TECHNISCHE UNIVERSITÄT DRESDEN

ECEMP

ECEMP - European Centre for Emerging Materials and Processes Dresden

Alignment of 1D nanoparticles at interfaces using external fields

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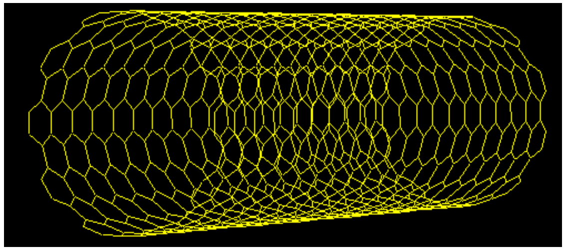
ECEMP – VOM ATOM ZUM KOMPLEXEN BAUTEIL

Outline

- Motivation
- Nanoparticles at interfaces - theory
- Factors influencing nanoparticles at interfaces
- Alignment techniques – background and experiment
- Results – calculations and observations
- Summary

Motivation

Why carbon nanotubes?



Nanotubes as an ideal model 1D nanobody
- stiff and straight
- (almost) perfect walls
- interesting properties

SWNTs: properties / world records

Maximum Tensile Strength:	**~30-100 Gpa**
Young's modulus of a singled tube:	**~1.0-1,2 Tpa**
Maximum current density:	**~10^9 A/cm²**
Electron mean free path:	**~100 nm – 1 µm**
Thermal conductivity:	**~37000 W/(m K) [@ 100K]**
Matter transport:	**~30 molecules/ns**
Aspect ratio:	**~10^8**

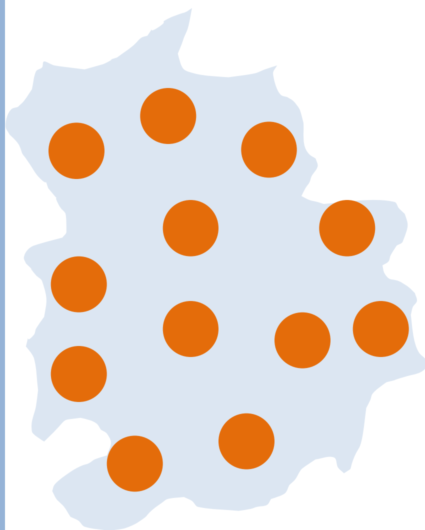
(all values parallel to the nanotube axis)

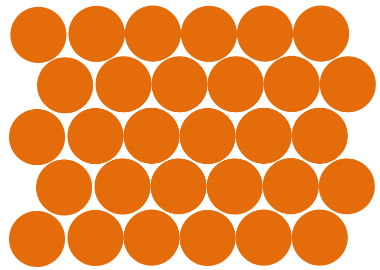
extremely anisotropic properties

→ alignment highly advantageous

Motivation

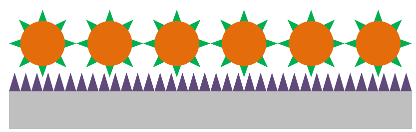
Why alignment at the interface?





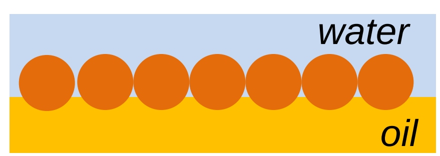
3D – superlattices

→ ordering extremely difficult to obtain with 1D-materials



2D - supramolecular ordering

→ ordering extremely difficult to obtain with 1D-materials



contact angle close to 90°

2D - interfacial ordering

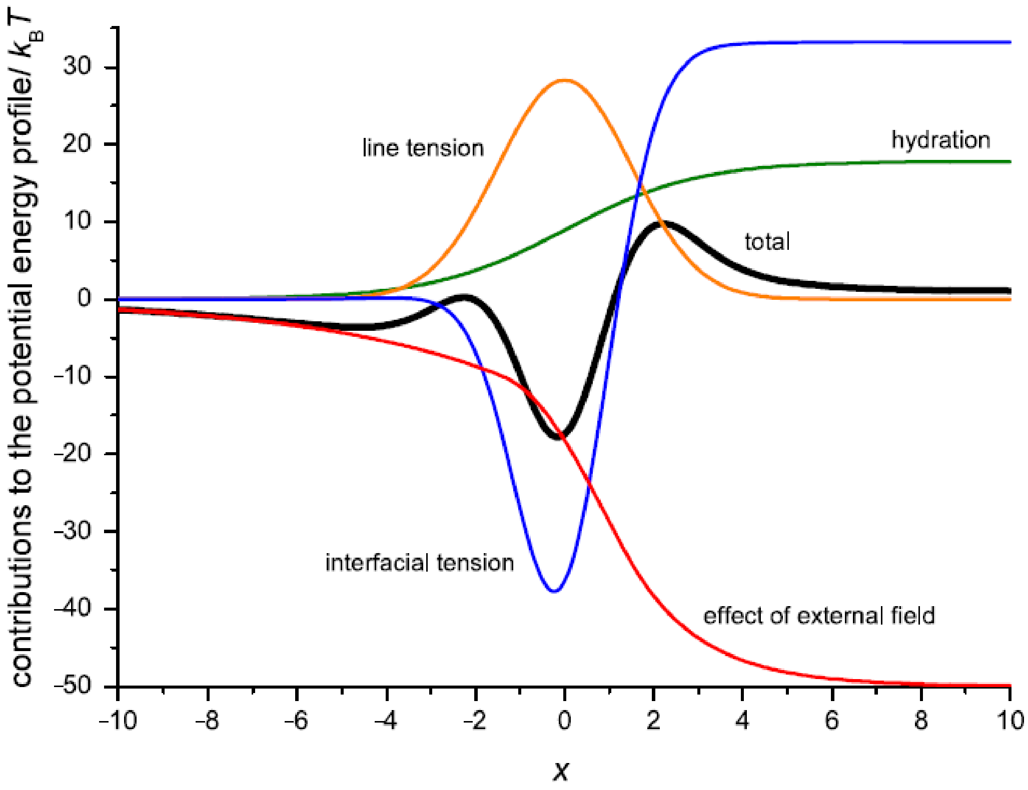
→change in interfacial energy
→ possibility to align by properly applied external fields for both 0D- and 1D- materials

combination of two self-assembly effects at the same time → **3D → 2D → 1D**

…interesting…

0D-nanoparticles at interfaces

Speed of 2D-alignment depends on
(1) concentration
(2) size of the particles
(3) interfacial energy change



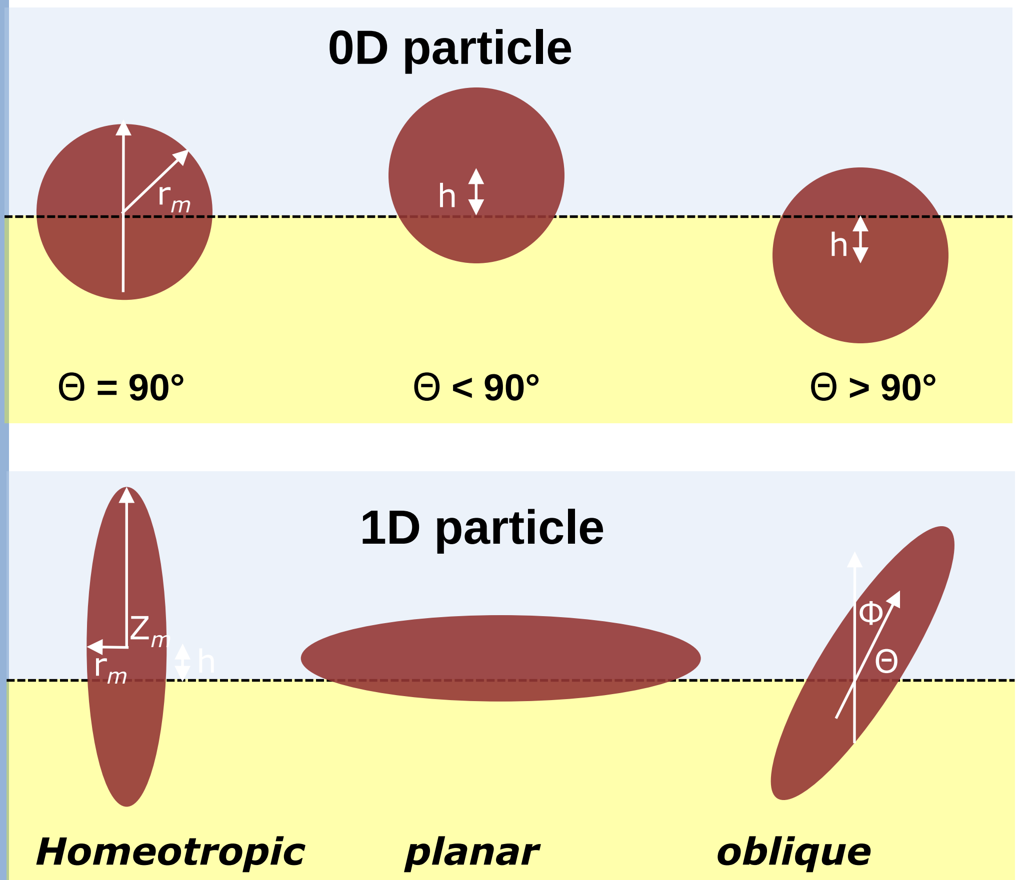
Interactions between particles at interfaces

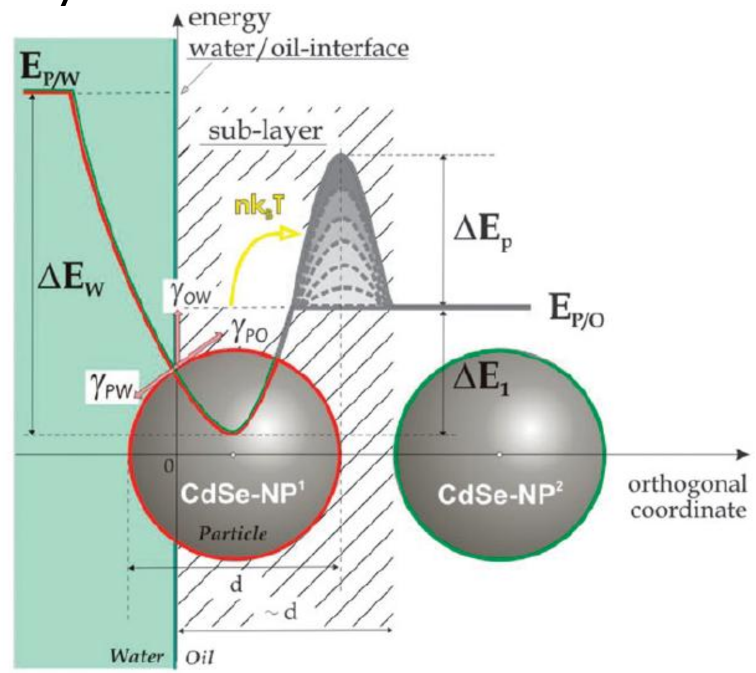
- Van der Waals forces
- Surface tension
- Line tension
- Capillary forces
- Electrostatic interactions
- Brownian motion
- Solvation forces

M. E. Flatte, A. A. Kornyshev and M. Urbakh, Proc. Natl. Acad. Sci. U. S. A., 2008, 105, 18212.

1D-nanoparticles at interfaces

1D vs. 0D: additional factors play a decisive role





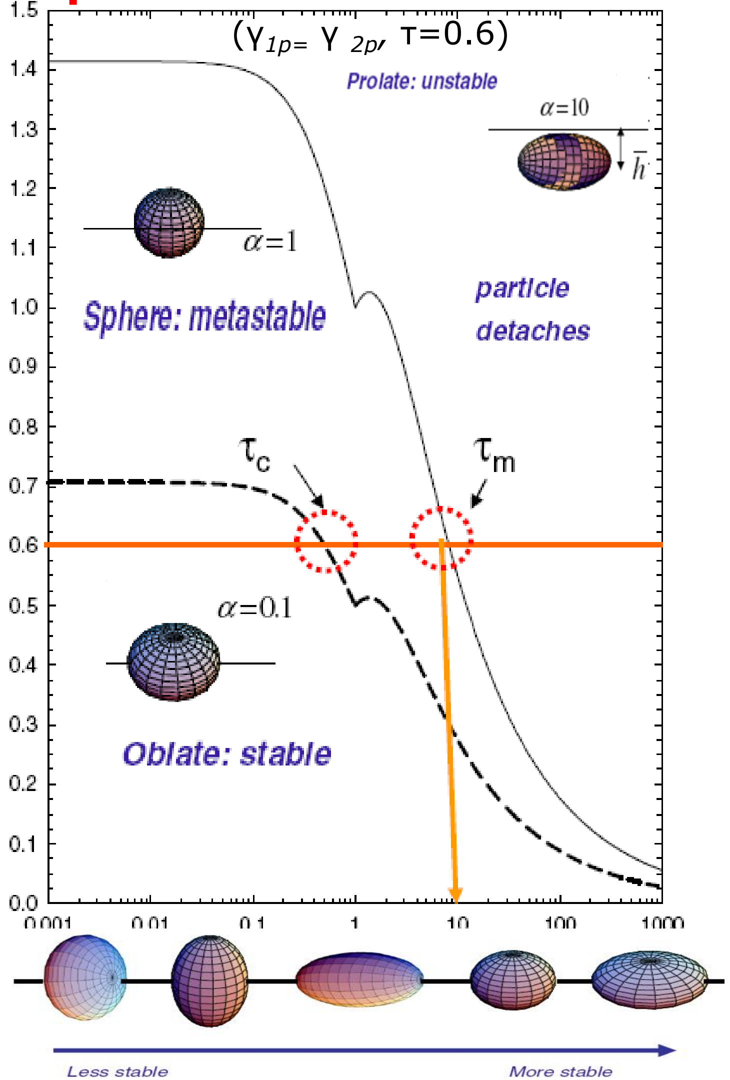
Schematic of spherical CdSe nps at oil/water interface

2D-alignment of 1D-materials depends on the
(1) Concentration **(2)** Size & orientation **(3)** interfacial energy change
(4) Aspect ratio

S. Kutuzov, J. He, R. Tangirala, T. Emrick, T. P. Russell and A. Boker, Phys. Chem. Chem. Phys., 2007, 9, 6351–635

1D-nanoparticles at interfaces - factors

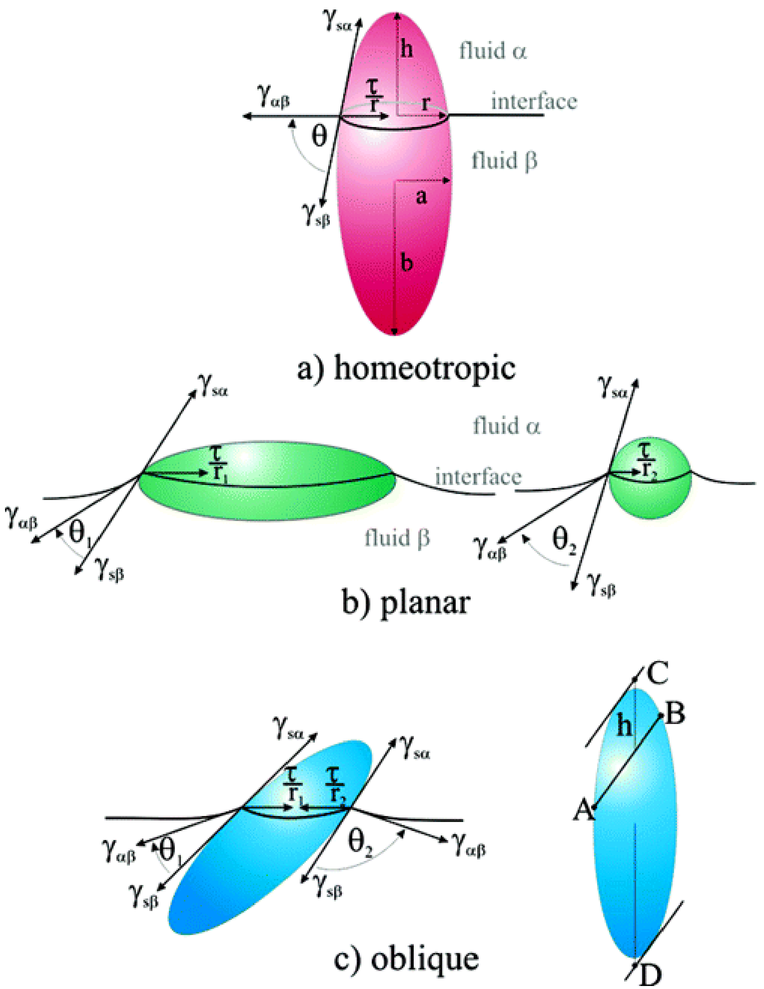
Relative stability of acicular particles at fluid interfaces



Bresme and Oettel, J. Phys.: Condens. Matter 19 (2007)

Role of Line Tension

Forces acting at the contact line between two fluids and a solid prolate nanoparticle



Dong and Jhonson, Langmuir 2005, 21, 3838-3849

Alignment techniques

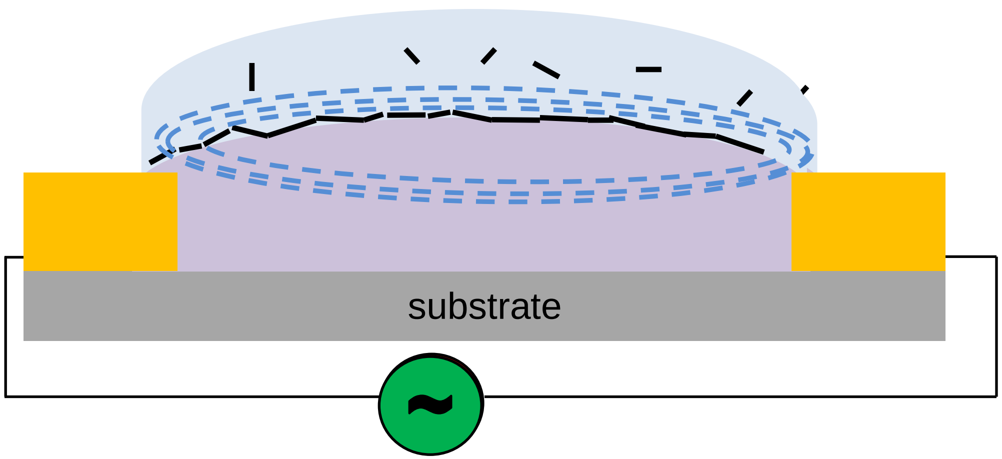
Dielectrophoresis (DEP)

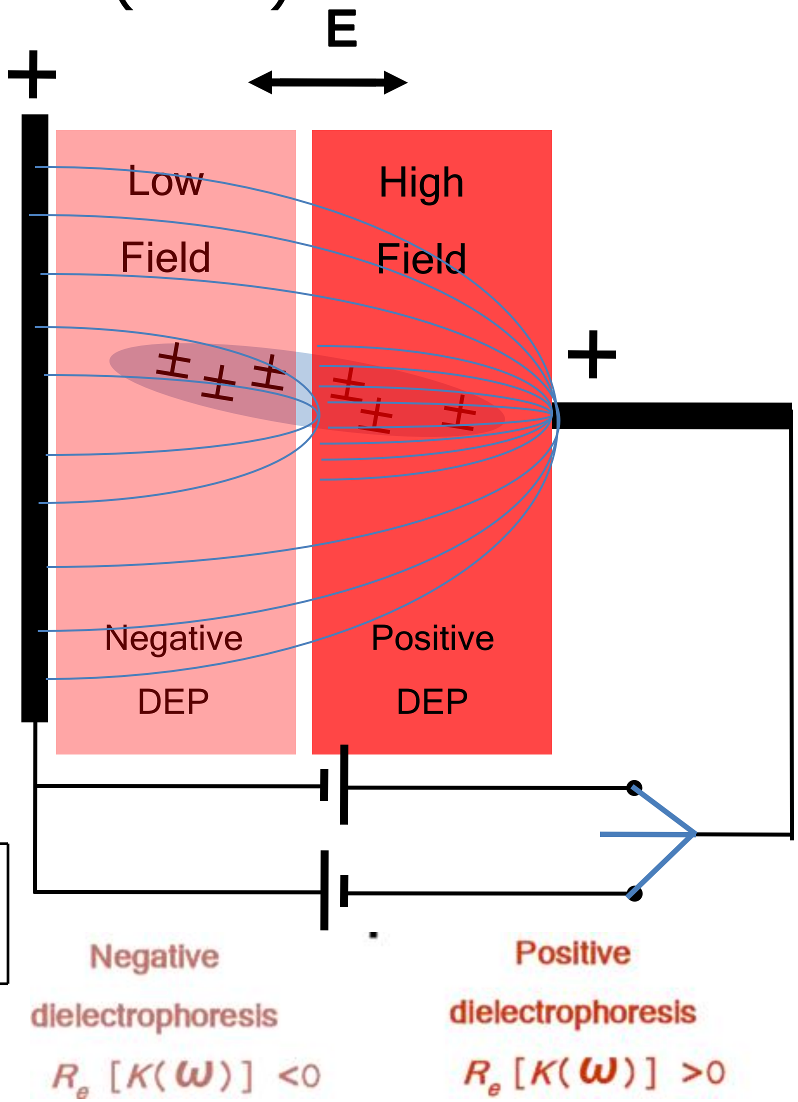
$$F_{DEP} = \frac{2\pi abc}{3}\epsilon_m R_e\left[\frac{\epsilon_p^*(\omega)}{\epsilon_m^*(\omega)} - 1\right]\nabla|E|^2$$

2пabc/3 = geometric factor

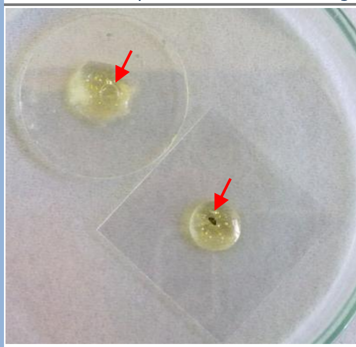
R_e = Clausius Mossotti (CM)Factor

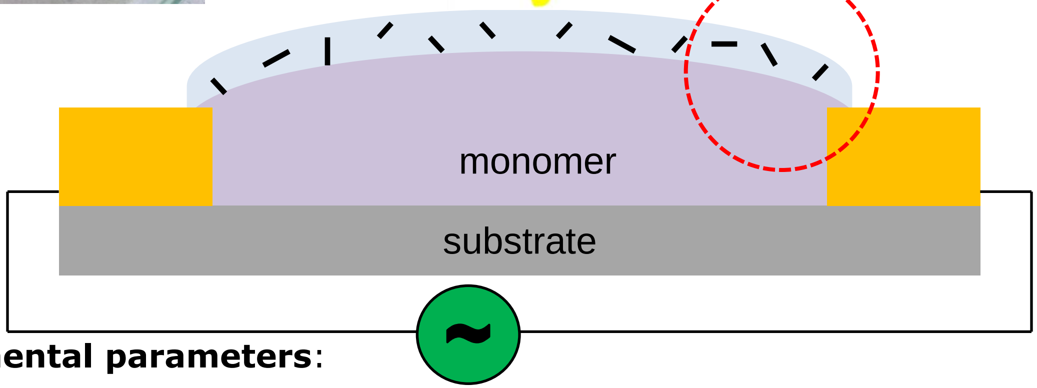
E = Electric field

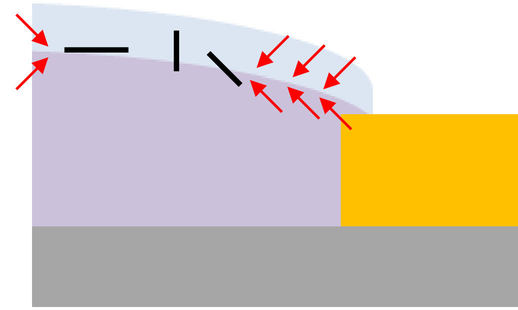


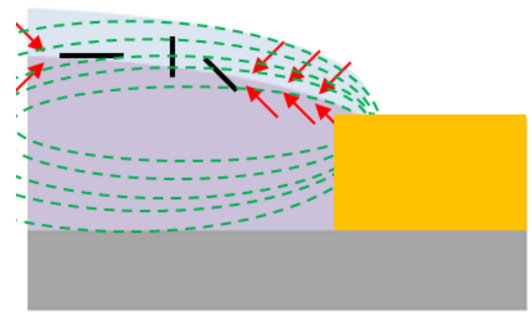


Experimental Setup









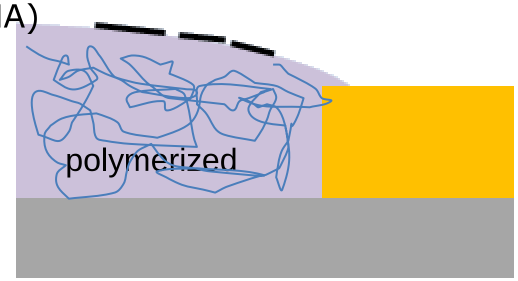
Experimental parameters:

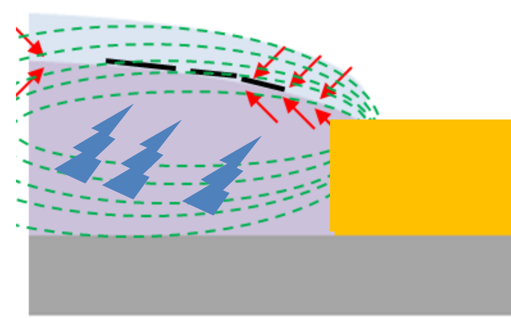
Polymer:
urethane dimethacrylate (UDMA)
+
1,6-hexanediol dimethacrylate (HDDMA)

Photoinitiator:Camphorquinone

Accelerator: N,N-dimethylaminoethyl methacrylate

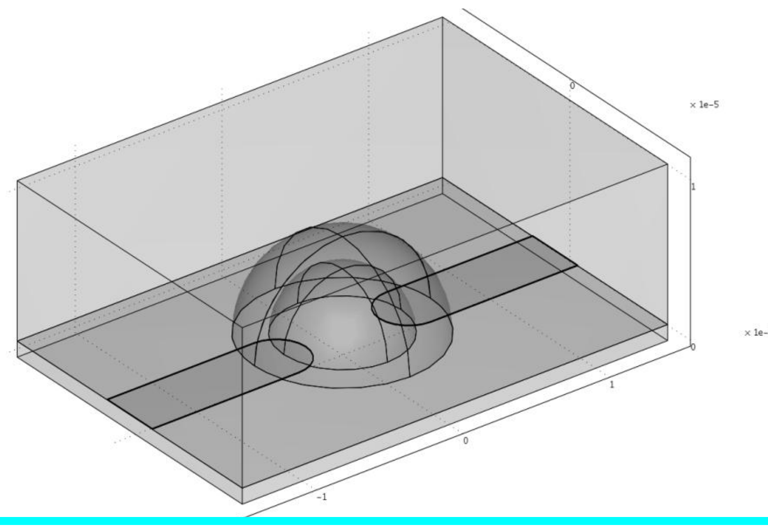
Swcnt dispersed in SDS
DEP: 300 KHz, 10 V



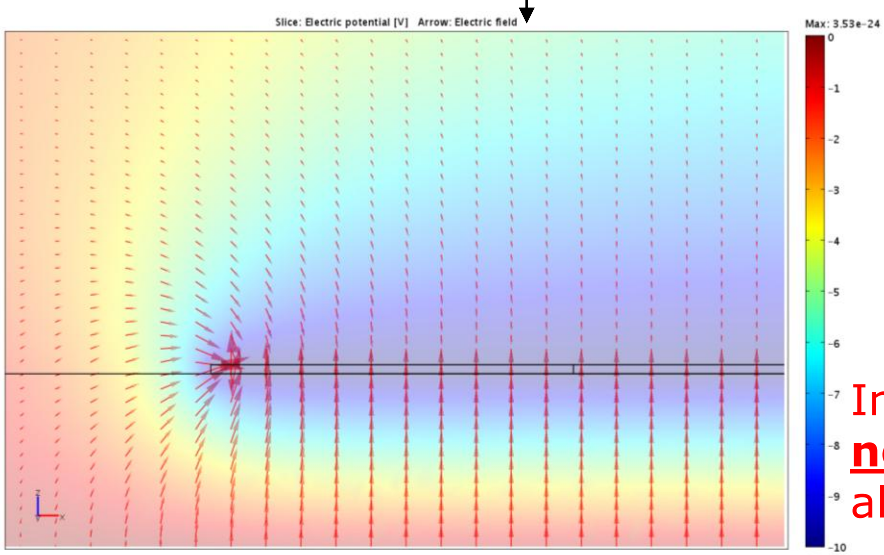


Electrical field - results

Electrical field in two liquids

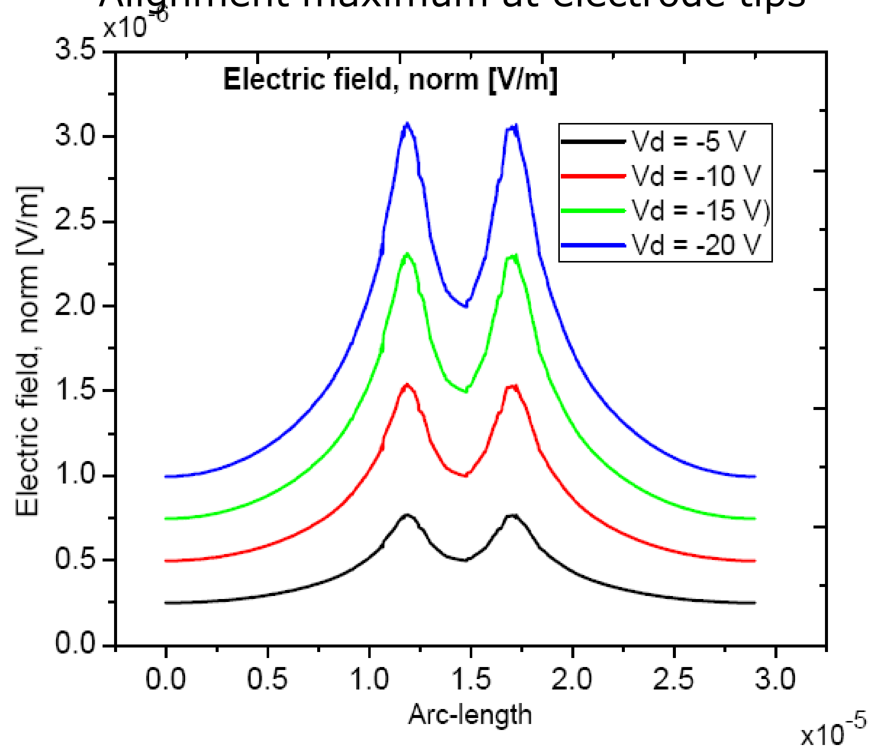


in-plane view



Electrical field – calculations

- Interface of two fluids with different permittivity few µm above the electrode
-Field gradient is highest at the corner of the electrodes
-Alignment maximum at electrode tips



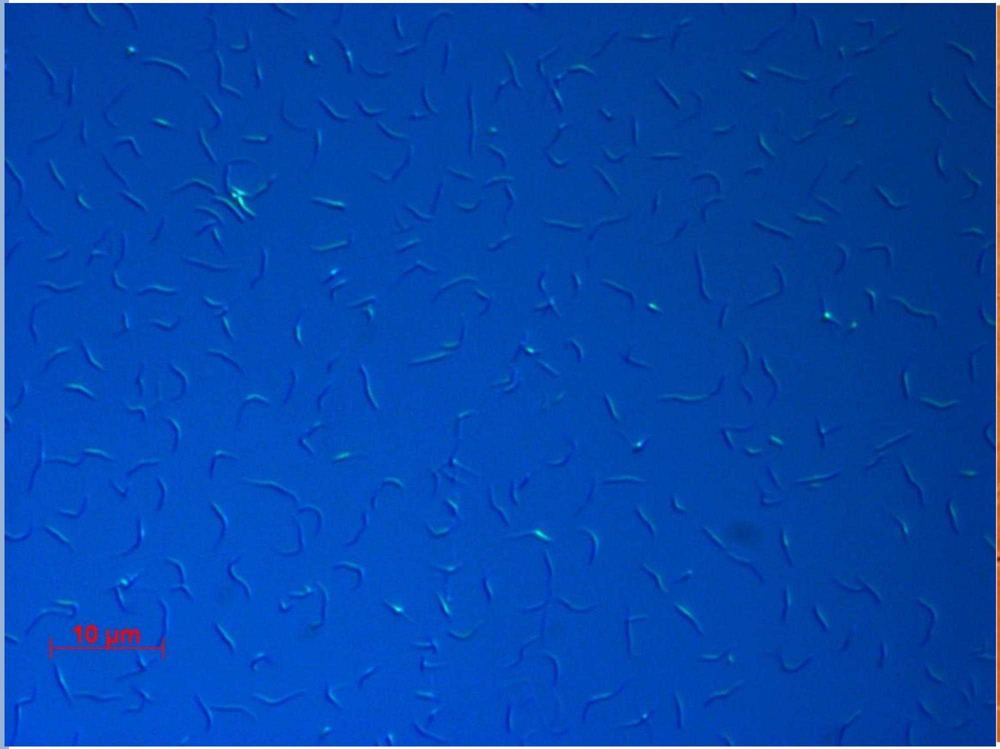
Inhomogeneous fields at the tips should **not** favor some proper homogeneous alignment

Defined nanotubes - results

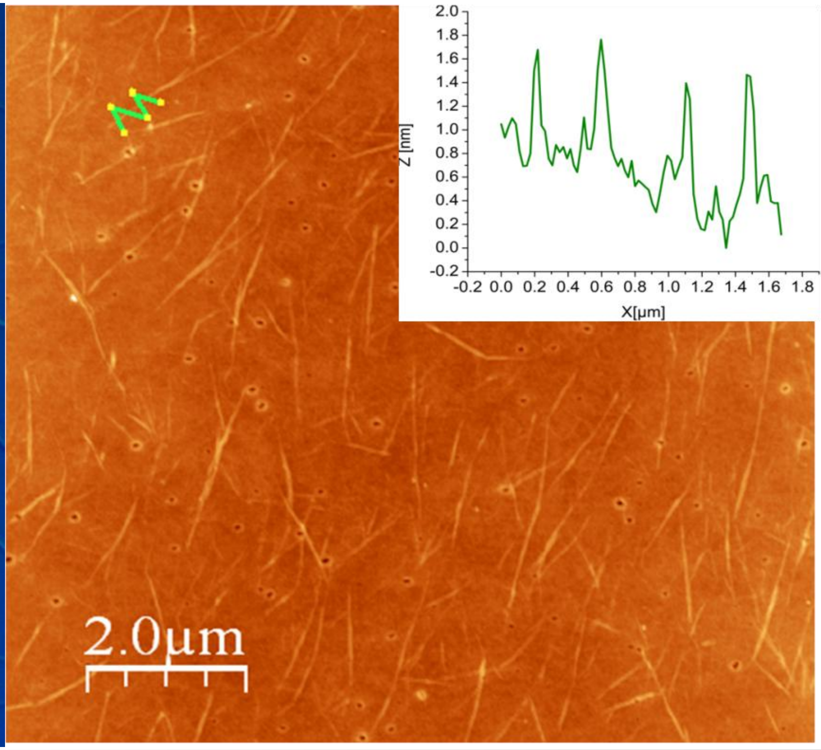
Experiment: SWCNTs with well-defined and in part adjusted properties by using a high shear mixer

- Gaussian diameter distribution centered at 1.3 nm
- SWCNT length distribution adjustable

SWCNT confocal microscopy with nanolane extension

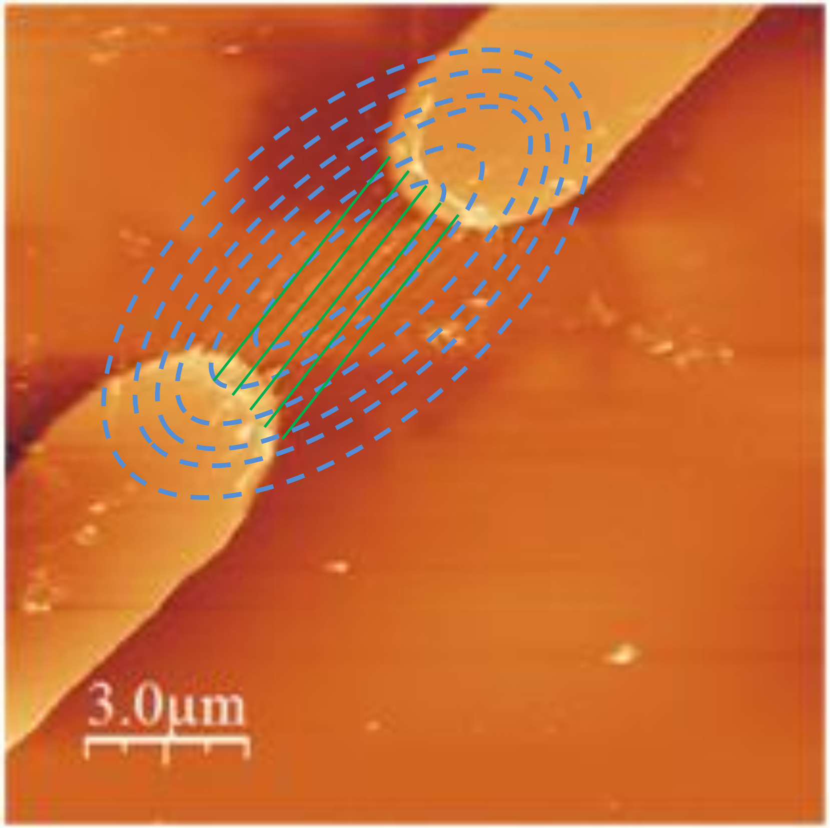


AFM image with SWCNT diameters in the inset



Electrical field - results

Electrical field – experiment says something different

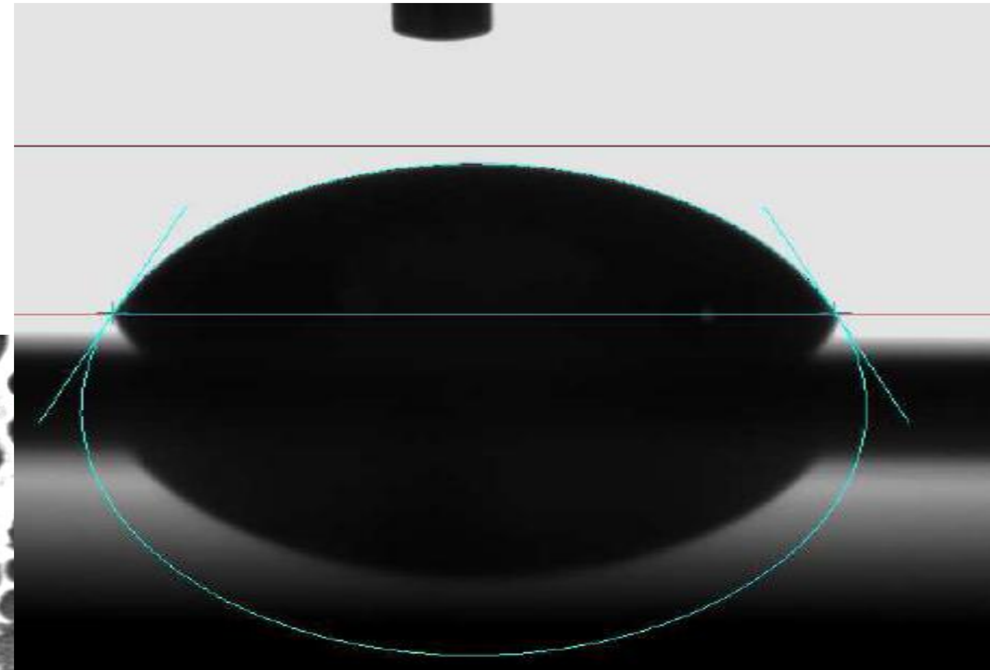


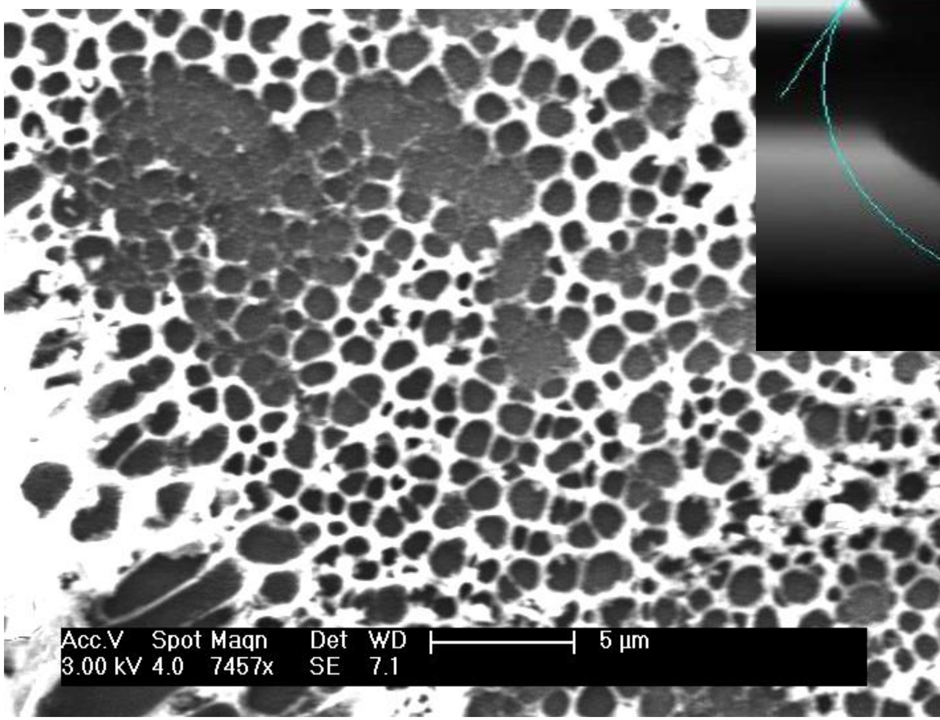
lots of parallel lines
→ proper alignment possible between two tips despite theory predicting curved field lines
→ alignment in IDT structures should even be better

Interface engineering - results

SA at interface due to surface energy with addition of Toulene to CNT dispersion

Contact angle measurement of of cnt dispersion – contact angle 67°

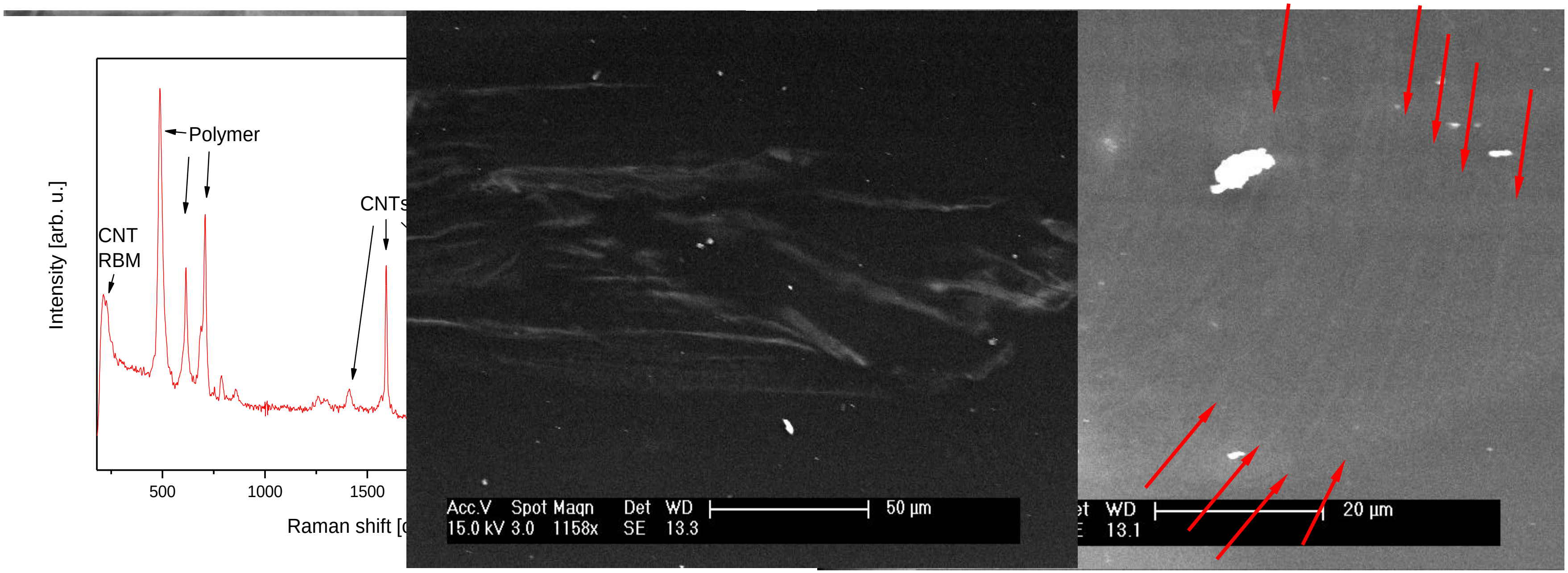




2D- assembly succeeded – 1D alignment difficult (aggregation issues)

Results

Alignment of SWCNT bundles at interface with aid of DEP as external field



- Non-alignment of swcnts networks in PDMS

- Raman measurements show the presence of swcnts in the (transparent) polymer

- Non-alignment of swcnts networks at interface under the influence of external field

- Alignment of swcnts along electric field lines at the interface. The swcnts appear to be embedded in the polymer matrix

Summary

- Dynamic platform for alignment of 1D nanoparticles with possibility of error correction and versatile applications
- Calculation shows inhomogeneous field around electrodes,however experimentally alignment is homogeneoous
- Presence of nanotubes in polymer confirmed by Raman spectroscopy
- Positive evidences of alignment at interface using external fields

- **Outlook**
  - Refined calculation of functionalized nanoparticles at interfaces
  - Experiments, with different concentraton and sizes of NPs

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Thanks for

Your attention