NanowireSensor RTD 2009

Metal Nanostructures for Biosensing - Plasmonics, Electrical Detection & Simulations

B. Dielacher [1], R. MacKenzie [1], V. Guzenko [2], R. Minamisawa[2], J. Vörös [1]

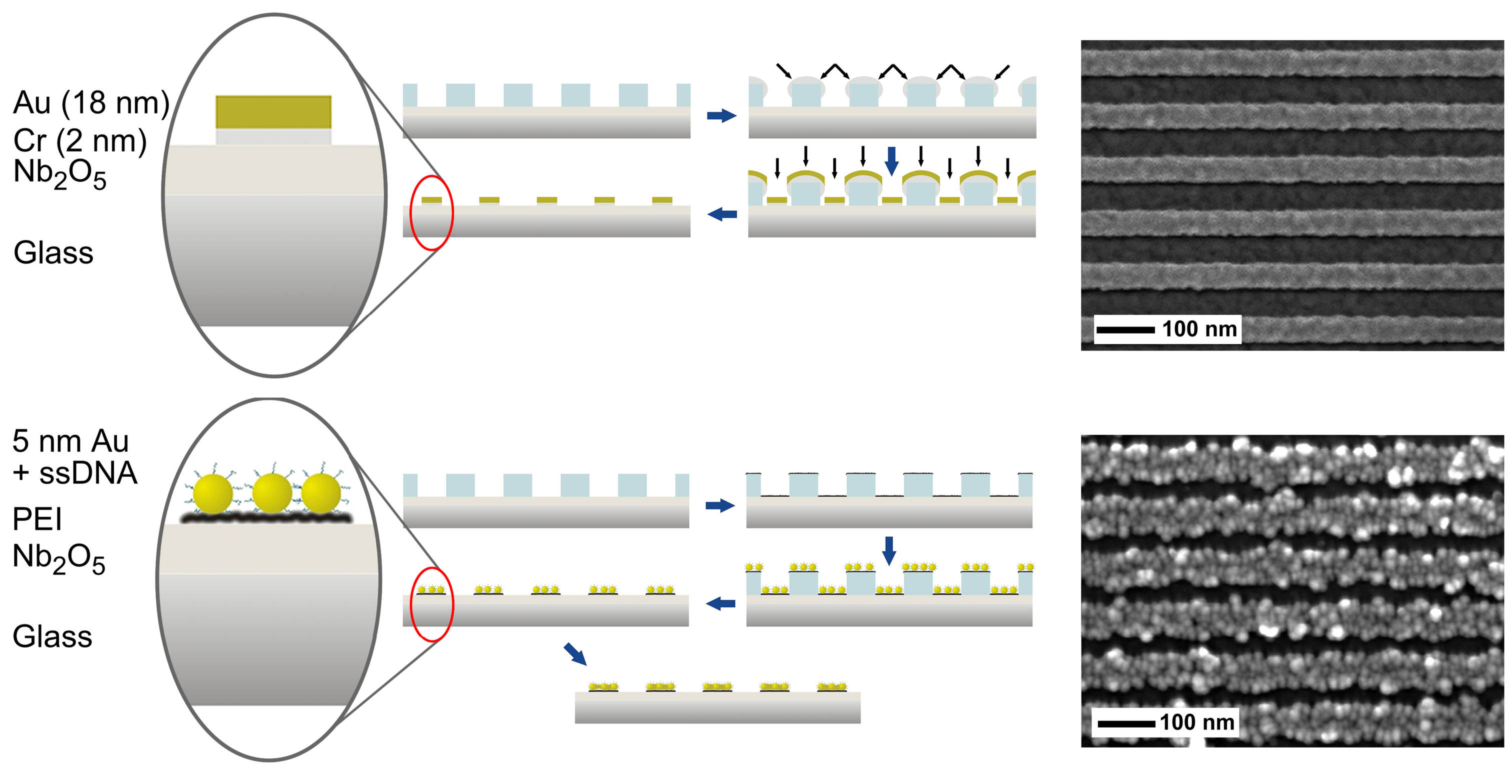
1 Laboratory of Biosensors & Bioelectronics, ETH Zürich, Gloriastrasse 35, 8092 Zürich Switzerland
2 Laboratory for Micro- and Nanotechnology, Paul Scherrer Institute (PSI), 5232 Villigen Switzerland

Introduction & Motivation

Nanowires are of increasing interest for biosensing devices since their diameter is comparable to the size of biochemical analytes and their surface to volume ratio makes them extremely sensitive to surface perturbations. Noble metal nanowires offer the advantage of being an optical as well as electrical transducer for surface reactions. Therefore the fabrication of a combined optical-electrical system with metal nanowire arrays should offer a unique and powerful new platform, which will enable more complex chemical sensing and biosensing applications, as well as open new possibilities to explore the fundamental *in-situ* behavior of nanowires.

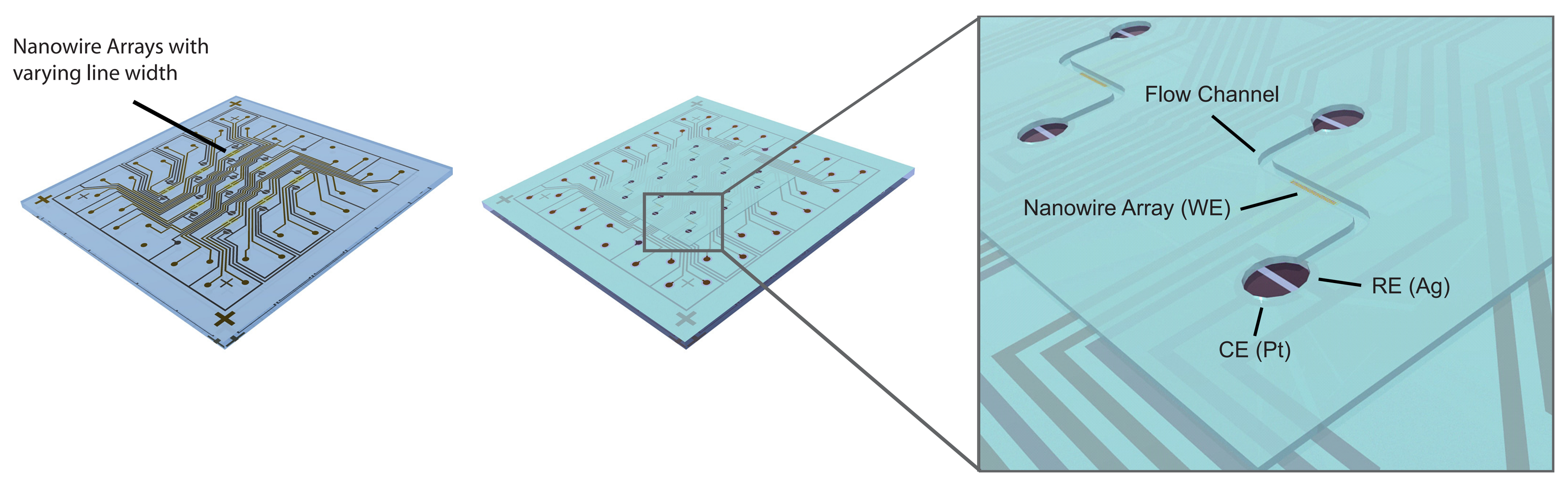
Nanowire Fabrication

Extreme UV Interference Lithography (EUV-IL) enables the fabrication of ultrathin (< 10 nm) large-scale nanoline arrays. The synchrotron light is diffracted by a grating, created by either e-beam Lithography or XIL itself.

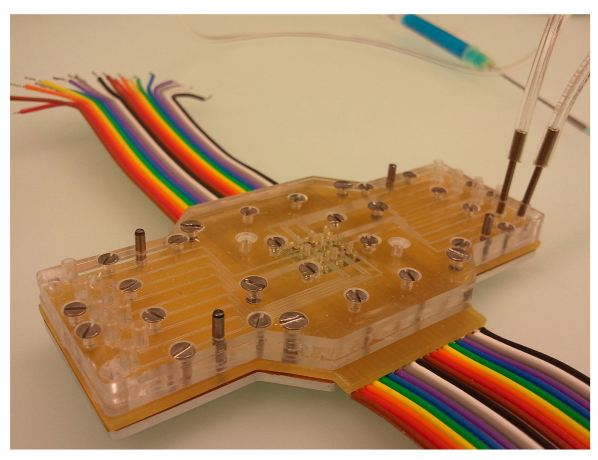


The resulting nanoline structure from EUV-IL is transformed into two different nanowire arrays either with metal evaporation or with a particle self-assembly process.

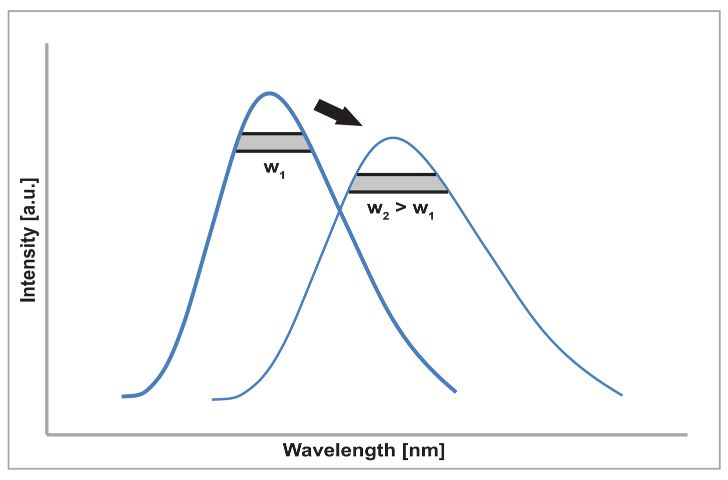
Chip Design

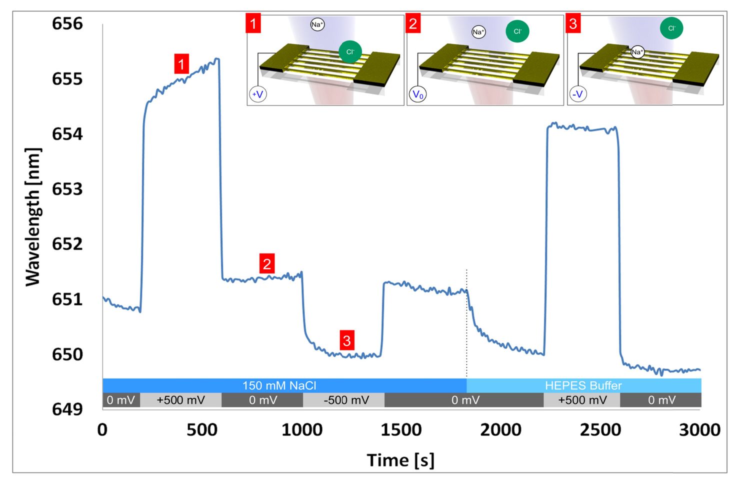


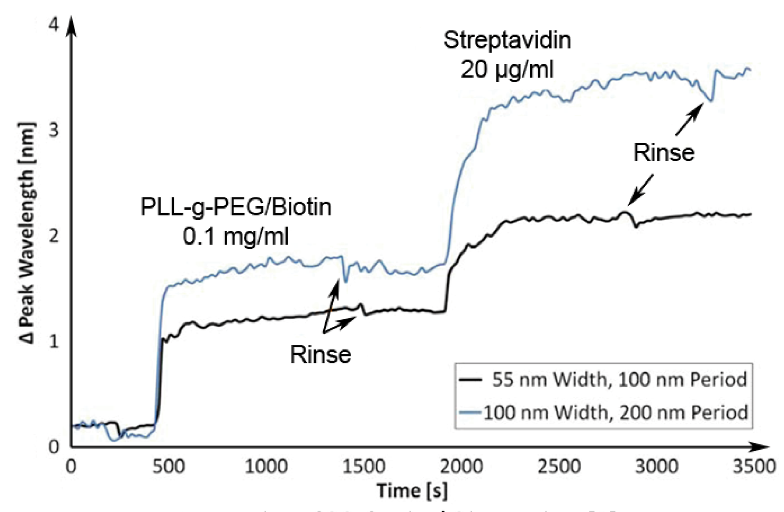
- Several large scale nanowire arrays with varying line width on each chip.
- Multiple electrical connections on each nanowire array (e.g. for individual functionalization)
- Tiny flow channel over each nanowire array
- Integrated electrochemical cell
- Transparent flow cell allowing optical sensing based on Localized Surface Plasmon Resonance (LSPR).



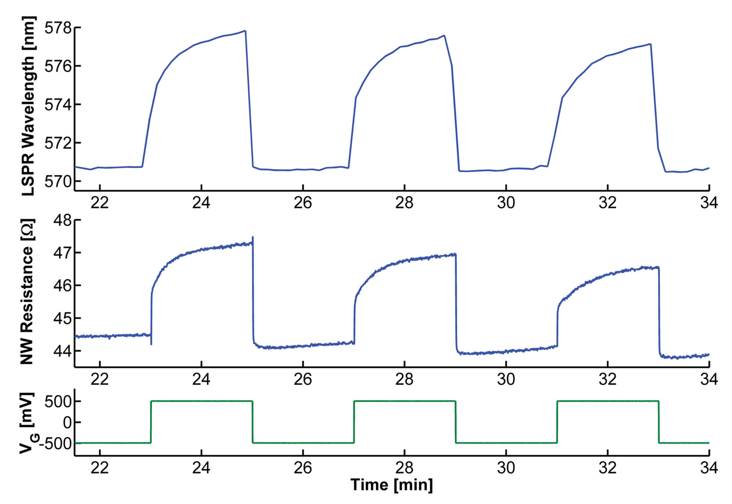
Optical & Electrical Biosensing







Nanowire LSPR Optical Biosensing [3]

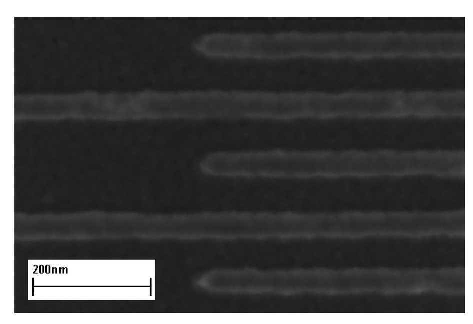


In-situ combination of LSPR and electrochemistry as well as resistance measurements across the nanowire array [3]

- Optical characterization has been performed by measuring a bulk refractive index sensitivity up to 114.6nm/RIU (Refractive Index Unit) and limits of detection as low as 4.5×10^{-5} RIU.
- Simultanous optical and electrical *in-situ* measurements while controlling the formation of an electrical double layer have shown LSPR peak shifts of over 4nm.

Simulations

- Finite element simulations using COMSOL Multiphysics for impedance based interdigitated nanowire arrays.
  - Impedance spectra optimization targeting highest sensitivity and signal-to-noise ratio for molecule adsorption and binding.



Interdigitated nanowire arrays

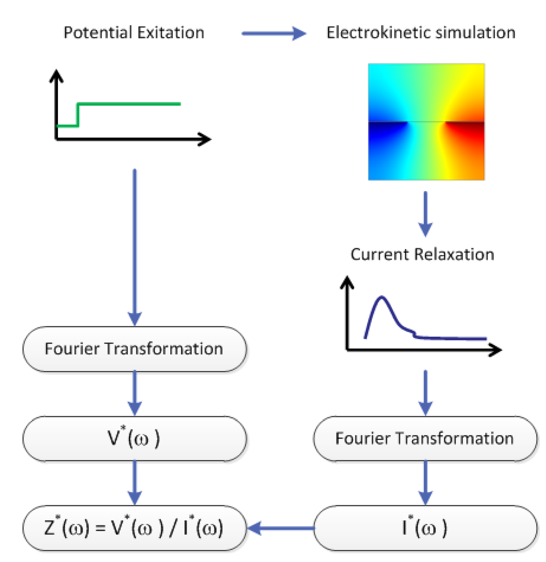
- Based on nonlinar Poisson Nernst Planck (PNP) theory.

$$\frac{\partial C_\pm}{\partial \tau} = -\nabla(-D_\pm \nabla C_\pm \pm \mu z e C_\pm \nabla \Phi)$$
$$\nabla^2 \Phi = -\frac{e}{\varepsilon}(C_+ - C_-)$$

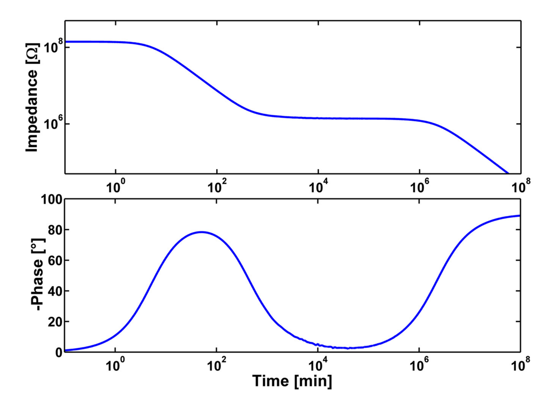
  - Self-consistently generates charge density and potential distribution including the important electrical double layer on any geometry.
  - Total current is the sum of ion flux currents and displacement current

$$I_i = \mathrm{F} z_i J_i = F(-z_i D_i \nabla c_i + \mu_i {z_i}^2 c_i \nabla \Phi)$$
$$I_{tot} = \sum_i I_i - \epsilon\, \partial_t \partial_x \Phi$$

  - Represents the pysical behavior more relistically than common equivalent circuit models.



- Current work:
  - Including adsorption kinetics, Stern layer effects and surface charges on all interfaces.



Example impedance spectrum

Outlook

Biosensing concepts based on detection of charges • Individual functionalization • Exploring the fundamental in-situ behavior of nanowires • Optimization

1. Auzelyte V., et al., "Extreme ultraviolet interference lithography at the Paul Scherrer Institut", Journal of Micro-Nanolithography Mems and Moems, 2009. 8(2): p. 10.
2. MacKenzie R., et al., "Controlled in situ nanoscale enhancement of gold nanowire arrays with plasmonics", Nanotechnology, 2011. 22(5): p. 055203.
3. MacKenzie R., et al., "Optical Sensing with Simultaneous Electrochemical Control in Metal Nanowire Arrays", Sensors, 2010. 10(11): p. 9808-9830.
4. MacKenzie R., Dielacher B., et al., "Simultaneous Measurement of the Electrical and Plasmonic Properties of Metal Nanowire Arrays upon Potential Induced Ion Binding", submitted.

uzh | eth | zürich