Fabrication of the Tunnel Gap

Requirements:

- 1-3 nm gap width
- Atomic-scale stability



Fabrication of the Tu

Requirements:

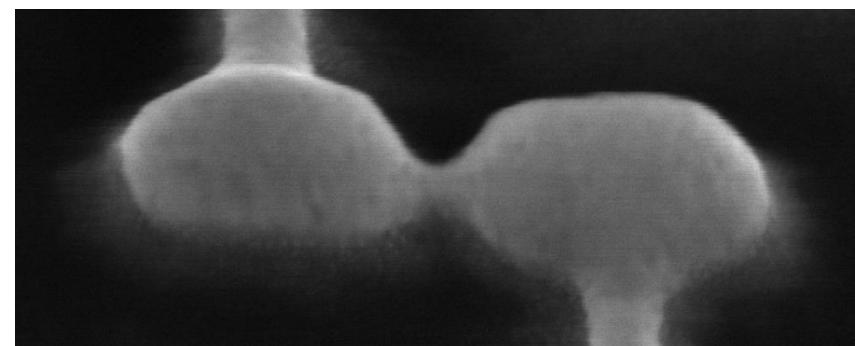
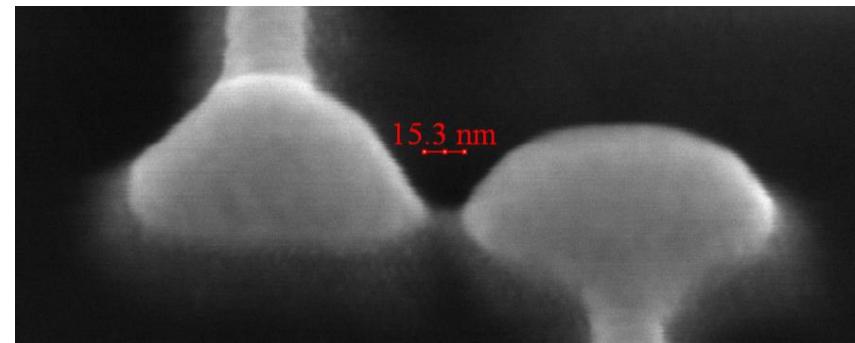
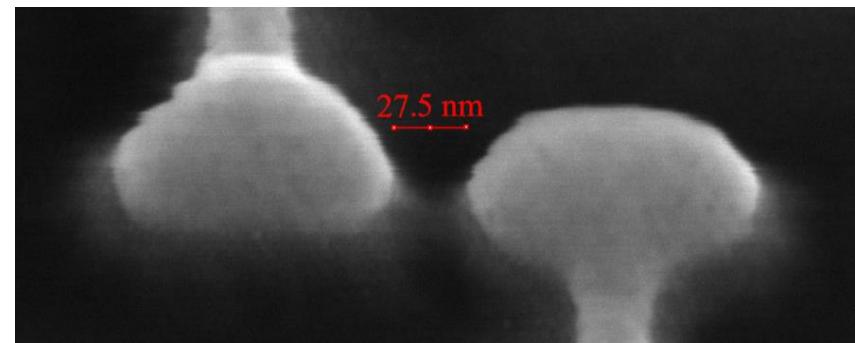
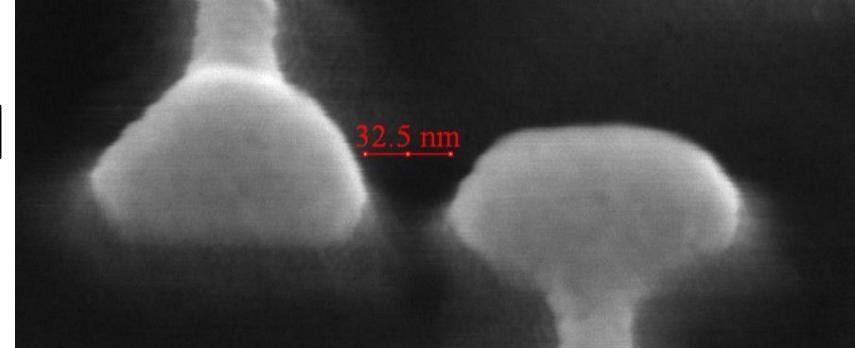
- 1-3 nm gap width
- Atomic-scale stability

Ga-Ion Focused Ion Beam Milling:

- Single-crystalline gold flakes
- Resolution limit around 15 nm
- Leakage currents

Solution:

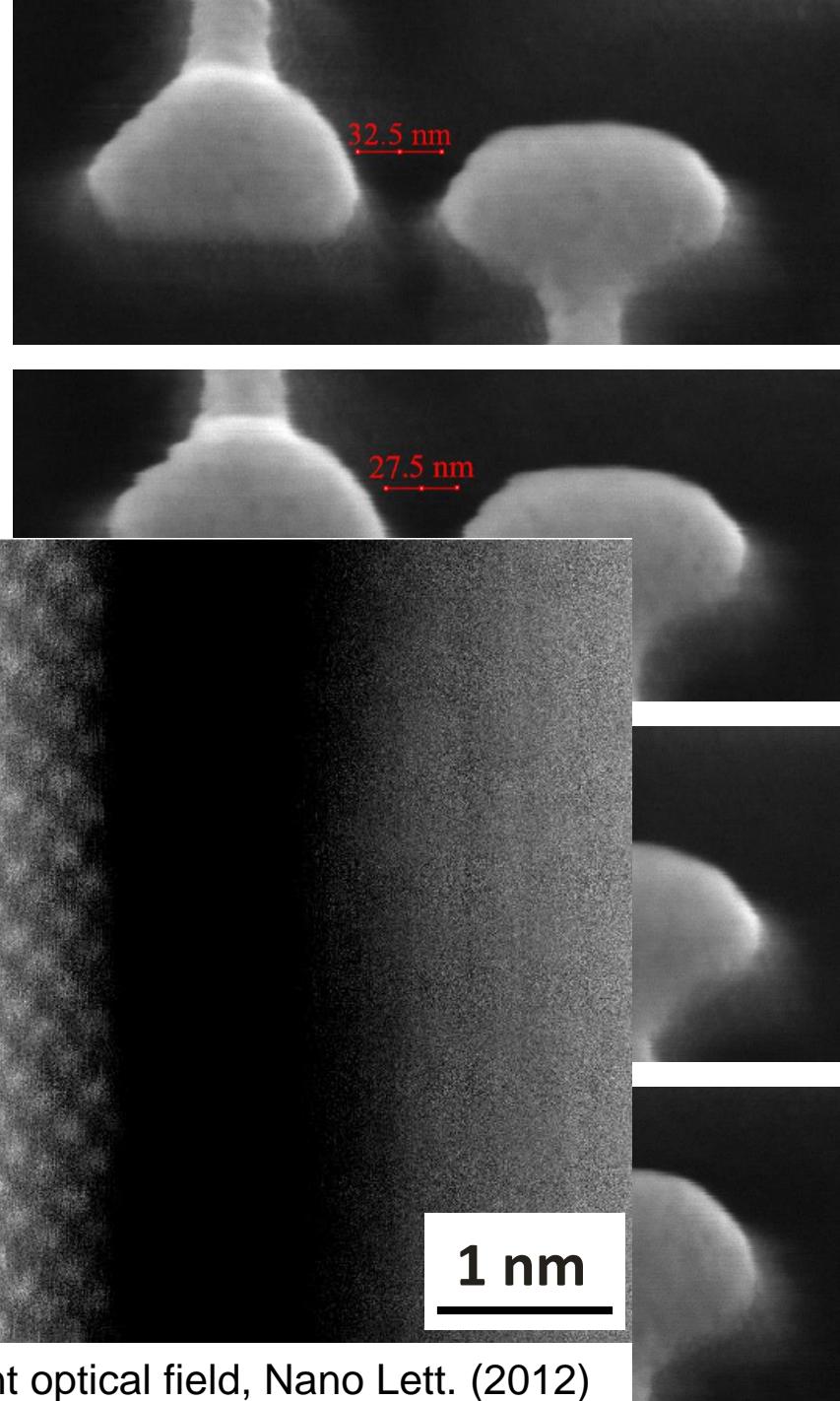
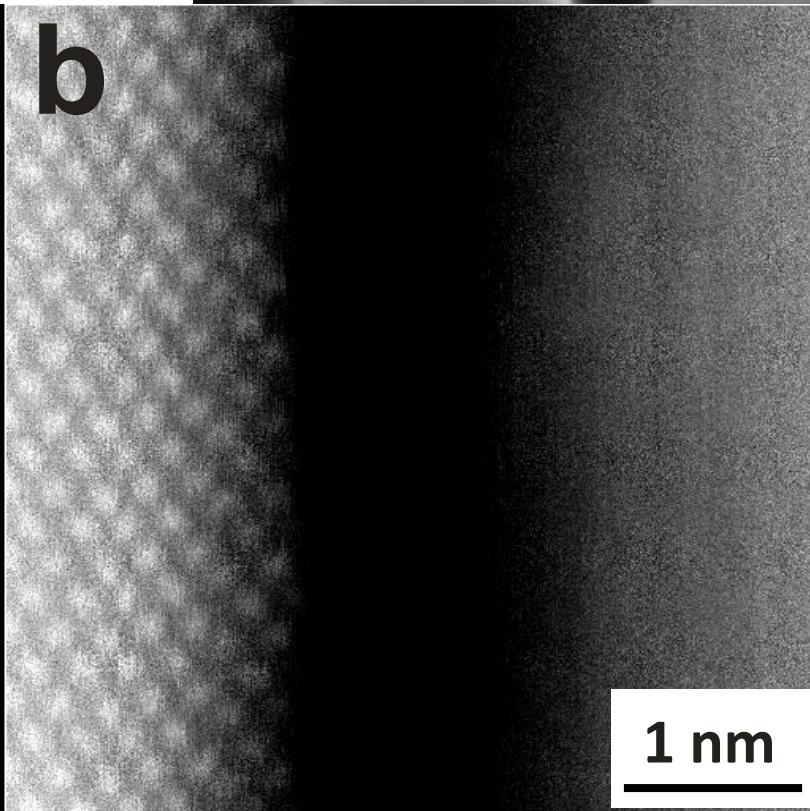
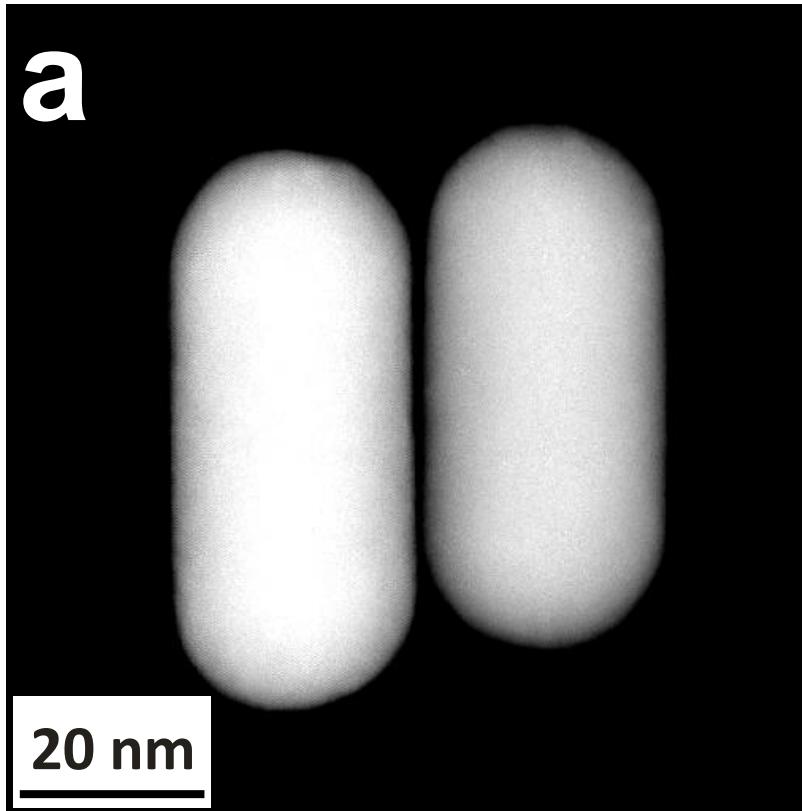
- Stable 1-nm gaps for CTAB decorated nanoparticles



Fabrication of the Tu

Requirements:

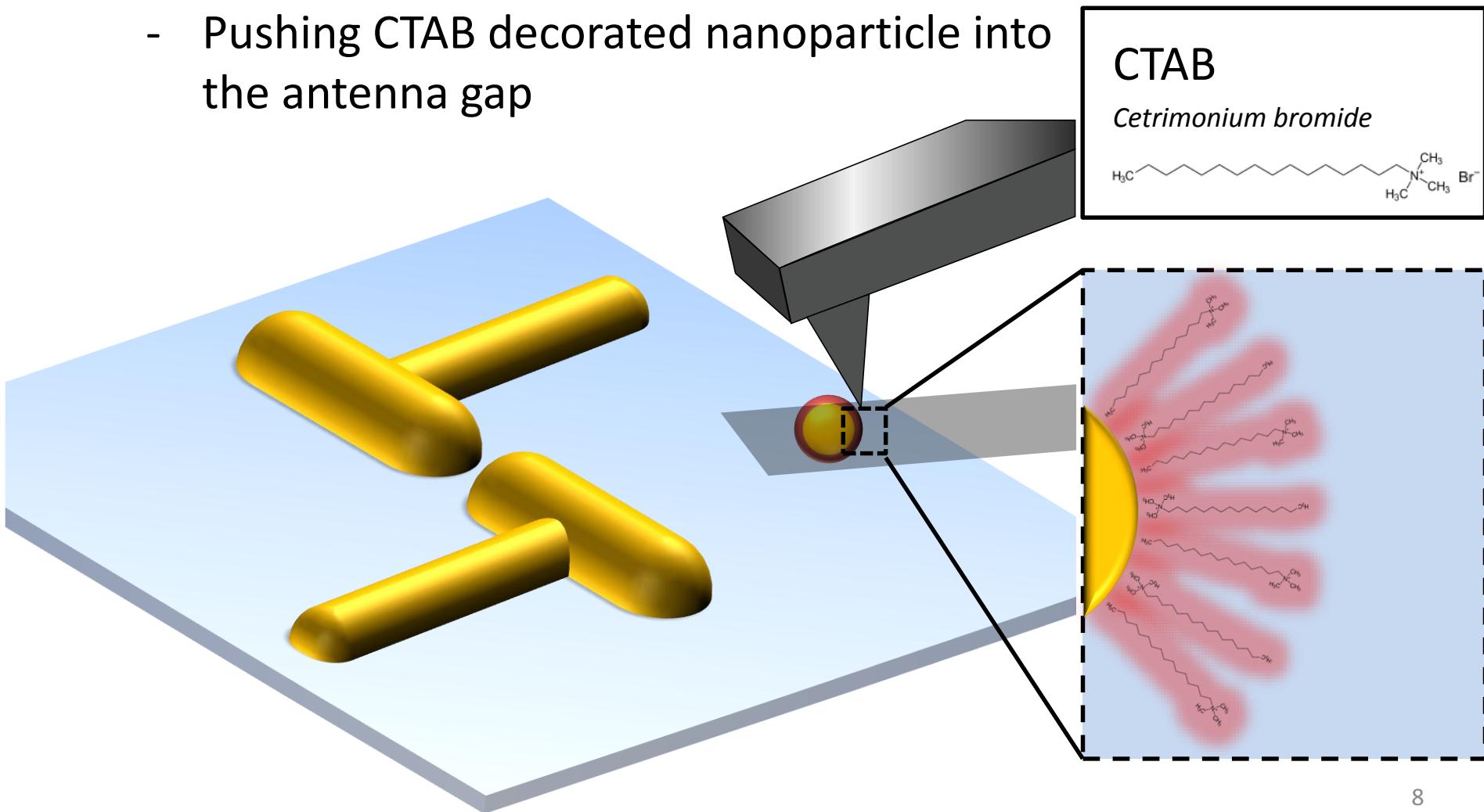
- 1-3 nm gap width
- Atomic-scale stability



Fabrication of the Tunnel Gap

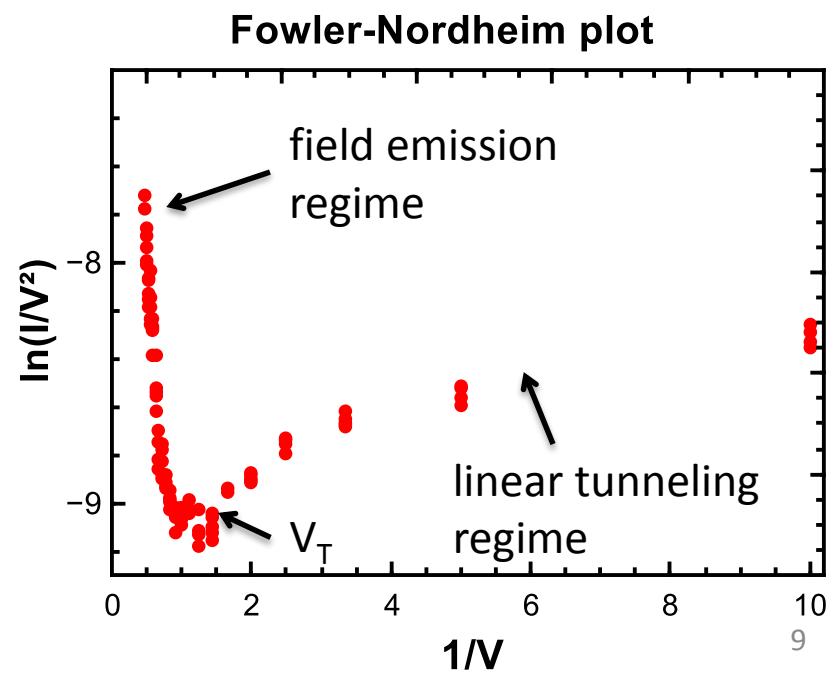
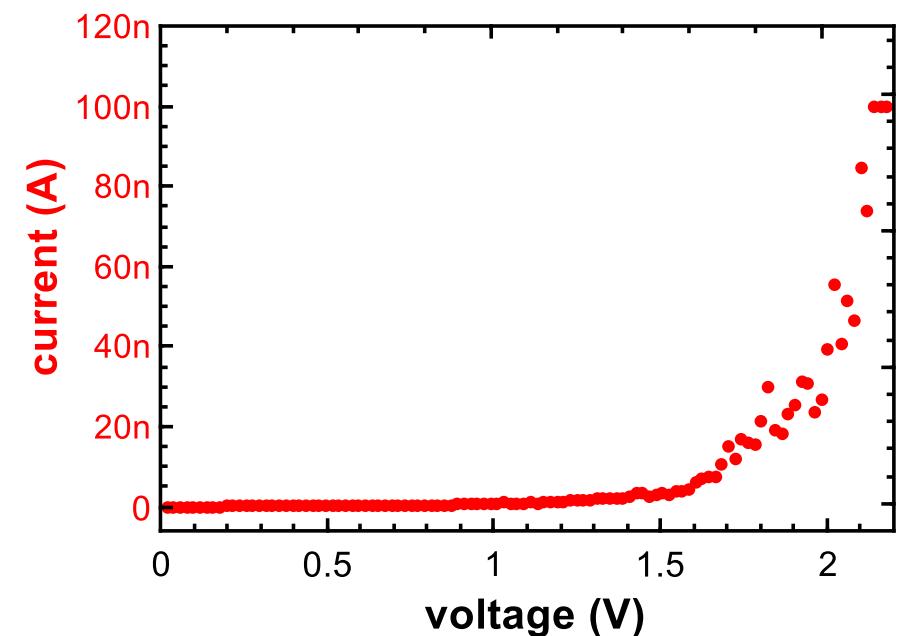
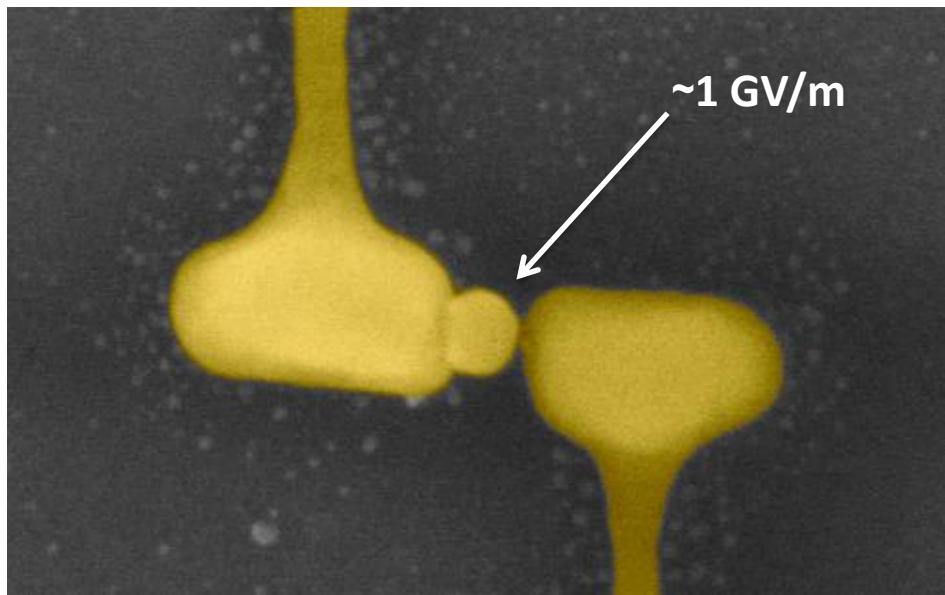
New Approach:

- Pushing CTAB decorated nanoparticle into the antenna gap



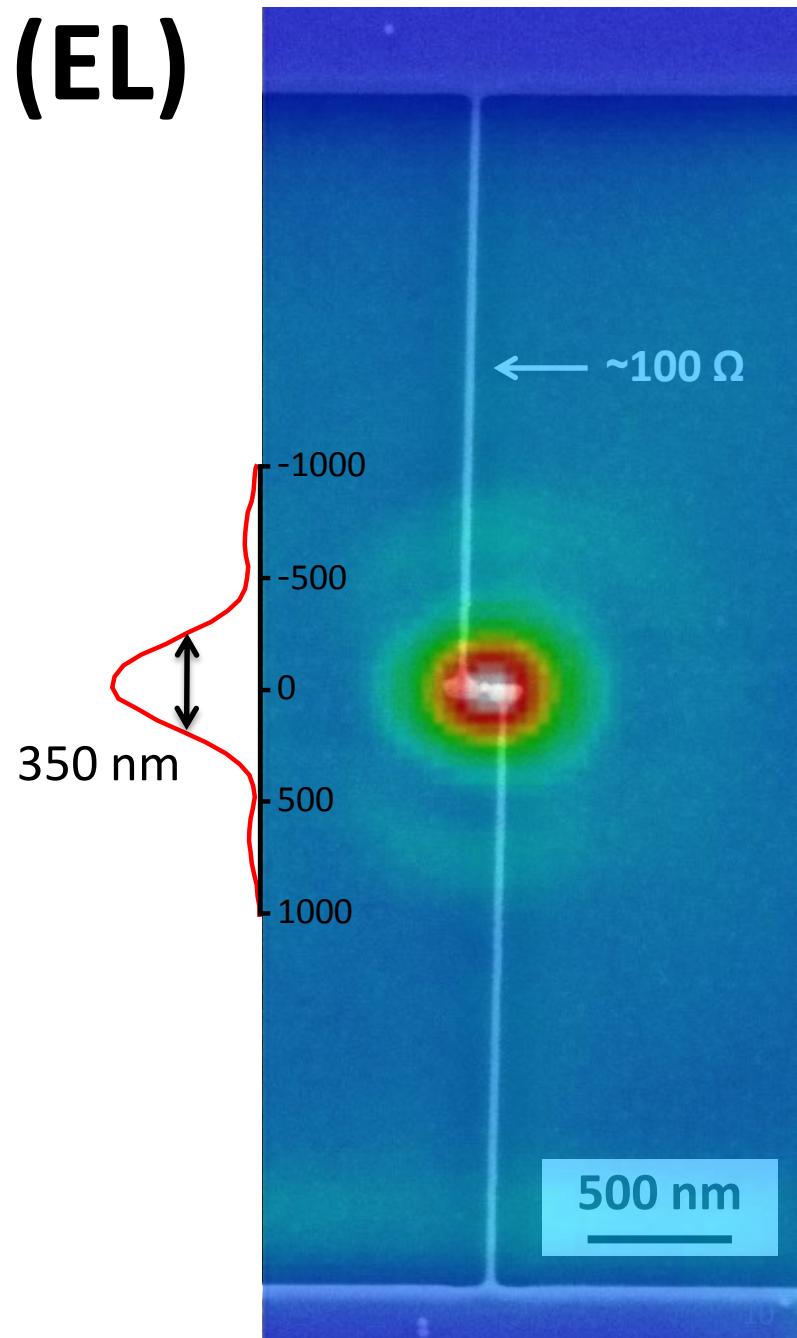
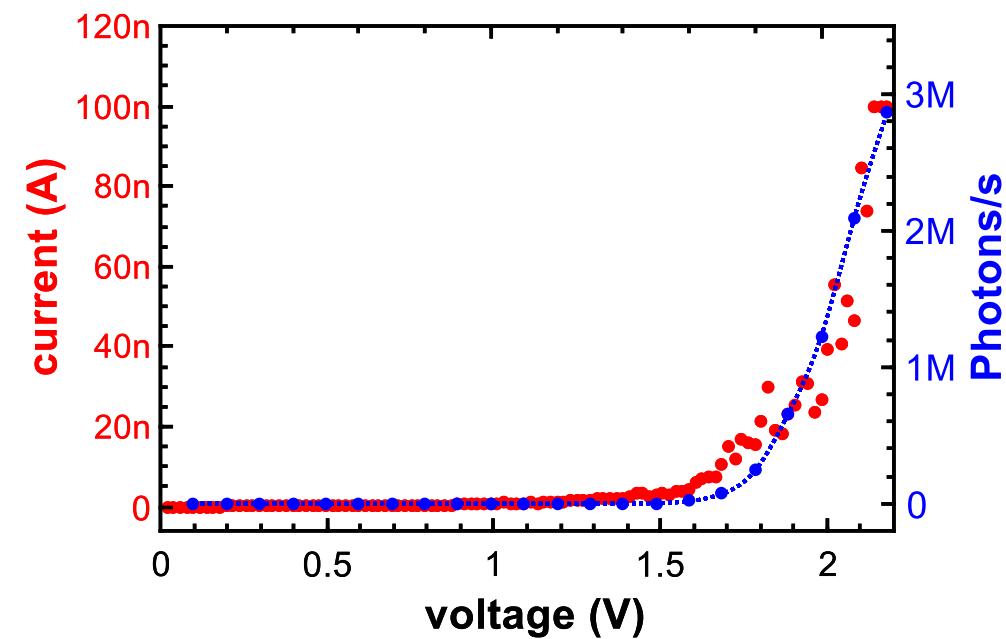
Results

- Nanometer-scale gap formed
 - Tunneling characteristics
 - Particle positioned asymmetrically
- > only one significant contact



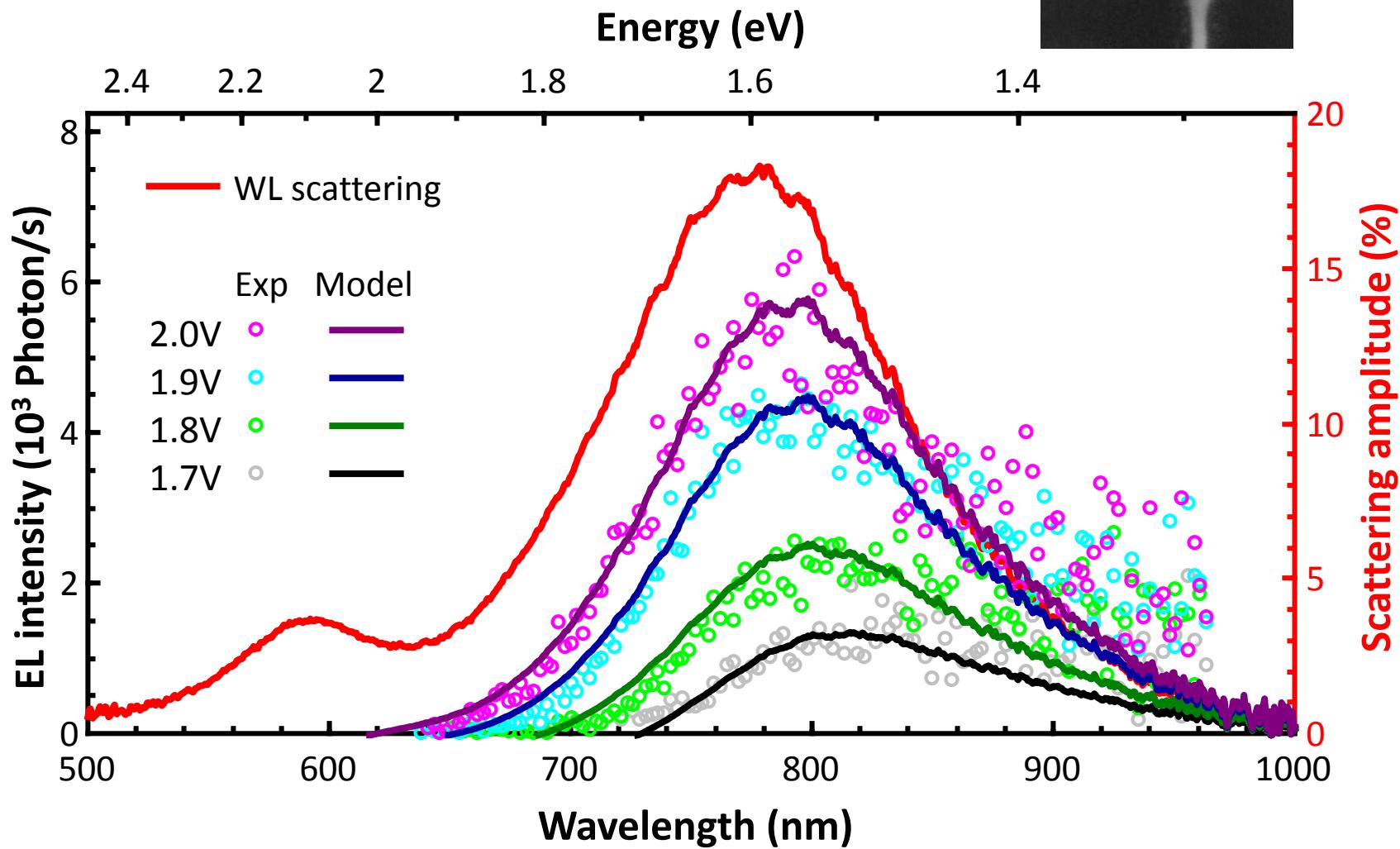
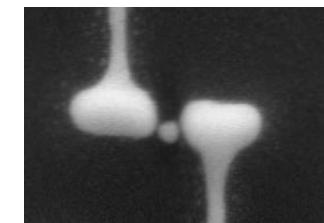
Electroluminescence (EL)

- Light detected: 500...1000 nm
 - Typical spot sizes: 300...400 nm
- > Electrically-driven point source!



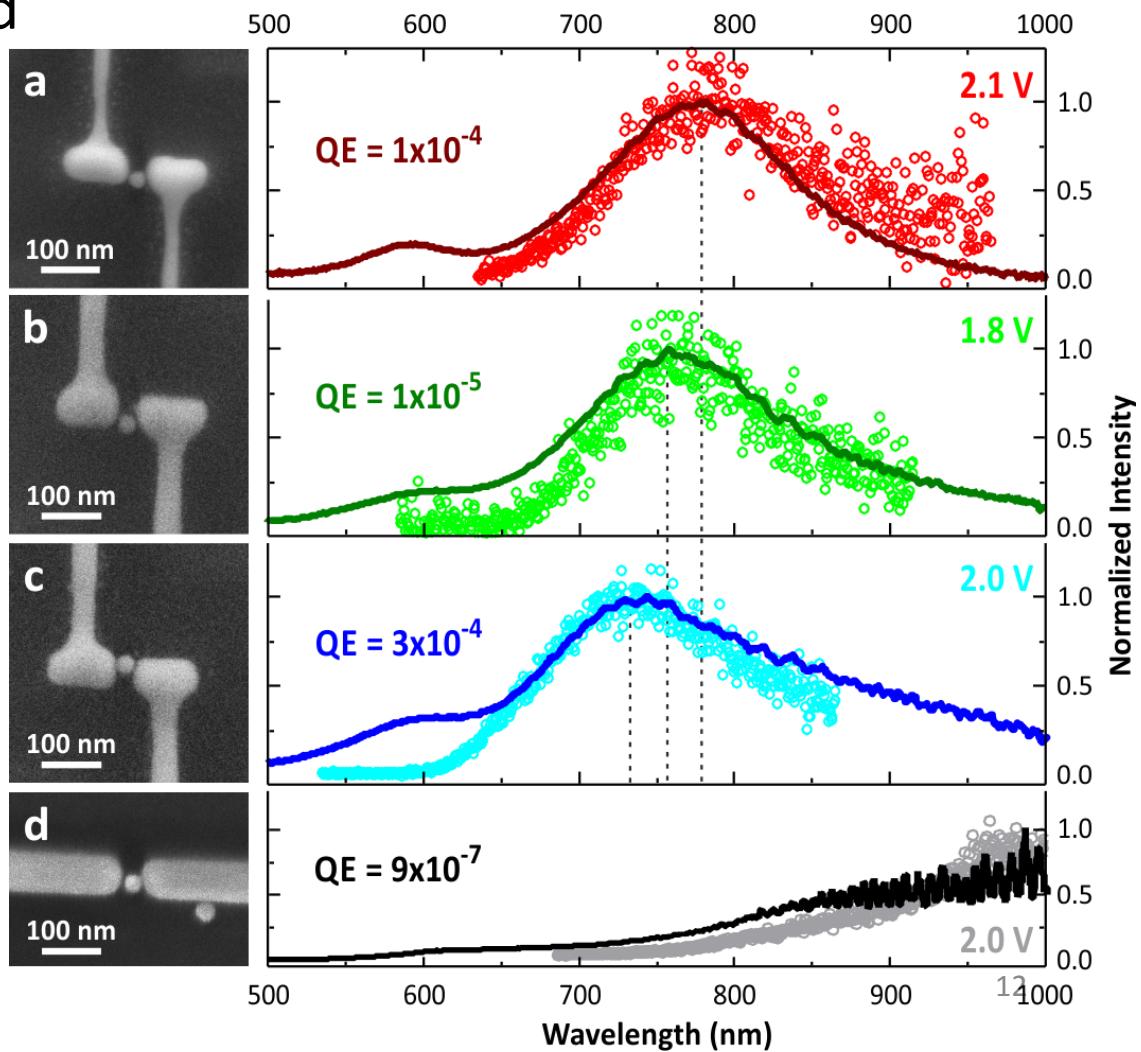
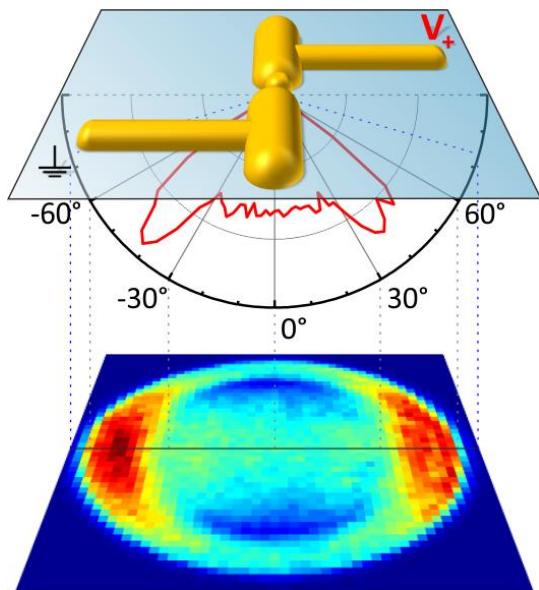
Influence of the Antenna

- EL is shaped by the antenna resonance



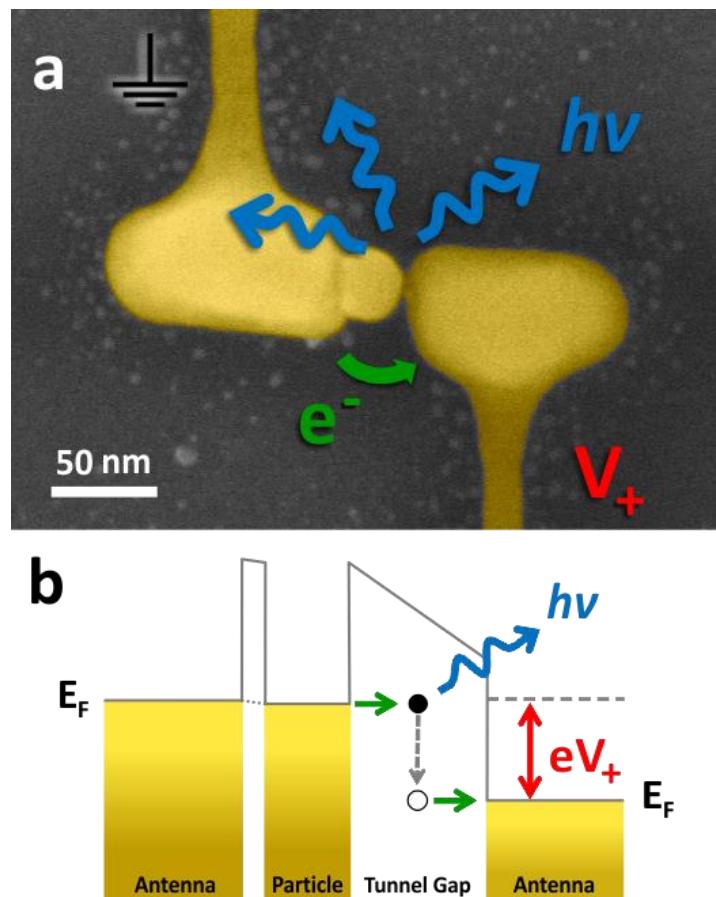
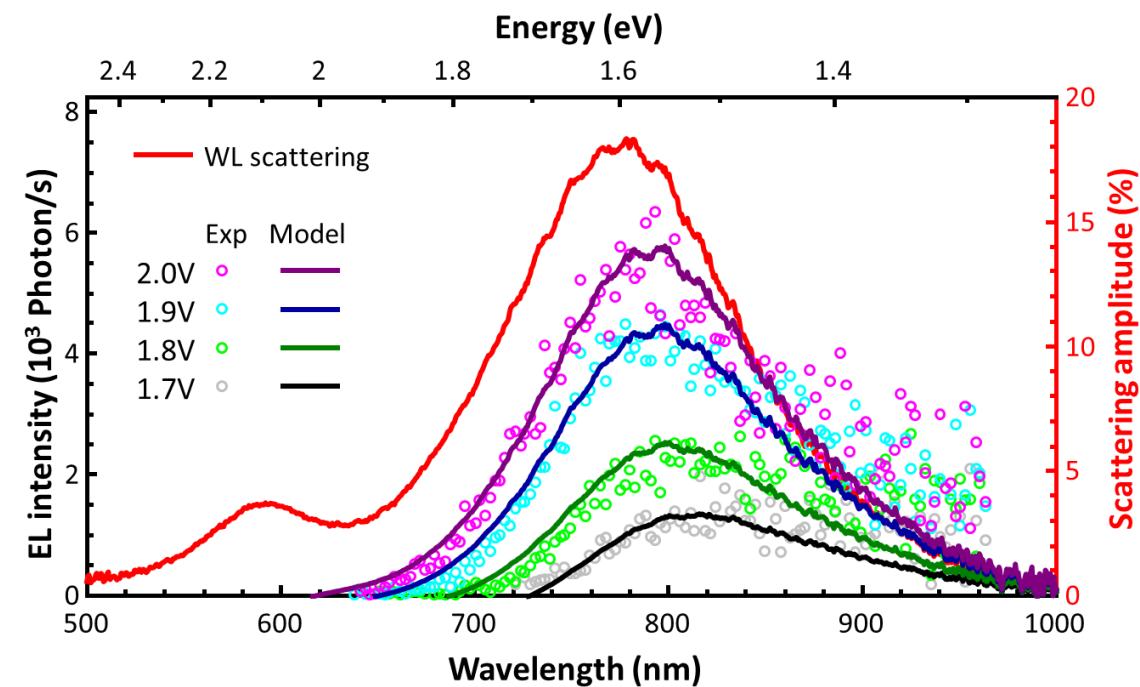
Influence of the Antenna

- EL is shaped by the antenna resonance
- QE up to 100x enhanced
- Polarized emission
- Dipolar emission pattern

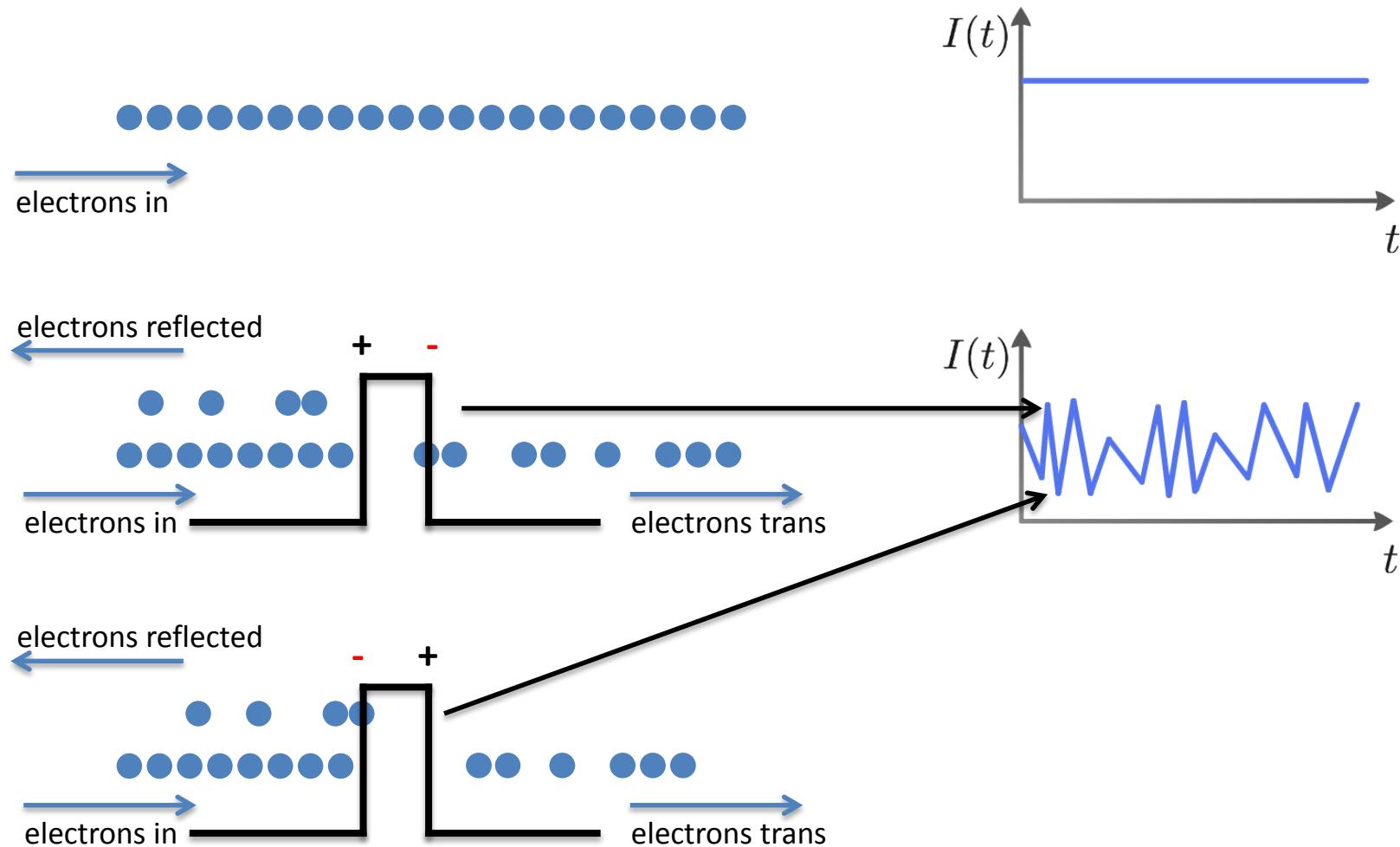


Modelling?

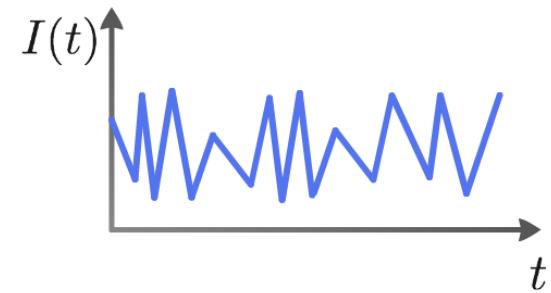
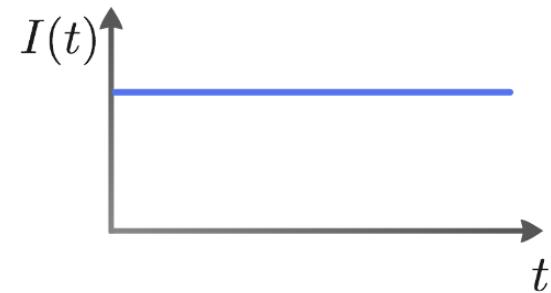
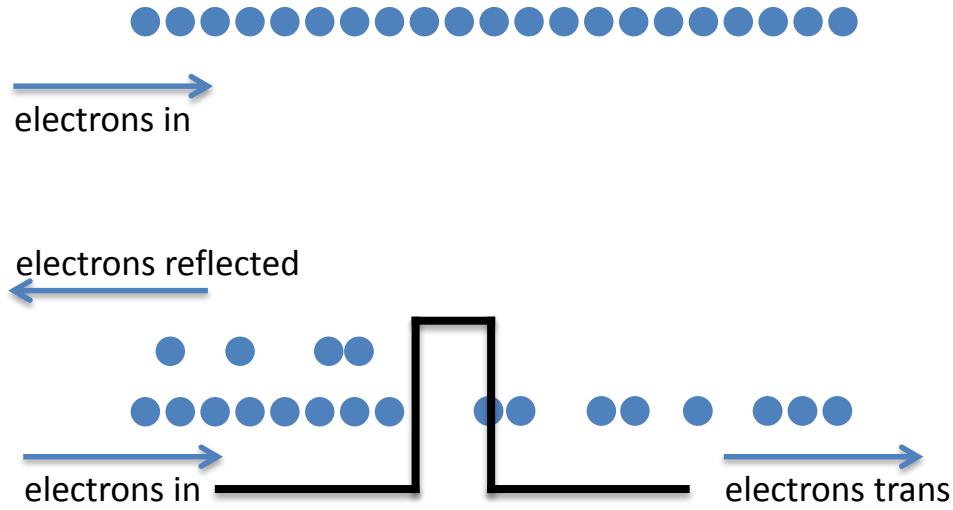
- How to understand the light-emission process?
- And the spectral shift?



Modelling: Quantum shot noise



Modelling: Quantum shot noise



current power spectrum:

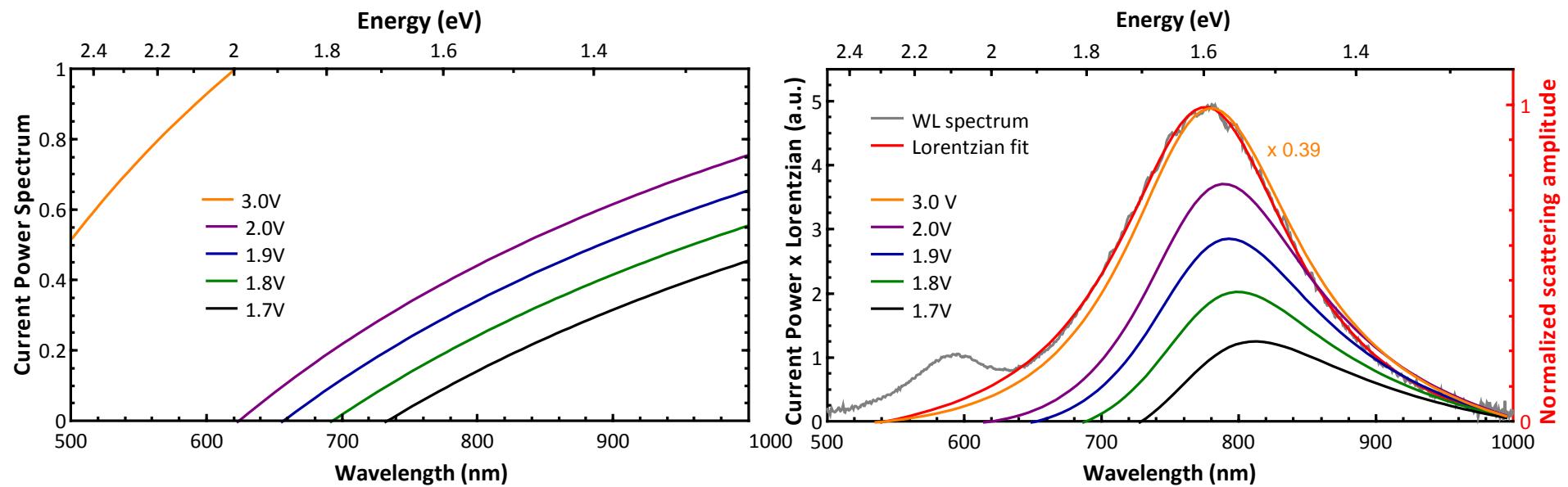
$$C(\omega) = \frac{eV}{2\pi R_0} \left(1 - \frac{\hbar\omega}{eV} \right)$$

Hone, Mühlschlegel, and Scalapino, Appl. Phys. Lett. **33**, 203 (1978).

P. Johansson, Physical Review B **58**, 10823 (1998).

Schneider, Schull, and Berndt, Phys. Rev. Lett. **105**, 026601 (2010).

Modelling: Quantum shot noise



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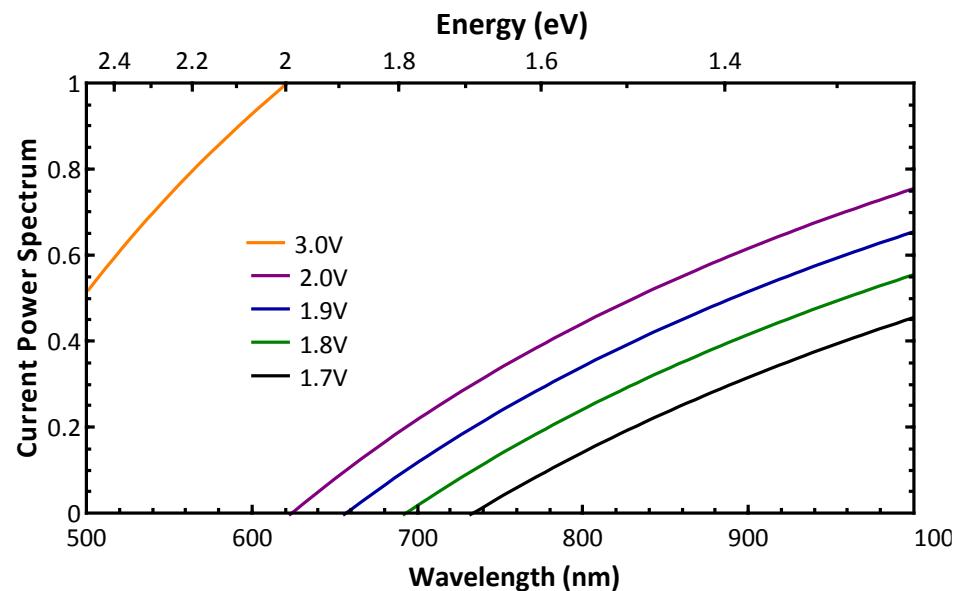
$$I(\omega) = A(\omega)C(\omega)$$

Hone, Mühlsgel, and Scalapino, Appl. Phys. Lett. **33**, 203 (1978).

P. Johansson, Physical Review B **58**, 10823 (1998).

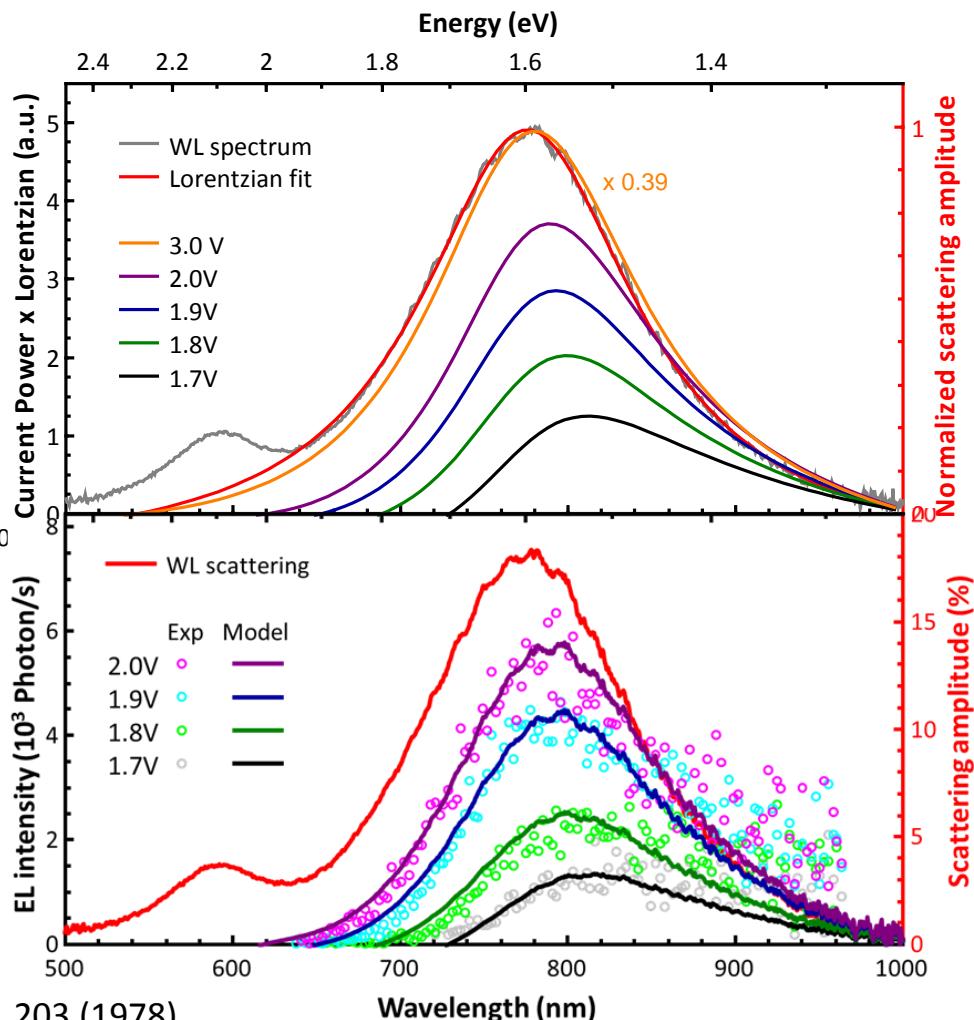
Schneider, Schull, and Berndt, Phys. Rev. Lett. **105**, 026601 (2010).

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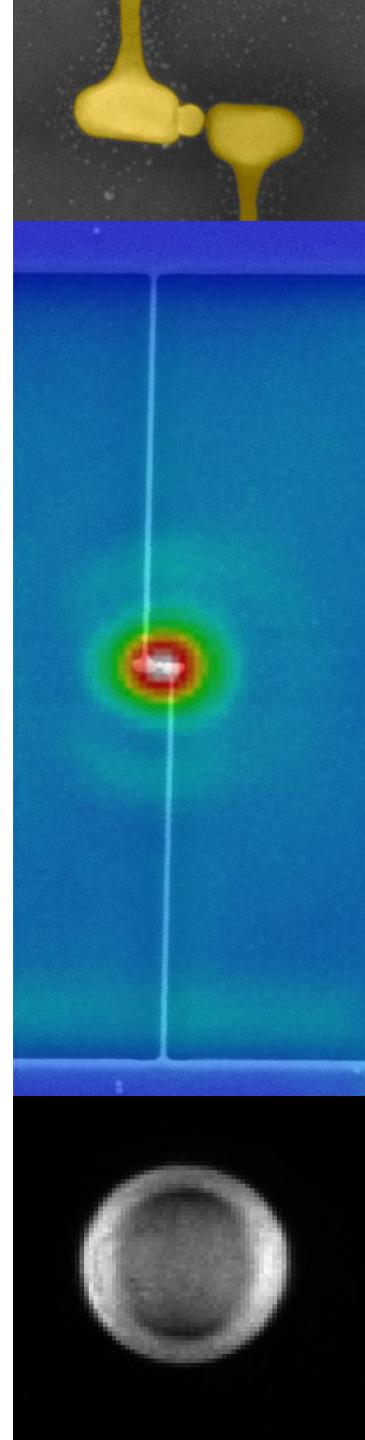
Schneider, Schull, and Berndt, Phys. Rev. Lett. **105**, 026601 (2010).

Conclusion

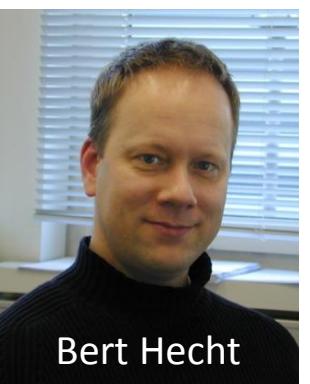
- Built an electrically-driven subwavelength light source
- Connected nanoantenna + functionalized particle
- Light emission governed by the antenna
- QE enhanced by up to 100x
- Quantum shot noise

Outlook

- Directed emission via Yagi-Uda antennas
- Improve stability, QE, ...
- Launch propagating plasmons
- Usable for field-induced non-linearity



Acknowledgements



Bert Hecht



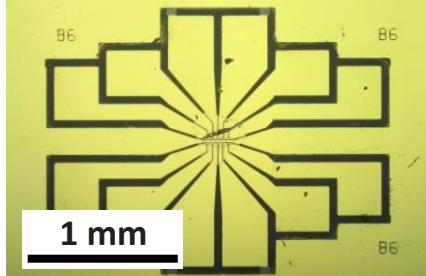
Johannes Kern



Jord Prangsma

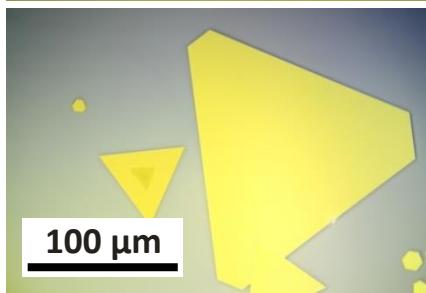
Electrode Structures Monika Emmerling

Flake Transfer Heiko Groß

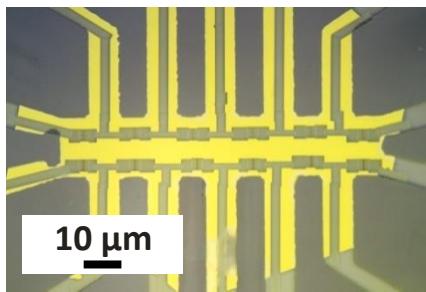


Flake Growth Xiaofei Wu

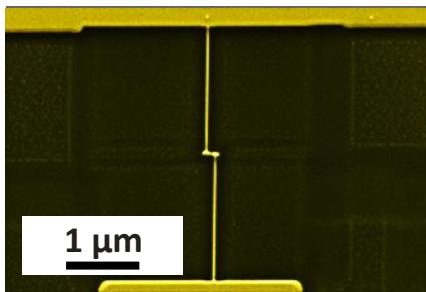
Enno Krauss



FIB Provider Martin Kamp

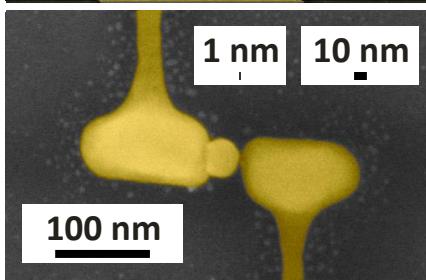


Connected Antennas Jord Prangsma



Pushing Johannes Kern

Optics Swen Großmann



kullock@physik.uni-wuerzburg.de

