

# Wafer-Level Functionalization of Integrated Carbon Nanotubes with Metal Nanoparticles

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## Motivation

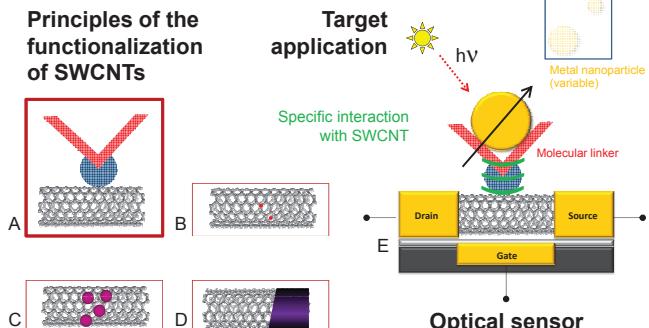
Semiconducting single-walled carbon nanotubes (s-SWCNTs) are a key material for nanometer-scale integrated sensors as well as micro and nano electromechanical systems (MEMS/NEMS). For these applications, a scalable technological solution for the integration of the SWCNTs on wafer level is a severe challenge. Especially for sensoric applications, a suitable **chemical functionalization** of the SWCNTs keeping the electronic band structure intact is another key issue, as is the combination of functionalization and integration on wafer level. In this contribution, we report on recent attempts towards optical sensors on the basis of functionalized SWCNTs.

The functionalization of carbon nanotubes is expected to yield a tunability of particular optical properties or an enhancement of the optical signal. Four different approaches can be exemplified for SWCNT functionalization (cartoon to the right):

- A. covalent chemical (sidewall) functionalization with molecular linkers
- B. doping
- C. exohedral decoration with nanoparticles and
- D. coating (e.g. metal layer)

For the optical sensor (E) as target configuration, priority was given to a covalent functionalization with (R)-oxycarbonyl nitrenes without surface defects to the SWCNTs, followed by the attachment of metallic nanoparticles.

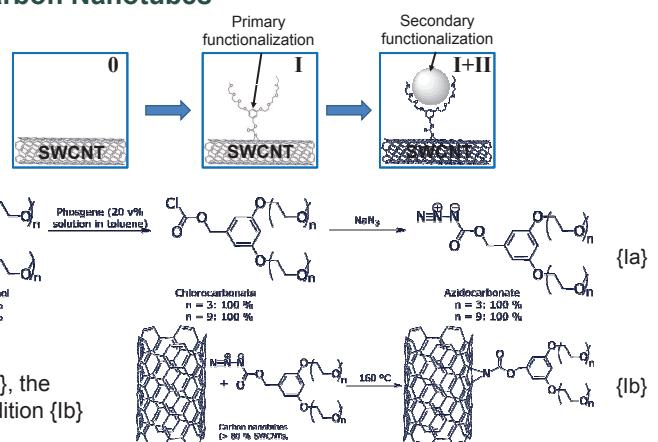
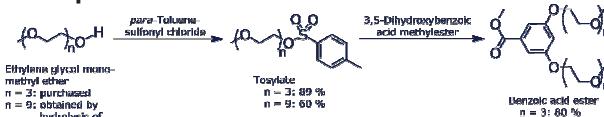
## Principles of the functionalization of SWCNTs



## Technological approach

- Two-step functionalization of the SWCNT side walls:
  - I. Attachment of (R)-oxycarbonyl nitrenes as primary functionalization
  - II. Attachment of metallic nanoparticles as secondary functionalization to the ethylene glycol chains of the (R)-oxycarbonyl nitrenes

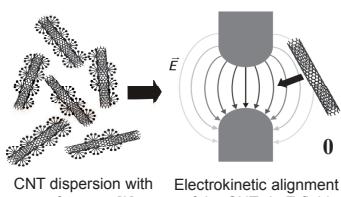
## Synthesis protocols



## Wafer-Level Integration & Functionalization of Carbon Nanotubes

### Integration of SWCNTs on a silicon wafer

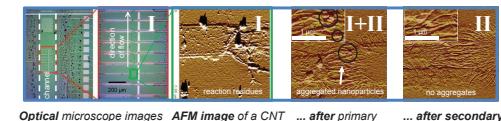
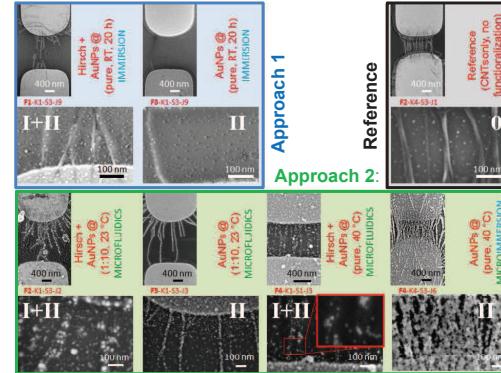
Principle: dielectrophoretic deposition



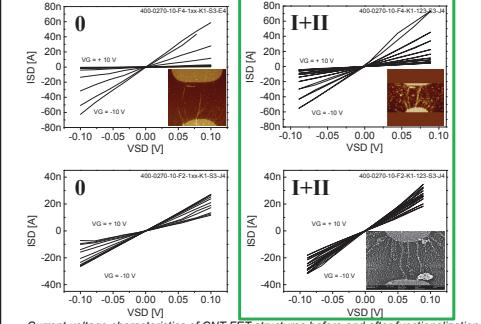
### Functionalization of SWCNTs on a silicon wafer

**Approach 1:**  
Primary and secondary functionalization by liquid immersion of the wafer  
Tool: wafer on heating plate  
140 °C

### Morphological characterization



### Electrical characterization



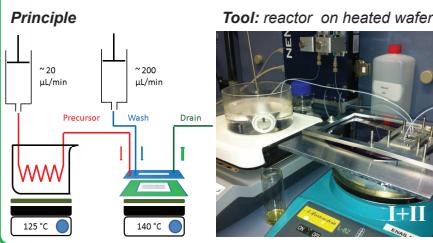
### Results

- SEM results indicate a successful adsorption of gold nanoparticles on SWCNTs (secondary functionalization) in the presence of a primary functionalization with (R)-oxycarbonyl nitrenes. The density of gold particles on the CNTs can be varied by concentration and temperature of the dispersion.
- Current-voltage characteristics prevail after the functionalization process
- Raman spectra indicate intact CNT sidewalls (no raised D peak)

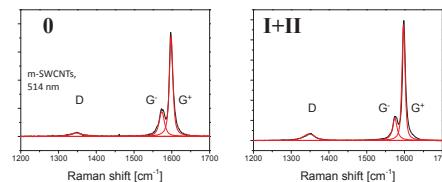
### Summary & Outlook

- Electrokinetic integration of SWCNTs and subsequent functionalization with gold nanoparticles via (R)-oxycarbonyl nitrenes on wafer scale is possible
- The most promising results are obtained by a **microfluidic approach** adapting the chemical reaction to the wafer

**Approach 2:** Primary and secondary functionalization in microfluidic flow on the wafer



### Raman characterization



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