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Bottom-up Nanostructures – just a research hype?

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Dresden, 22.09.2017

Pd “Coaly flower”

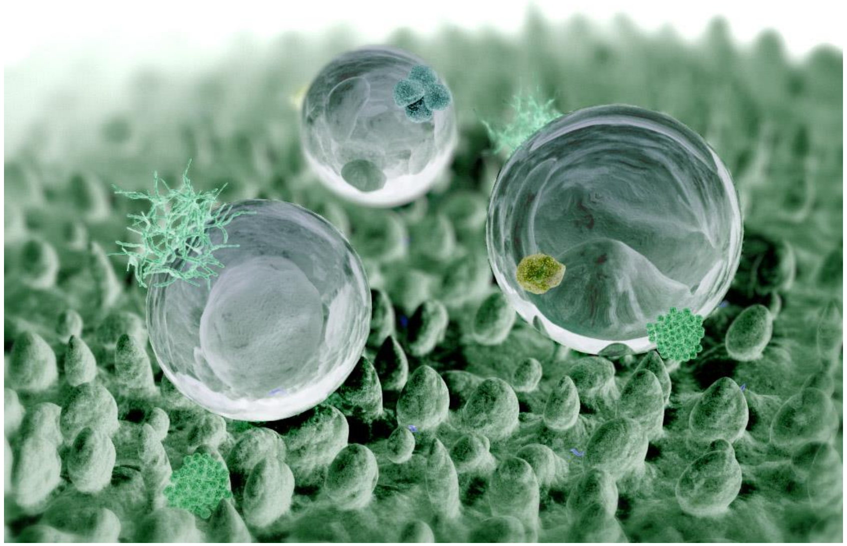
Why (bottom-up) Nano?

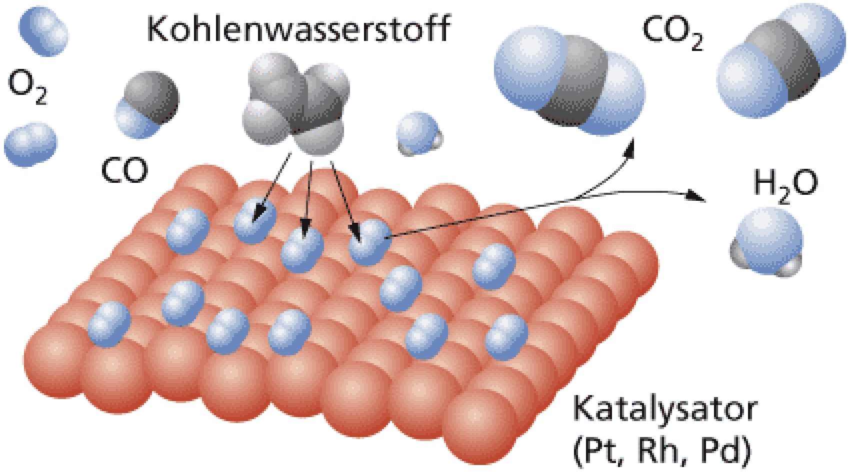
Today's applications of nanotechnology

Zinc-Oxide Nanoparticles → UV light diffraction

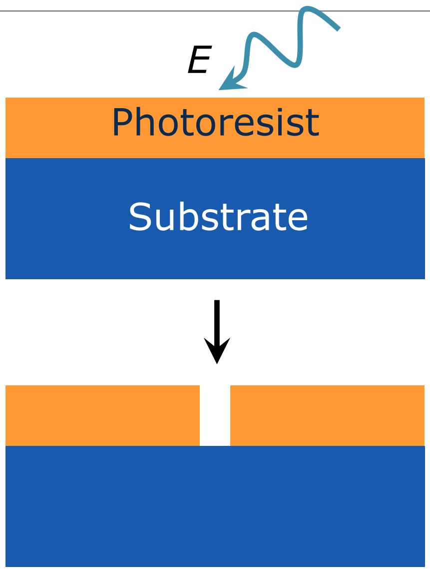
Lotos effect (paint, cars…)

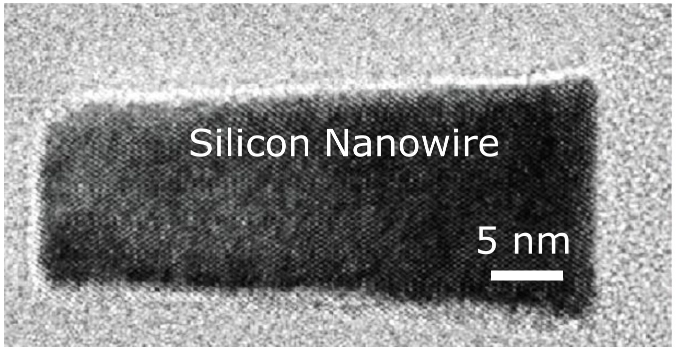
Catalyst





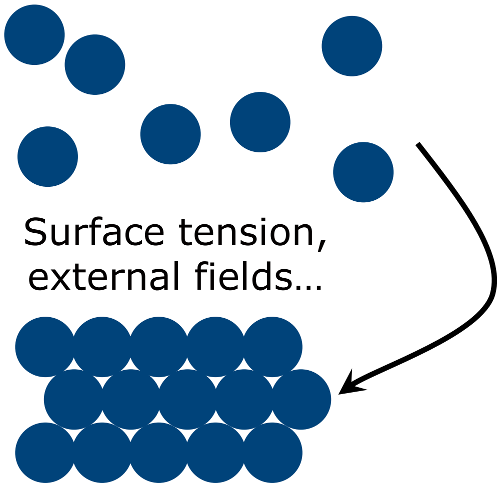
Top-Down vs. Bottom-Up

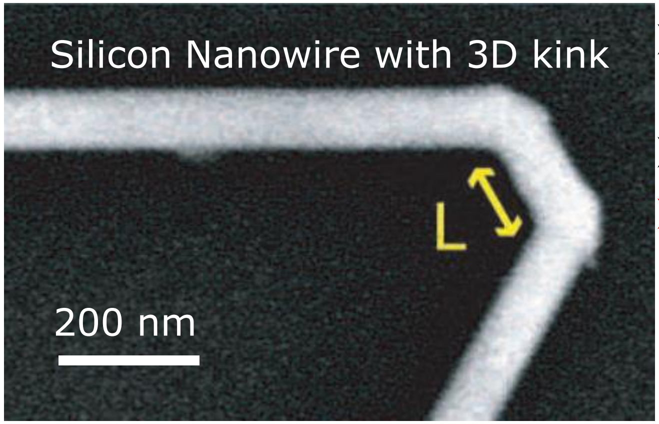




R. G. Hobbs *et al*. *Chem. Mater.* **24**, 1975 (2012)

- Well defined, integrated structures
- For < 500 nm: relatively expensive equipment (*e.g.* e-beam lithography)





B. Tian *et al*. *Science* **329**, 830 (2010)

- Relatively well defined structures
- 3D structures feasible
- Hard to integrate into microcircuits

Content

1. **(Example for) Fabrication of Metal Nanowires**

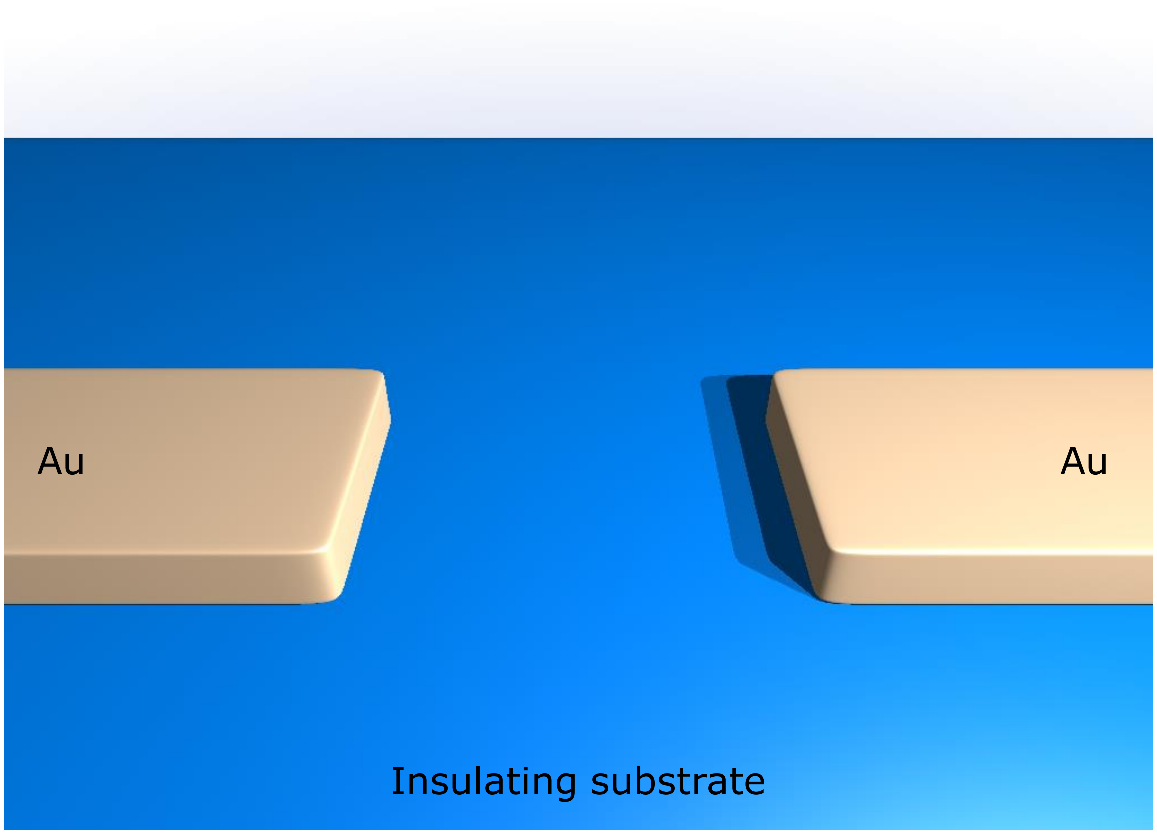
2. **(Example for) Metal Nanowire Sensor Application**

3. **(Example for) Silicon Nanowire Sensor Application**

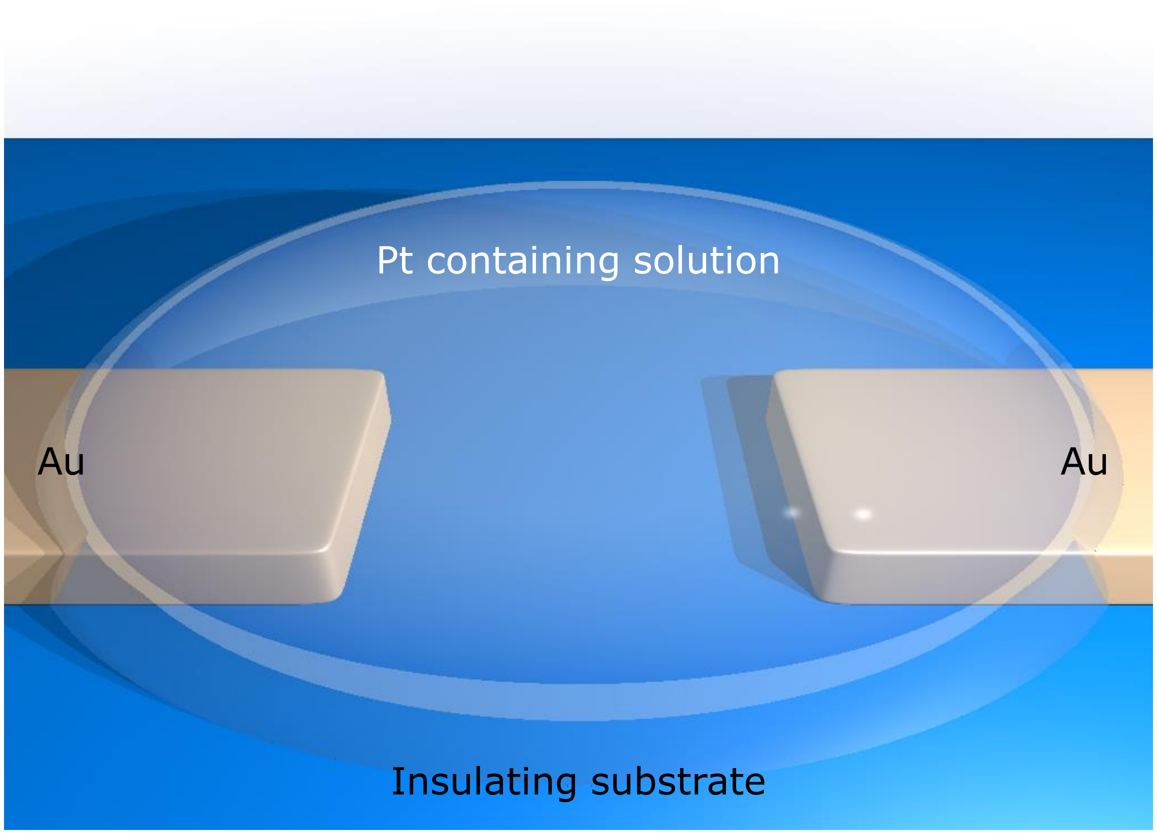
4. **Conclusion & Outlook**

1. Fabrication of Metal Nanowires

Combining bottom-up and top-down

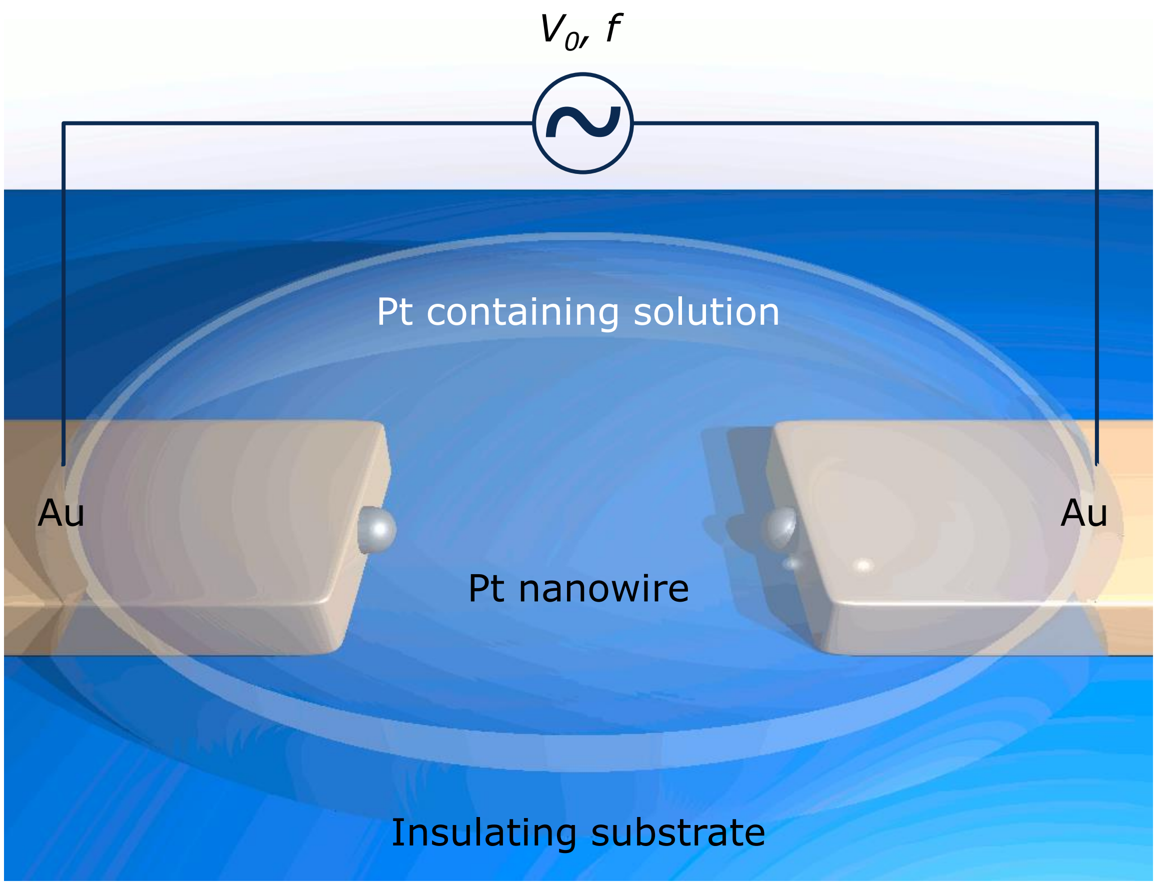


Combining bottom-up and top-down



1. Fabrication of Metal Nanowires

Combining bottom-up and top-down

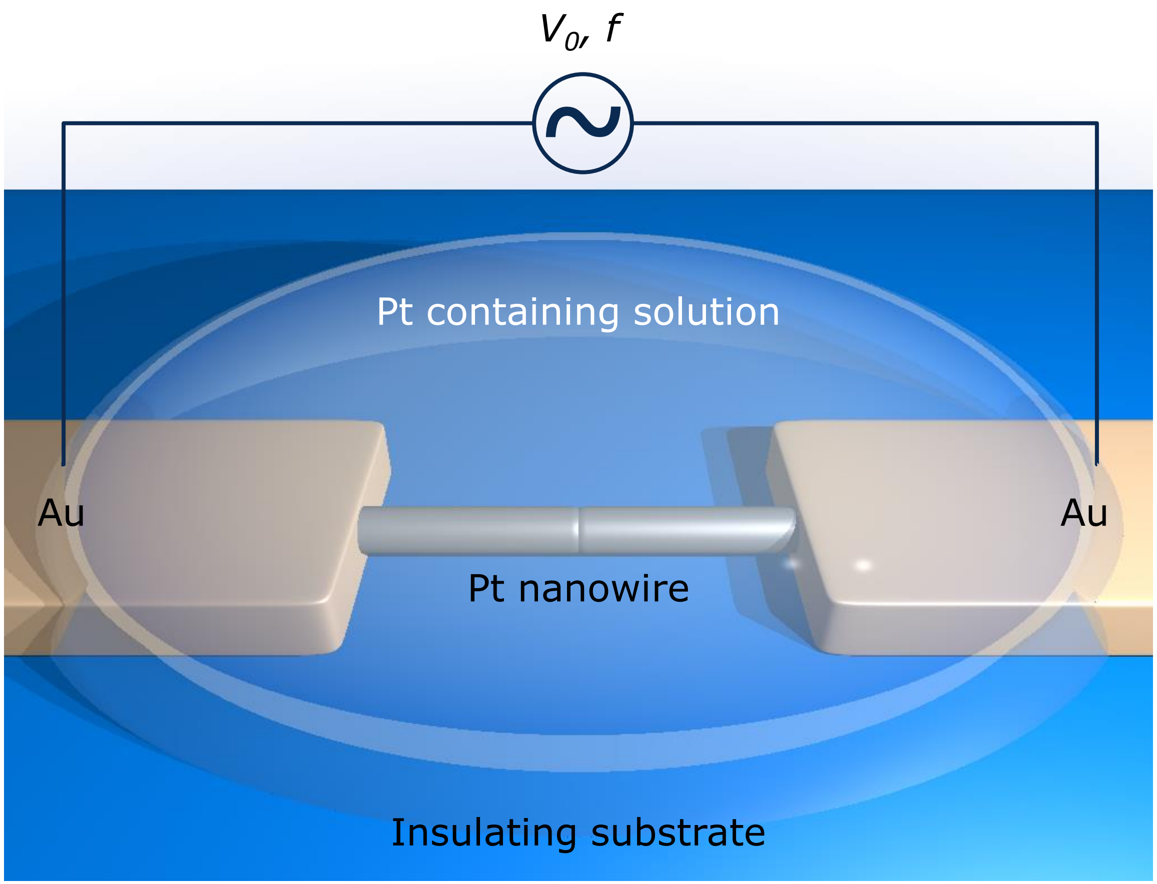


Advantages

- Integration
- Costs
- Speed
- Conditions (T, p)

1. Fabrication of Metal Nanowires

Combining bottom-up and top-down



Advantages

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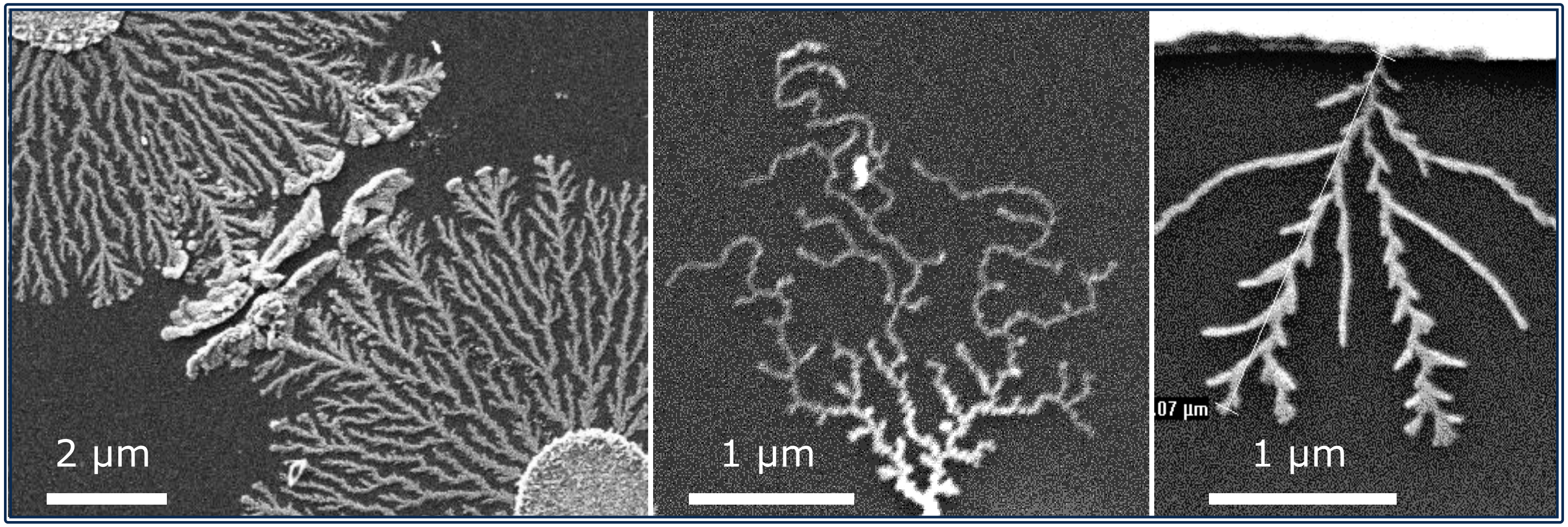
1. Fabrication of Metal Nanowires

Challenges



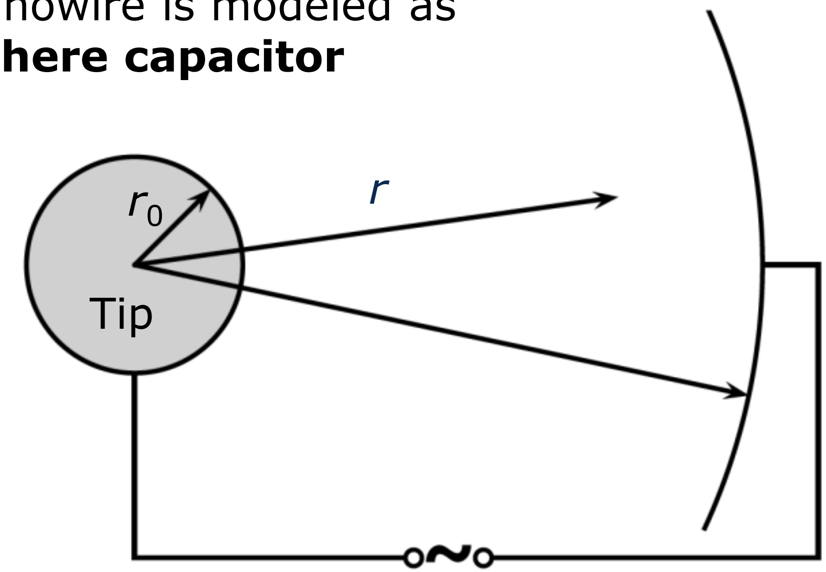
Growth influenced by many parameters…

- Voltage
- Frequency
- Solution type
- Concentration of solution
- …

Goal: growth control ➔ straight, thin and unbranched wires

1. Fabrication of Metal Nanowires

Nanowire is modeled as
sphere capacitor



A. Nerowski & M. Poetschke *et al.*
Langmuir **28**, 7498 (2012)

Flux of Pt complexes $\vec{j}$ is influenced by:

- Dielectrophoretic force $\vec{F}_{\mathrm{DEP}}$
- Concentration gradient ∇c

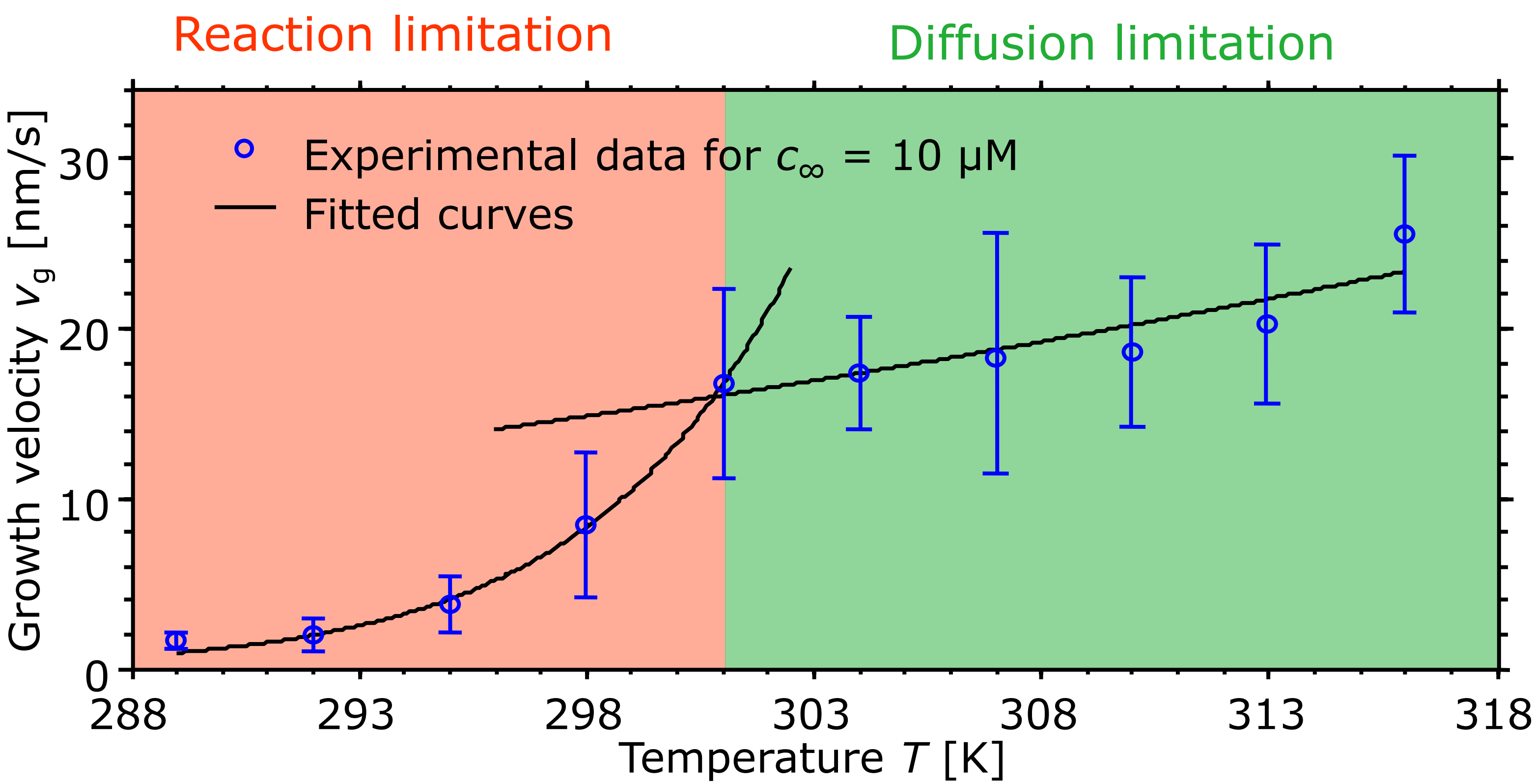
Boundary conditions:

- Far from tip ($r \rightarrow \infty$): bulk concentration c_∞
- At tip surface: reaction rate $k_r(T)$

Resulting differential equation for **concentration *c***:

$$\frac{\partial}{\partial r}\left(r^2 L \left(\underbrace{F_{\mathrm{DEP}}}_{\text{Convection}} - \underbrace{k_B T \frac{\partial}{\partial r} \log \frac{c(r)}{c_\infty}}_{\text{Diffusion}}\right)\right) = 0$$

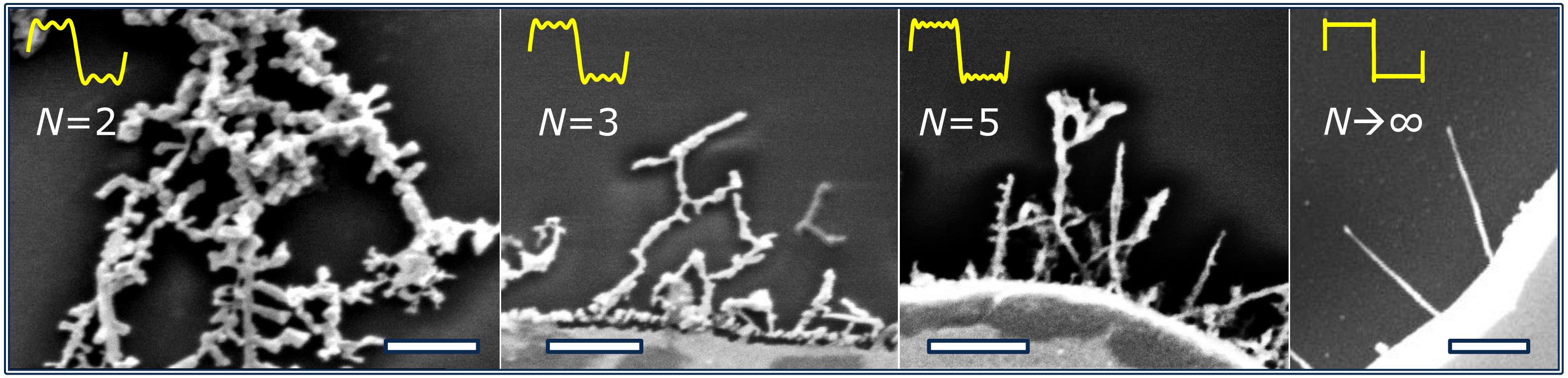
Growth kinetics – temperature dependence



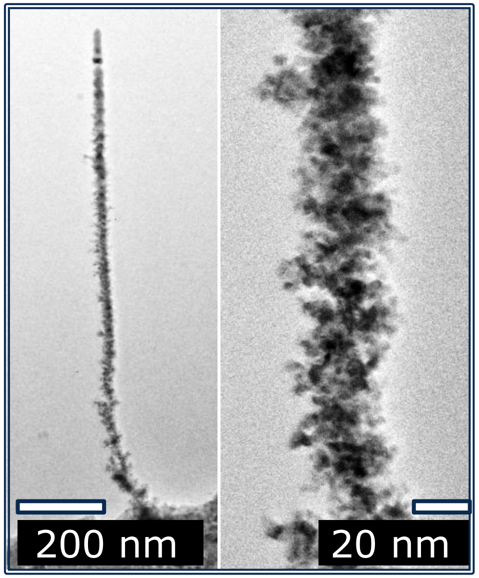
➔Qualitative agreement with theory

A. Nerowski & M. Poetschke *et al. Langmuir* **28**, 7498 (2012)

Morphology: Signal variation



Scalebars: 500 nm

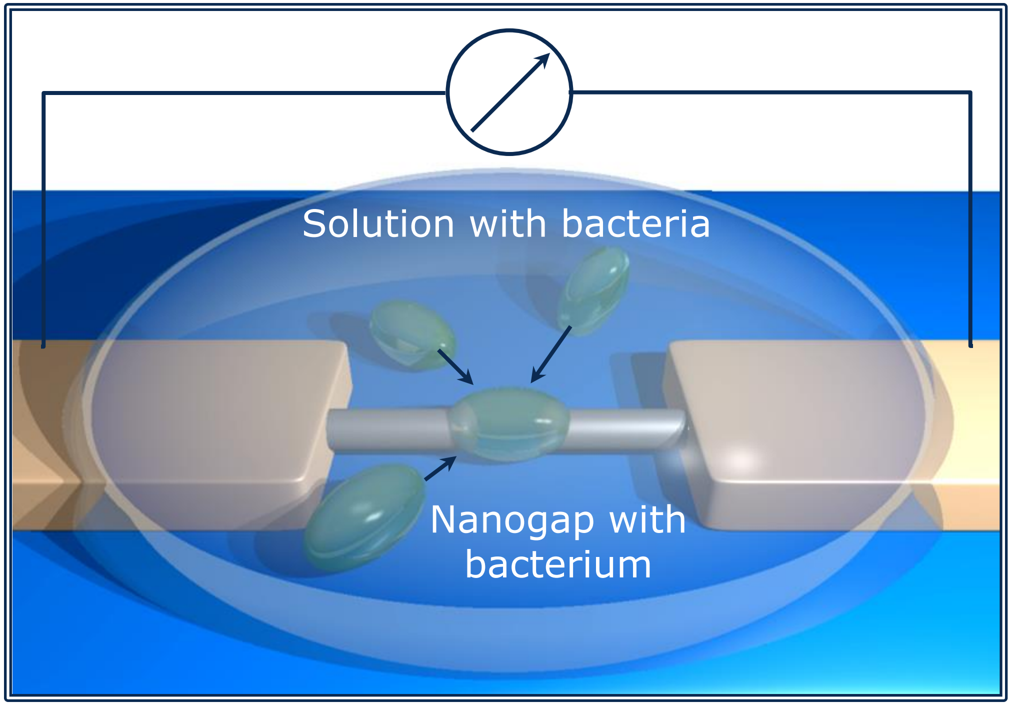


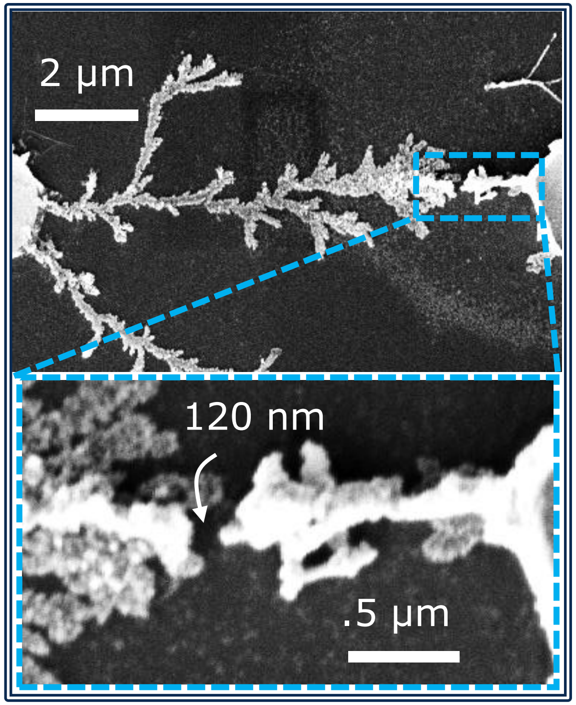
- Variation of **voltage slope** during polarity change
- Morphology from branched to straight

A. Nerowski *et al.*
Langmuir **30**, 5655 (2014)

2. Metal Nanowire Sensor Application

Impedimetric nanobiosensor

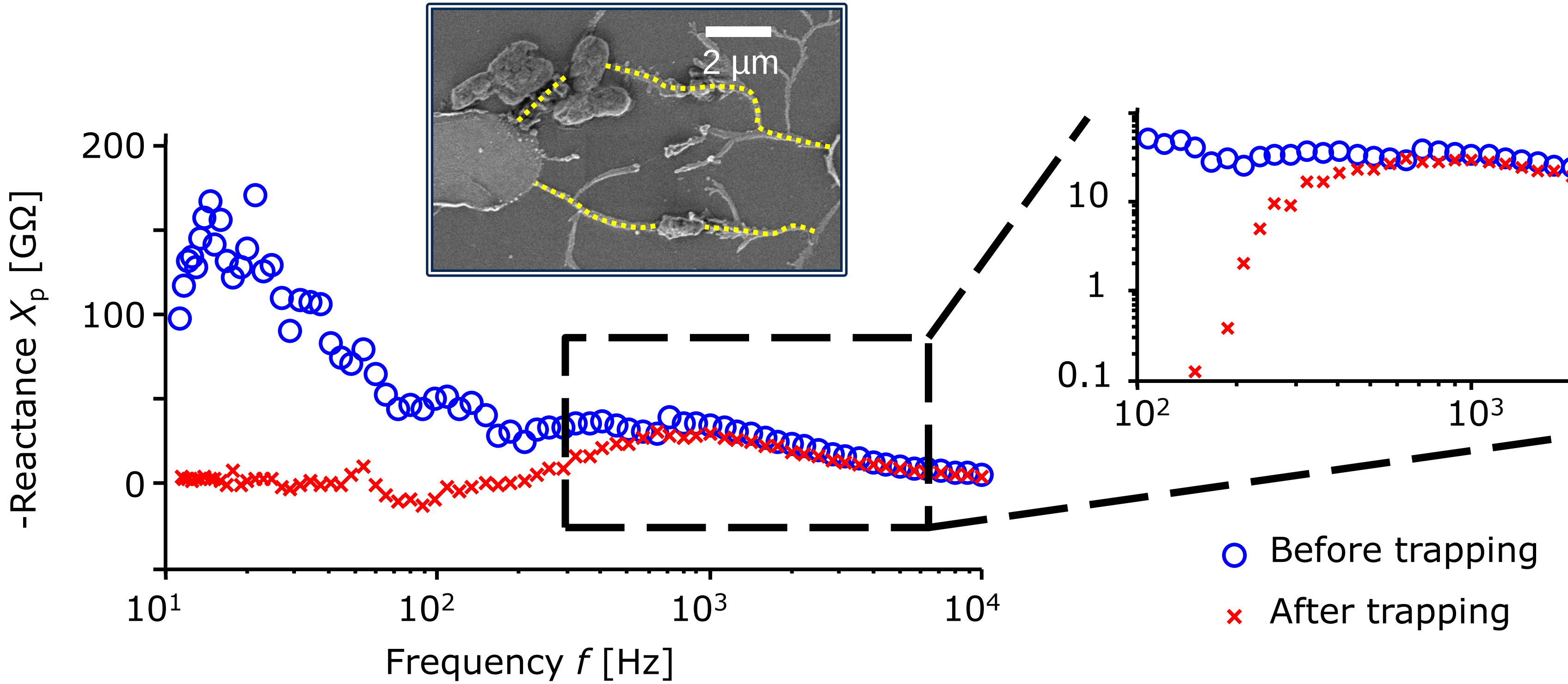




- Production of nanogap using electromigration
- Dielectrophoretic attraction of nanoscaled objects into gap
- Electrical impedance measurement of **single** objects

A. Nerowski *et al.*, Utility patent DE 20 2013 002 076.8

2. Metal Nanowire Sensor Application



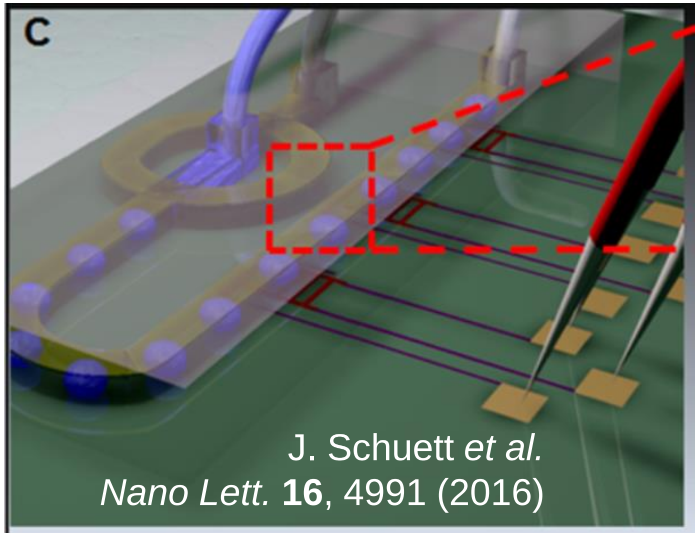
- Impedance spectroscopy of *E. Coli* reveals parallel *RC*-circuit **in accordance with literature** (50 GΩ, 3 fF)
- High frequencies: substrate resistance is equal to analyte resistance

A. Nerowski *et al.*, Utility patent DE 20 2013 002 076.8

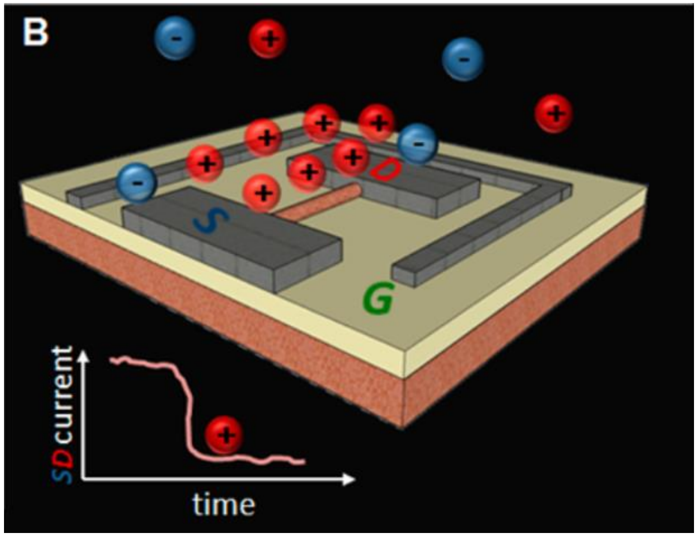
3. Silicon Nanowire Sensor Application

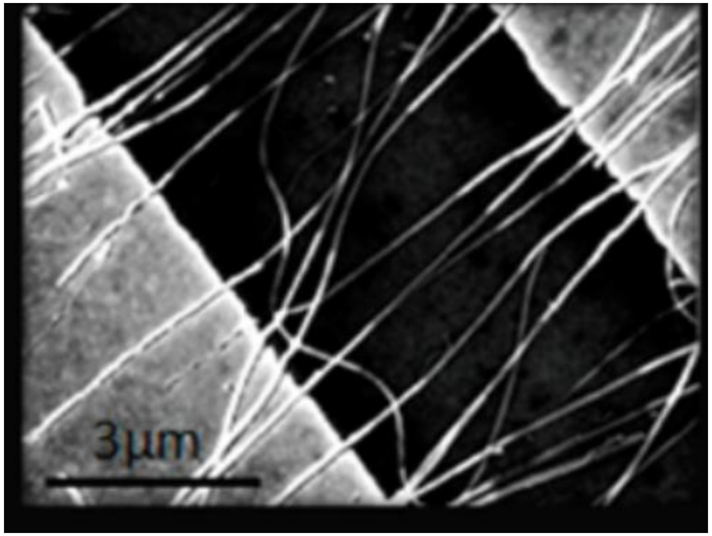
Microfluidic pH sensor(s)

- Bubbles with analyte pass nanostructures
- Sensitive, optics-less analysis of biochemical processes
- Use of a single device for thousands of independent sensors



J. Schuett *et al.*
Nano Lett. **16**, 4991 (2016)

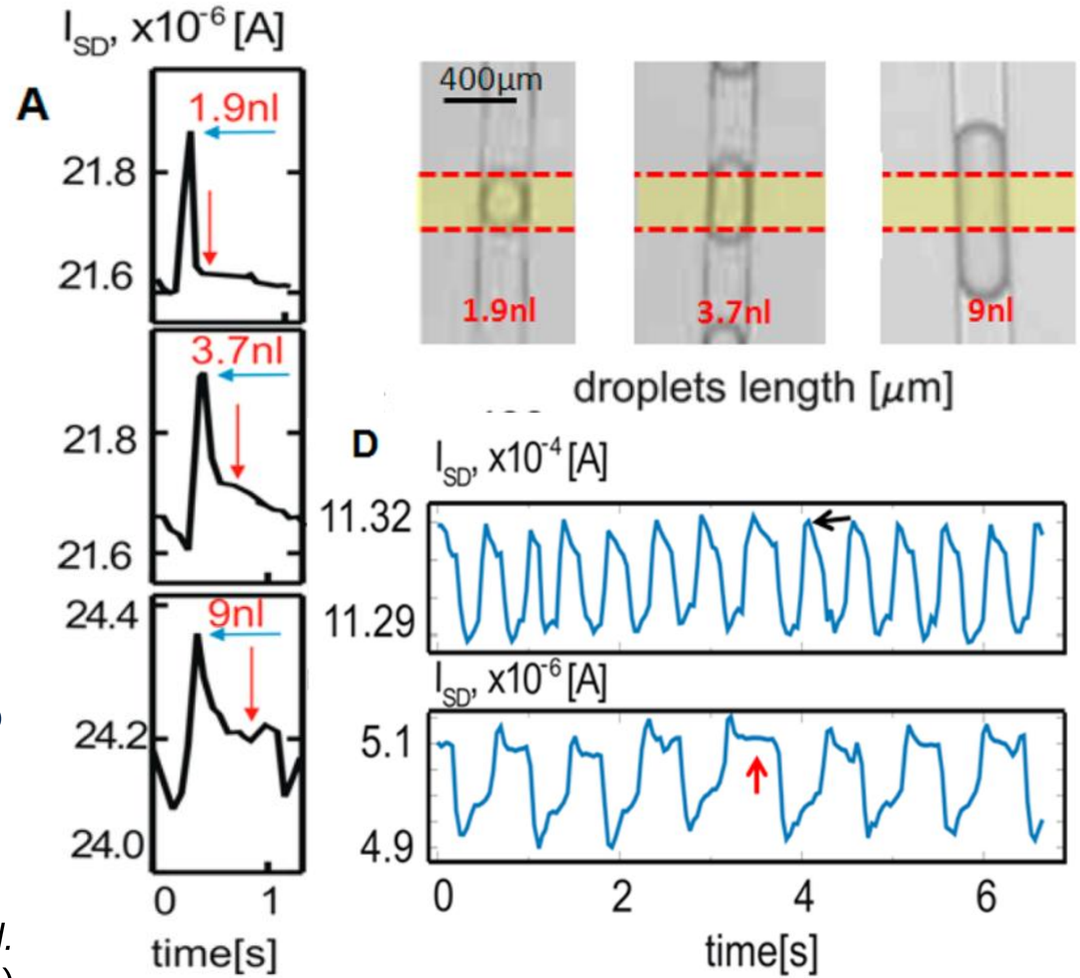




Droplet microfluidics with silicon nanowire based FET

- Increase in current when droplet passes
- Current characteristics dependent on size of droplet
- Current amplitude dependent on content of bubble

Here: pH-sensor, but also others feasible



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Conclusion for Bottom-Up Nanotechnology

Research hype?

Already:

- Fabrication of controlled bottom-up nanostructures on industry scale
- Electronics like OLED TVs

Research in applications still ongoing:

- Biosensorics
- Chemosensorics

ToDo: Environmental sustainability/health, longevity

Acknowledgements

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