Dispositivos baseados em nanomembranas híbridas: um caso onde o micro e o nano se complementam através da auto-organização

Carlos César Bof Bufon

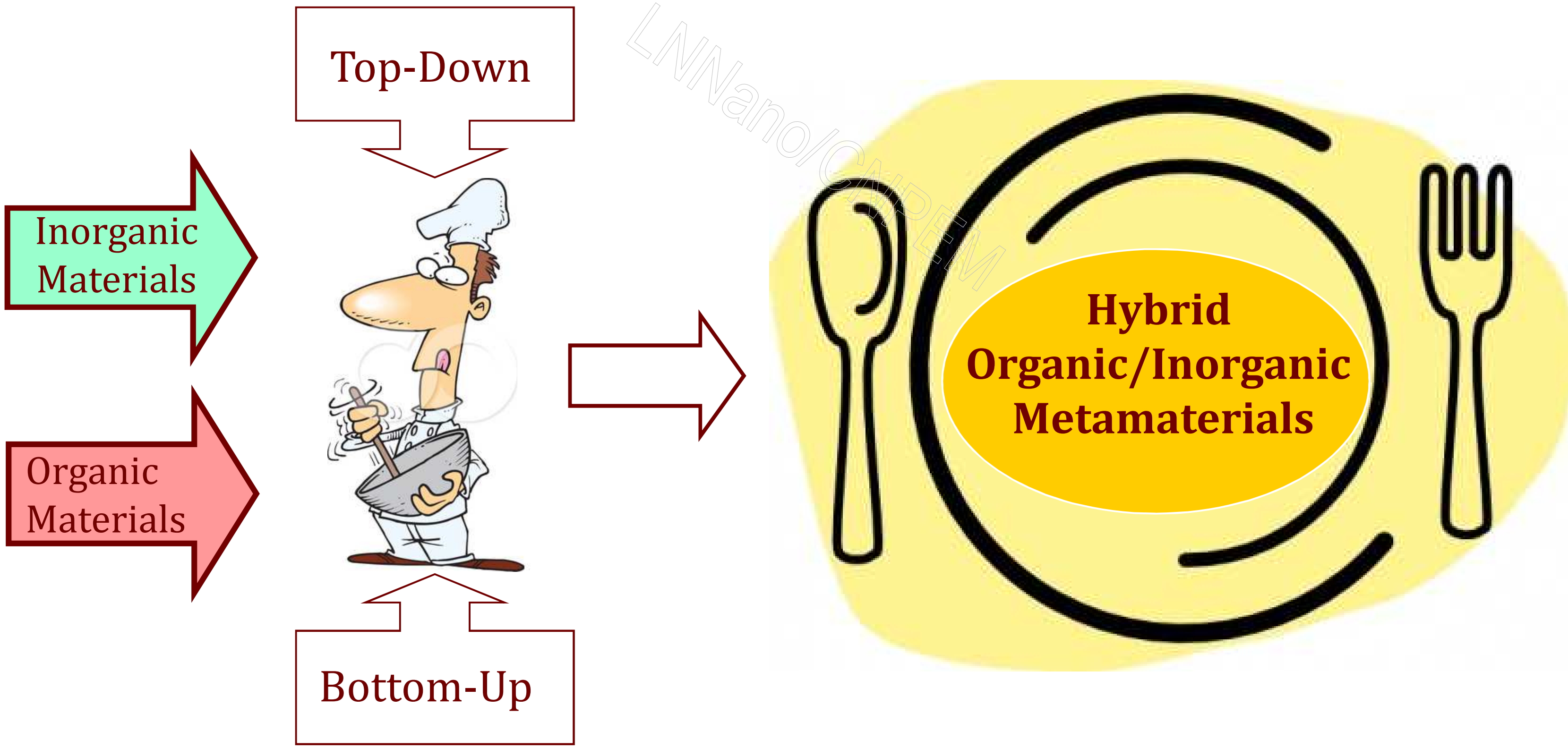
Grupo de pesquisa em Dispositivos e Sistema Funcionais

Research scope

- Materials Science
- Strain-Engineering
- Nano/microfabrication
- Self-assembly

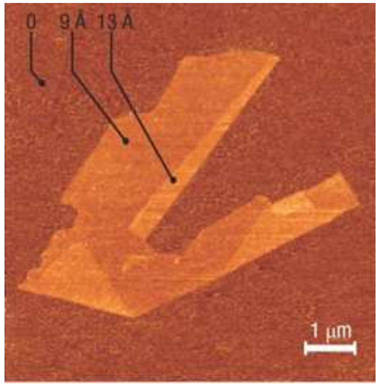
Smart Architectures

Novel Functional Devices and Structures



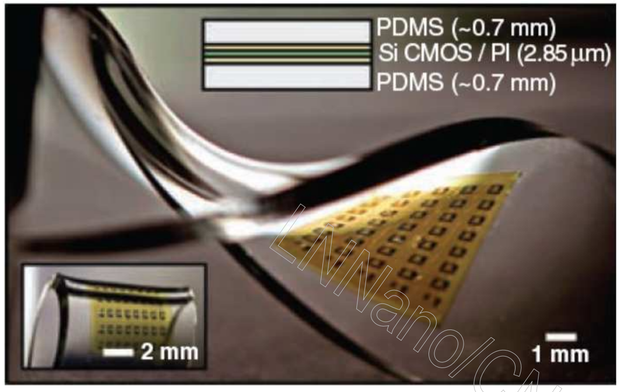
Nanomembranes are structures with *thicknesses of less than a few hundred nanometers* and with minimum *lateral dimensions at least two orders of magnitude larger than the thickness.*

Thin



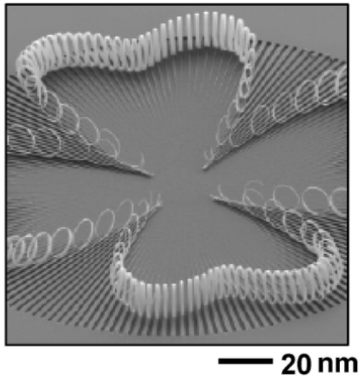
Geim, *Nat. Mater.* 2007

Flexible



Kim, *Science* 2008

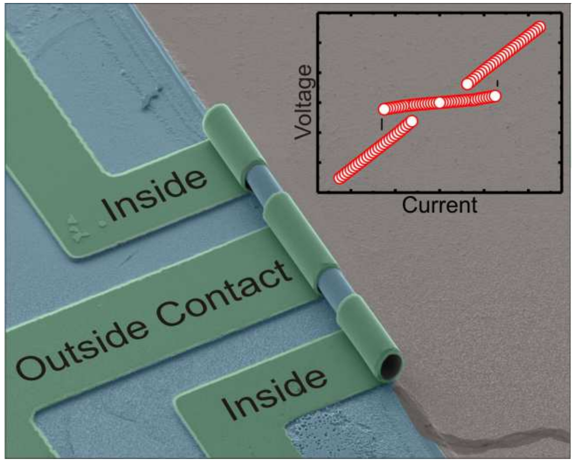
Strain engineered



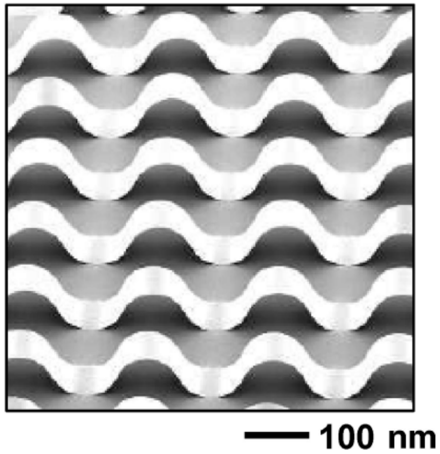
Zhang, *Nano Lett.* 2006

Deneke, *Appl.Phys.Lett.* 2007

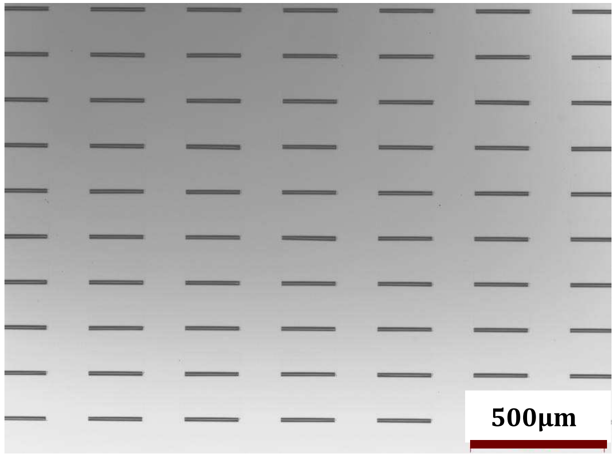
Patternable



Thurmer, *Nano Lett.* 2010



Sun, *Nat. Nanotechnol.* 2006



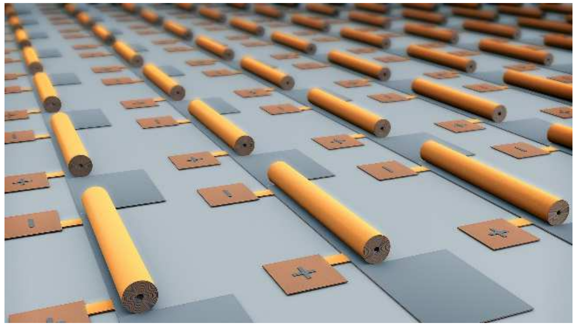
Bof Bufon ; IIN Chemnitz, 2010

Applications of nanomembranes

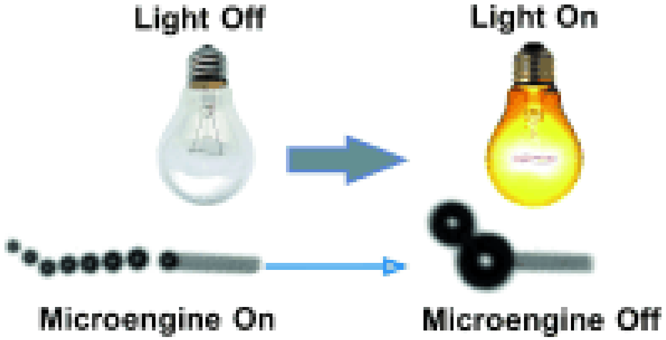
- ultra-compact functional devices;
- µ-containers and µ-fluidic elements;
- 3D electronics.

NANO LETTERS
pubs.acs.org/NanoLett

Self-Assembled Ultra-Compact Energy Storage Elements Based on Hybrid Nanomembranes



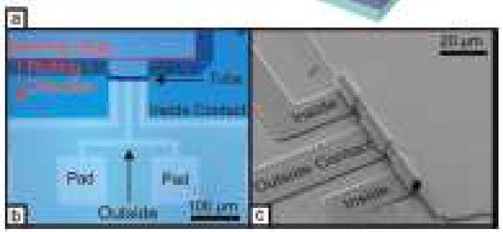
Angewandte Chemie International Edition



Light-Controlled Propulsion of Catalytic Microengines

NANO LETTERS

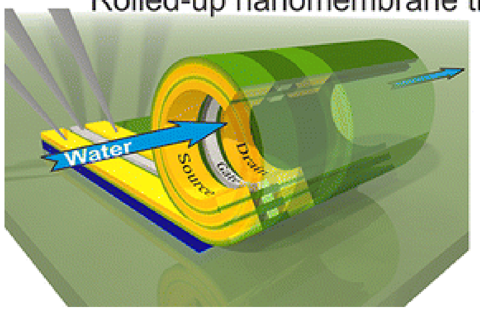
Nanomembrane-Based Mesoscopic Superconducting Hybrid Junctions

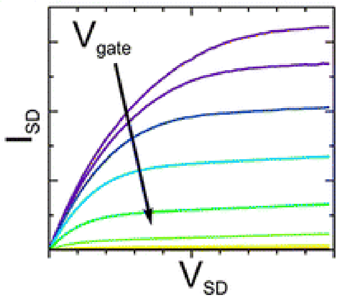


NANO LETTERS
Letter
pubs.acs.org/NanoLett

Rolled-up nanomembranes as compact 3D architectures for field effect transistors and fluidic sensing applications

Rolled-up nanomembrane transistor for microfluidics



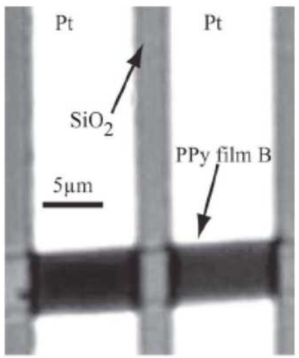


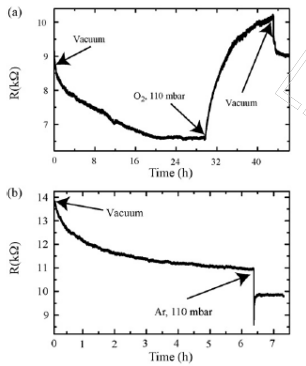
Hybrid organic – inorganic heterojunctions based on nanomembranes

- **Molecular heterojunctions;**
- **Hybrid sensors;**
- **3D ultra-compact organic devices;**

AIP Applied Physics Letters

Polypyrrole thin-film field-effect transistor

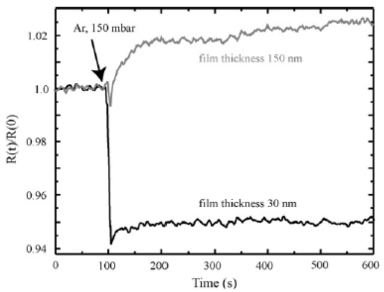




Contents lists available at ScienceDirect

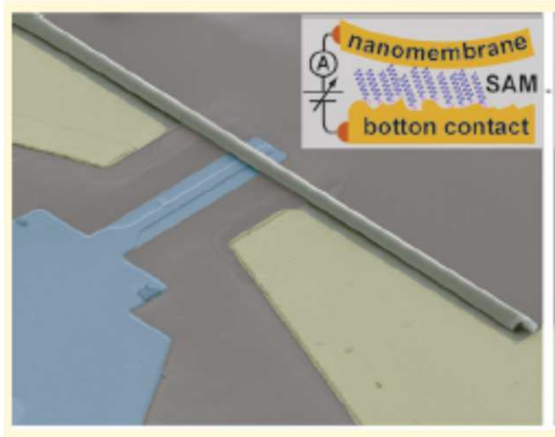
Sensors and Actuators A: Physical

Piezoresistance in chemically synthesized polypyrrole thin films



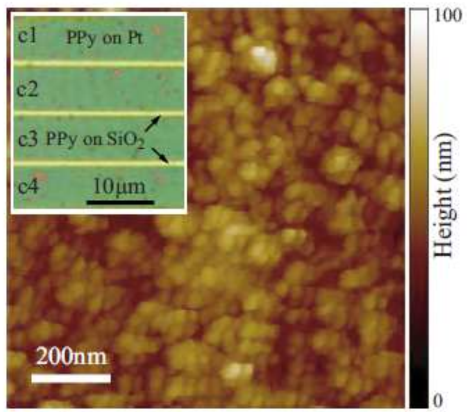
NANO LETTERS LETTER
pubs.acs.org/NanoLett

Hybrid Organic/Inorganic Molecular Heterojunctions Based on Strained Nanomembranes



PHYSICAL REVIEW B 76, 245206 (2007)

Transport properties of chemically synthesized polypyrrole thin films



Self-releasing in everyday life

The Tension of Metallic Films deposited by Electrolysis.

By G. Gerald Stoney.

(Communicated by the Hon. C. A. Parsons, C.B., V.-P.R.S. Received January 16,
—Read February 4, 1909.)

It is well known that metallic films deposited electrolytically are in many cases liable to peel off if deposited to any considerable thickness. This is the case with nickel which, when deposited over a certain thickness, will curl up into beautiful close rolls, especially if it does not adhere very tightly to the body on which it is deposited. For example, if a piece of glass is

From nano to micro: the art of shaping nanomembranes

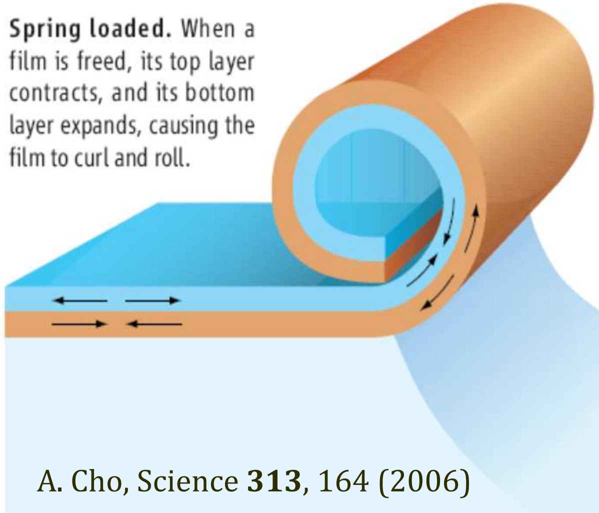
(a research field by itself)

"Deterministic" Self-assembly

Substrate: glass, Si/SiO_2, Si, GaAs ...

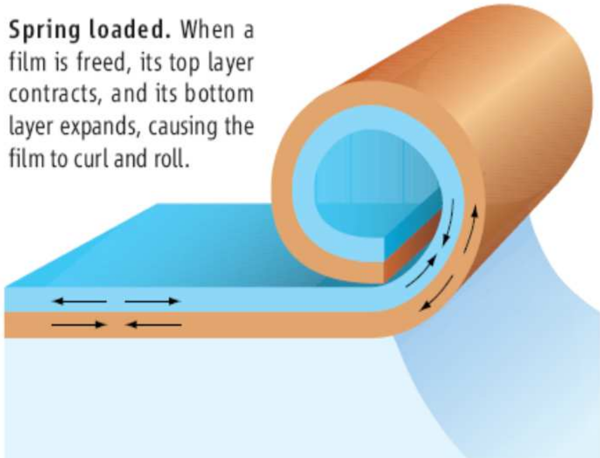
Sacrificial layer: photoresist, GeO_2, AlAs, Ge ...

Strained layer: metals, oxides and semiconductors

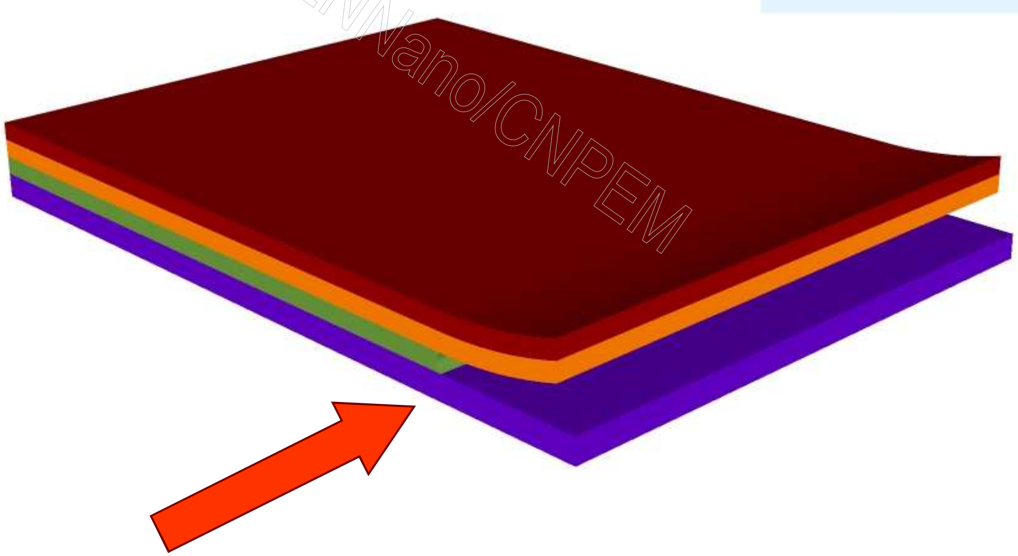


A. Cho, Science **313**, 164 (2006)

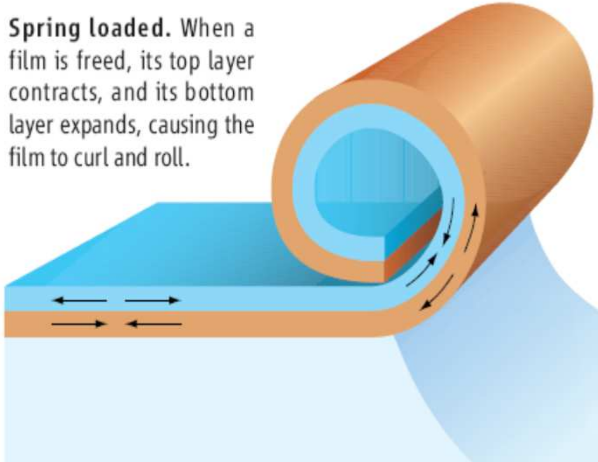
Selective removal of the sacrificial layer:
- $H_2O + H_2O_2$ (0% to 3%)
- H_2O + HF (0.5% to 2%)
- Acetone



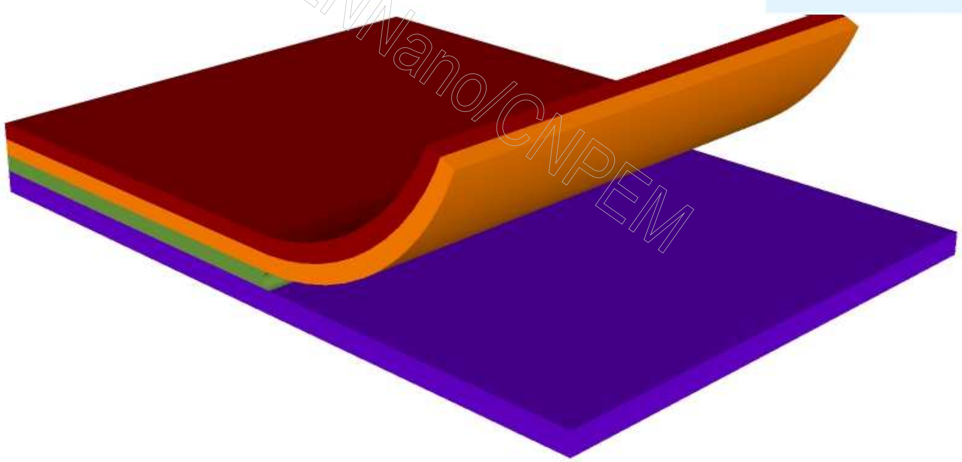
A. Cho, Science **313**, 164 (2006)



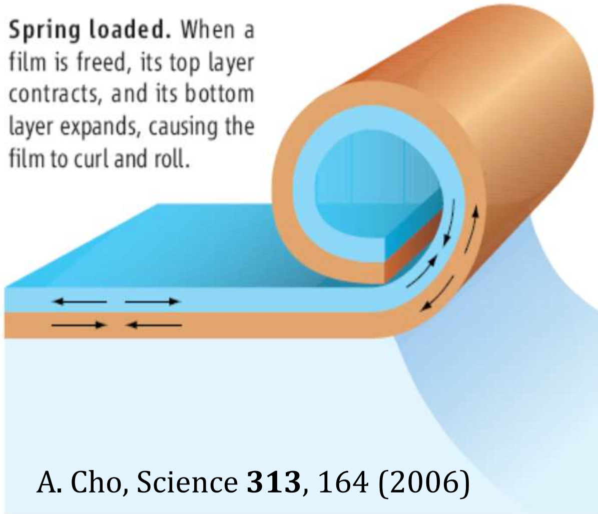
“Deterministic“ Self-assembly



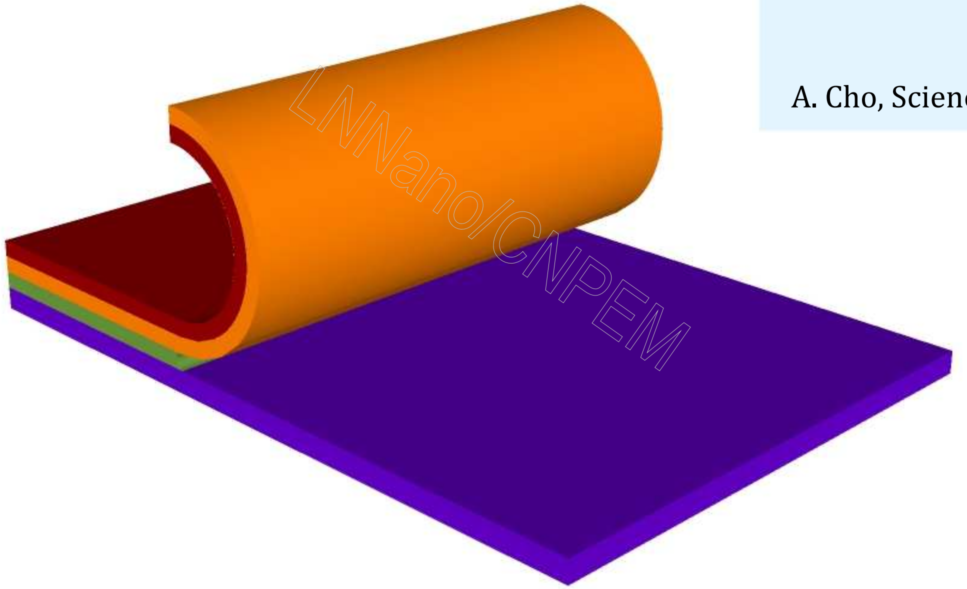
A. Cho, Science **313**, 164 (2006)



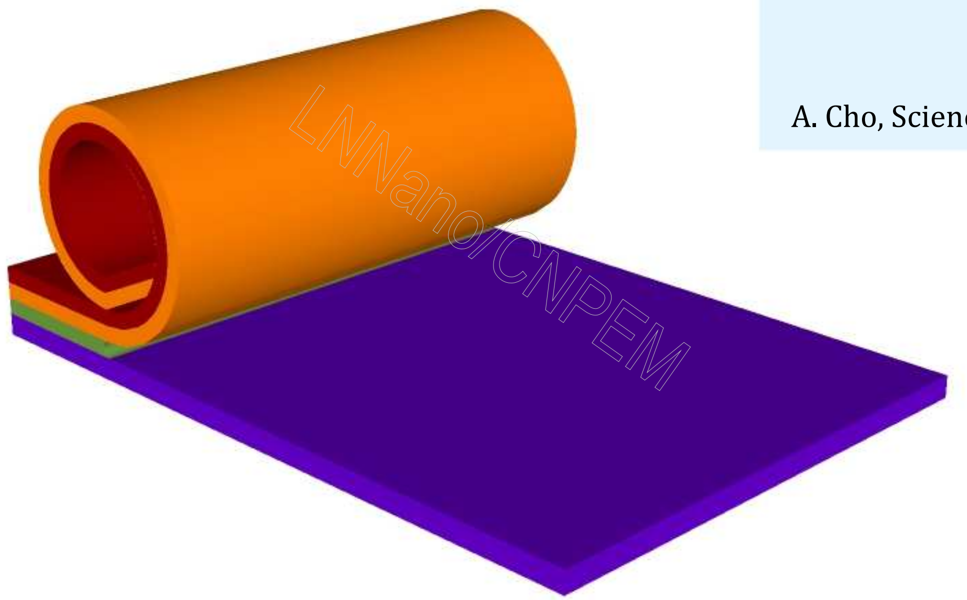
"Deterministic" Self-assembly

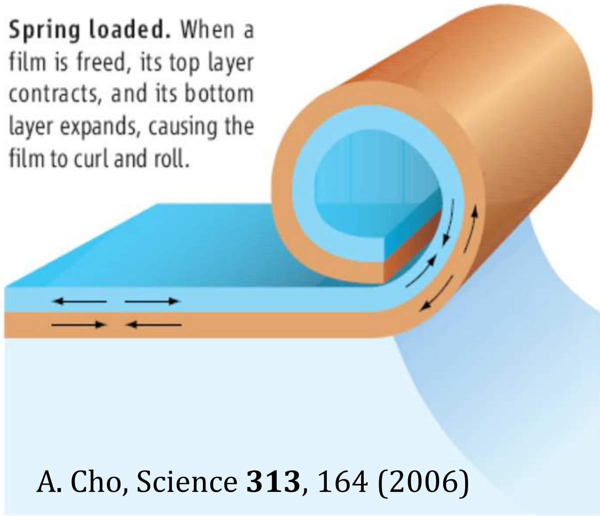


A. Cho, Science **313**, 164 (2006)



“Deterministic“ Self-assembly



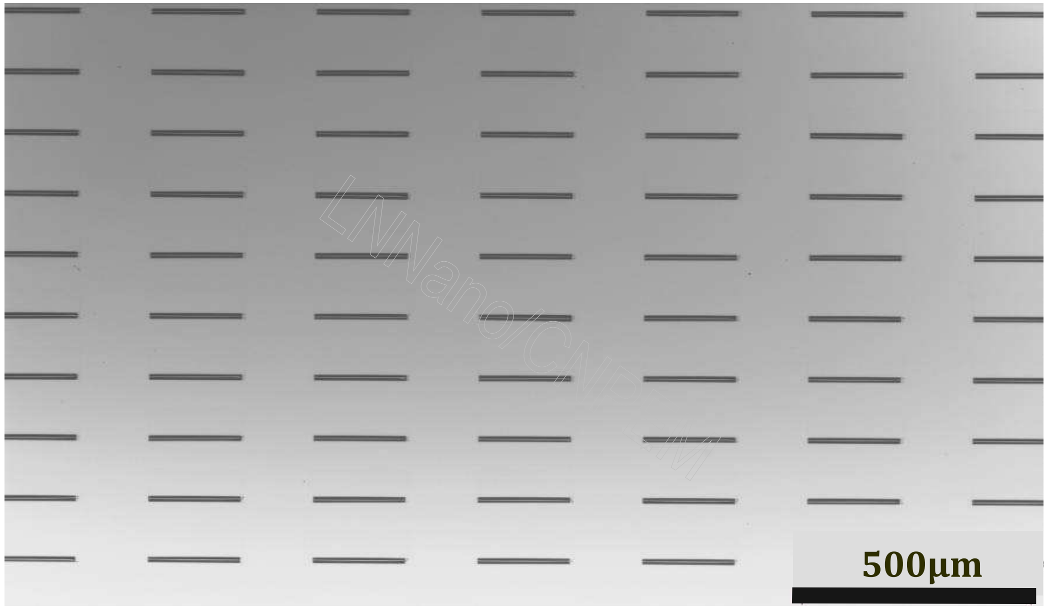


A. Cho, Science **313**, 164 (2006)

Patterning of regular arrays

Strained bilayer: Ti/Cr (15/20nm)
Sacrificial layer: GeO_2 (~20nm)
Substrate: Si/SiO_2

Rolling in H_2O

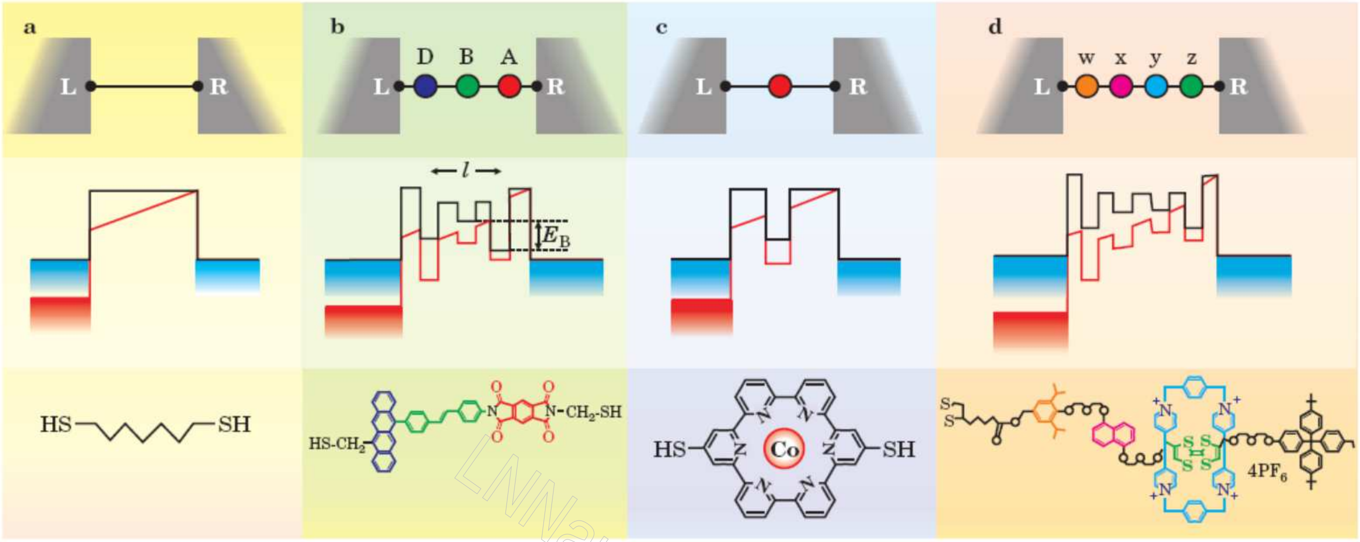


Φ = 1µm-100µm

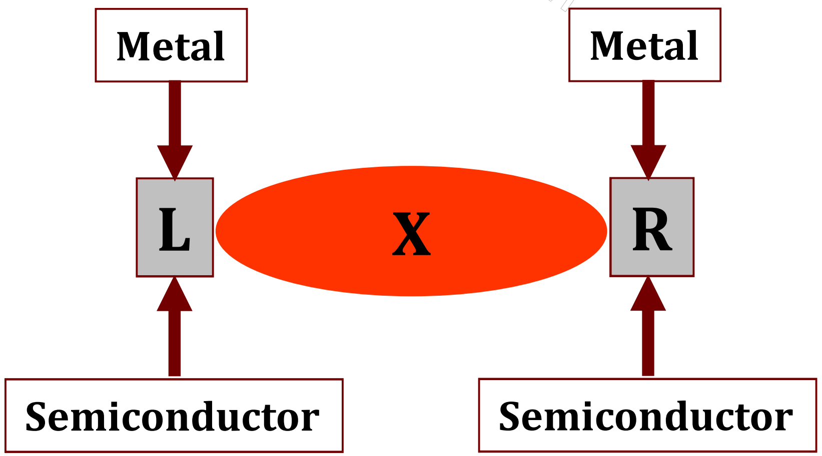
Schadewald and Bof Bufon; IIN Chemnitz, 2010

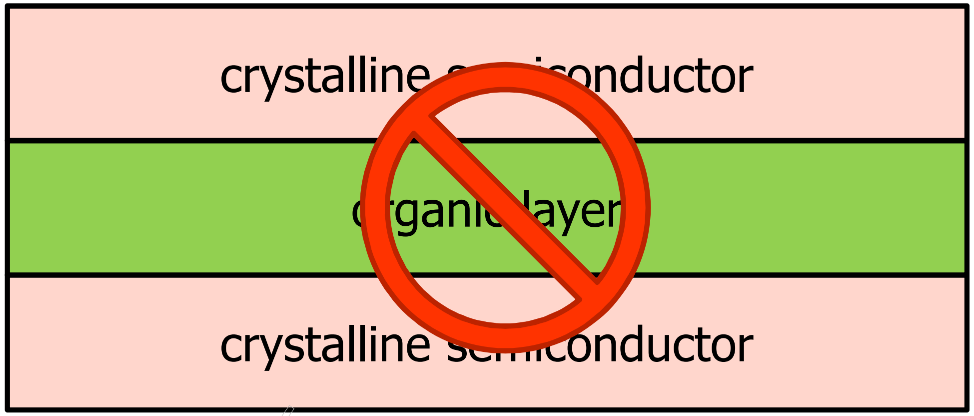
Hybrid Organic/Inorganic Heterojunctions

Molecular (hetero)-junctions

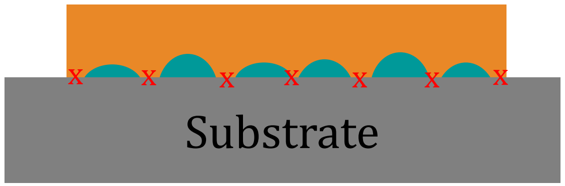


James R. Heath and Mark A. Ratner, Physics Today 2003

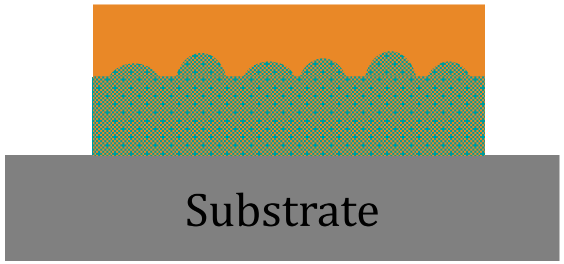




High temperature damages



Short-circuit via pinholes



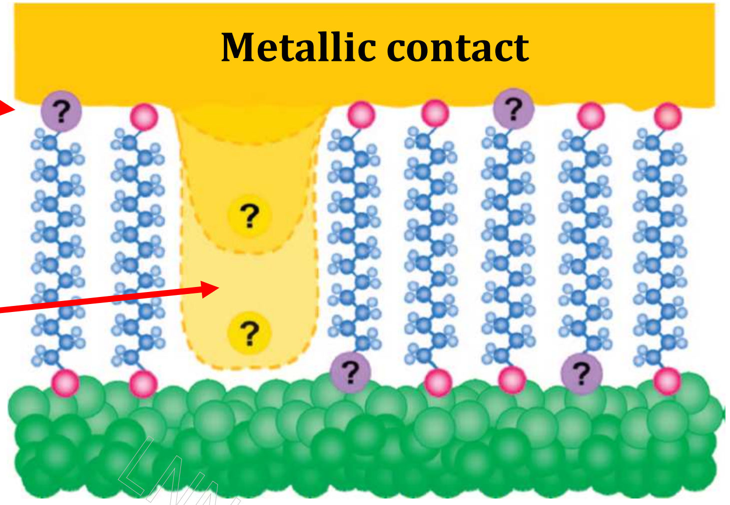
Metal interdiffusion.

Delicate materials require new contacting methods

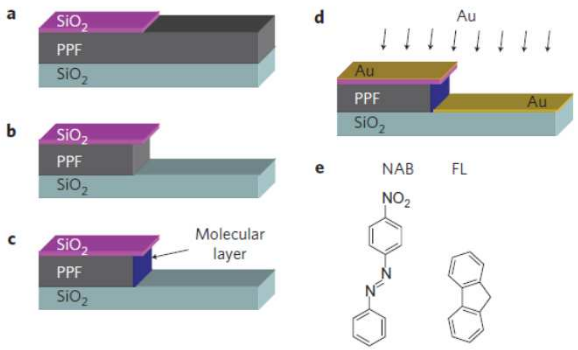
Contacting molecular layers: challenges

bonding damage
(charge localization)

pinholes
(short circuit)

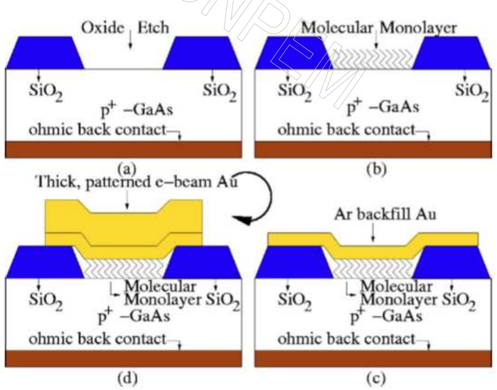


Haick and Cahen, *Acc. Chem. Res.* 41, 359 (2008)



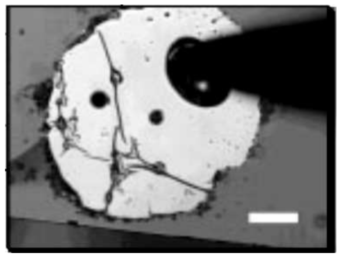
Evaporation of contacts

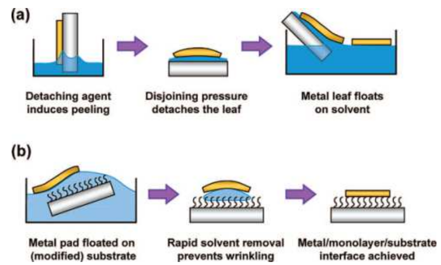
Bonifas and MacCreery, Nat. Nanotech. 2010



Evaporation of contacts

Lodha et al, J. Appl. Phys. 2006



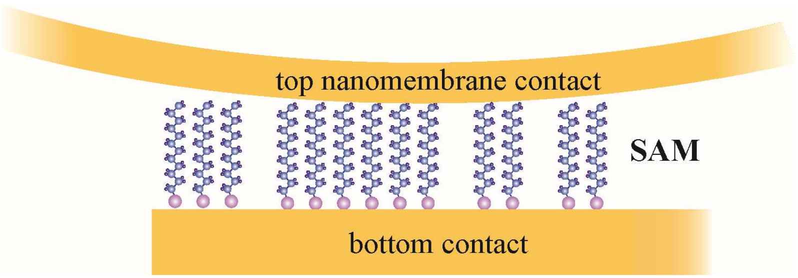


Lift-off Float-off

Cahen et al, Nature 2000

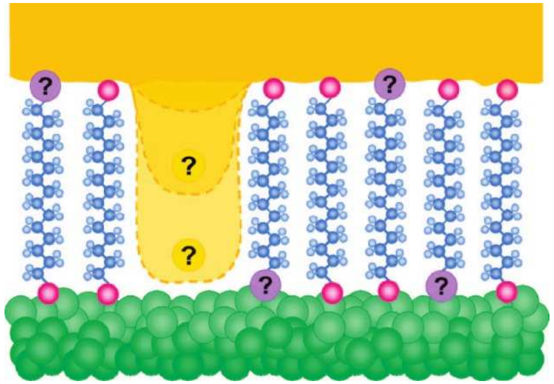
Haick and Cahen, Acc. Chem. Res. 2008

Hybrid junctions based on nanomembranes



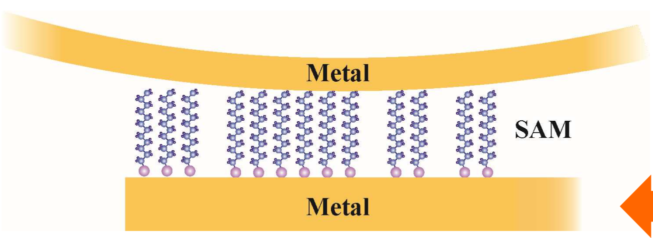
- Pinhole-proof;
- Soft contact: low damage to the MoLa;
- "Large scale" production and integration;
- Versatile material composition;
- Self-adjusting gap.

Soft mechanical contacting method: Self-adjusting contacts.

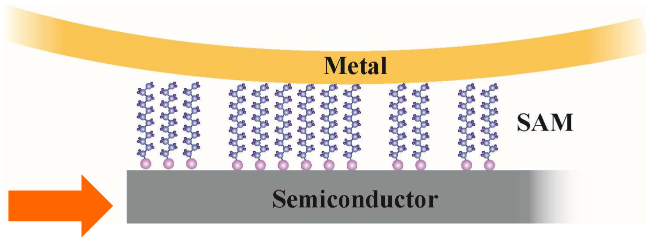


Haick et al., Acc. Chem. Res. **41**, 359 (2008)

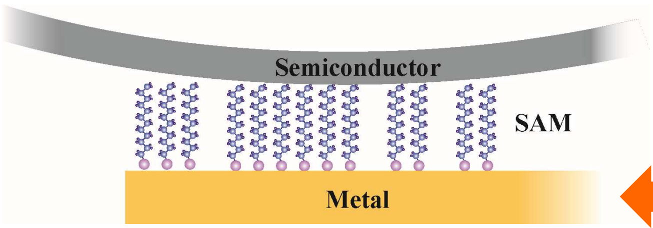
Nanomembrane based top metallic contact



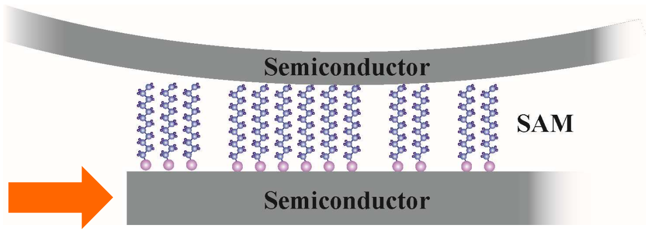
Bottom contact



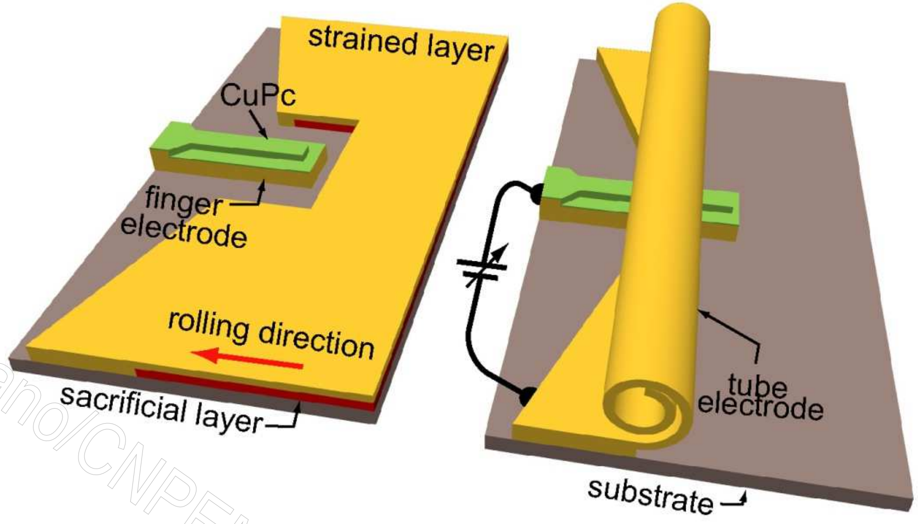
Nanomembrane based top semiconducting contact

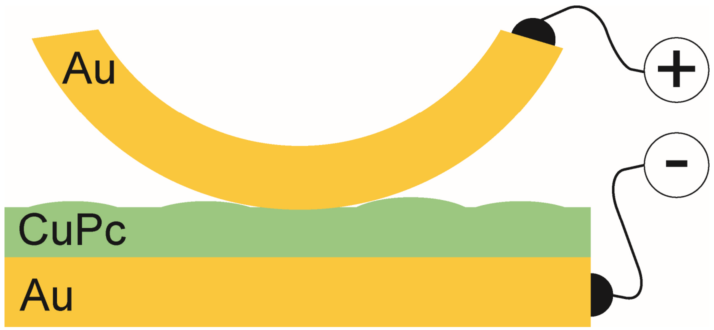


Bottom contact

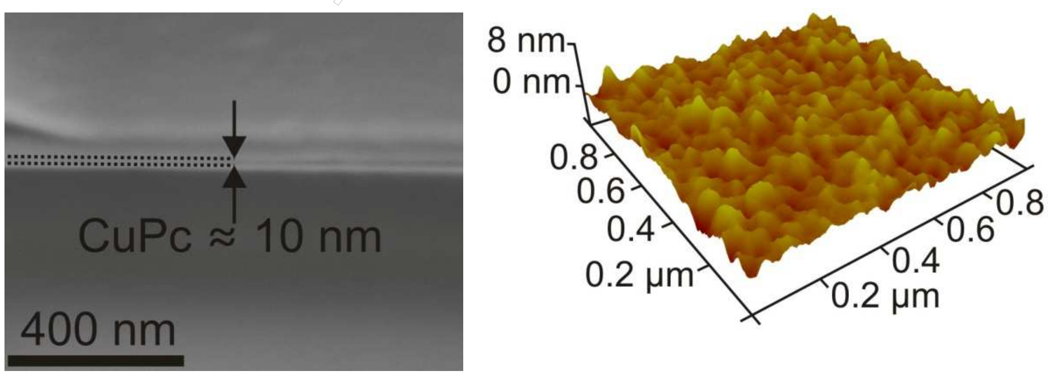


Contacting CuPc thin films (Au/CuPc/Au)

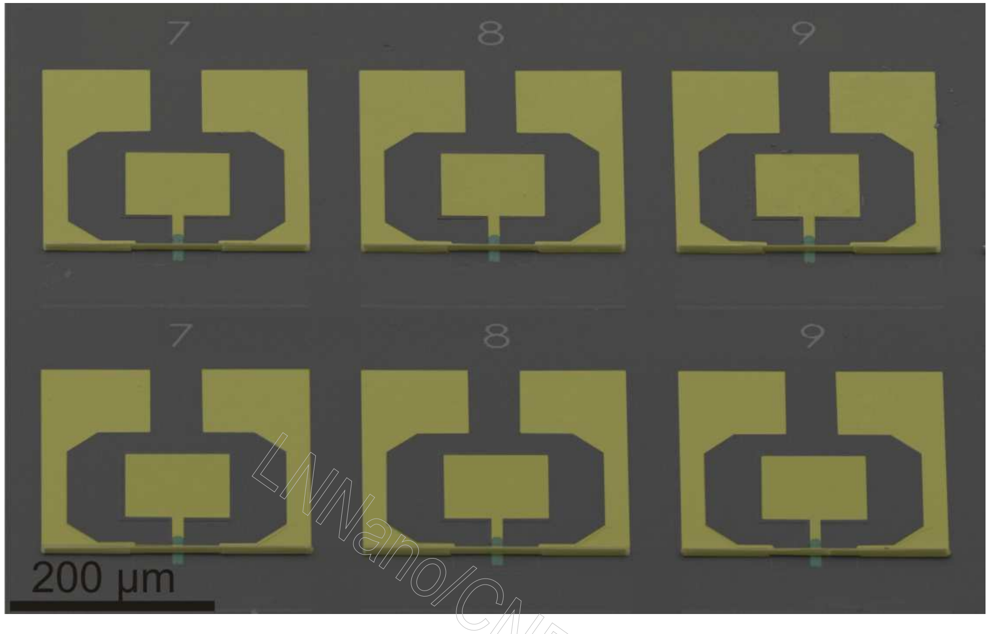


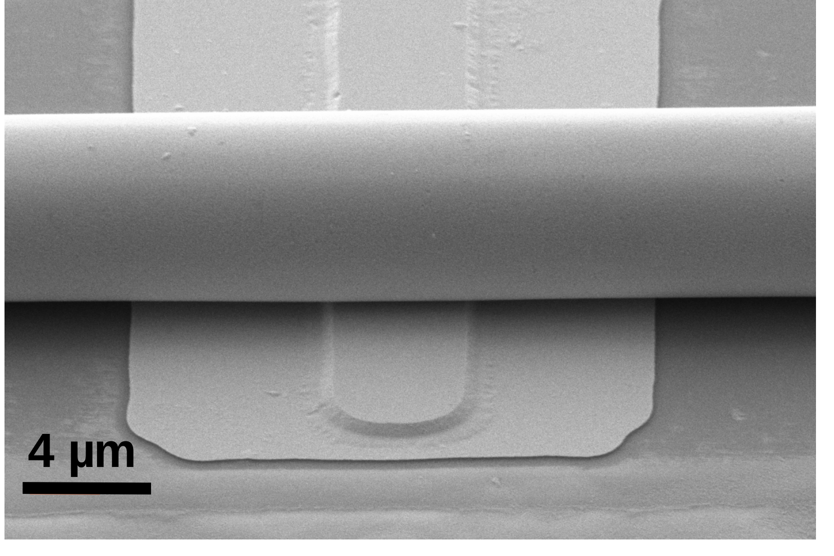


Electrode gap ~ 6.5 nm



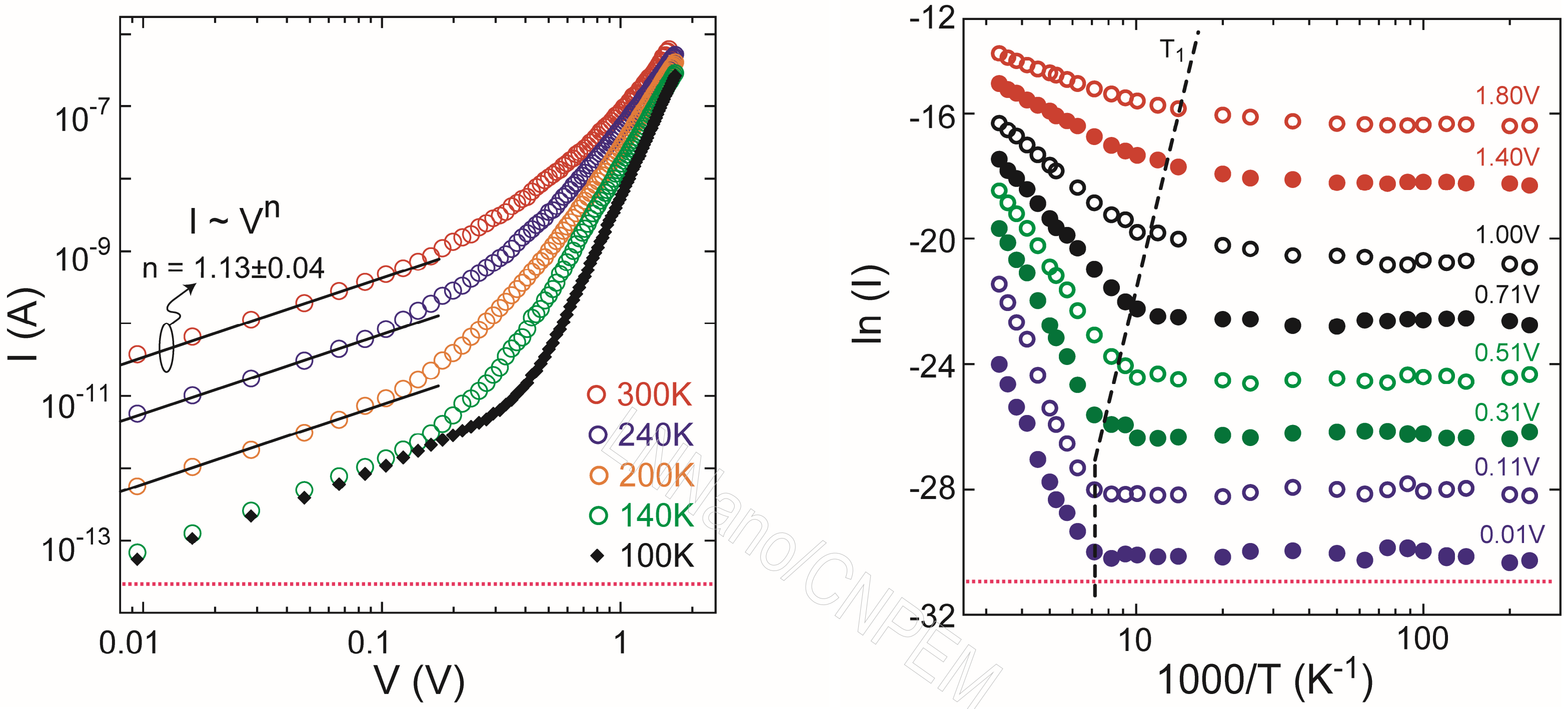
Submittend to JPC-C





Submittend to JPC-C

Transport properties of CuPc thin films: IV and IT traces



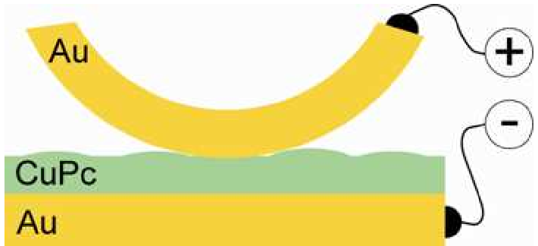
- For V < 0.15V and T > 100 - 140 K, hopping conduction dominates;
- At T = T_1: transition from thermally activated transport to tunneling;
- Strong temperature dependence for T > T_1 associated to impurity/defect (ID) sites;
- For T > T_1:

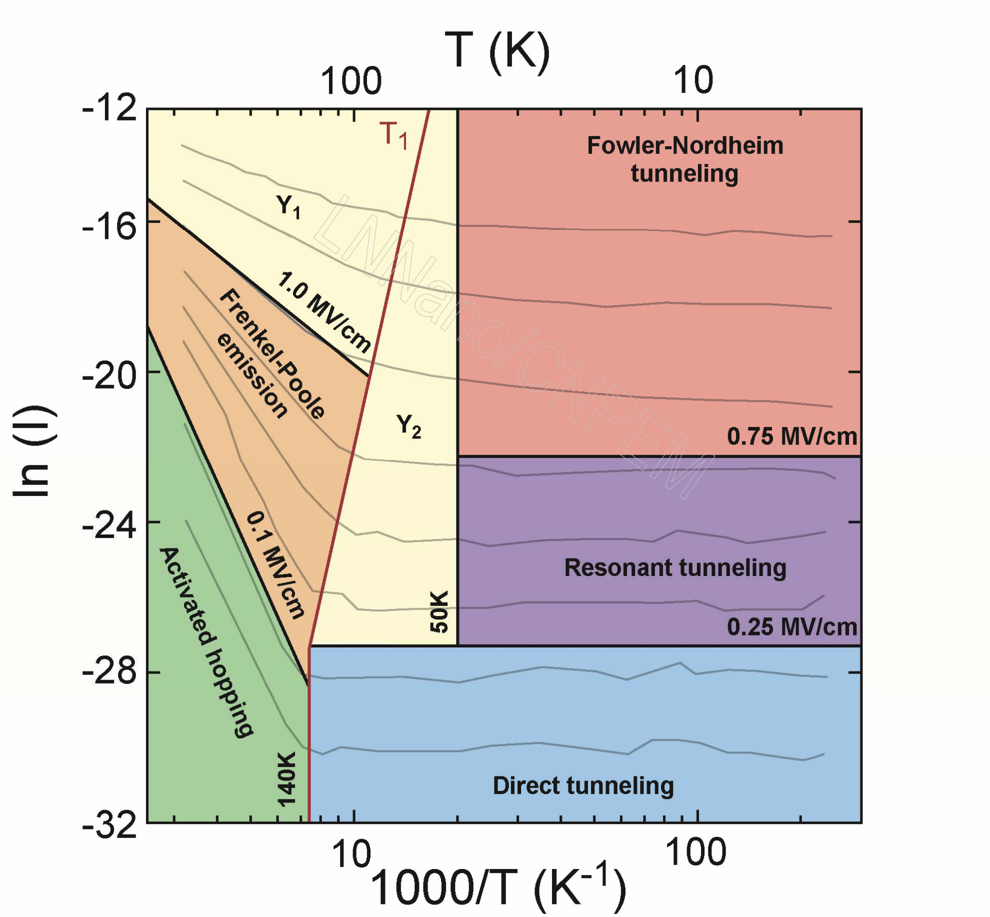
$$I \propto V \exp\left(-\frac{E_a}{kT}\right)$$

Submittend to JPC-C

Au/CuPc/Au

- Rolled-up nanomembranes can gently contact ultra-thin organic semiconducting layers from the top;
- No interdiffusion of metallic atoms was detected.

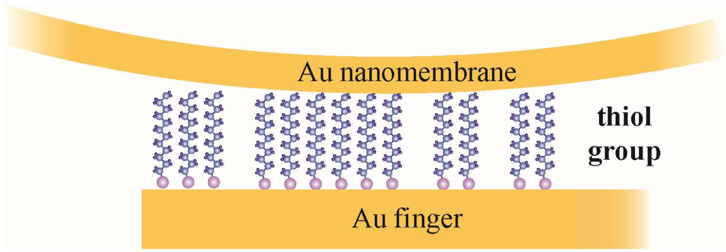




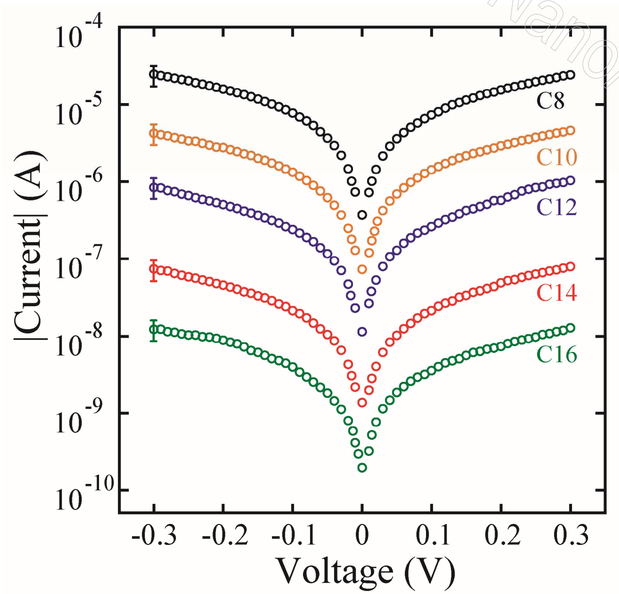
Submittend to JPC-C

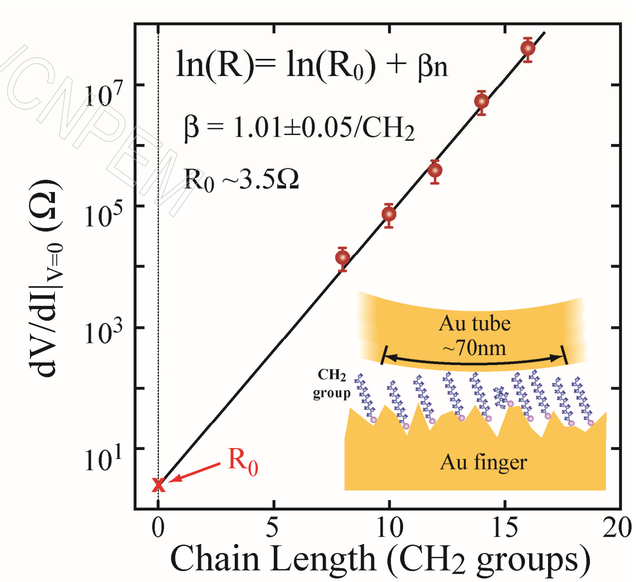
Au/SAM/Au heterojunctions

Contacting sulfur terminated alkanes



Non-resonant tunneling transport

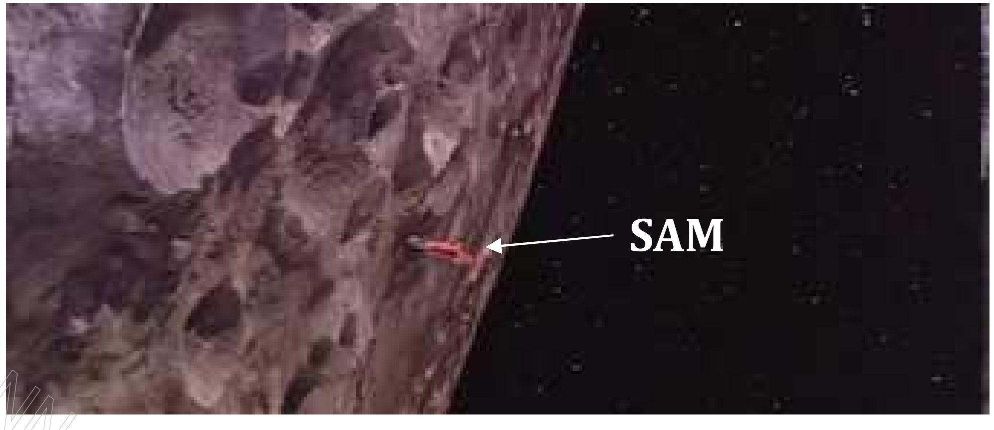


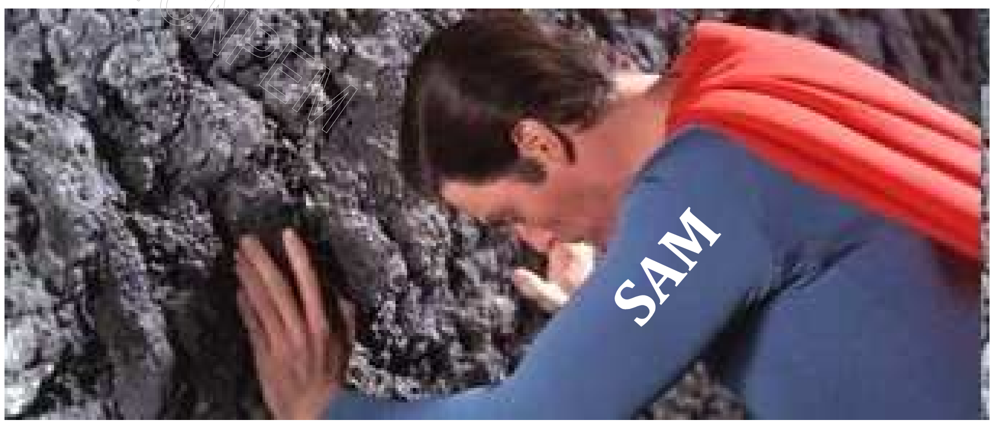


C.C.Bof Bufon *et al., Nano Lett. 11, 3727 (2011)*

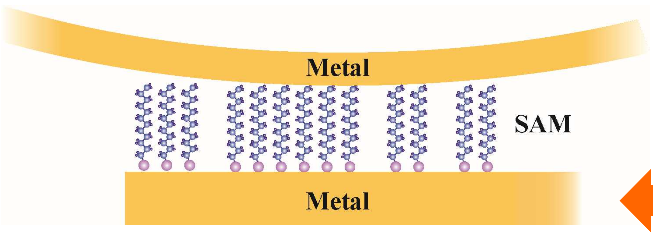
Tube Ø
~ 5-10µm

Chain Length
(C6-C18 thiol)
~ 0.7-2.3nm

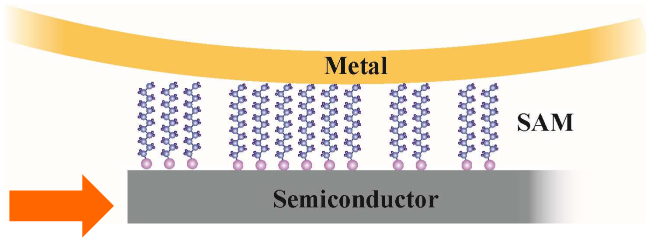




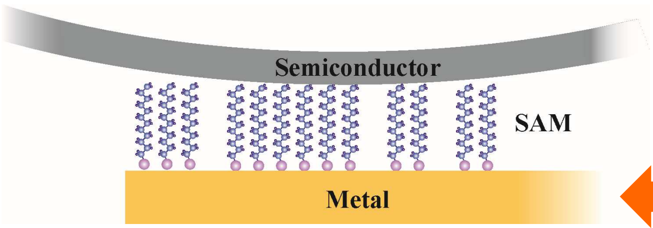
Nanomembrane based top metallic contact



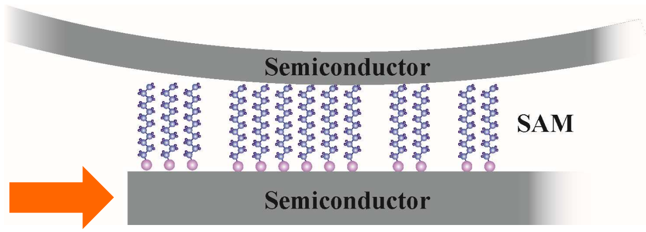
Bottom contact



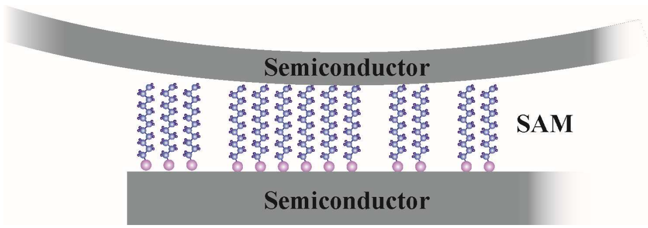
Nanomembrane based top semiconducting contact



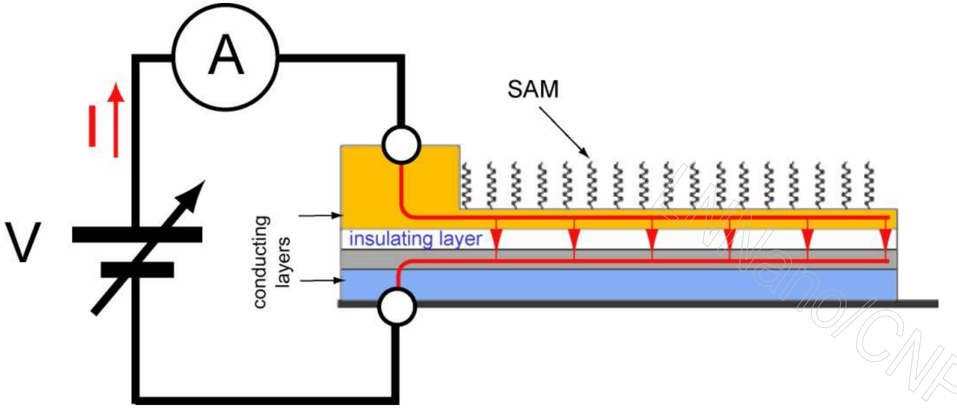
Bottom contact

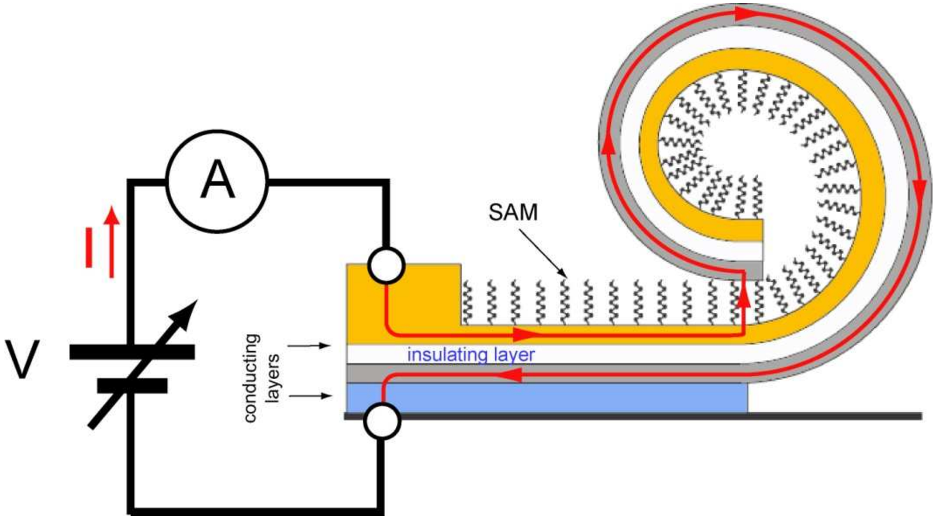


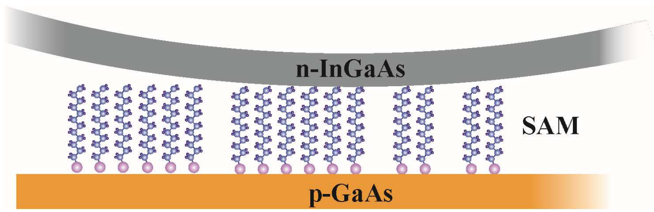
Contacting molecules on semiconducting fingers with semiconducting tubes



Concept of radial injection and tangential







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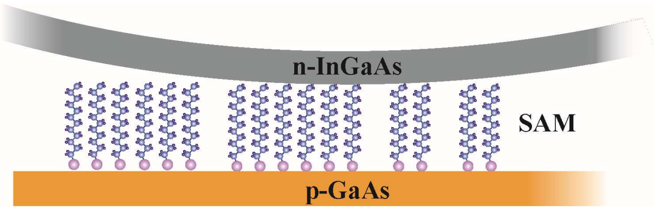
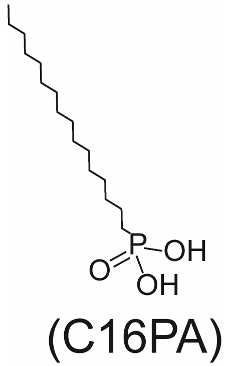
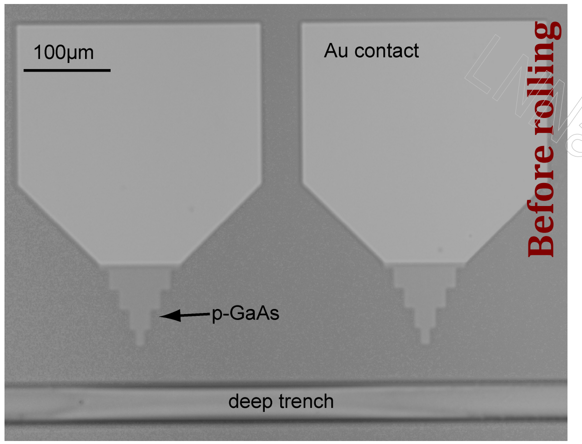
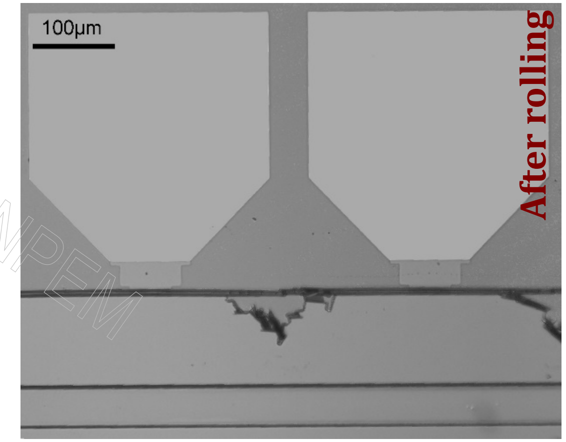
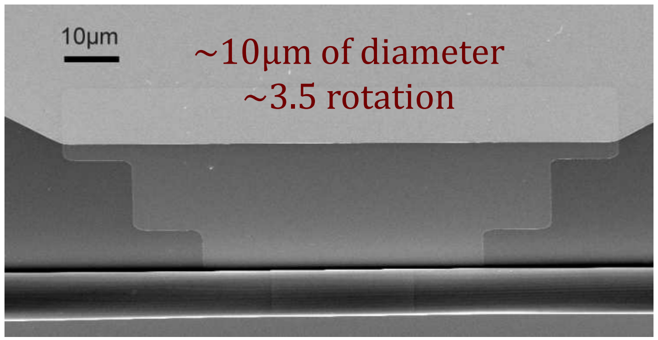


SAM = hexadecylphosphonic acid

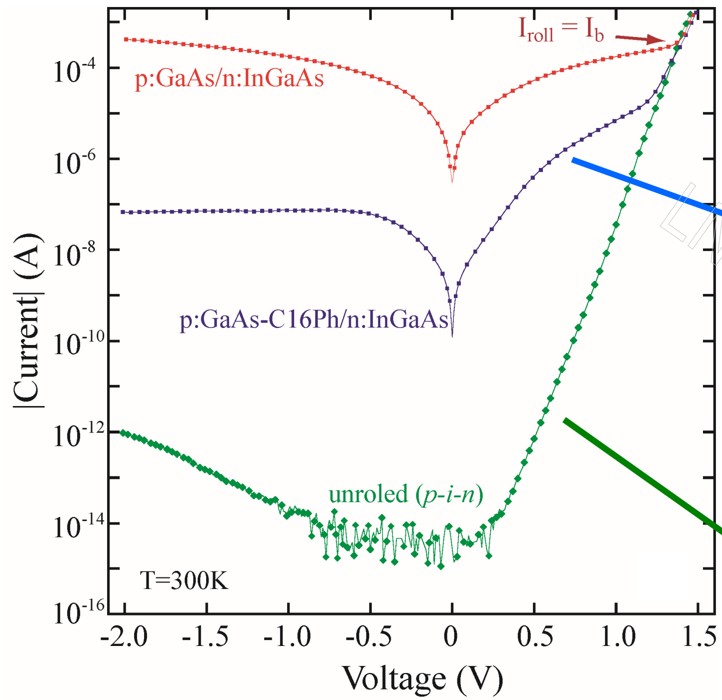


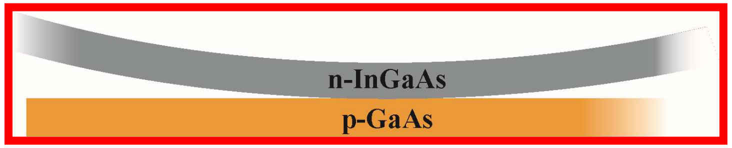


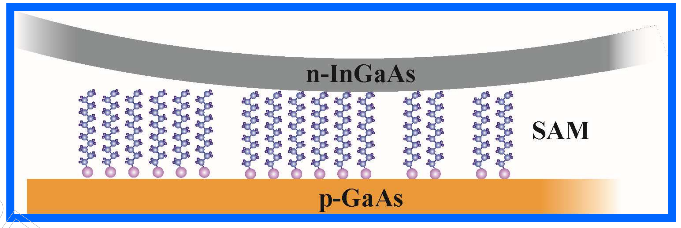


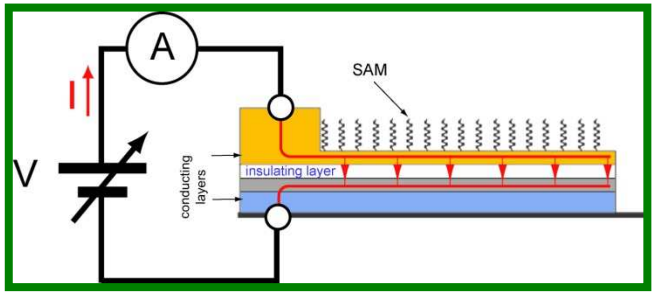


Transport across the hybrid junctions









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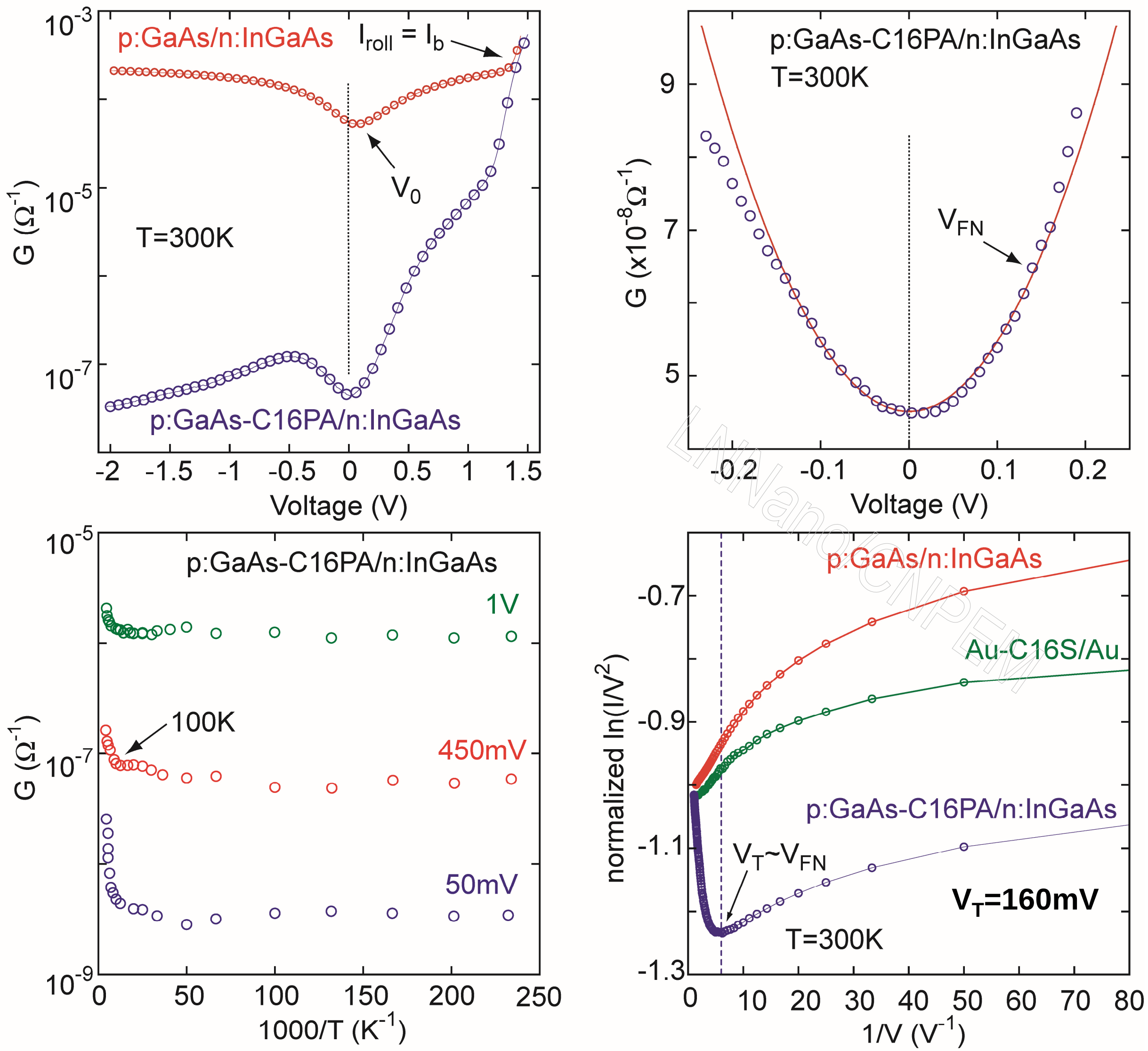
Transport across the hybrid junctions



Simmons model for conductance [1] :

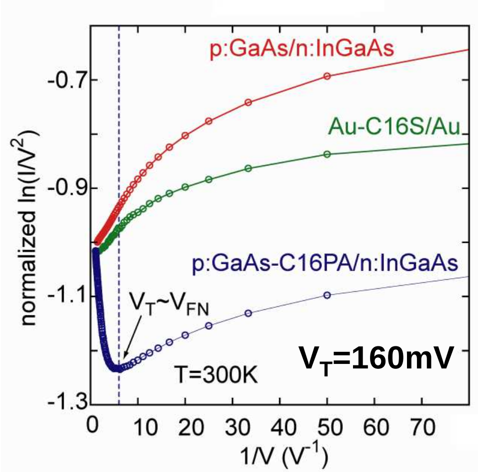
$$G \cong G_0(1 + CV^2)$$

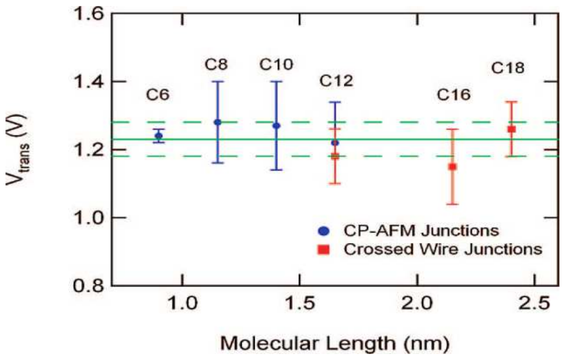
Field-emission [2] :

$$I \propto V^2 \exp\left(-\frac{4W\sqrt{2m_e\Phi^3}}{3\hbar qV}\right)$$

[1] Simmons, J. G. *Journal of Applied Physics* 1963, 34, (1), 238 -239.
[2] Gadzuk, J. W.; Plummer, E. W. *Reviews of Modern Physics* 1973, 45, (3), 487-548.

Transport across the hybrid junctions





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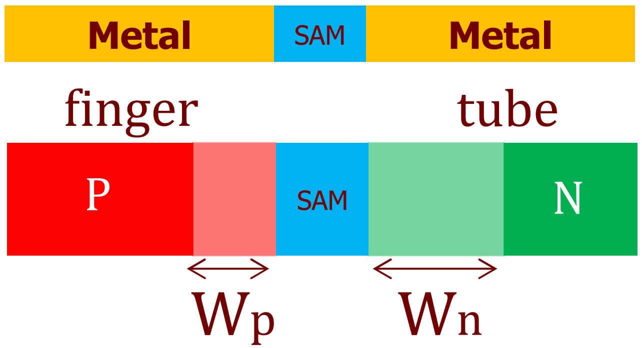
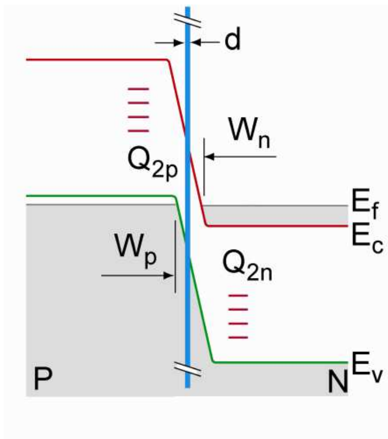
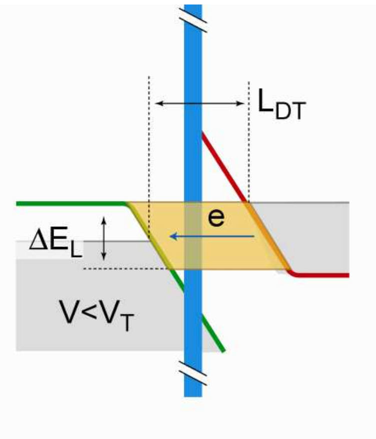
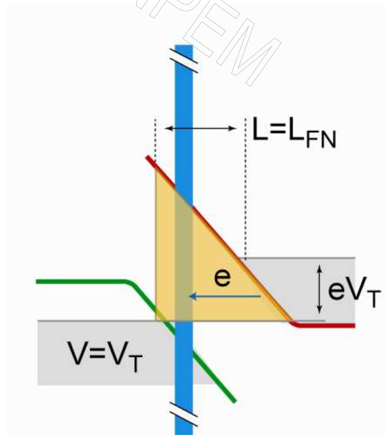


Direct tunneling

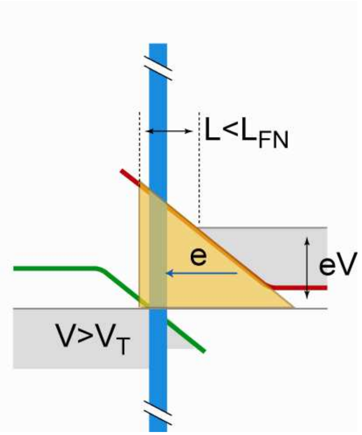


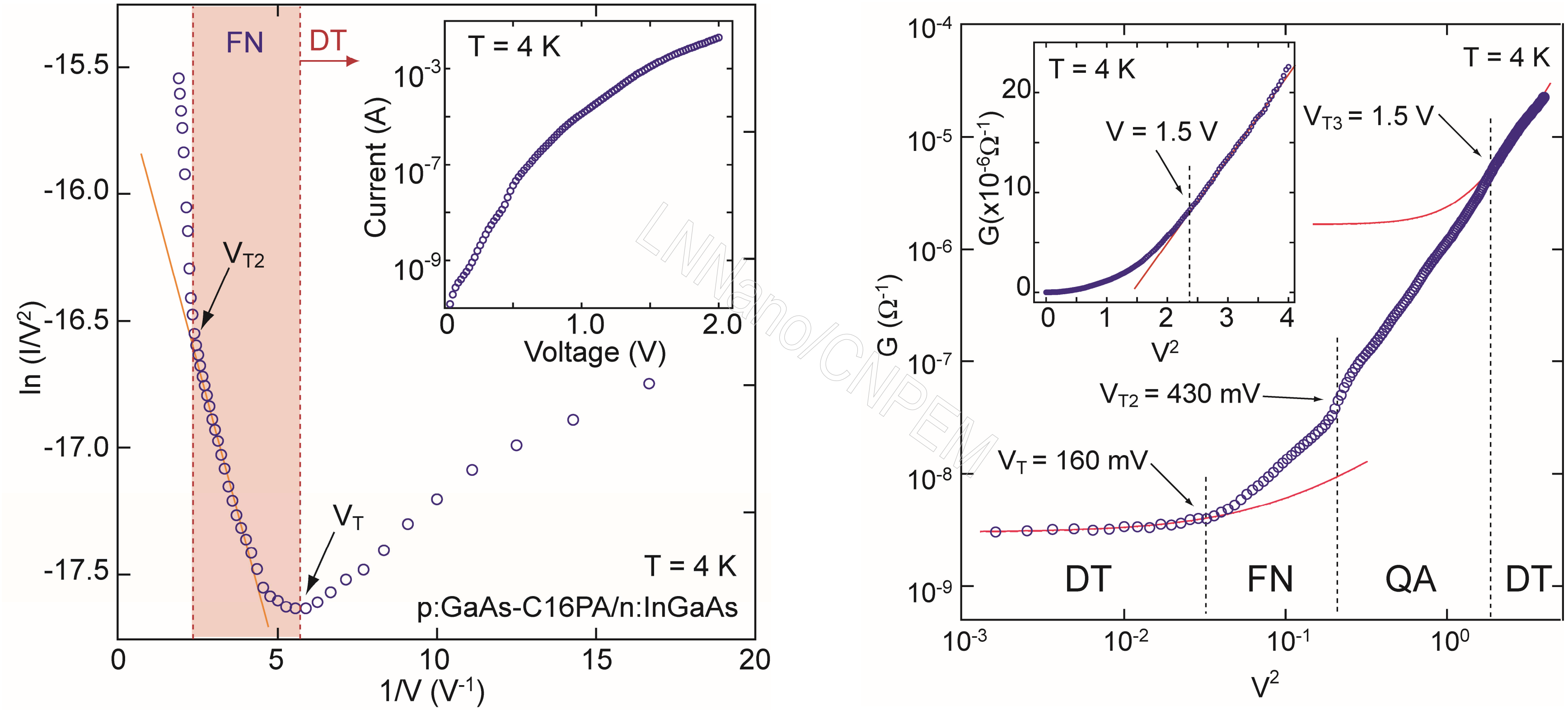


Field-emission



Direct tunneling





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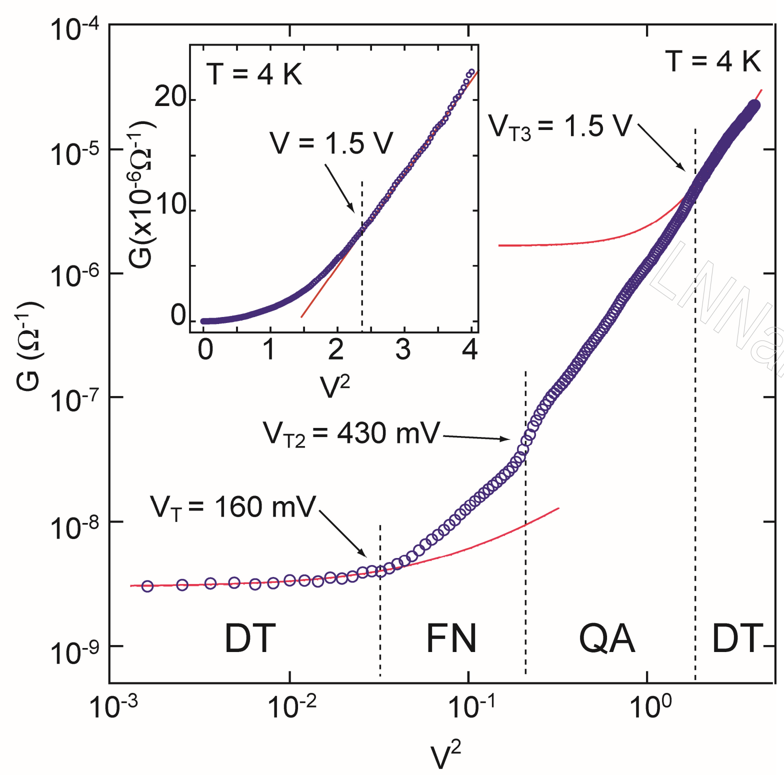
Transport across the hybrid junctions



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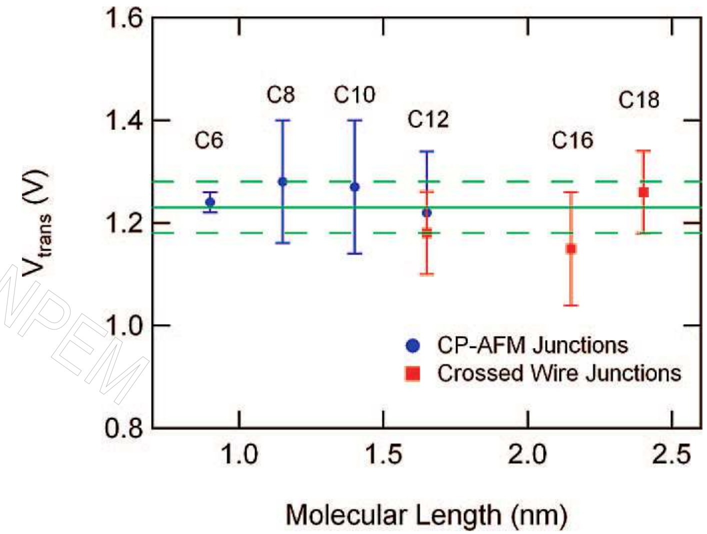
FN # 2?



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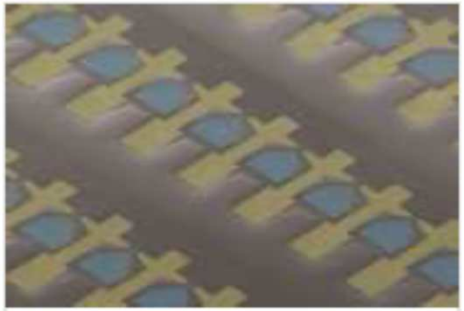
Curly contacts

Christian Martin

Nature Materials **10**, 724 (2011) doi:10.1038/nmat3135
Published online 23 September 2011

Applying reliable electrical contacts to self-assembled molecular monolayers poses a persistent challenge in molecular electronics. Evaporated metal top electrodes can cause short circuits at monolayer defects, and solution-processed conducting polymer electrodes may show temperature-dependent electrical characteristics that disguise the physics of molecular charge transport. Carlos Cesar Bof Bufon and colleagues have now developed a process that allows them to contact molecular monolayers using predefined metal and inorganic semiconductor lay…



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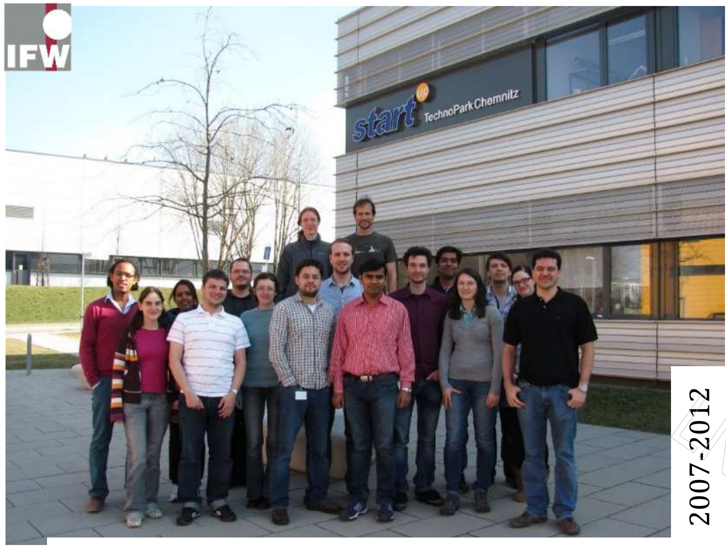
Conclusion

"The interesting fundamental science, the diverse possibilities for creative engineering and the strong potential for broadly influential outcomes make this field of nanomembranes research a fertile one for future investigation."

J. A. Rogers, M. G. Lagally & R. G. Nuzzo
Nature 477, 45, 2011

cesar.bof@lnnano.cnpem.br



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Thank you for your attention

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