Nanolithography at ICMM

i). ICMM Facilities

ii). Scanning Probe Lithography: oxidation SPL

iii) Nanopatterning & Nanodevices

2D Materials

iv). Summary

rednanolito

Instituto de Ciencia Materiales de Madrid

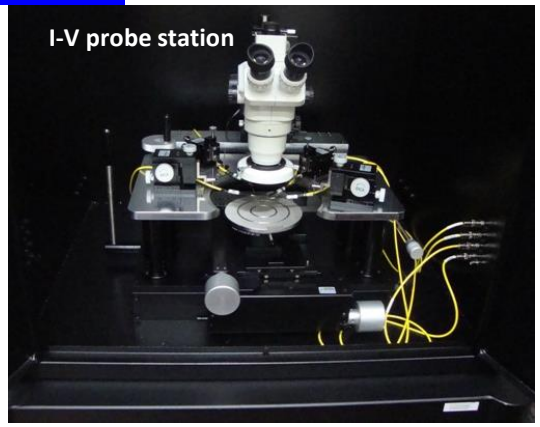
103 staff
360 staff+pot-docs+gradduate students+technistians+administrative

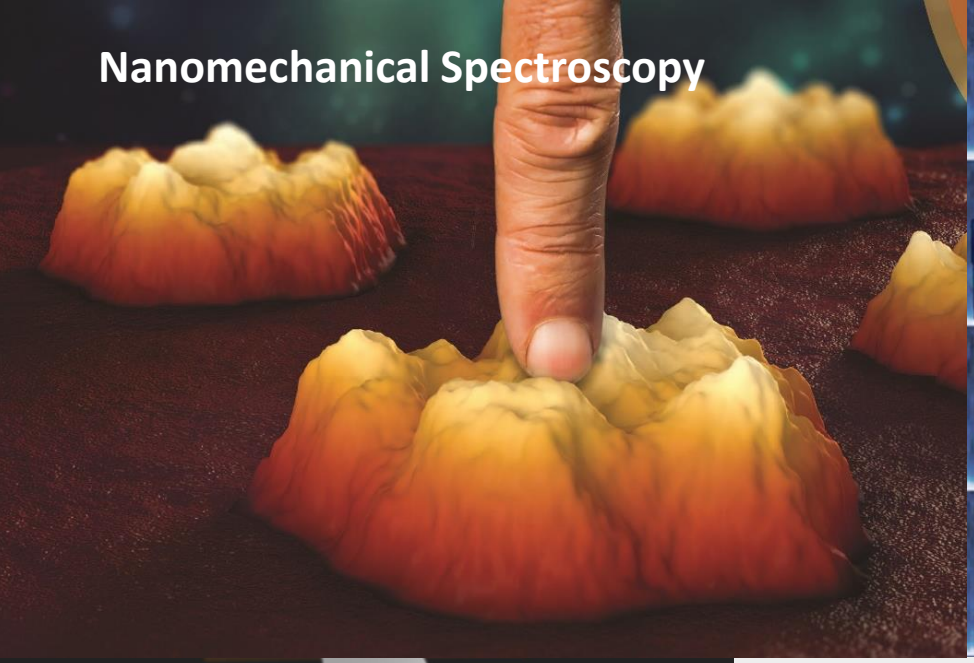
Materiasl for a sustainable world
Materials for health
Materials for emerging technologies

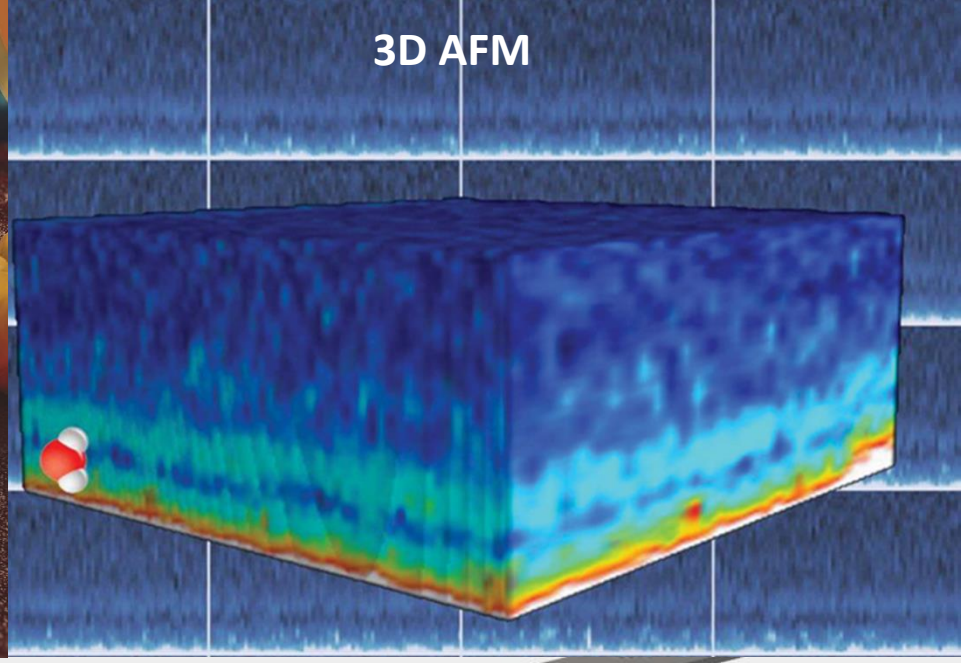
Quantifiable scientific excellence in Materials Science and Nanotechnology

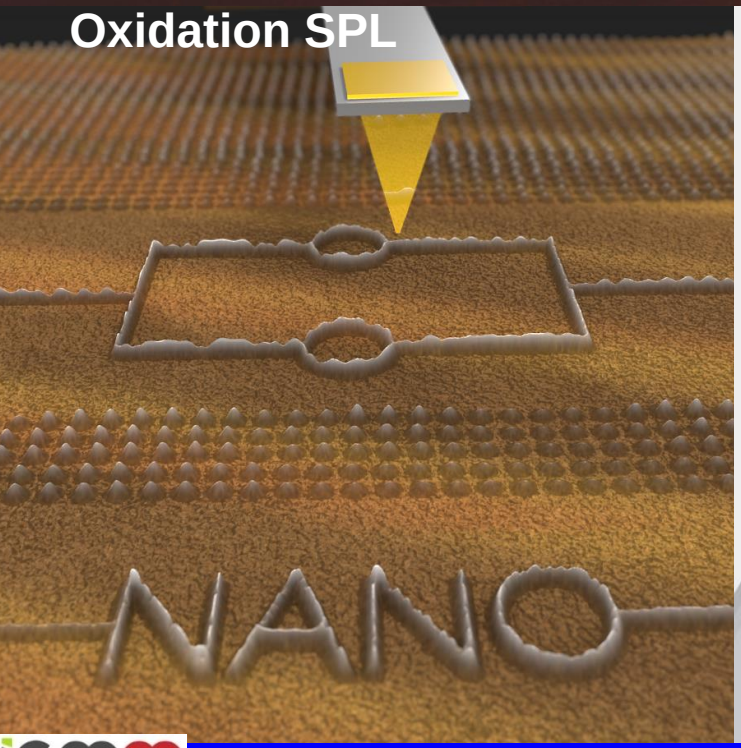
33 staff

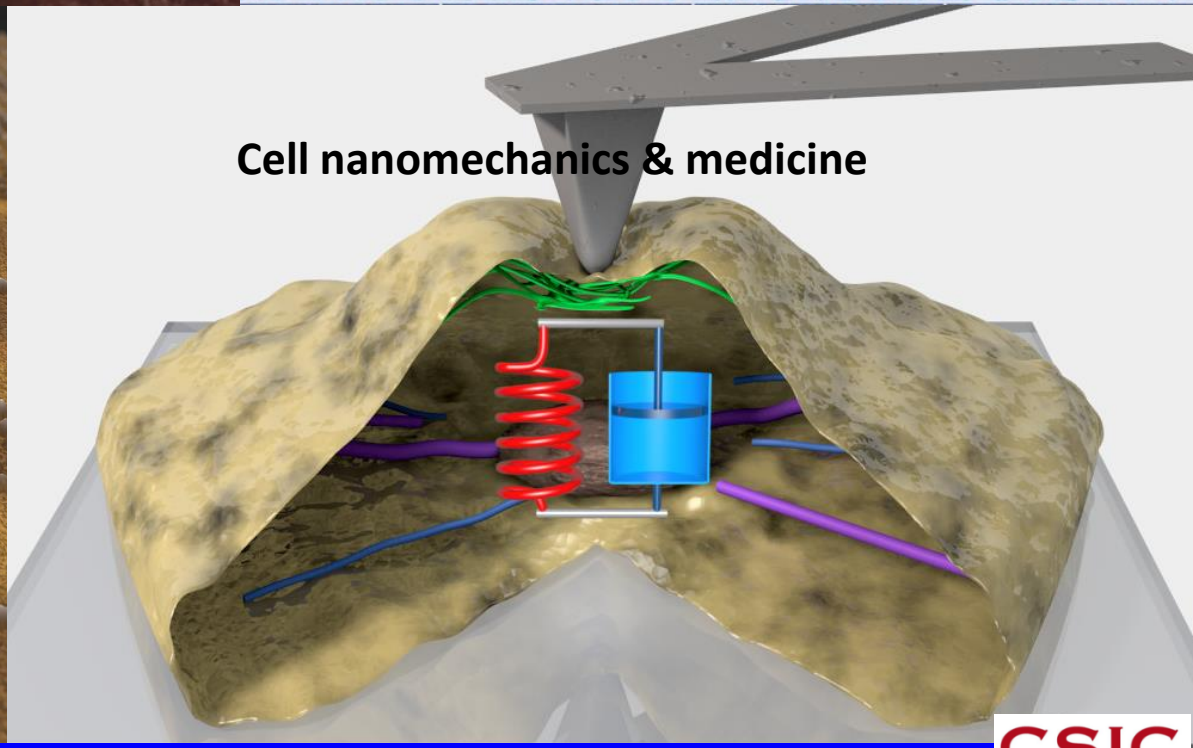
Clean room equipment

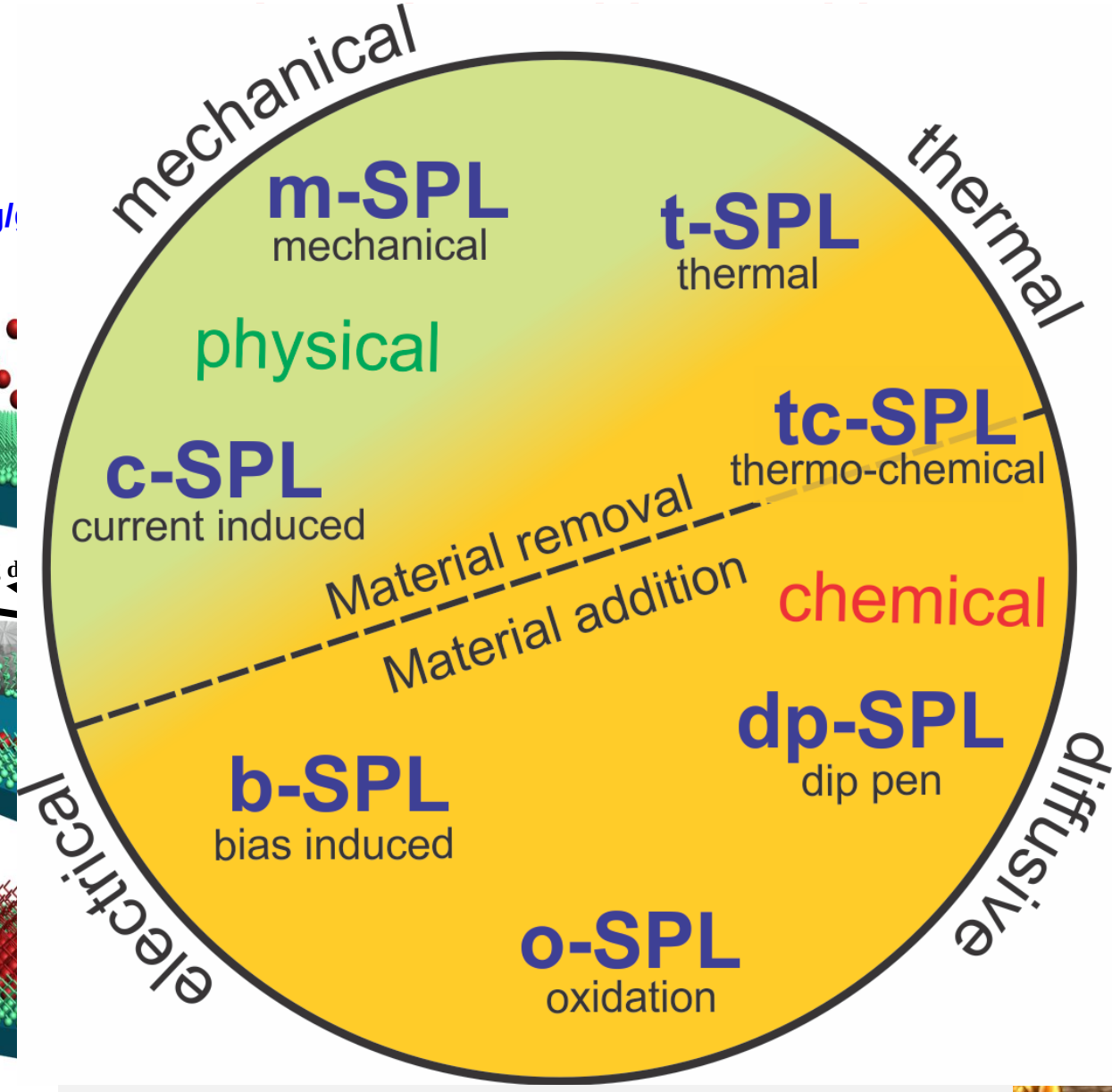



Nanomechanical Spectroscopy


3D AFM


Oxidation SPL
NANO


Cell nanomechanics & medicine



Nanoshaving/

(a)

(b)

patterning d

(c)

G. Liu (1997)

g Probe
y

raphy

); H. Butt (1995)

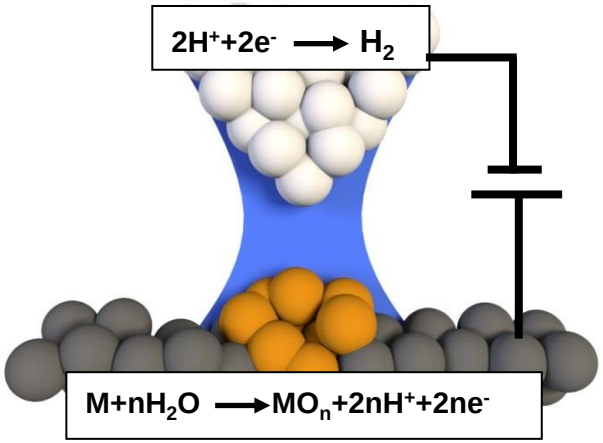
eposition

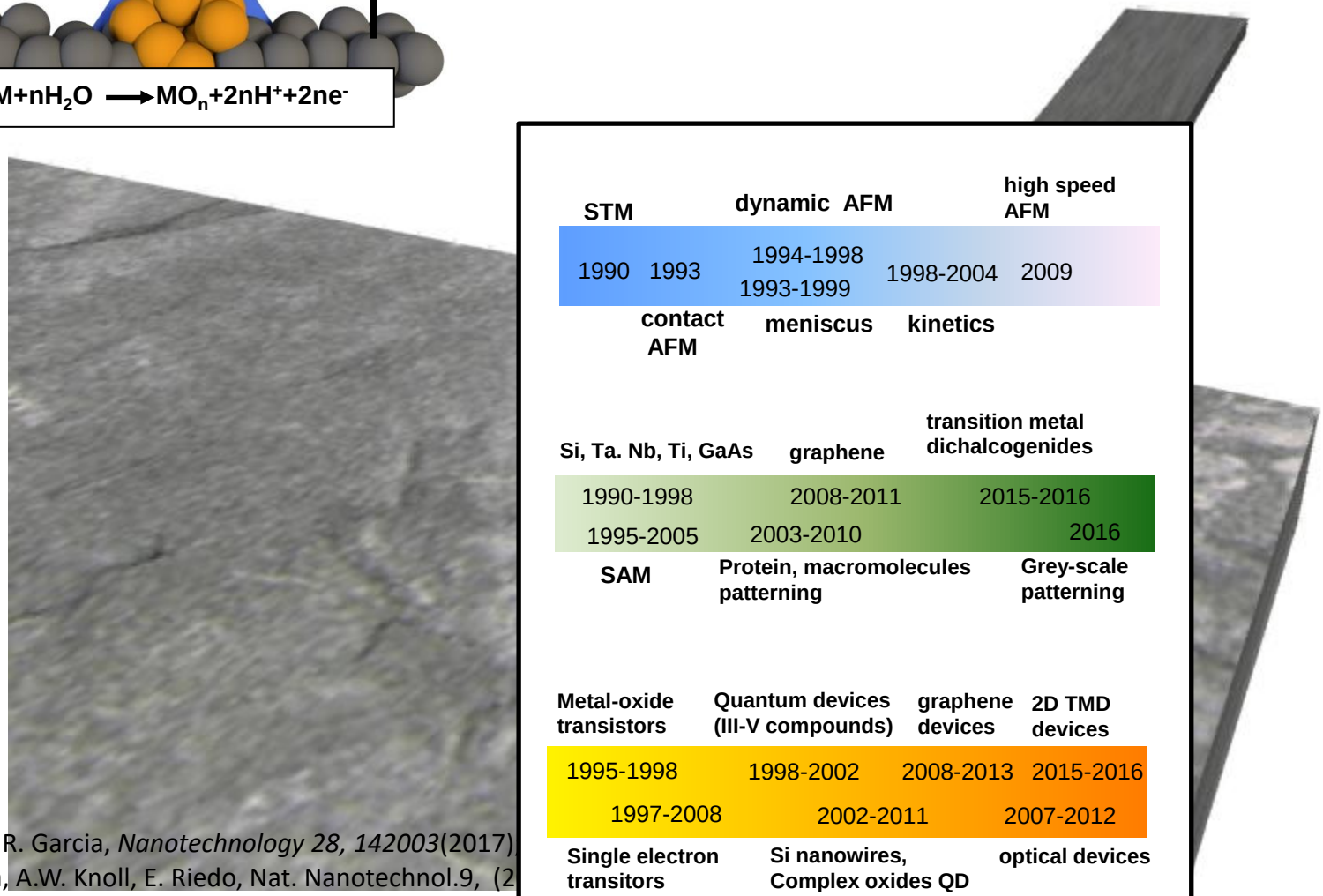
100
nm

gelow (2014)

R. Garcia, A.W. Knoll, E. Riedo, *Nature Nanotechnology* **9**, 577 (2014)

Oxidation SPL





STM — dynamic AFM — high speed AFM

1990 — 1993 — 1994-1998 / 1993-1999 — 1998-2004 — 2009

contact AFM — meniscus — kinetics

Si, Ta. Nb, Ti, GaAs — graphene — transition metal dichalcogenides

1990-1998 — 2008-2011 — 2015-2016

1995-2005 — 2003-2010 — 2016

SAM — Protein, macromolecules patterning — Grey-scale patterning

Metal-oxide transistors — Quantum devices (III-V compounds) — graphene devices — 2D TMD devices

1995-1998 — 1998-2002 — 2008-2013 — 2015-2016

1997-2008 — 2002-2011 — 2007-2012

Single electron transitors — Si nanowires, Complex oxides QD — optical devices

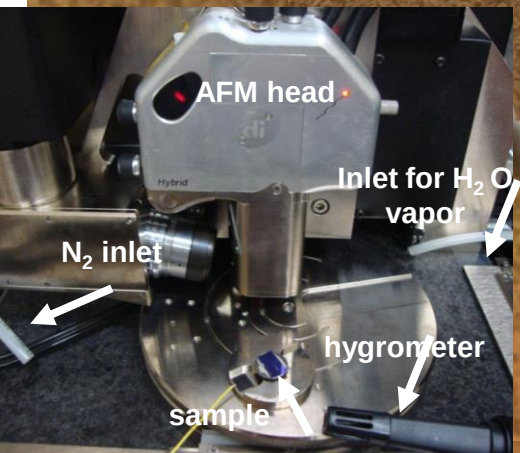
Y.K. Ryu, R. Garcia, *Nanotechnology 28, 142003*(2017)

R. Garcia, A.W. Knoll, E. Riedo, Nat. Nanotechnol.9, (2

R. Garcia, RV. Martinez, J. Martinez, Chem. Soc. Rev. 3

Oxidation SPL

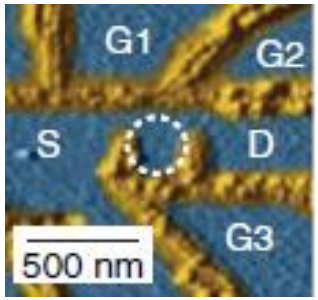
dielectric barriers
Templates
Masks
local conductivity



o-SPL:

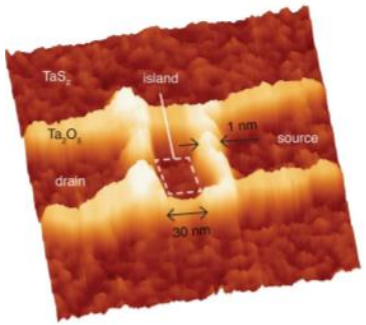
Direct Nanppatterning a large variety of materials

GaAs



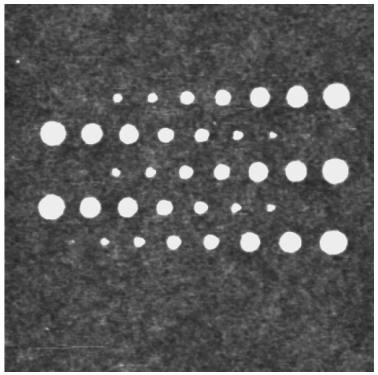
A.W. Heine, R.J. Haug et al. PRL 116, 096802 (2016))

Ta

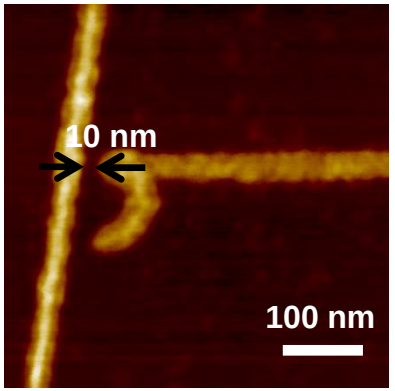


E. Coronado

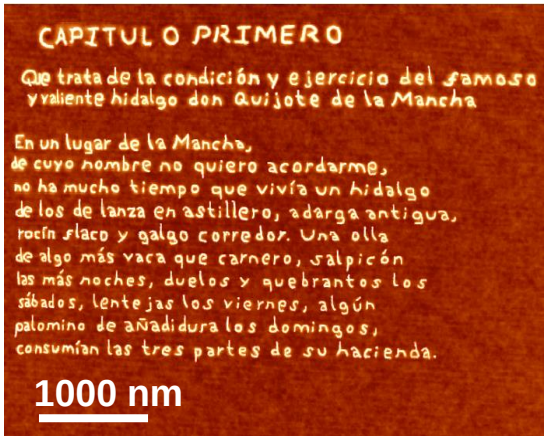
Niobium



graphene

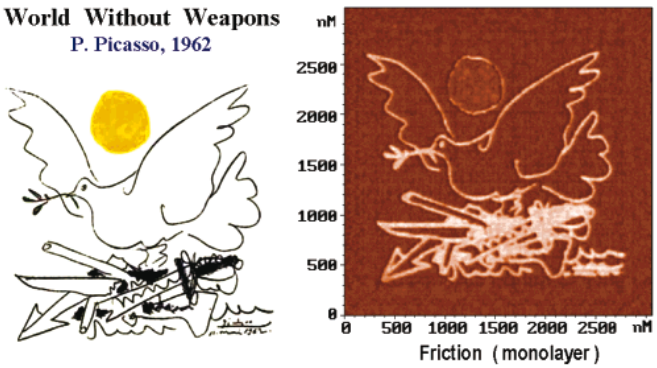


silicon



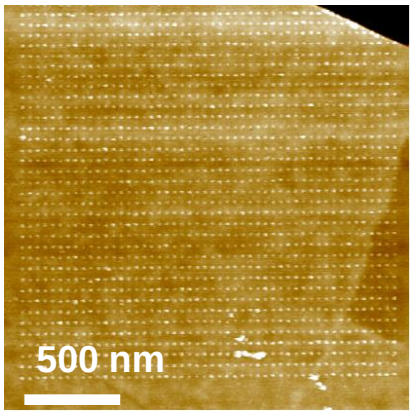
R. Garcia

SAM templates



R. Maoz, S.R.Cohen and J. Sagiv.

WSe2

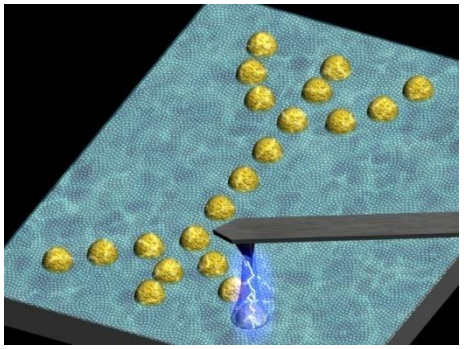


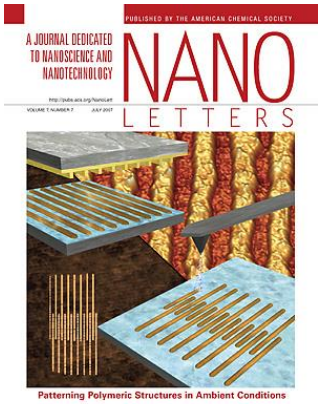
A. I. Dago, Y.K. Ryu, R. Garcia

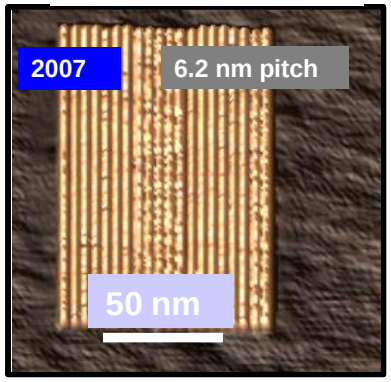
Metals, semiconductors, Organosilanes, 2D materials, complex oxides ...

TIP-BASED NANOFABRICATION

Nanopatterning

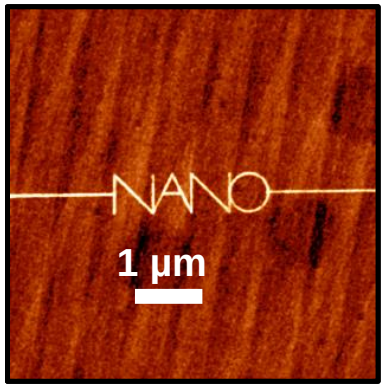


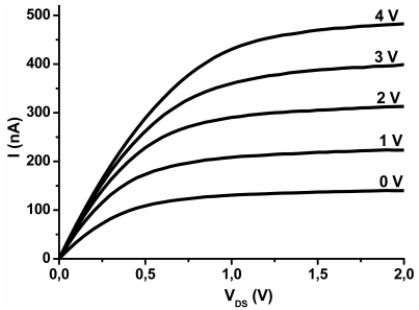




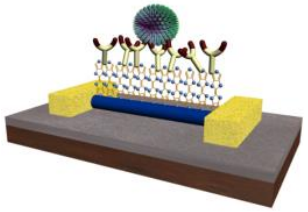
Nano Letters 7, 1846 (2007)

Nanoelectronic devices

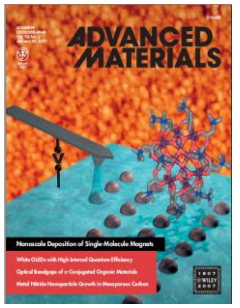


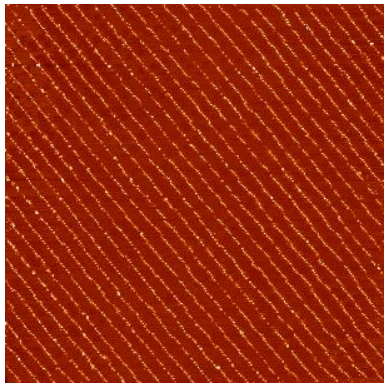


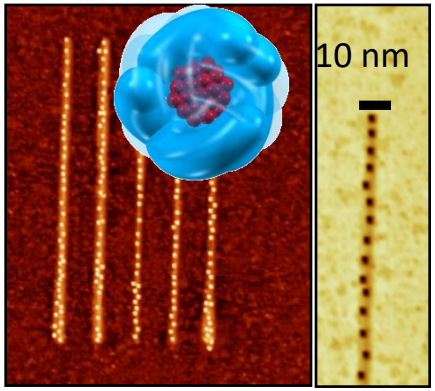
Nano Letters 11, 3636 (2008)



Molecular Architectures

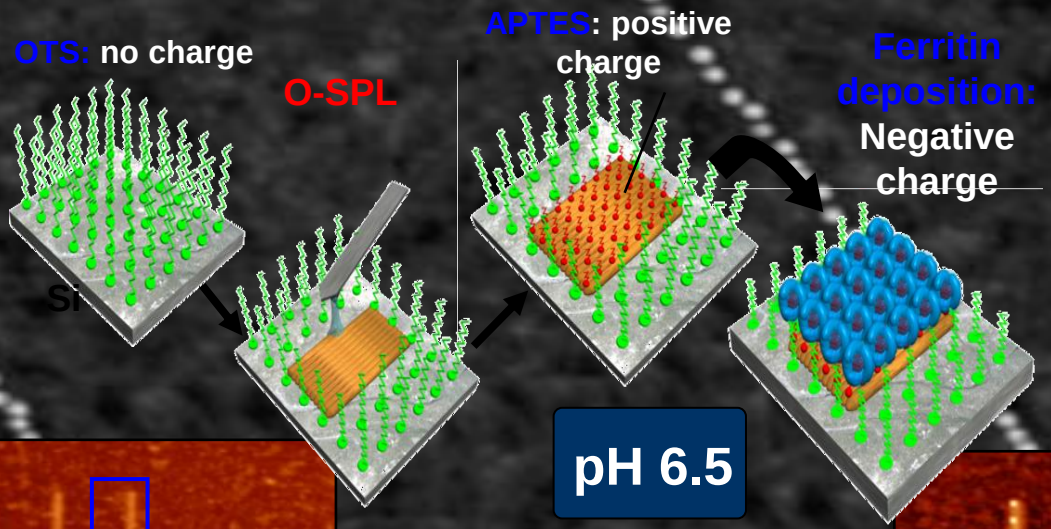


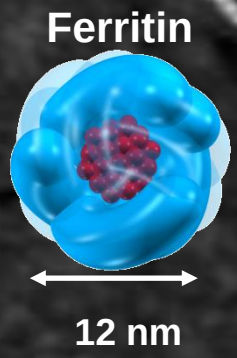


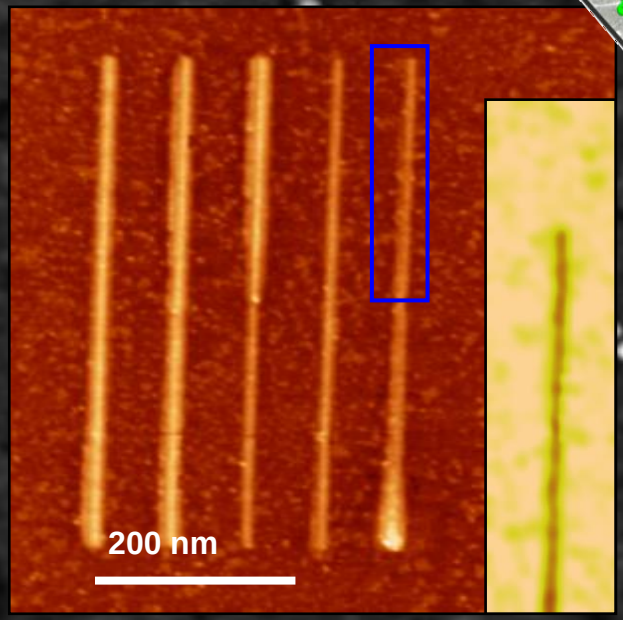


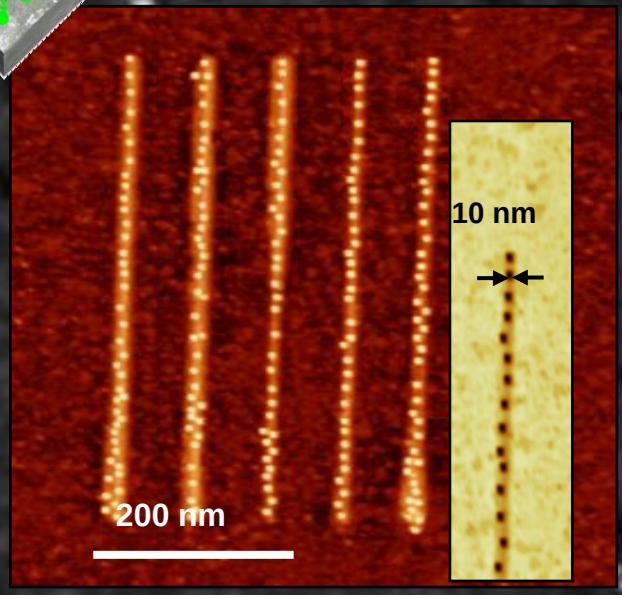
Protein Patterning on SiNW

By combining nanolithography (top-down) and electrostatic interactions (bottom-up)





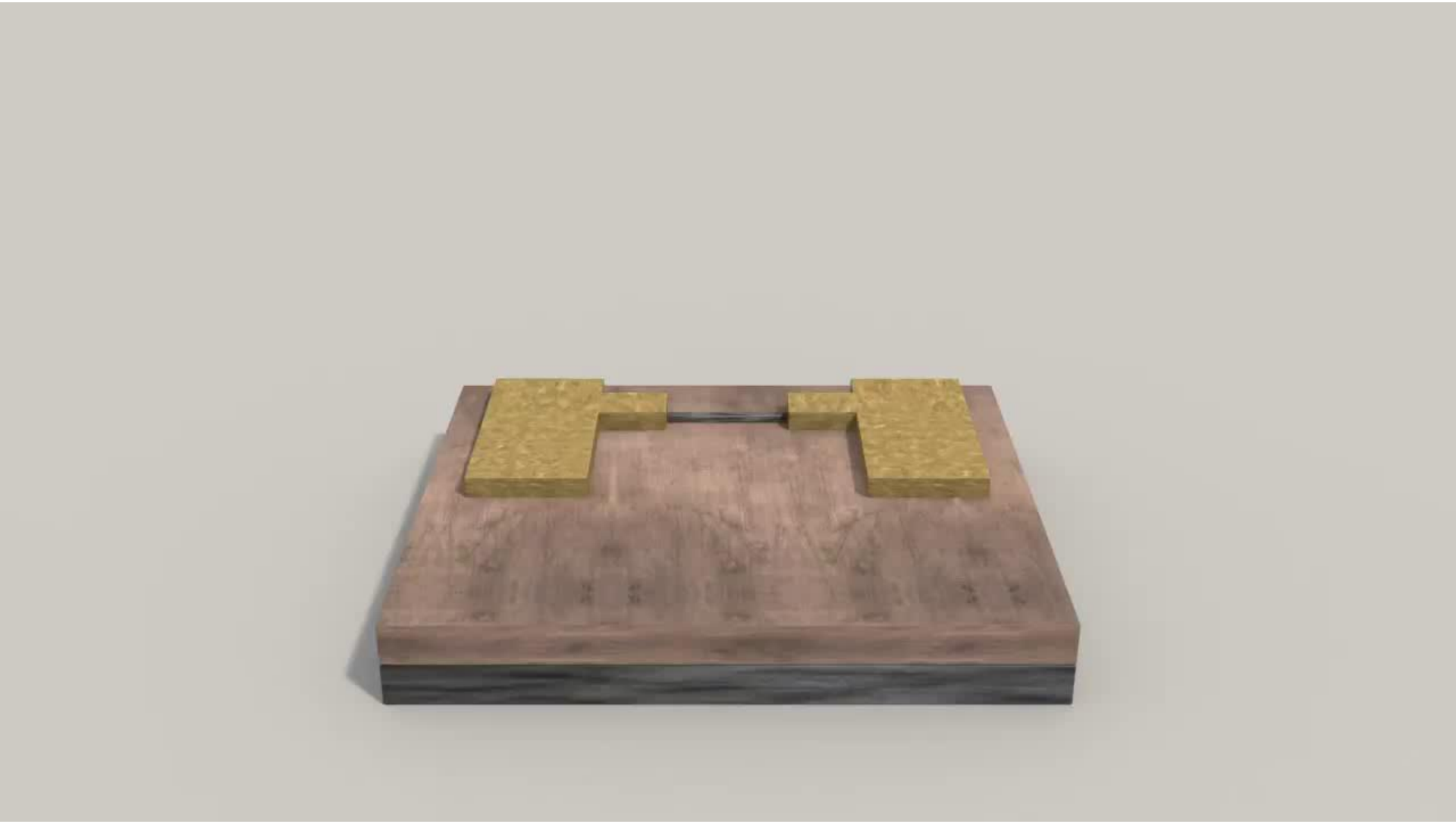




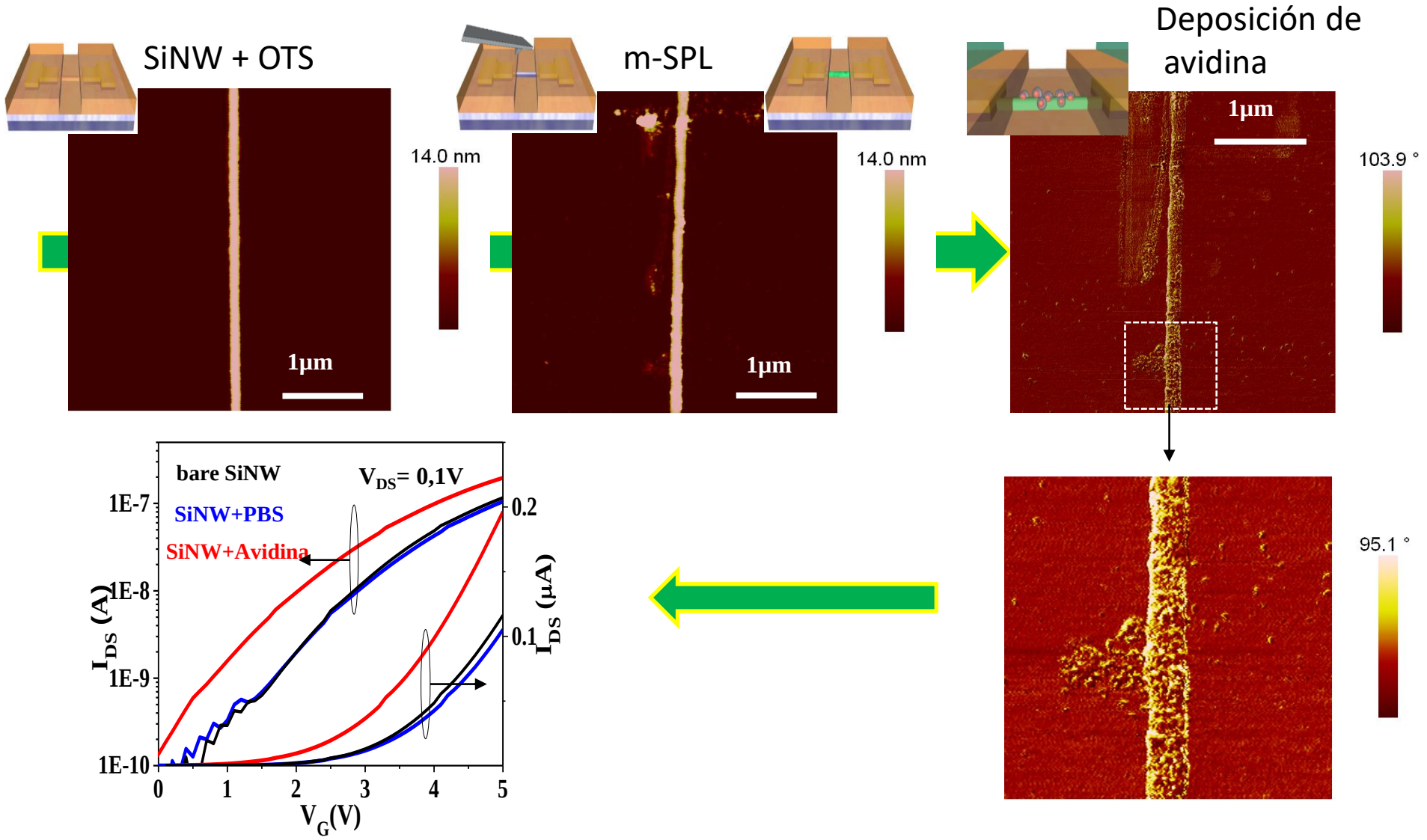
Garcia, A.W. Knoll, E. Riedo, *Nature Nanotechnology* **9**, 577 (2014)

F.M. Espinosa, M. Uhlig, R. Garcia (2018);
R.V. Martinez , M. Chiesa, R. Garcia, Small 7, 2914 (2011)
R.V. Martinez *et al.*, Adv. Mater. 22, 588 (2010);
R.V. Martinez et al., Adv. Mater. 19, 291 (2007) .

SiNWs for molecular recognition

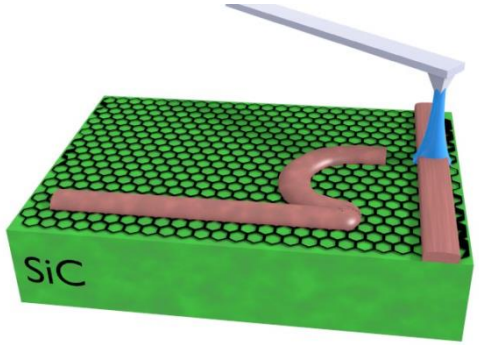


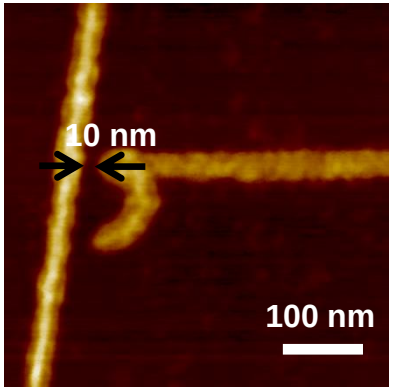
SiNWs for molecular recognition

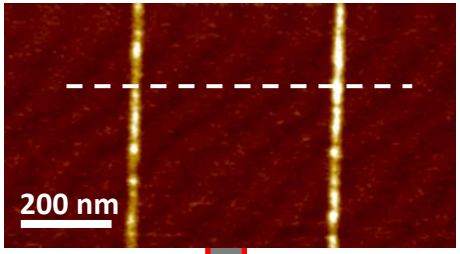


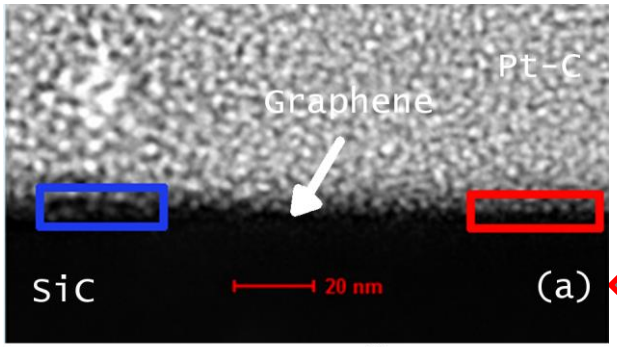
F.M. Espinosa, M.Uhlig, R. Garcia (2018).

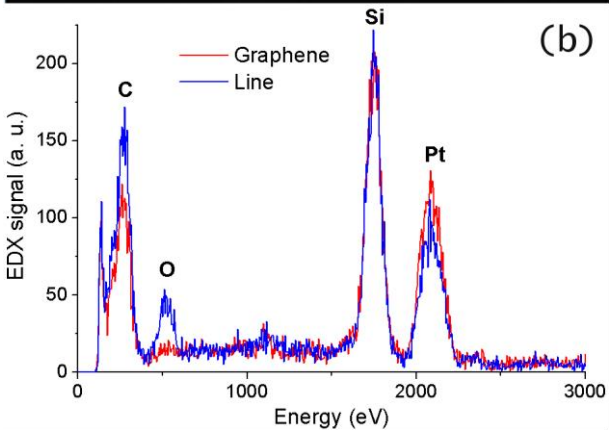
STEM & CHEMICAL ANALYSIS of GRAPHENE PATTERNS

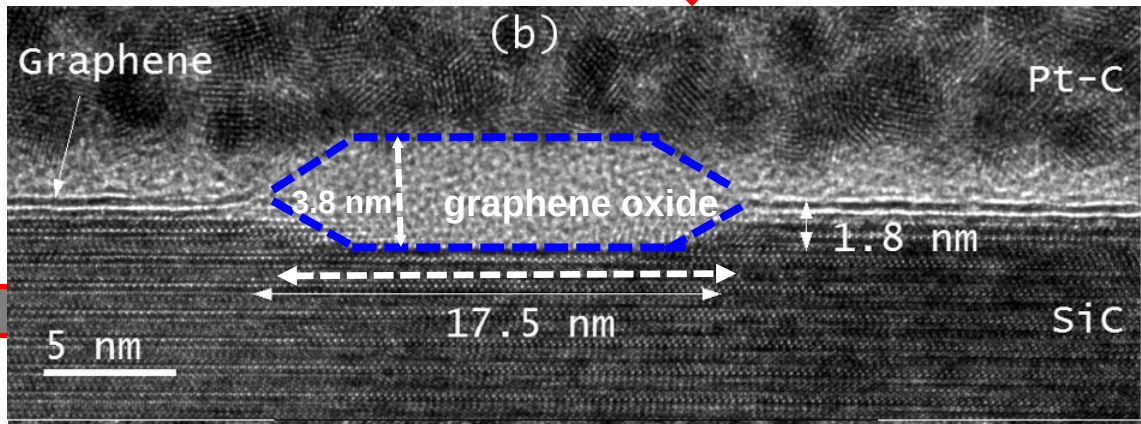


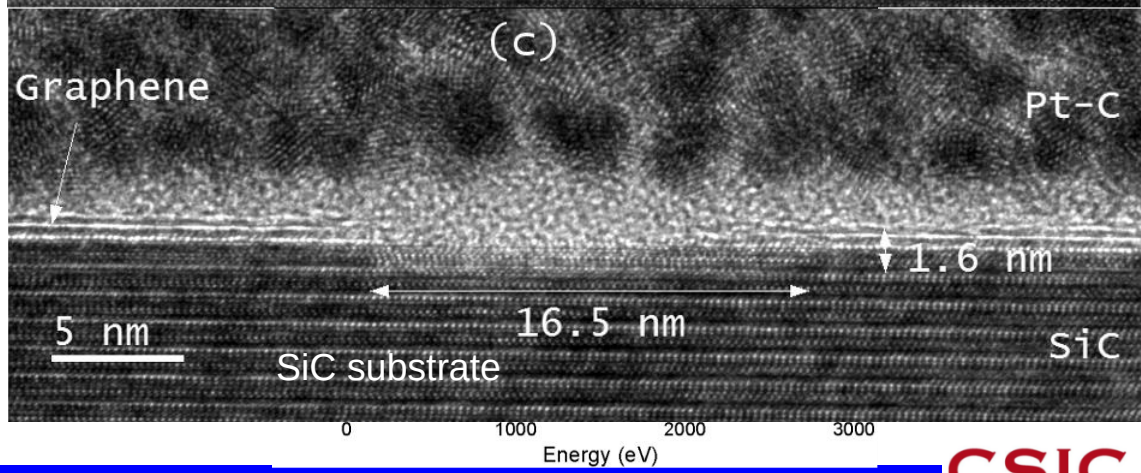






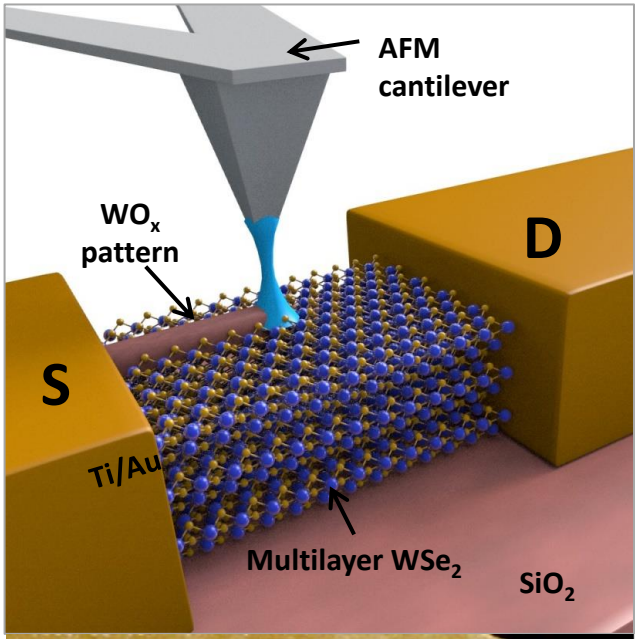


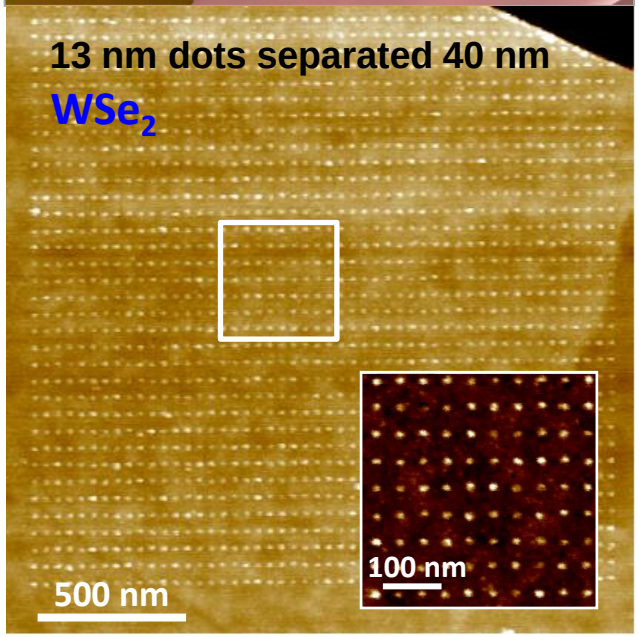




A. I. Dago, S. Sangiao, F. Rodriguez, J.M. de Teresa, R. Garcia, *Carbon* **129**, 281 (2018)

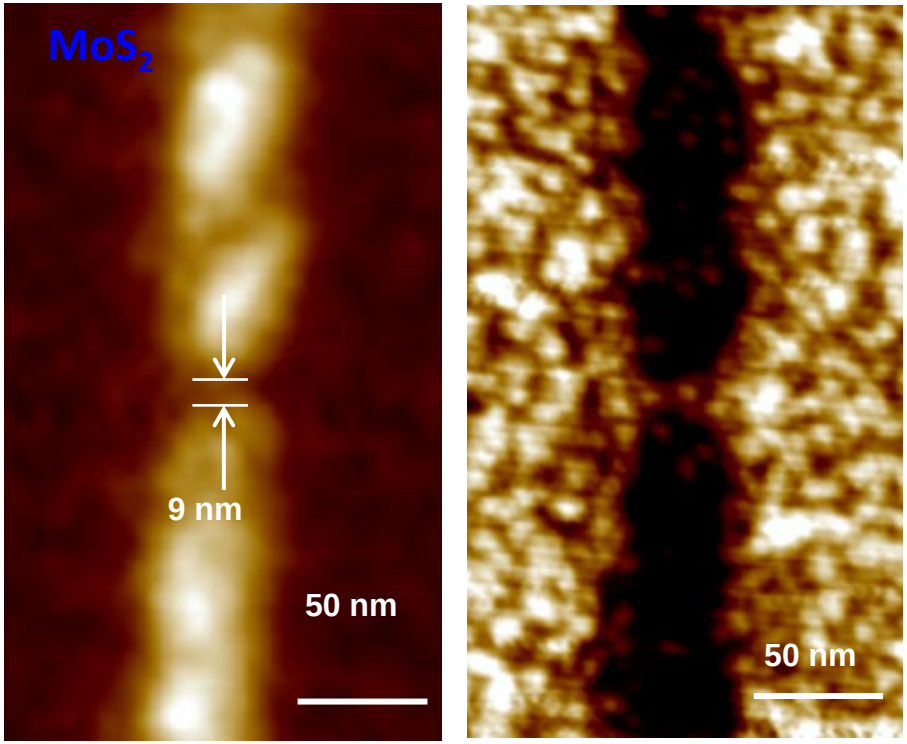
Direct fabrication of 2D Transition Metal Dichalcogenides devices: WSe_2





V=20 1 V t=1.8 ms; 38.5% RH

After immersion in H_2O

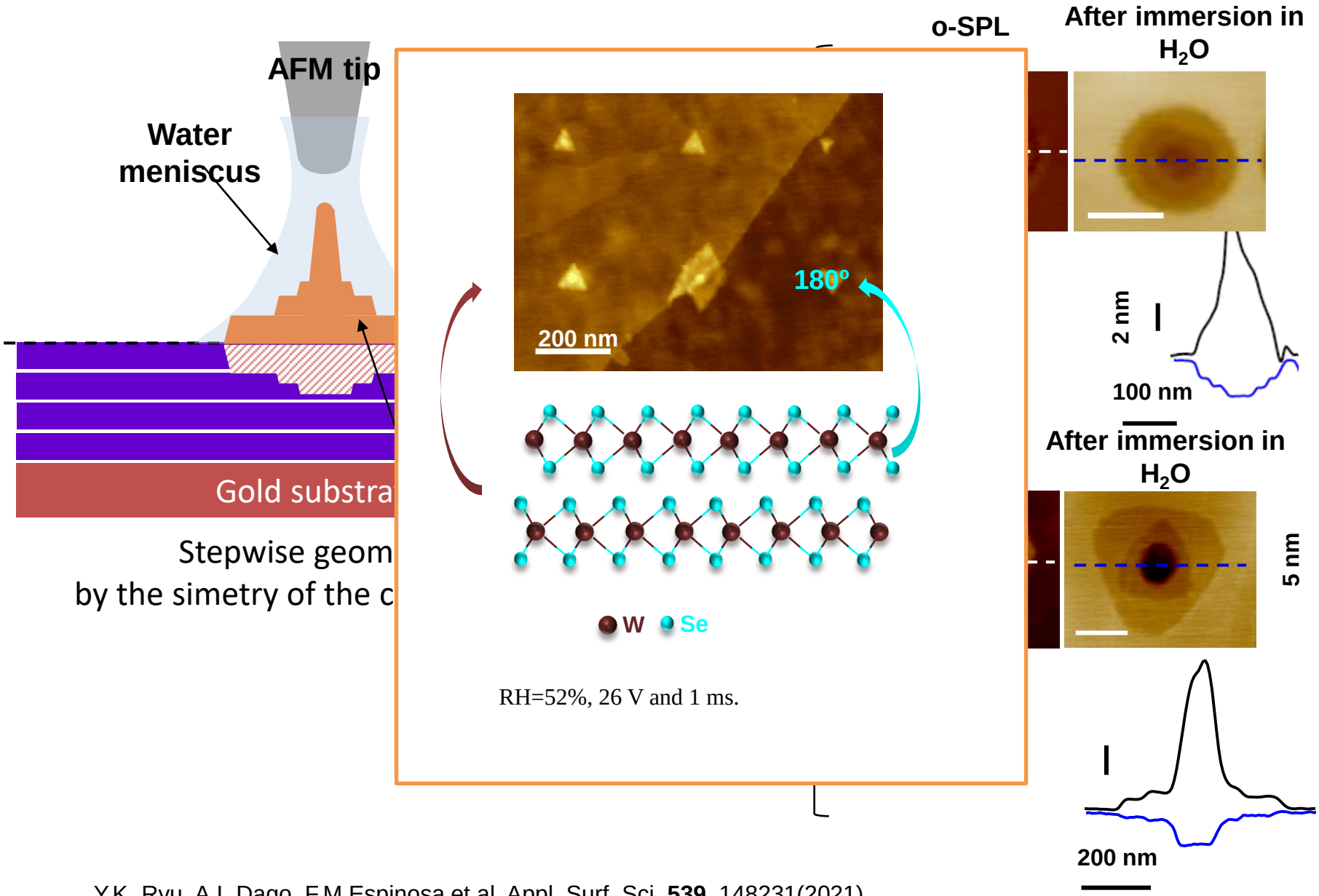


V_{ox}= 15 V; t_{ox}= 1 ms; RH= 36 %

Y.K. Ryu, A.I. Dago, F.M.Espinosa et al. Appl. Surf. Sci. **539**, 148231(2021)

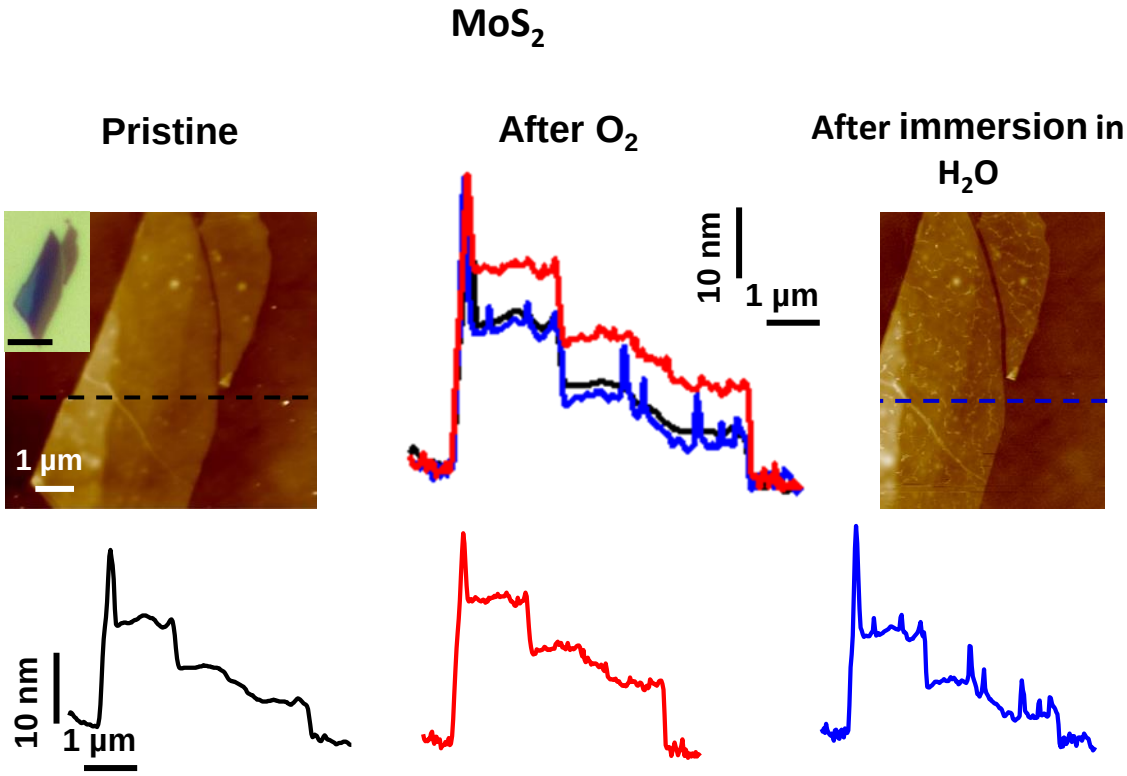
A. I. Dago, Y.K. Ryu, R. Garcia APL **109**, 163103 (2016)

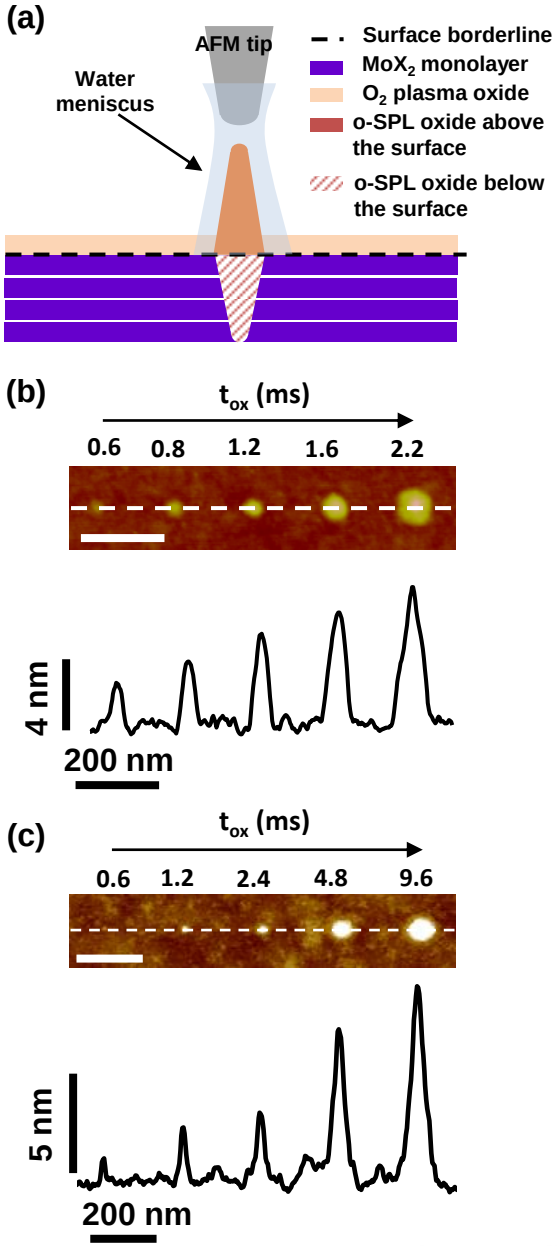
Anisotropic o-SPL process



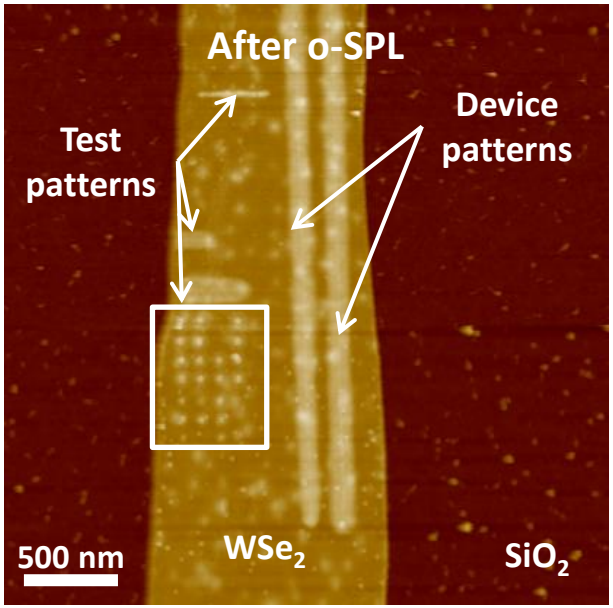
Y.K. Ryu, A.I. Dago, F.M.Espinosa et al. Appl. Surf. Sci. **539**, 148231(2021)

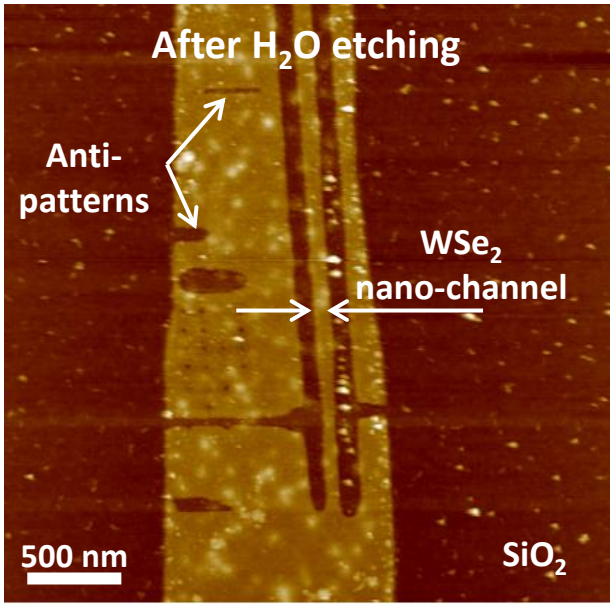
Oxygen plasma produces a very thin and uniform oxide that facilitates o-SPL





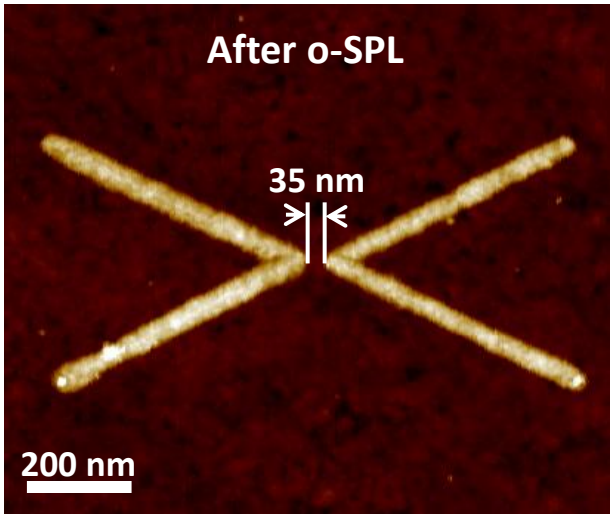
A.I. Dago, Y.K. Ryu, R.Garcia, ACS Appl. Mat. & Interfaces 10, 40054 (2018)
Y.K. Ryu, A.I. Dago, F.M.Espinosa et al. Appl. Surf. Sci. **539**, 148231(2021)

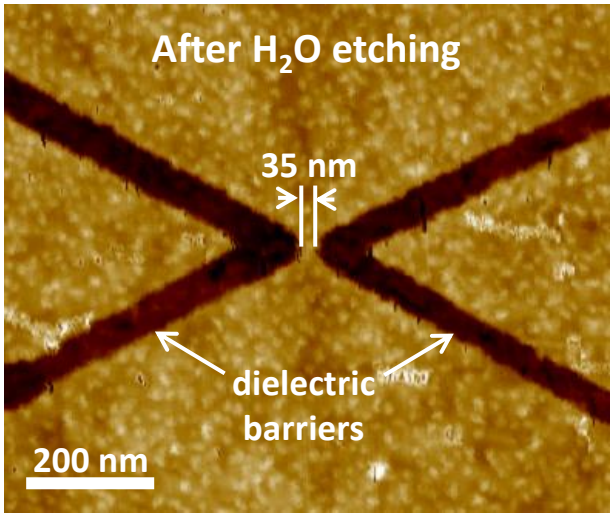




The oxides of TMD are removed by immersion in water

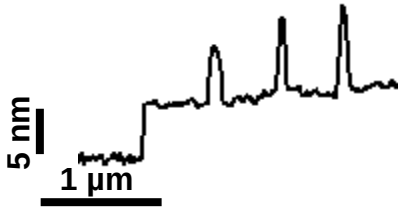
Pattern for a Quantum point contact on WSe2

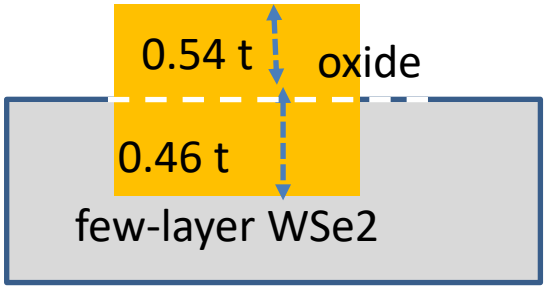




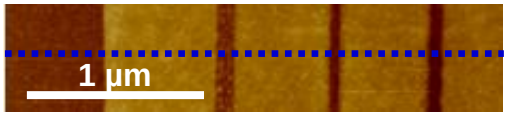
- Improves the electrical response of the device
- Facilitates processing

o-SPL lines





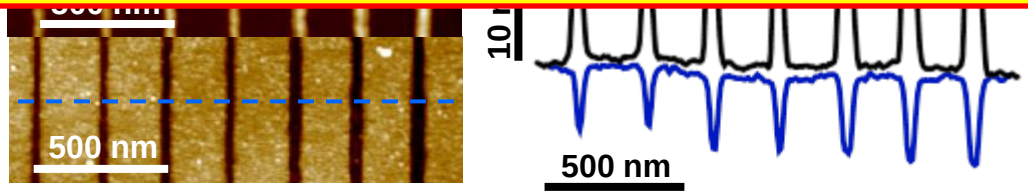
After etching in H_2O



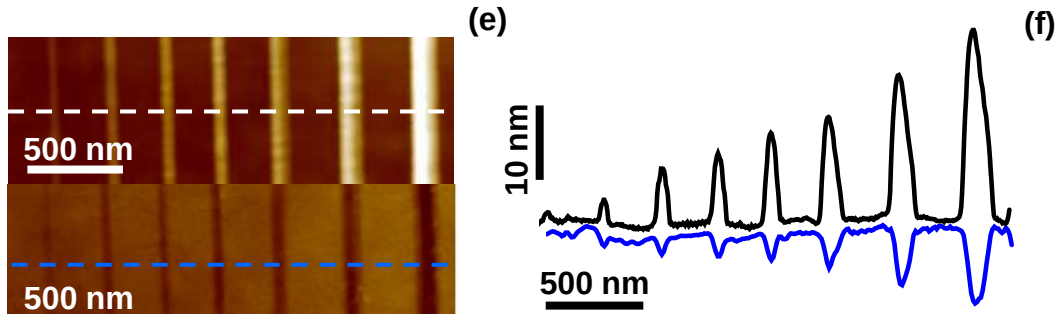
$$WSe_2 + 9H_2O + 14h^+ \rightarrow WO_3 + 2SeO_3^{2-} + 18H^+$$

o-SPL oxides for MoS_2 $MoSe_2$ and WSe_2 are soluble in water

MoS_2



$MoSe_2$



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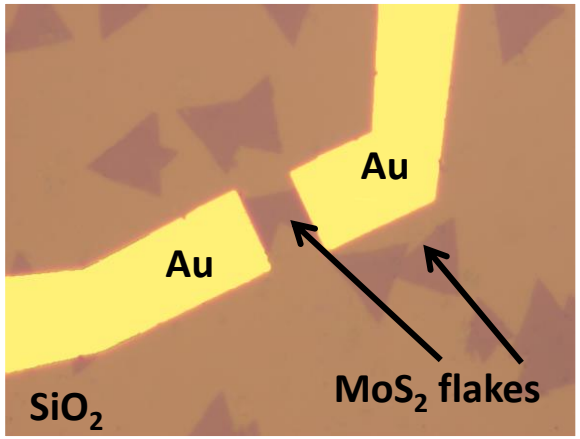
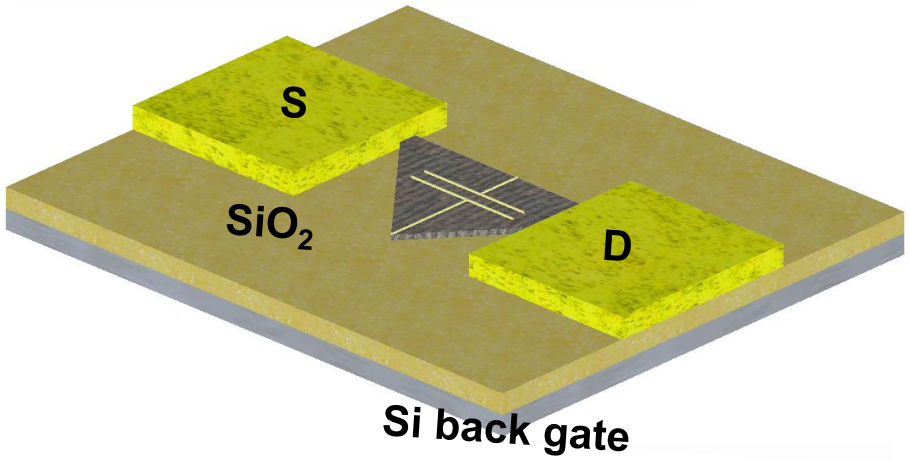
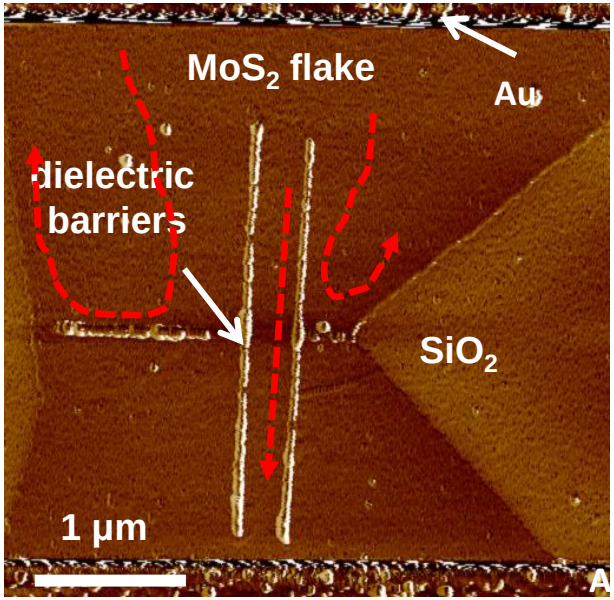
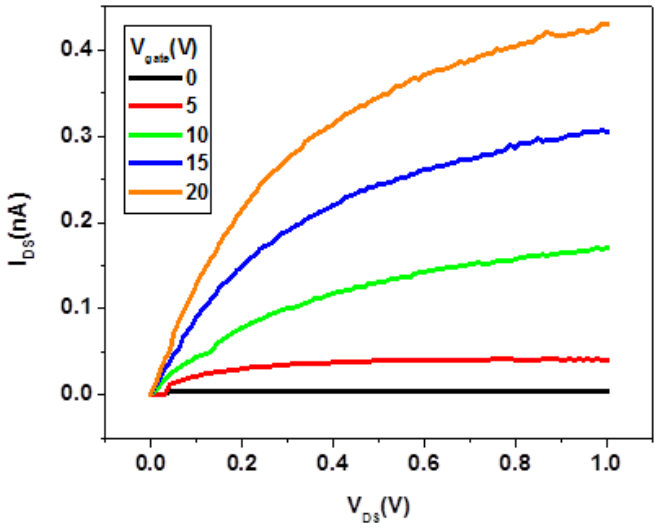
Nano-FETs based on single layer MoS_2









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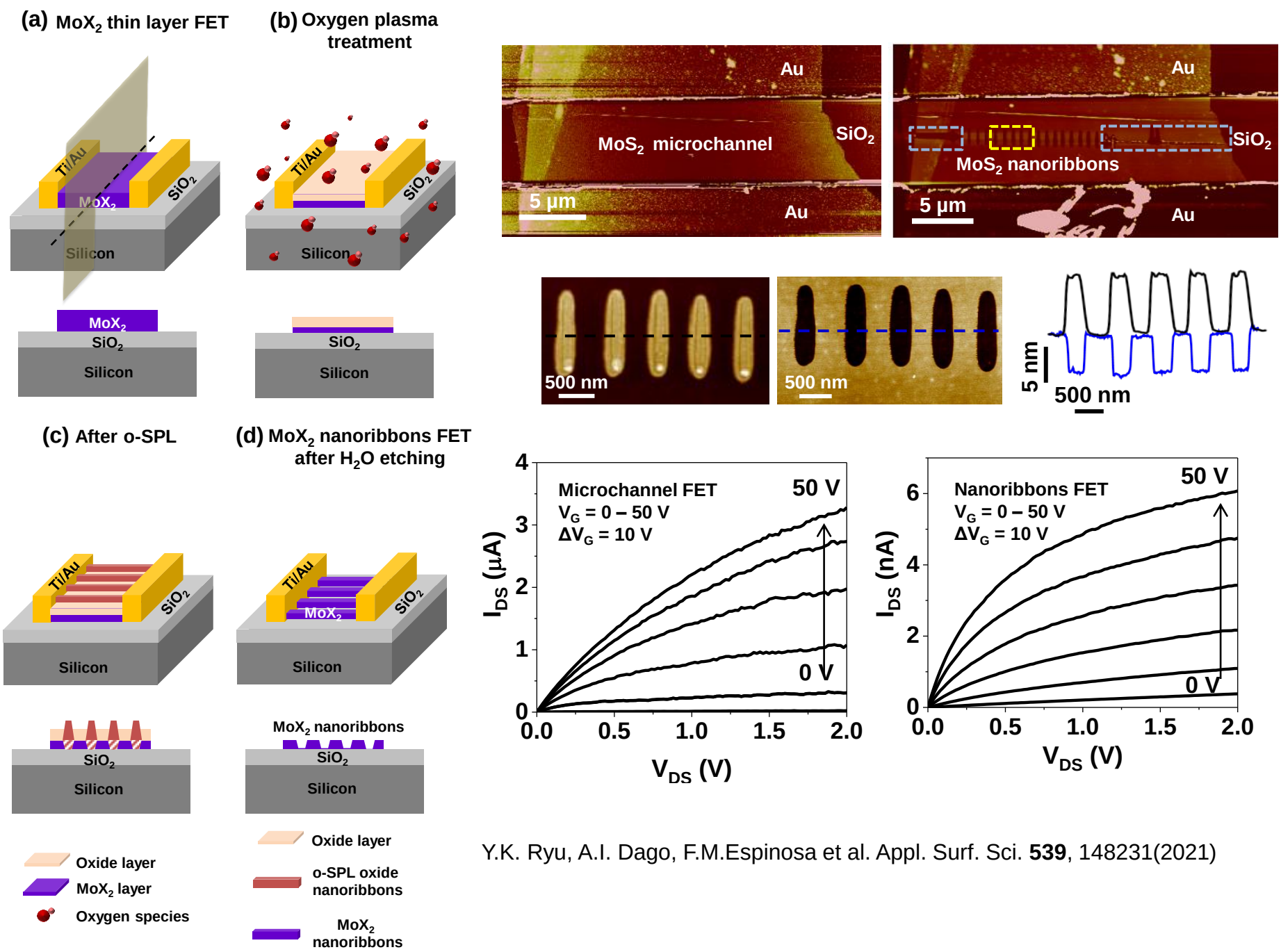

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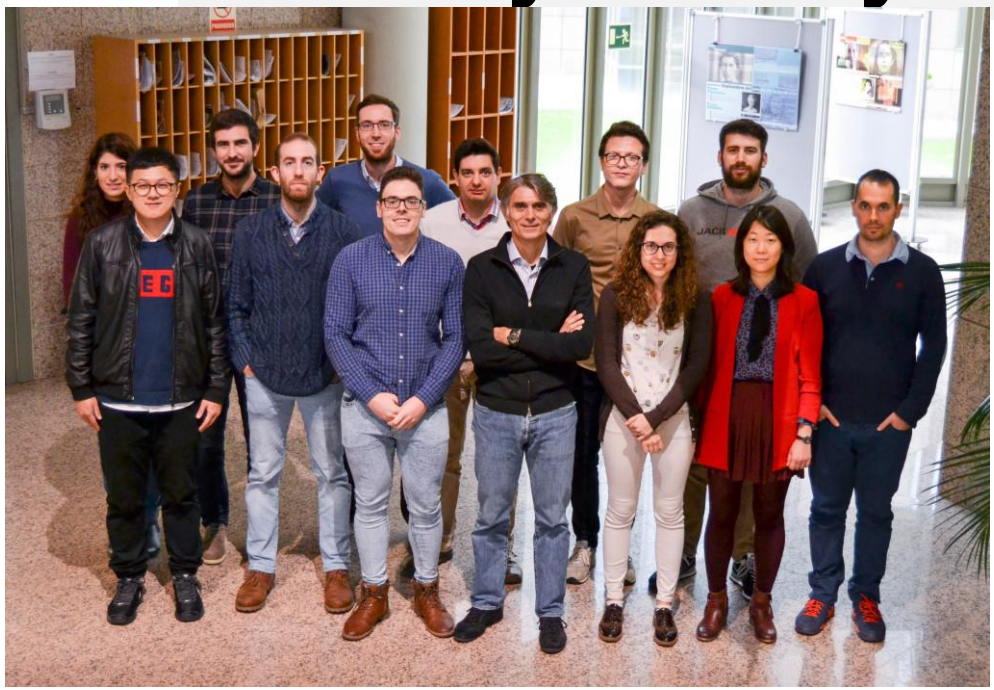
Acknowledgements

Thank you for your attention !



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