



ECEMP International Graduate School

SOLUTION-BASED NANOWIRE GROWTH

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wotivation

Why are nanowires interesting?

Results

Complex dissociation behavior of K₂**PtCl**₄

Simulation vs. experiment

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- Why grow them with dielectrophoresis (DEP)?
- CMOS-compatibility
- Cheap and easy setup
- By means of theory and experiment we aim to
- grow straight and thin wires
- elucidate the effect of process parameters on nanowire growth

Experimental method

insulating substrate

Lithographically manufactured electrodes with thin asperities are covered with a K₂PtCl₄ solution (Fig. 1). In the electric field nanowires grow from the electrodes (Fig. 2).



Based on dissociation rates by Elding et al. [2], we calculated the dissociation of K_2 PtCl₄ at 25 °C. After 28-87 hours, a concentration peak of cis-PtCl₂ appears in case of a 0.01 mmol K₂PtCl₄ solution.



- **Figure 3:** Time-dependent dissociation of K₂PtCl₄
- Height and duration of the cis-PtCl₂ concentration peak change with the K_2 PtCl₄ concentration.



Figure 4: Time-dependent dissociation of K₂PtCl₄

Comparison of transport mechanisms



Figure 7: Measured growth velocities compared to calculated steady-state growth velocities for a 0.1 mM K₂PtCl₄ solution

The measurements show no significant correlation between nanowire growth velocity and applied voltage, in agreement with model prediction. The difference between the calculated growth velocity and the measured values could be due to

 poorly known diffusion coefficient and polarizability of the particles

neglect of transient concentration evolution

• additional presence of ions and the TH effect

The large scatter of measured growth velocities results probably from varying dissociation states of K₂PtCl₄ caused by differences in

solution age

• K₂PtCl₄ concentration



Figure 1: Experimental setup **Figure 2:** Pt-nanowire grown by dielectrophoresis

Modeling of nanowire growth

Our model includes the following particle transport mechanisms [1], where \overline{j} is the particle flux and *c* is the particle concentration:

- Dielectrophoretic forces (DEP) $\vec{j}_{\text{DEP}} = \frac{-\alpha Dc}{2kT} \operatorname{grad} E^2$
- Diffusion of Pt-complexes (Diff) $i_{\text{Diff}} = -D \, grad \, c$
- lons in an ac-field move on periodic trajectories. Collisions due to Brownian motion cause them to change to other trajectories, briefly called trajectory hopping (TH). This leads on average to a net particle flux.



The nanowire tip is approximated by a sphere and the problem is treated radially. We mainly focus on transport of uncharged particles.

Particle velocities due to different transport mechanisms strongly depend on distance from electrode.



Figure 5: Particle velocities corresponding to different transport mechanisms vs. distance from tip surface

Steady-state particle concentration profile



Figure 6: Concentration profile vs. distance from tip surface with applied voltage as parameter. Tip radius: $R_0 = 50 \text{ nm}$

Conclusions

- Tetrachloroplatinate exhibits complex dissociation behavior where high amounts of uncharged cis-PtCl₂ can appear under suited conditions.
- To ensure wire growth to occur solely by dielectrophoresis, optimum process parameters should be chosen, e.g. $10 \,\mu M \, K_2 Pt Cl_4$ and 28-87 h solution age.
- Particle transport is governed by dielectrophoresis near the tip and by diffusion farther away.
- The steady-state concentration profile was calculated.
- The derived nanowire growth velocity in steadystate is in modest agreement with experimental findings.

References

[1] Poetschke, M. Multi-scale simulation of mechanical properties and growth mechanisms of nanowires. In 1st ECEMP IGS Workshop; 2010.

Dielectrophoretic and diffusive flux contributions:

$$\vec{j} = \vec{j}_{\text{DEP}} + \vec{j}_{\text{Diff}} \quad (1) \qquad c(R_0) = 0$$
$$\frac{\partial c}{\partial t} = -\operatorname{div} \vec{j} \stackrel{!}{=} 0 \quad (2) \qquad c(\infty) = c_{\infty}$$

Within this model we compute the molecule velocity, the particle flux towards the nanowire tip, and the growth velocity of the nanowire.

The unexpected crossing of concentration profiles for different voltages at about 3 nm distance from the nanowire tip is obviously due to dielectrophoretic forces which cause two effects with increasing voltage

• larger concentration gradient at the electrode

• larger particle depletion far from the electrode

[2] Elding, L. Acta Chem Scand 1970, 24, 1527-1540.

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