nano-tera.ch
swiss scientific initiative in health / security / environment systems

CabTuRes RTD 2009

FNSNF

High Precision Catalyst Deposition for Location Controlled Growth of SWCNTs and their Integration into Field Effect Transistors

Massimo Spina[1], Axel Fanget[1], Jaćim Jaćimović[1], Primož Rebernik Ribič[2], László Forró[1], Arnaud Magrez[1]

[1]Laboratory of Physics of Complex Matter, École Polytechnique Fédérale de Lausanne, Switzerland

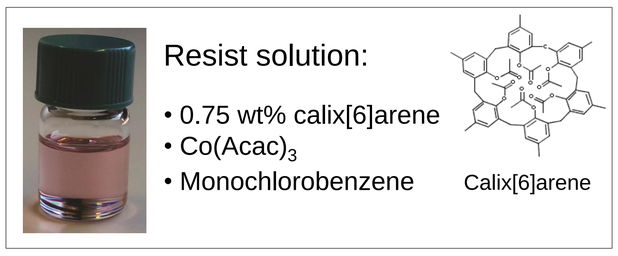
[2]Laboratory of Physics of X-rays, École Polytechnique Fédérale de Lausanne, Switzerland

Abstract

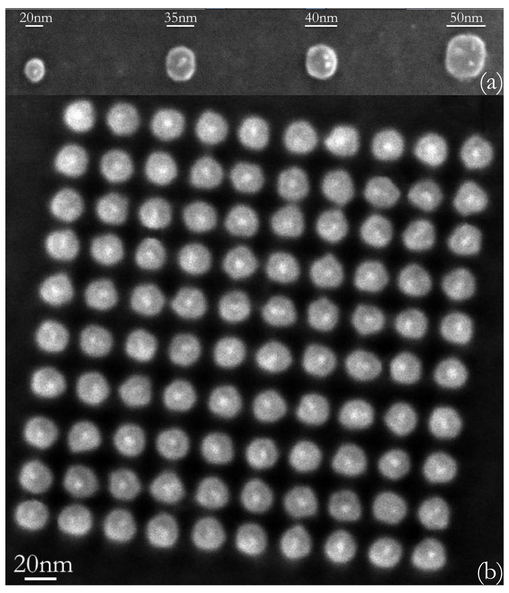
Electronic devices based on individual single walled carbon nanotubes remain at the prototype level because of the limited reliability of the growth processes (low yield and impurities) and the absence of control of the electrical properties of the obtained SWNT. The lack of specificity of the SWNT positioning is also a major limitation. To improve the location and narrow the electronic property distribution of the SWNTs, best strategy relies on the precise deposition of one single catalyst particle with controlled size. We have developed a method based on e-beam lithography. A negative tone resist is doped with Co. After patterning the resist, the metal is segregated at 800°C and the amorphous carbon generated by the decomposition of the resist is etched. At the end of the process, individual particles with a diameter of 1.5±0.2nm are localized within an area of 80nm^2, corresponding to the lithographed surface. High-quality SWCNTs are grown with a diameter of 1.4±0.2nm from ethanol. The semiconducting SWNTs are used for making bottom-gated field-effect transistors.The process is being integrated into the fabrication process of the nano electro-mechanical system (NEMS) developed by our partners at ETHZ.

Catalyst formation process

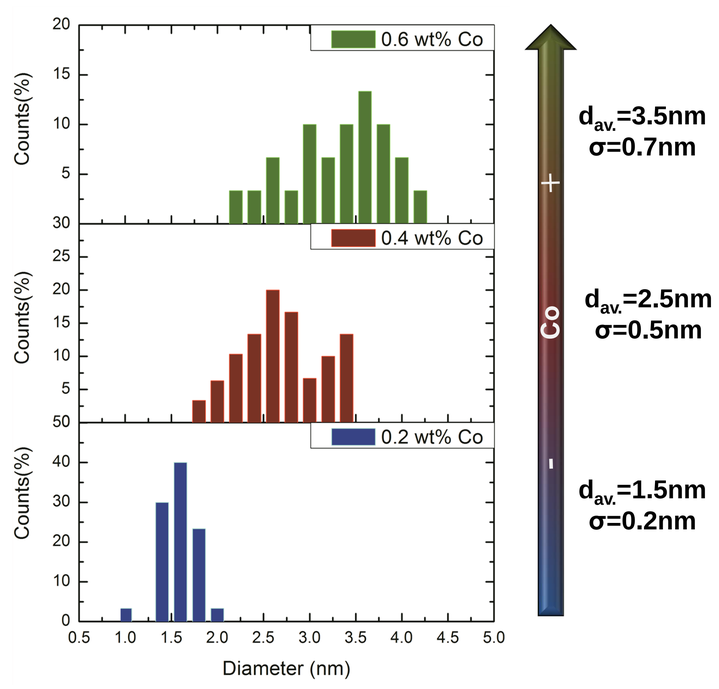
1: Resist preparation | **2: Spin coating** | **3: E-beam Lithography** | **4: Reactive Ion Etching** | **5: Annealing** | **6: Oxidation**



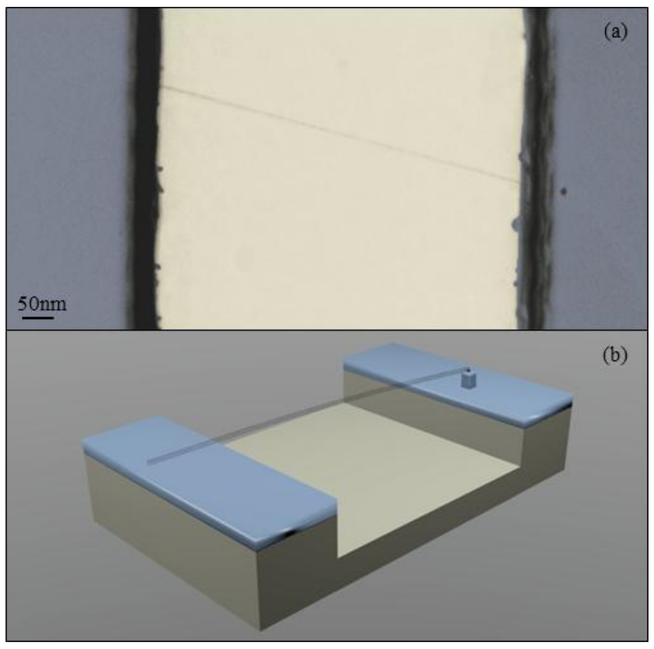
Characterization of the Catalyst Particles



High resolution SEM micrographs of a series of dots with increasing diameter along with particles' size and number (a); 100 dots with 1 or 2 Co nanoparticles on top of each pillar (b).

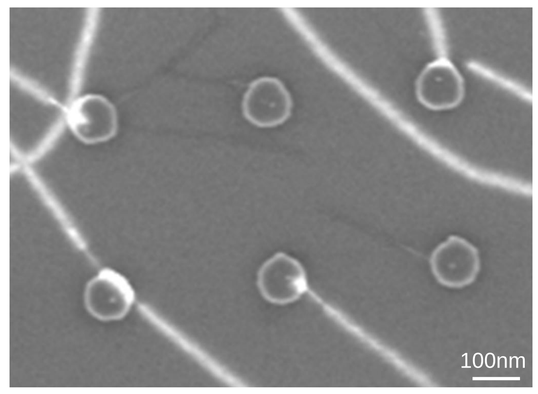


Growth of Single-walled carbon nanotubes



Colored high resolution SEM micrograph and its schematic representation. A SWCNT is grown by CVD from ethanol over a 2µm deep trench from one patterned Co nanoparticles. It has a diameter of 1.4±0.2nm corresponding to the diameter of the Co nanoparticles.

- **Growth temperature: 800°C**
- **Carbon source: Ethanol**



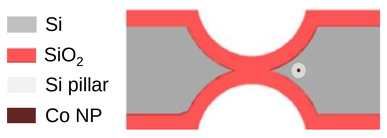
High resolution SEM micrograph of a set of six pillars with a diameter of 100nm. At least one SWCNT is grown by CVD from the patterned Co nanoparticles.

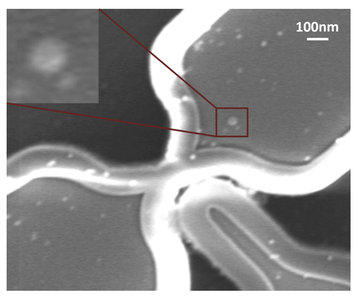
HIGHLIGHTS:

● 60- 70% of growth yield from a patterned area of 8000nm^2

● up to 17% of particles localized in an area of 2000nm^2 yield a SWCNT

Integration into NEMS process flow



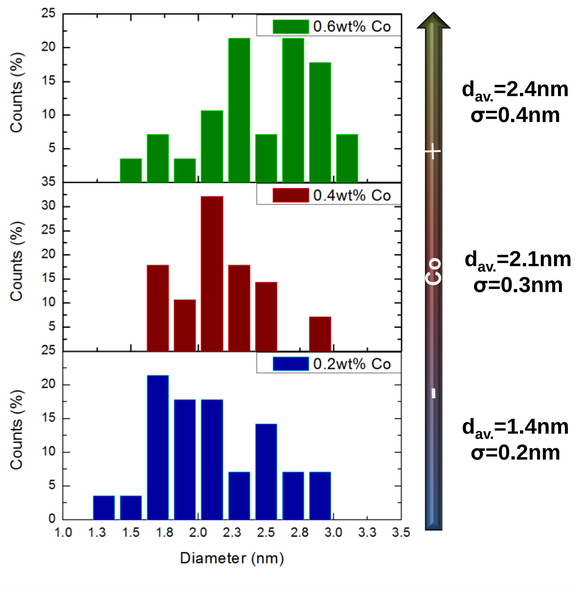


SEM micrograph of a NEMS with patterned catalyst particle.

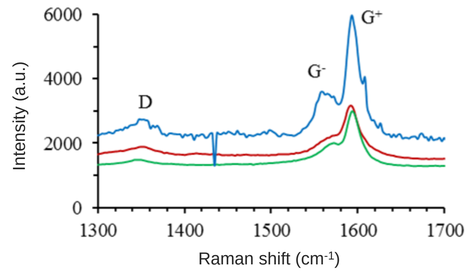
- **1 Cobalt nanoparticle (NP) in a 250nm^2 area**

Characterization of the Growth of Single Walled Carbon Nanotubes

AFM analysis

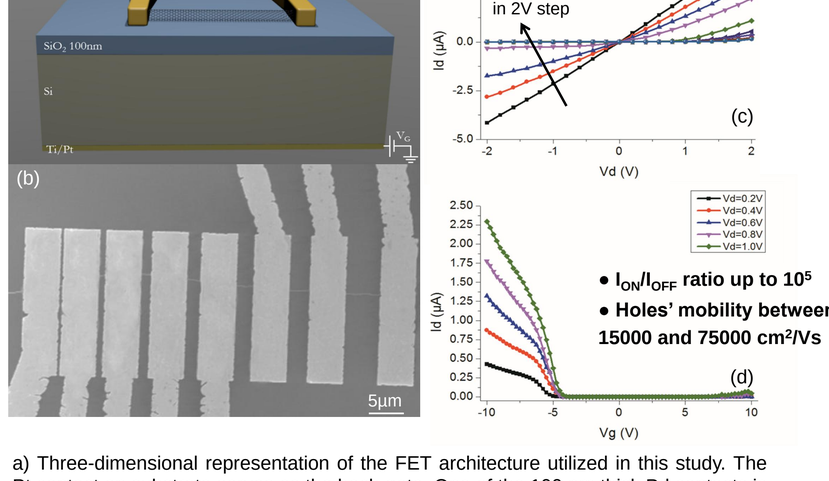


Raman analysis



Raman spectra of the grown SWCNTs for three concentrations of Co in the resist. Nanotube structure contains limited defects. Despite the increase of the metal concentration, their average diameter remains in the 1.4nm range.

● For a defined patterned area, the increase of the Co concentration in the resist leads to the growth of bundles of 1.4nm SWCNTs.



- **I_{ON}/I_{OFF} ratio up to 10^5**
- **Holes' mobility between 15000 and 75000 cm^2/Vs**

a) Three-dimensional representation of the FET architecture utilized in this study. The Pt contact on substrate serves as the back-gate. One of the 100 nm thick Pd contacts is grounded, while the other side serves as the drain. b) SEM image of a series of devices built on the same tube with different channel lengths. c) Output characteristic of a representative back-gated transistor. d) Transfer characteristics of the same device.

Acknowledgements

This research has been funded by Nano-Tera.ch, a program of the Swiss Confederation, evaluated by SNSF.

Contacts:

E-mail: massimo.spina@epfl.ch; arnaud.magrez@epfl.ch

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

EMPA Materials Science & Technology

CabTuRes Carbon nanoTube Resonators