BEYOND–NANO: a research infrastructure focused on high performance microelectronics

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Accademia Nazionale dei Lincei, Fondazione Edison, 2019, October 30th

BEYOND NANO

Lab_Mat

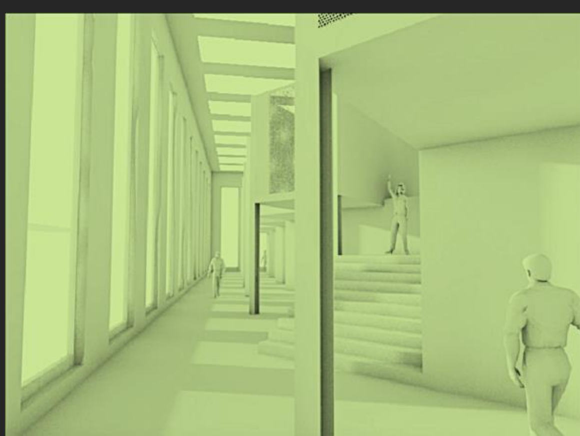
Investigation of materials for microelectronics applications

Lab_Power

Nanotechnological processes for power electronics

Lab_PV

Innovative processes for advanced photovoltaics

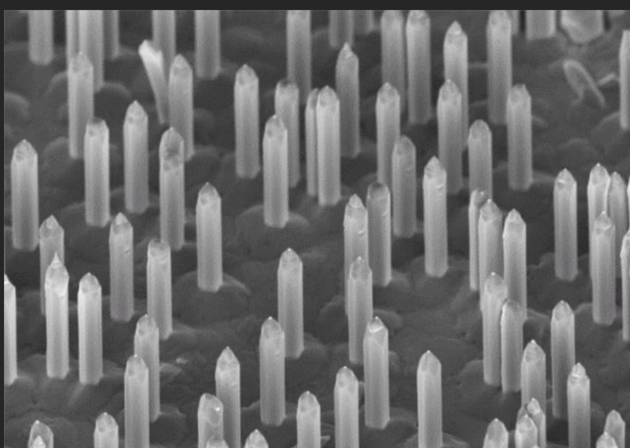


40 Millions of Euros

Regione Siciliana:	20 M€
Miur:	15 M€
Cnr:	5 M€

The approach

From fundamental science to device prototyping

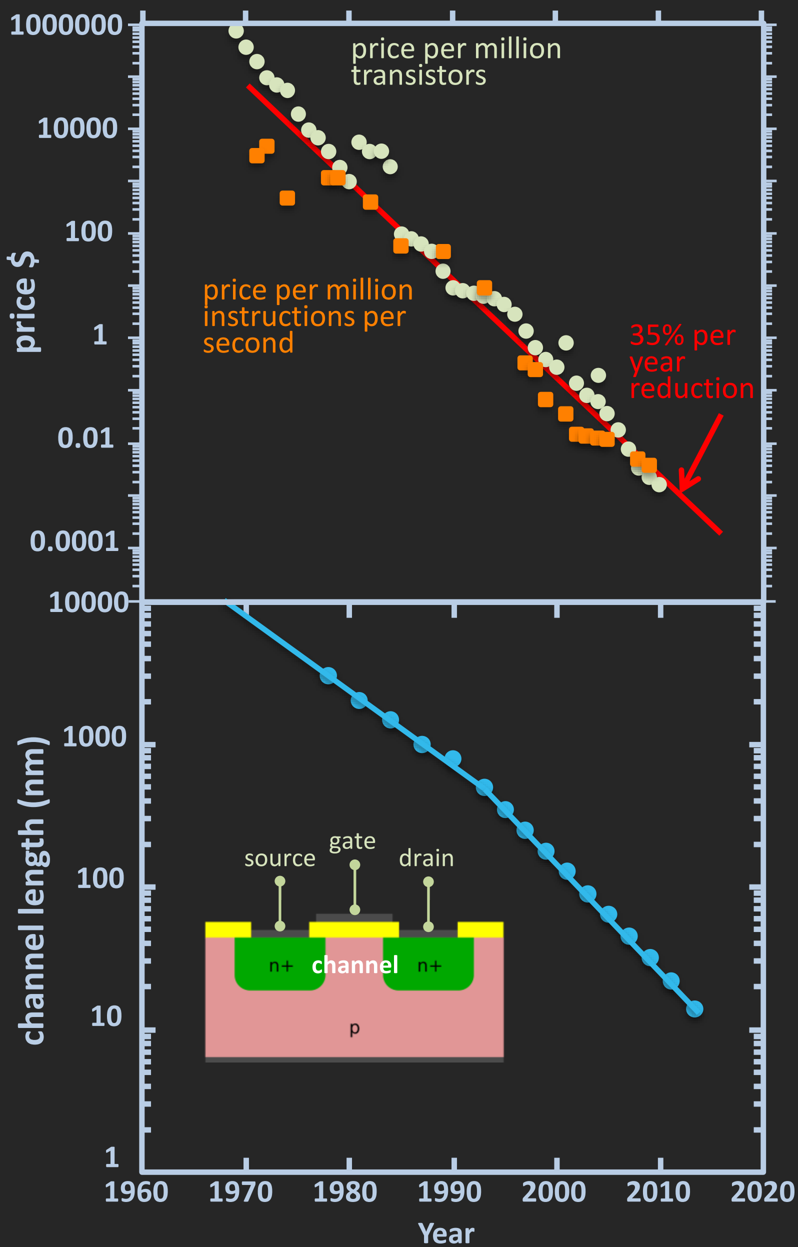


Fundamental science on materials properties

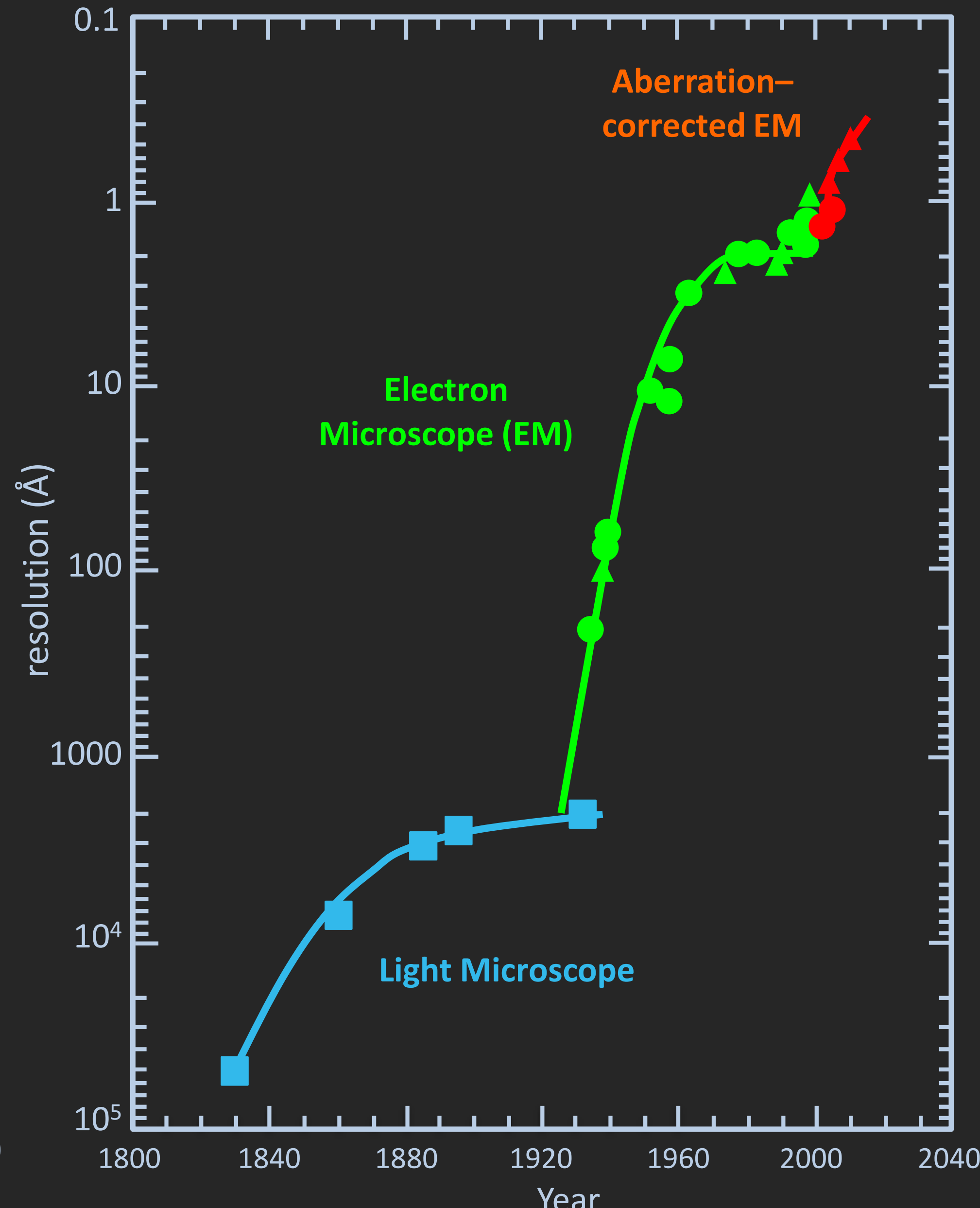
Nanofabrication processes

Materials and process integration in complex devices

The Moore Law



Improving resolution of microscoy techniques



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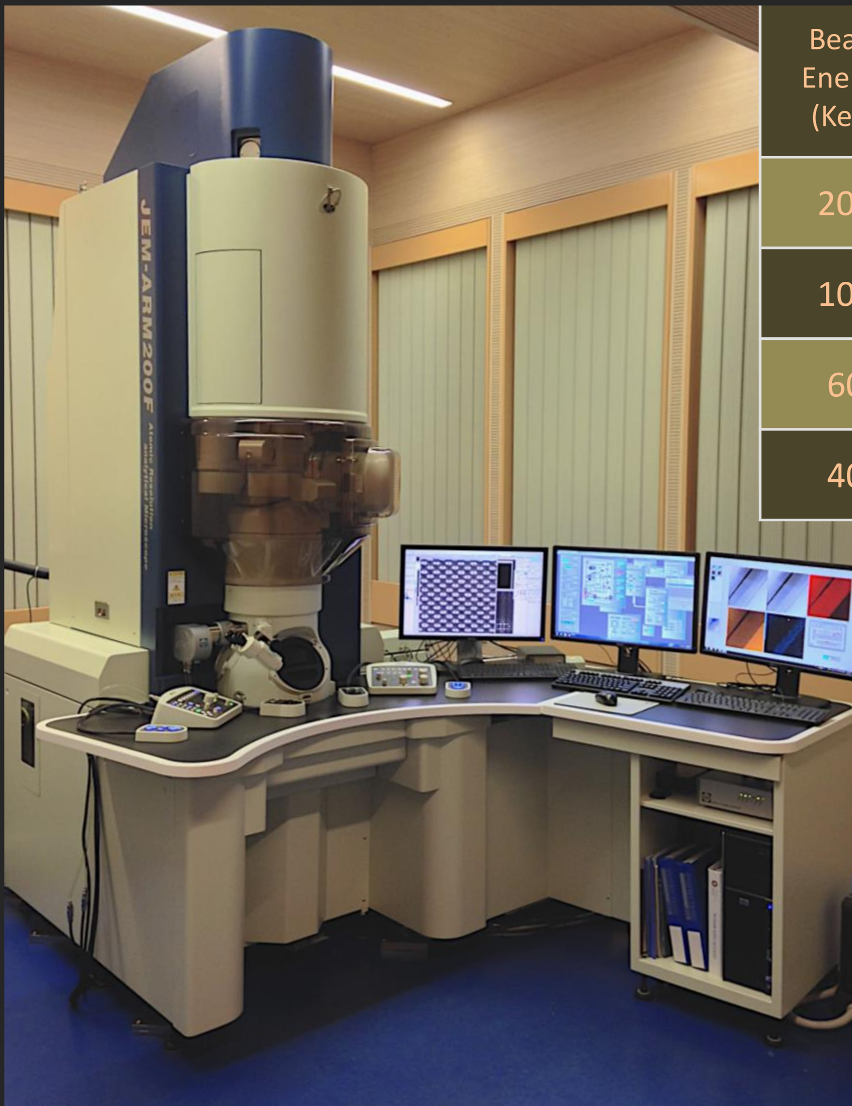
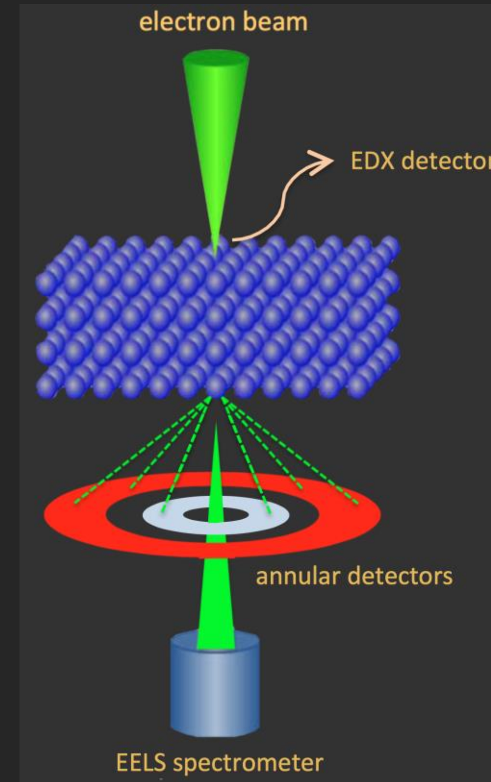
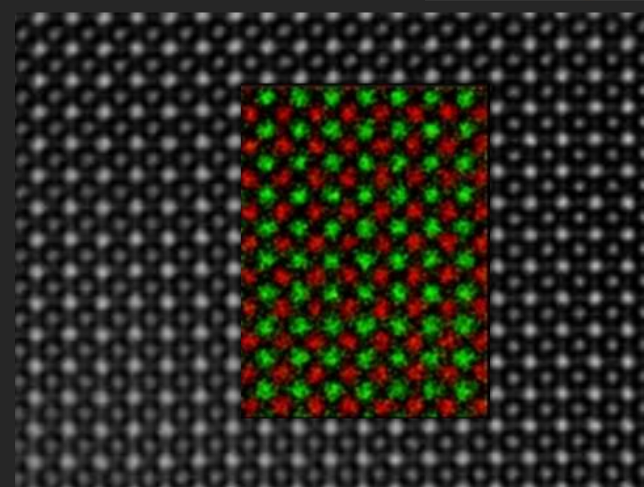
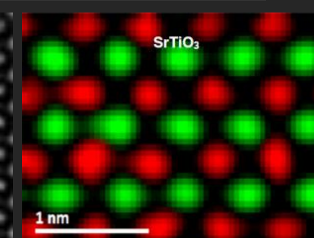
Atomic resolution Scanning Transmission Electron Microscopy



Beam Energy (KeV)	STEM resolution (Å)
200	0.68
100	0.83
60	1.1
40	1.36

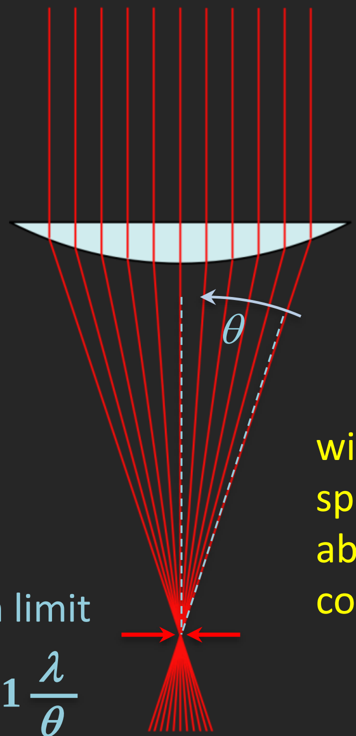






Ti
Sr

Sub–Ångstrom spatial resolution

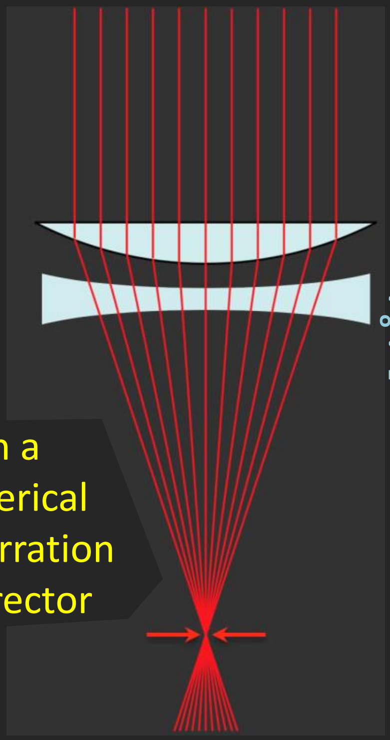


Rayleigh limit

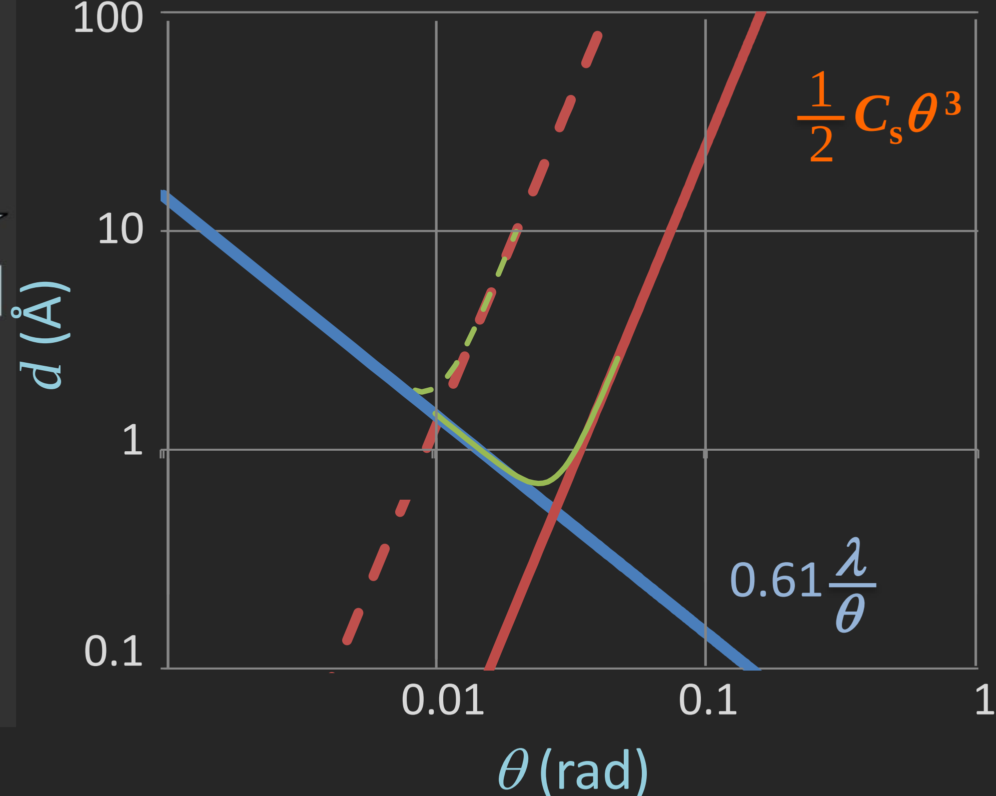
$$d \approx 0.61 \frac{\lambda}{\theta}$$

Inherent nature of bending of light/electron waves when passes through an aperture lens of finite size

with a spherical aberration corrector



Inherent nature of the lens used in the imaging system



λ = 0.025 Å @ 200 kV

ROCK–SALT

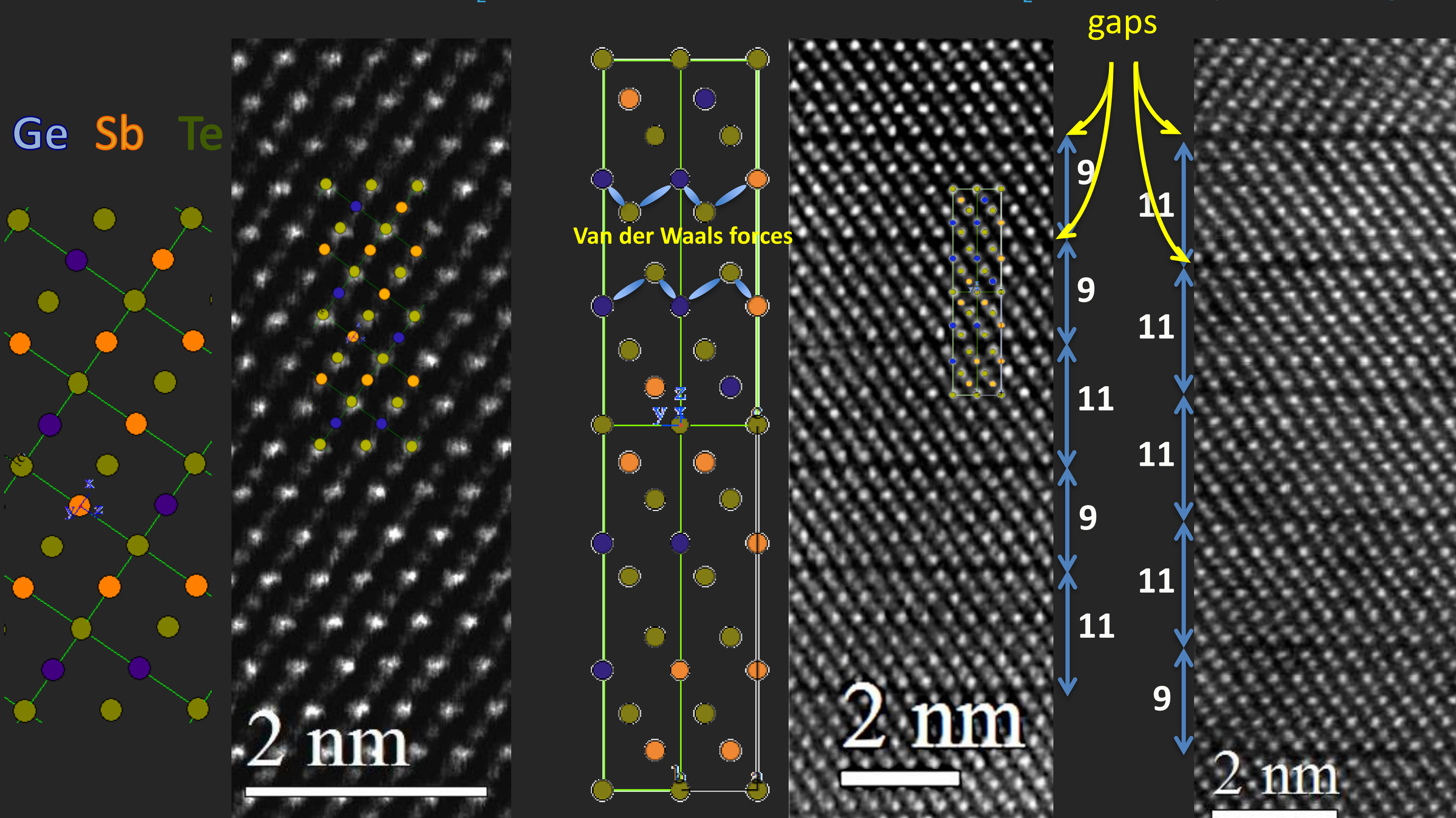
T = 150 °C on SiO_2

HEXAGONAL LOW–ORDER

T = 350 °C on SiO_2

HEXAGONAL HIGH–ORDER

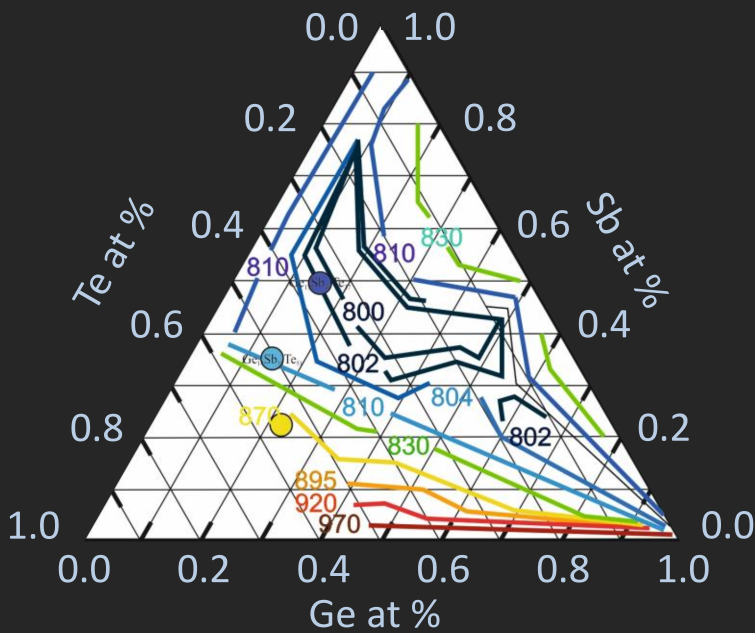
Epitaxial–Hexagonal

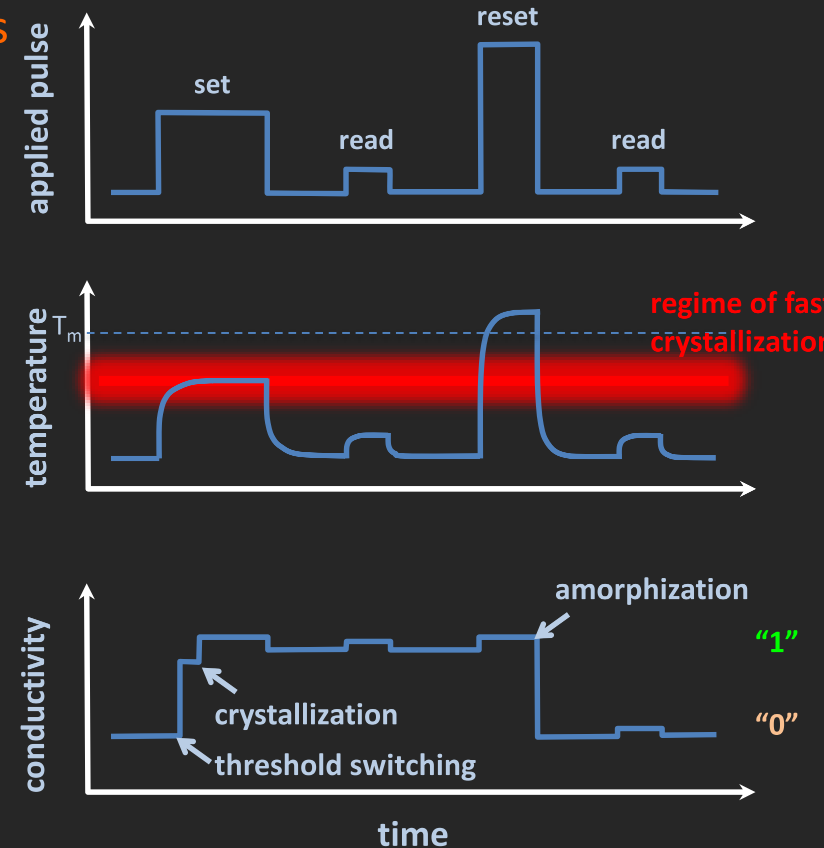


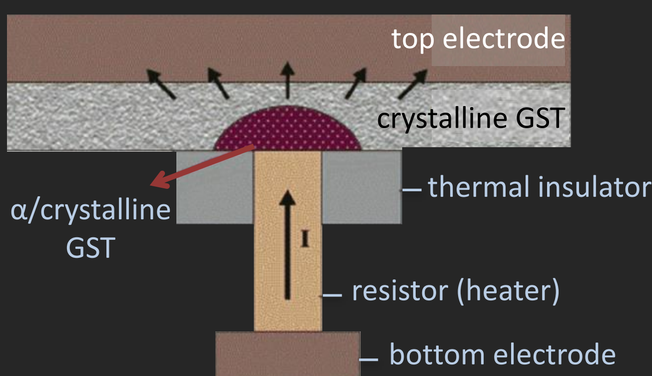
A.M. Mio et al., Nanotechnology 28(6), 065706 (2017)

More Moore: memory devices based on novel materials

Phase Change Memories based on chalcogenides

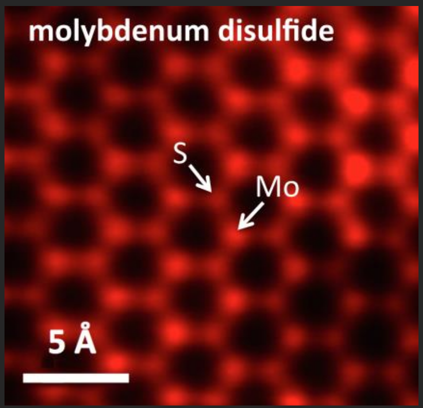






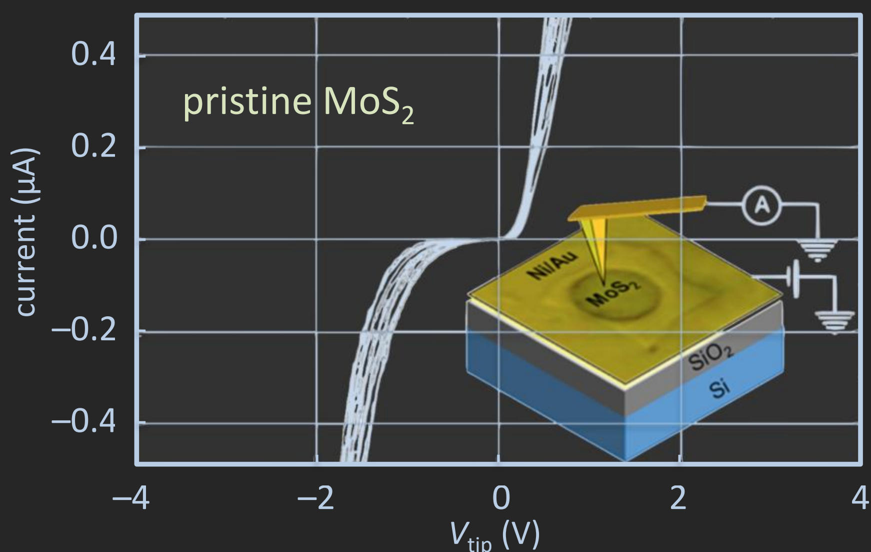
- ✕ Write/Erase velocity
- ✕ Scalability
- ✕ High RESET/SET Contrast
- ✕ Ciclability/Endurance
- ✕ Data Retention

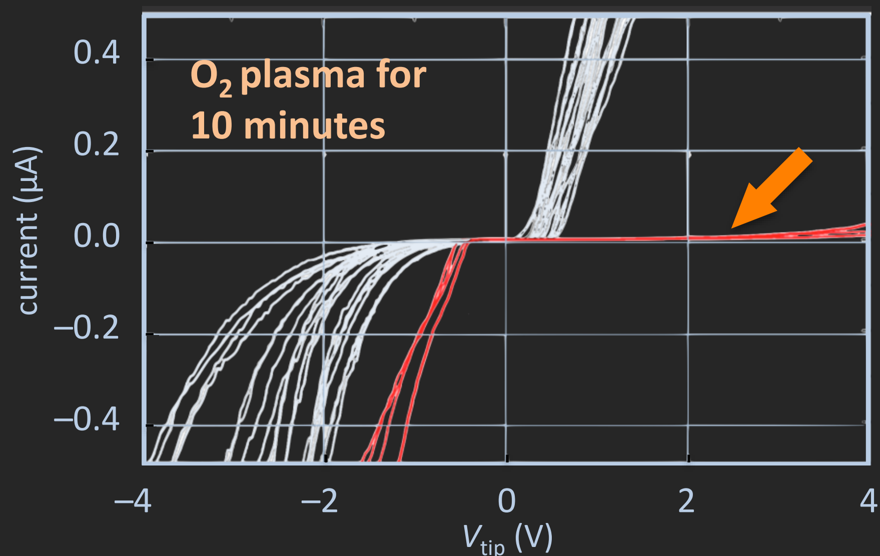
Nanoscale tailoring of Schottky metal/MoS_2 barrier by oxygen plasma functionalization



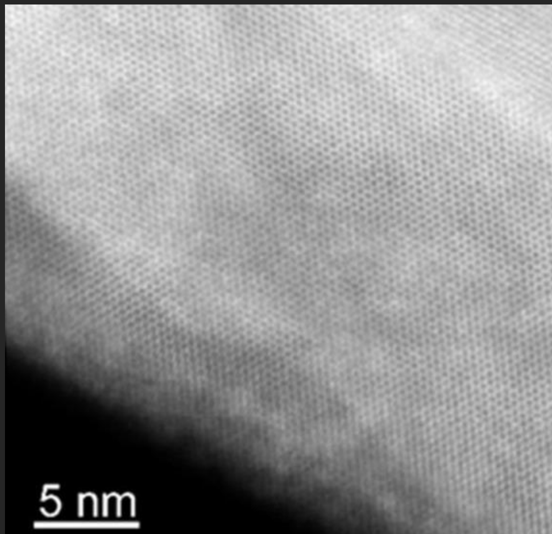
MoS_2 promising material for next generation post–Si CMOS technology

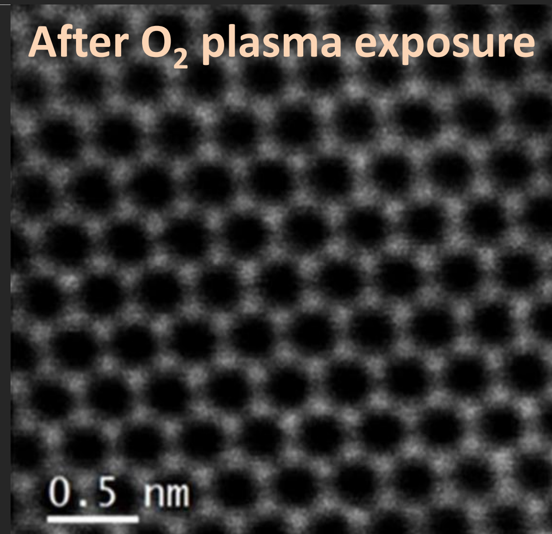
The high effective mass and large bandgap of MoS_2 minimize direct source–drain tunneling, while its atomically thin body maximizes the gate modulation efficiency in ultrashort–channel transistors.

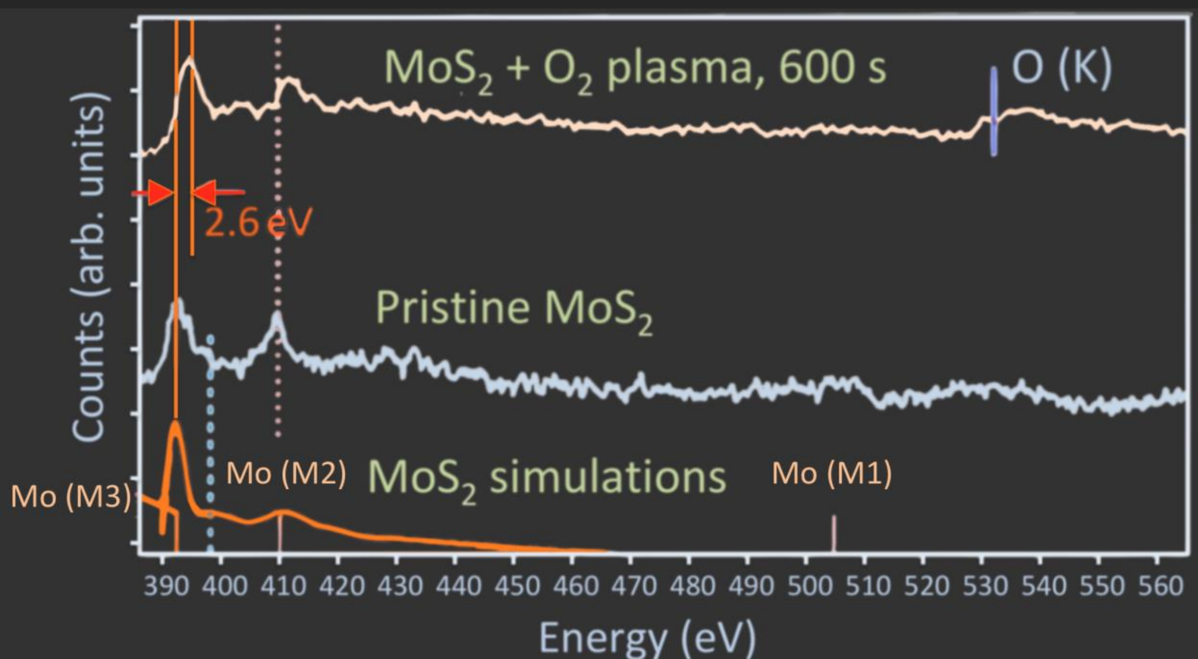


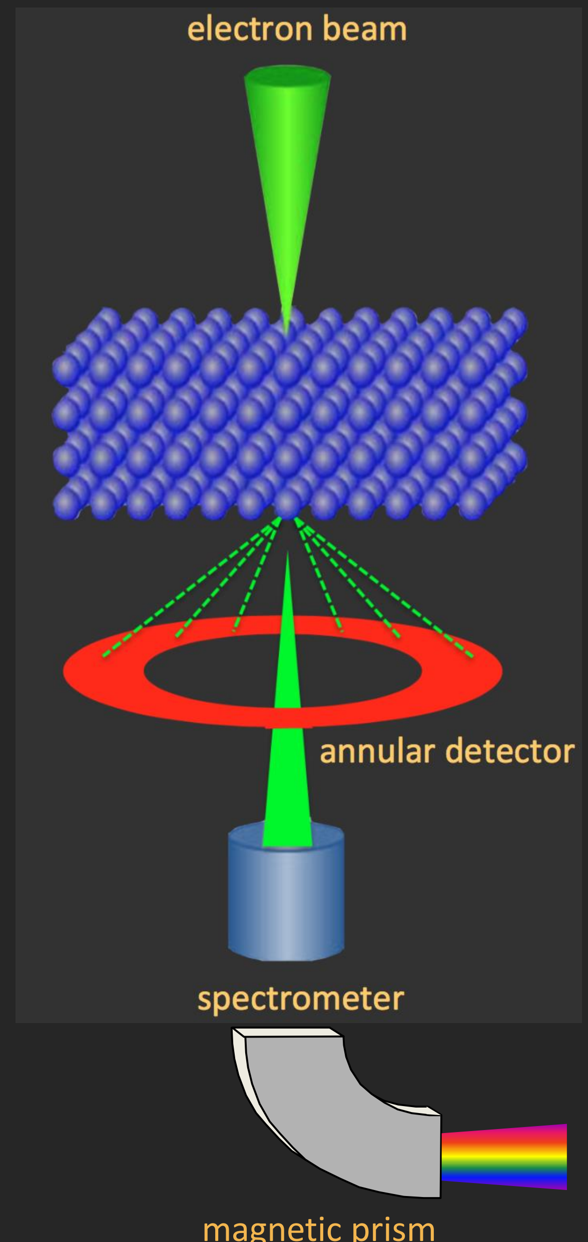


F. Giannazzo et al., ACS Applied Materials 9, 23164 (2017)

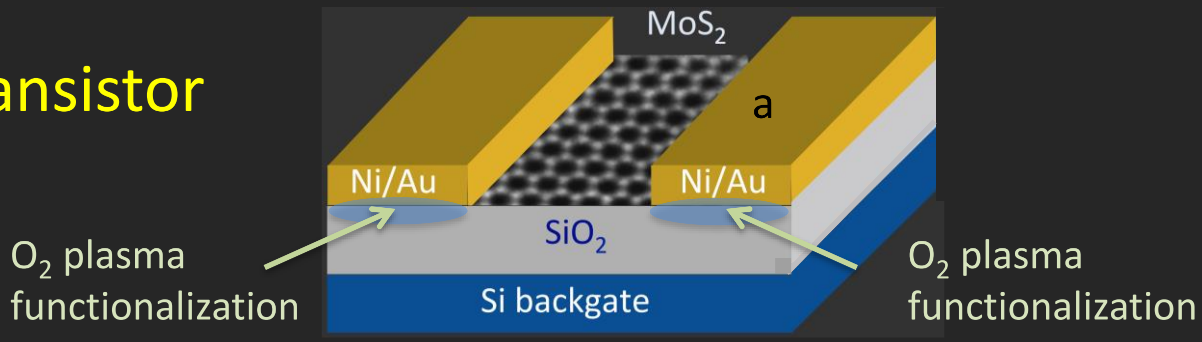

5 nm

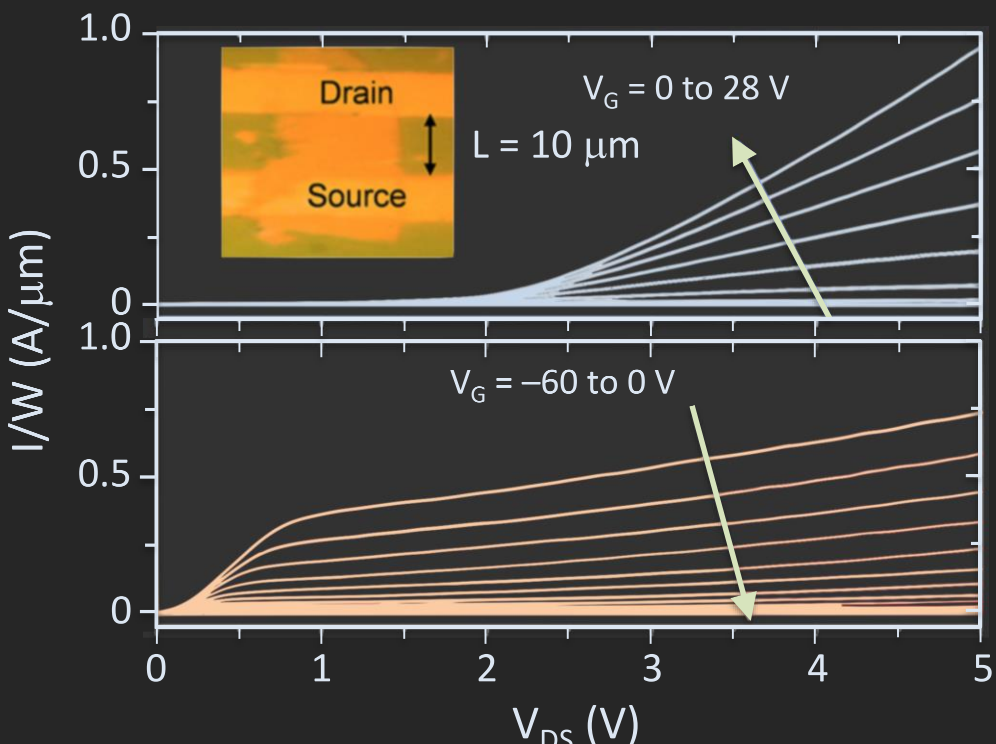

After O2 plasma exposure
0.5 nm

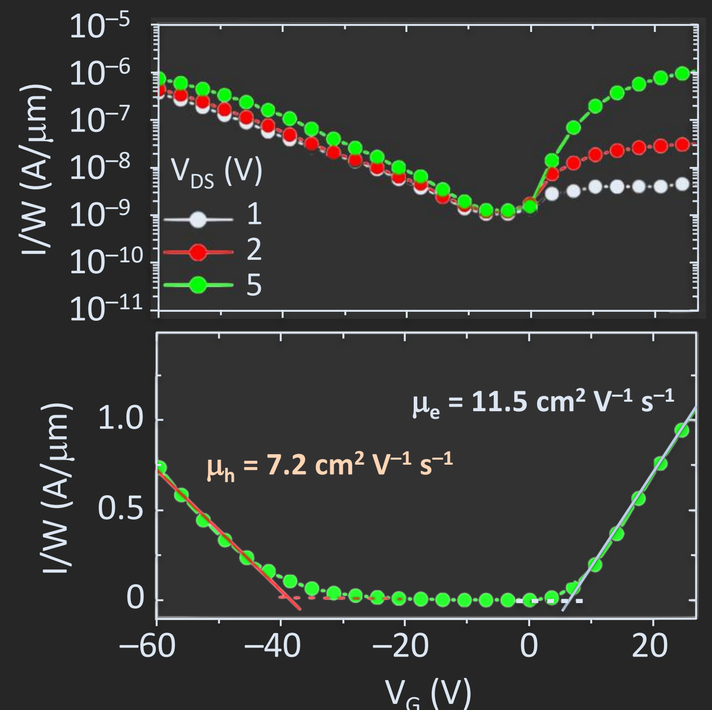

MoS2 + O2 plasma, 600 s
O (K)
2.6 eV
Pristine MoS2
Mo (M3)
Mo (M2)
MoS2 simulations
Mo (M1)
Counts (arb. units)
390 400 410 420 430 440 450 460 470 480 490 500 510 520 530 540 550 560
Energy (eV)

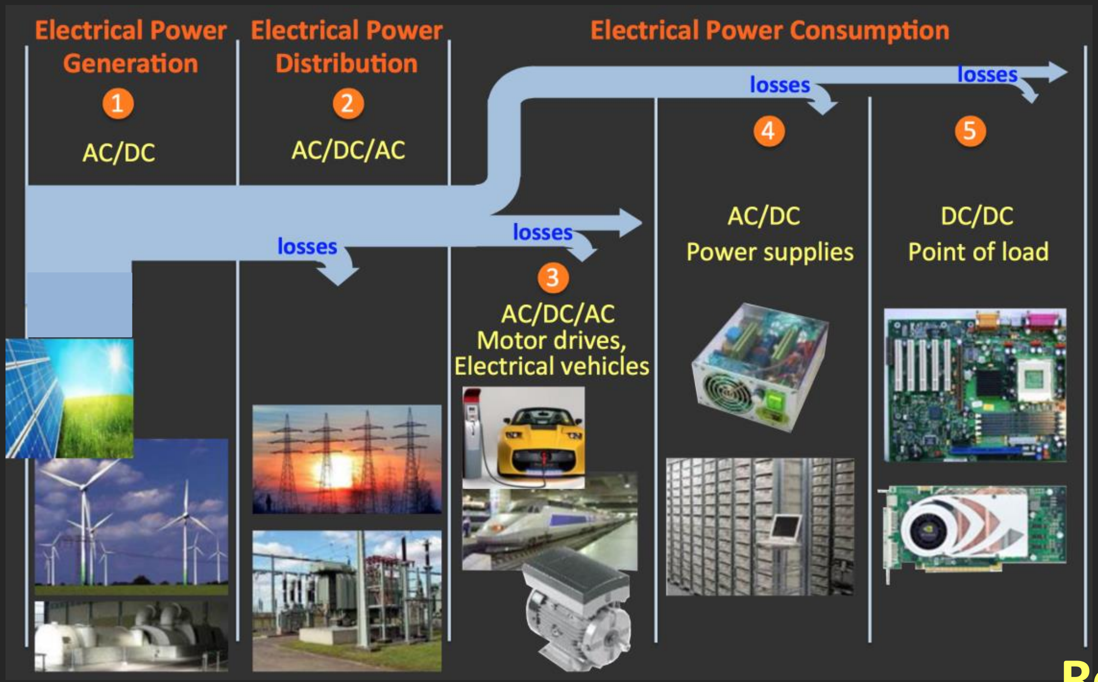

electron beam
annular detector
spectrometer
magnetic prism

Ambipolar MoS_2 Transistor



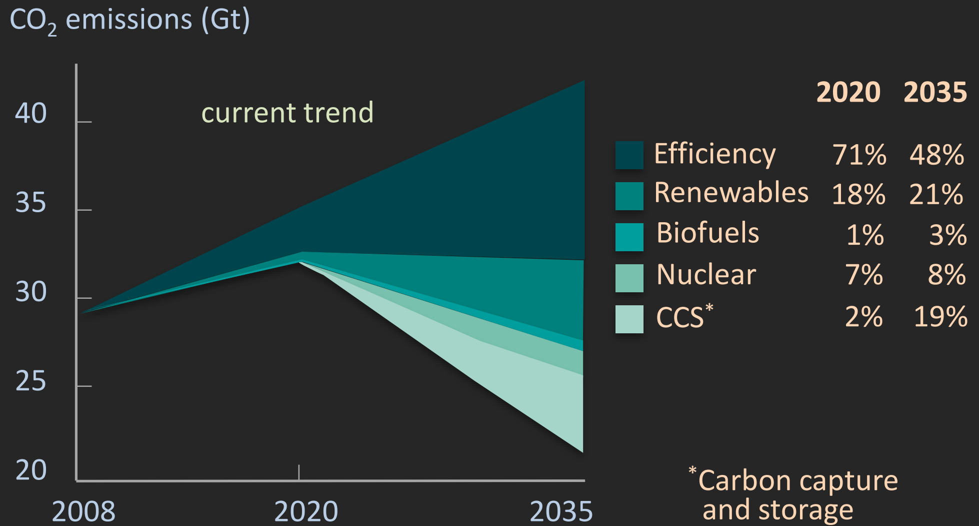






Electric power distribution chain

Reducing the CO_2 emissions



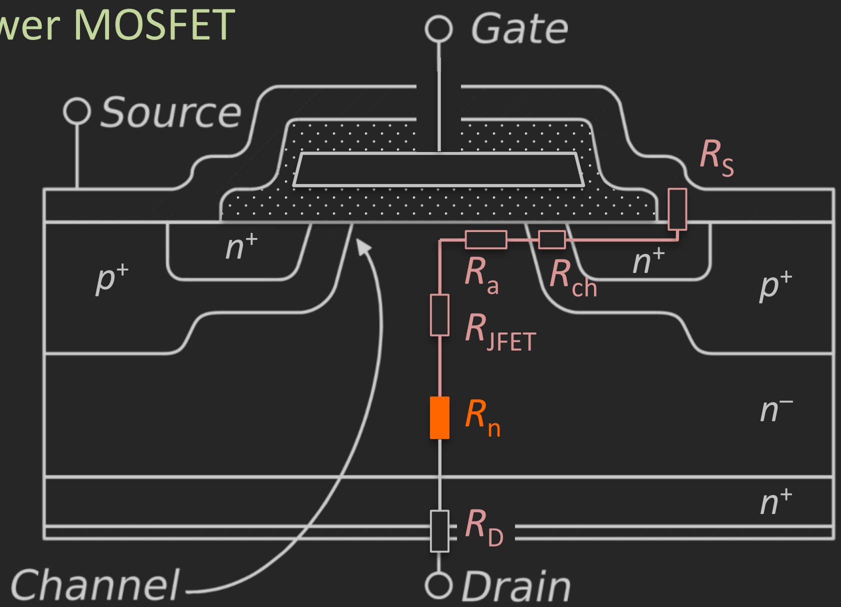
Source: IEA, World Energy Outlook report for 2010

Wide band–gap semiconductors

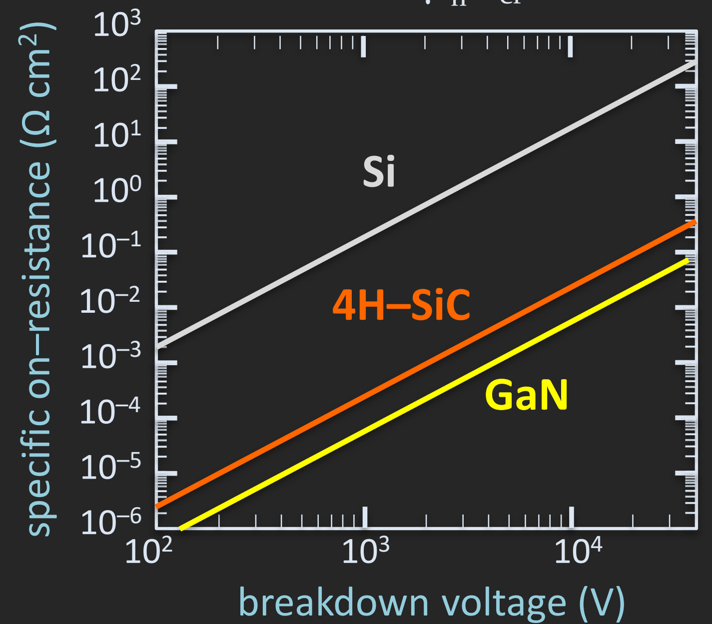
	Si	4H–SiC	GaN
E_{gap} (eV)	1.1	3.2	3.4
E_{cr} (MV/cm)	0.3	3.0	3.3
μ_n (cm²/Vs)	1350	800	1300*
k (W/m°C)	150	490	130

*2DEG

Power MOSFET



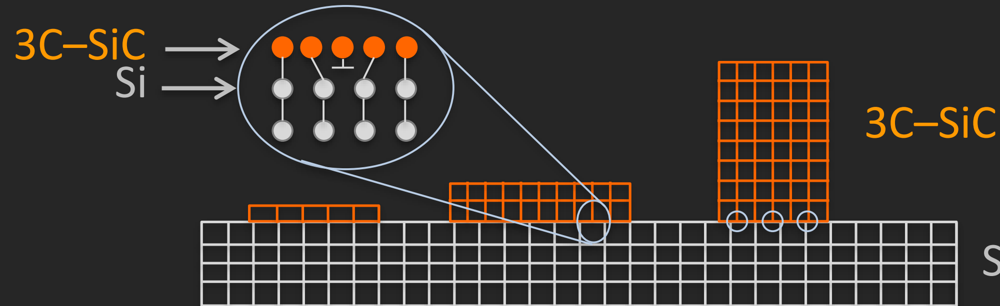
$$R_{on} \approx \frac{V_{bd}^2}{\varepsilon \mu_n E_{cr}^3}$$

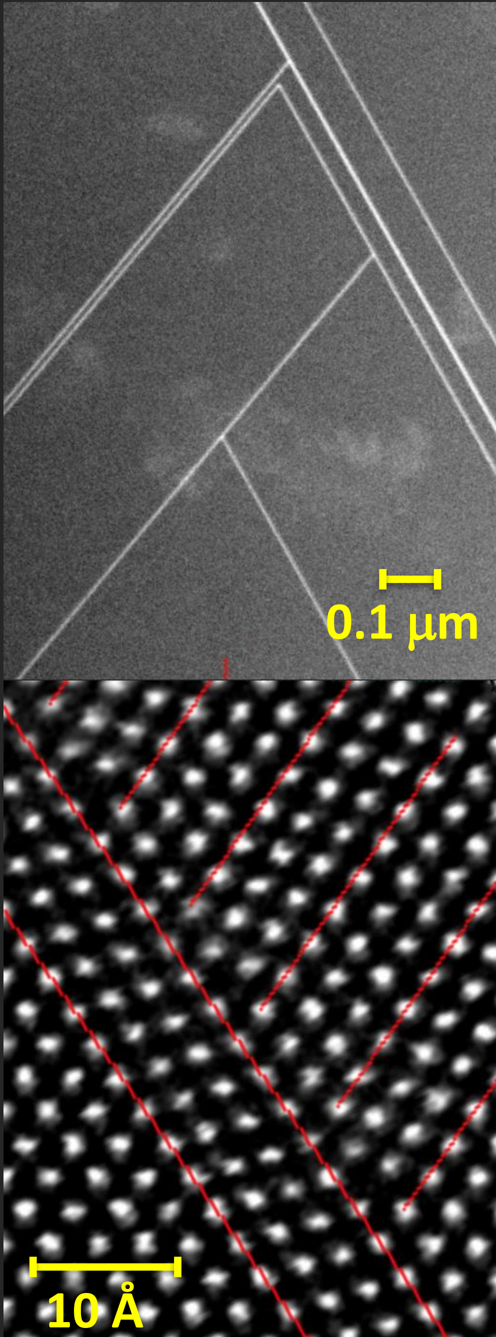


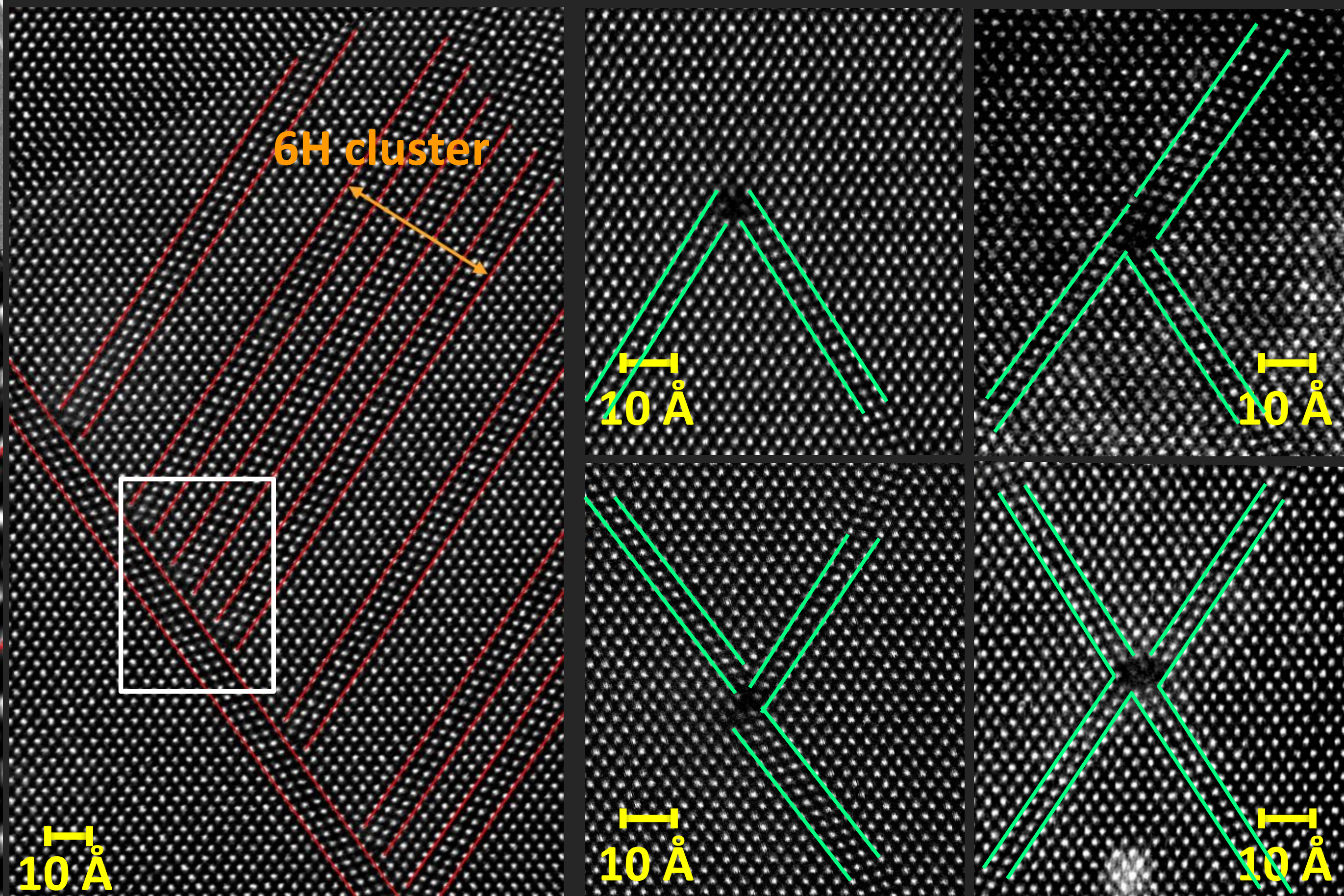
Lower R_{on} ➡ reduced device size

- **Reduction of the static and dynamic losses**
- **High power conversion efficiency**

Growht of 3C–SiC on Si







La Via et al., Mat. Sci. Semicon. Processing 78, 57 (2018)

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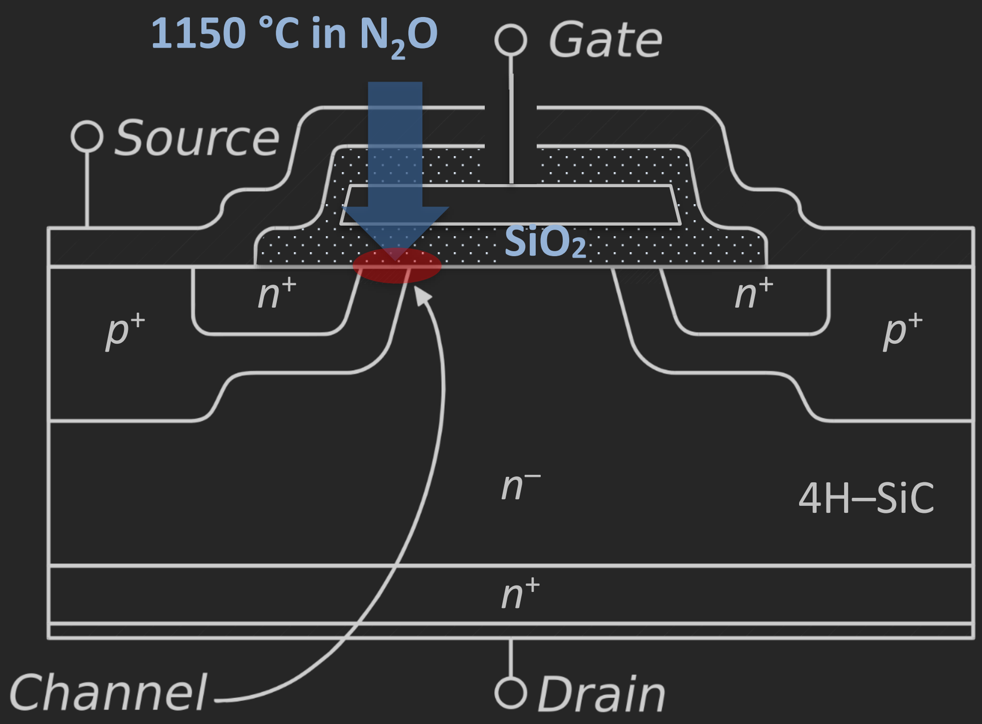
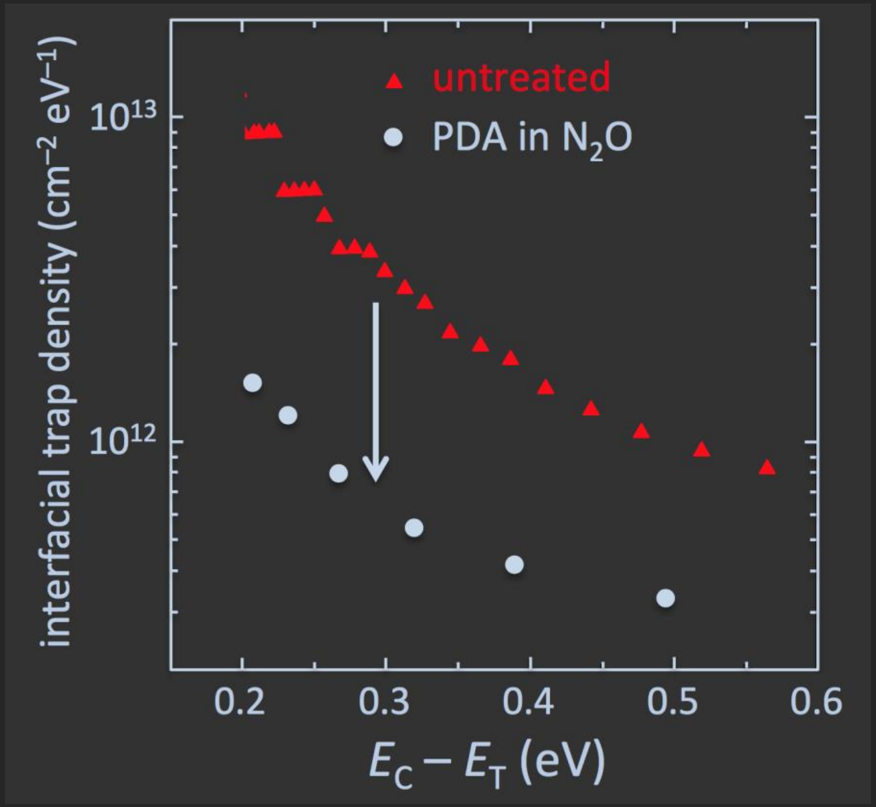
4H–SiC Power MOSFET

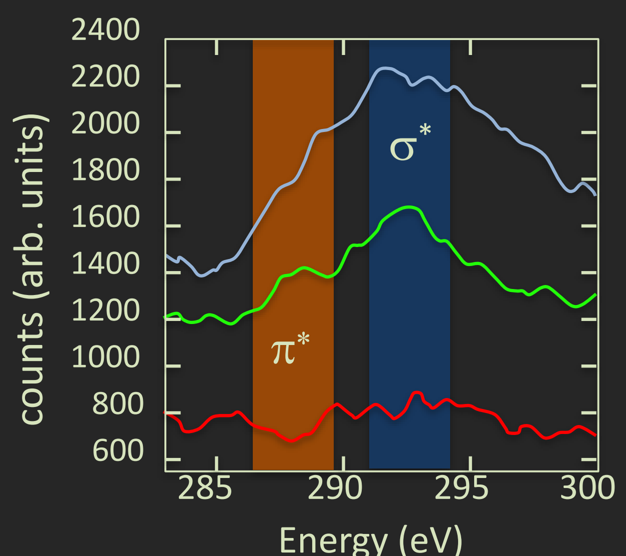
Issues:
High density of traps at SiO_2/SiC interface, low channel mobility

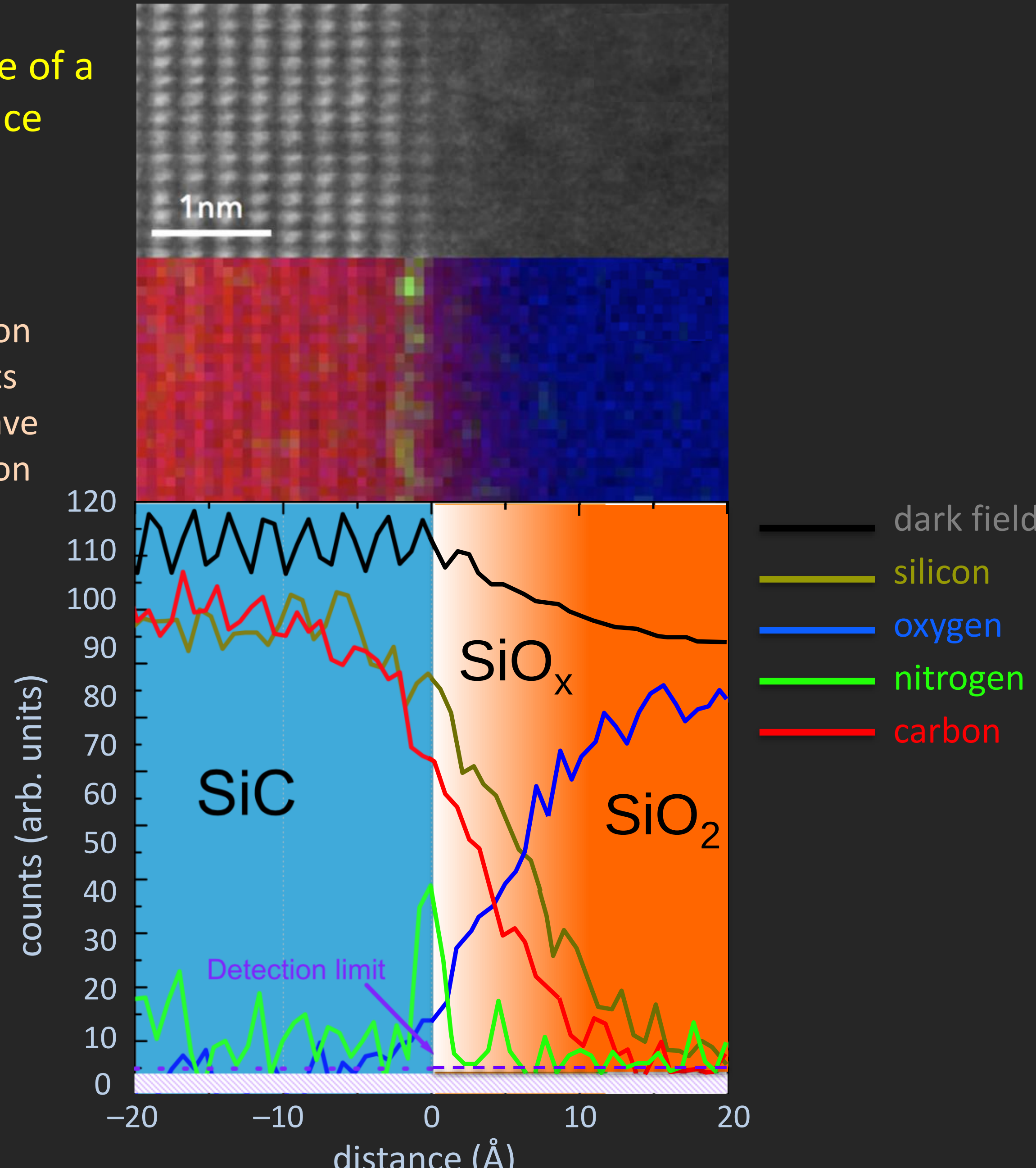




STEM–EELS reveals the presence of a non–abrupt SiO_2/4H–SiC interface

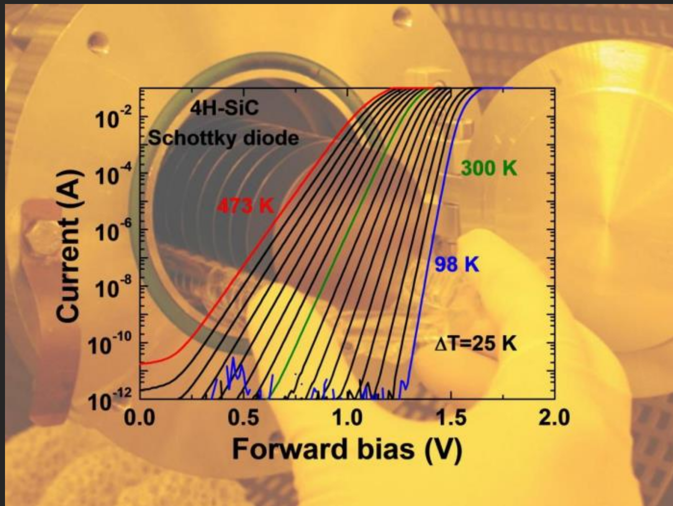
A mixed sp2/sp3 carbon hybridization in the non–abrupt interface suggests that the interfacial carbon atoms have lost their tetrahedral SiC coordination

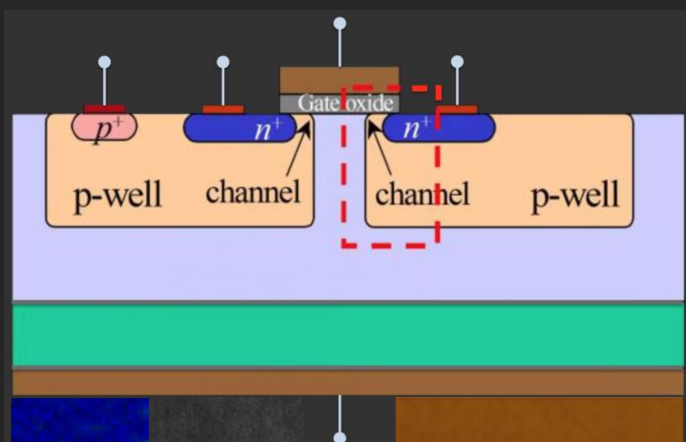


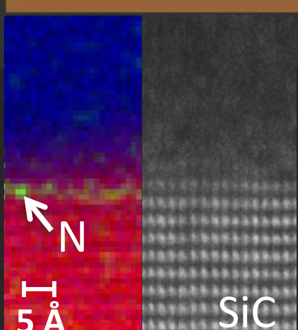


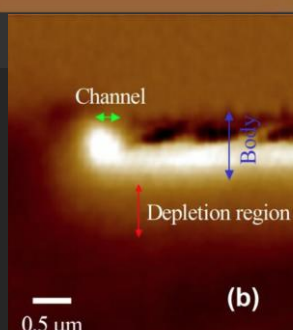
P. Fiorenza et al., Nanotech. 29, Art. No. 395702 (2018)

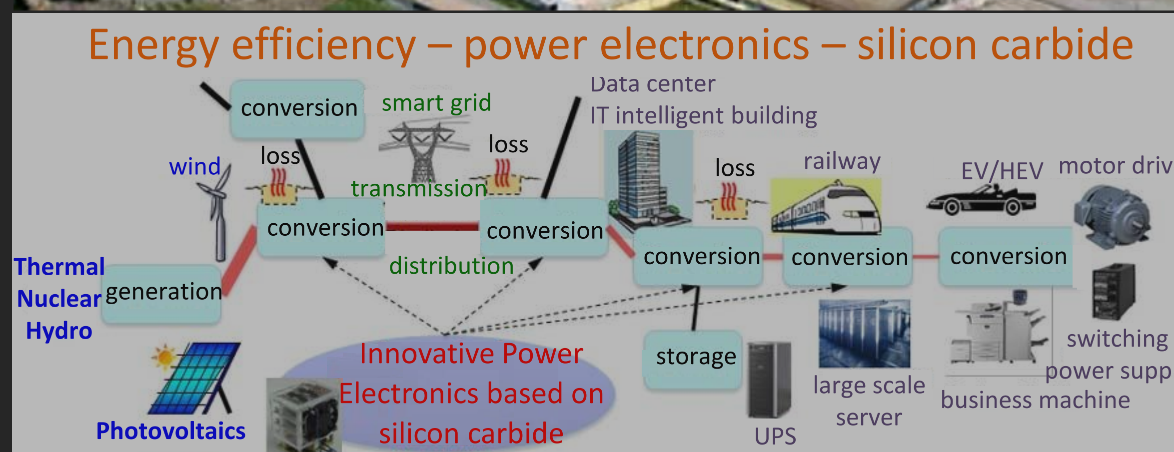
Technology transfer: the silicon carbide example





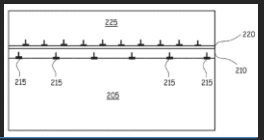




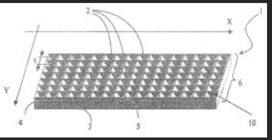


a selection of Patents

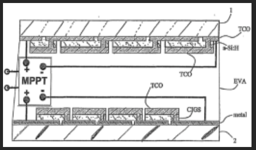
Manufacture of wafers of wide energy gap semiconductor material for the integration of electronic and/or optical and/or optoelectronic devices, US 20140264385 A1, 2014, September the 18th



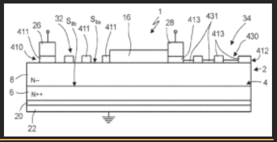
Semiconductor substrate suitable for the realization of electronic and/or optoelectronic devices and relative manufacturing process, US 20150031193 A 2015, January the 29th



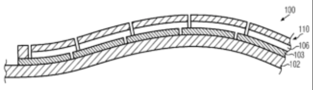
Solar panel having monolithic multicell photovoltaic modules of different types, US 9006558 B2, 2015, April the 14th



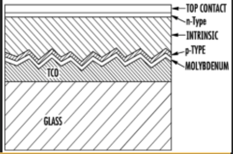
Integrated electronic device for detecting ultraviolet radiation, US 20160349108 A1, 2016, December the 1st



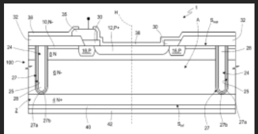
Thin film solar cell module including series-connected cells formed on a flexible substrate by using lithography, US 9276149 B2, 2016, March the 1st



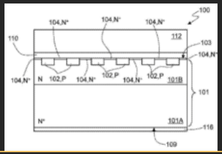
Thin refractory metal layer used as contact barrier to improve the performance of thin-film solar cells, US 20160079453 A1, 2017, March the 17th



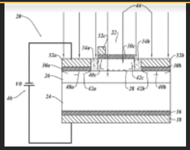
Avalanche photodiode for detecting ultraviolet radiation and manufacturing method thereof, US 20170098730 A1, April the 6th



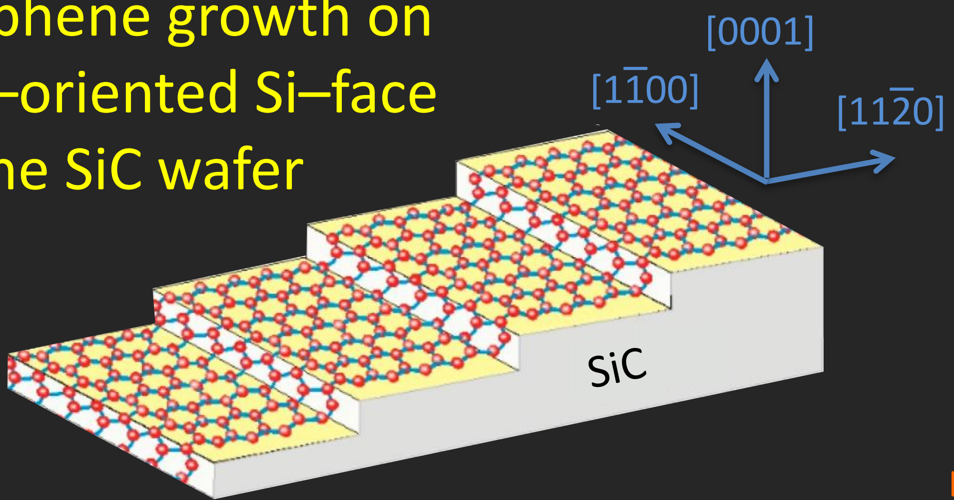
Wide bandgap high-density semiconductor switching device and manufacturing process thereof, US 9711599 B2, 2017, July the 18th



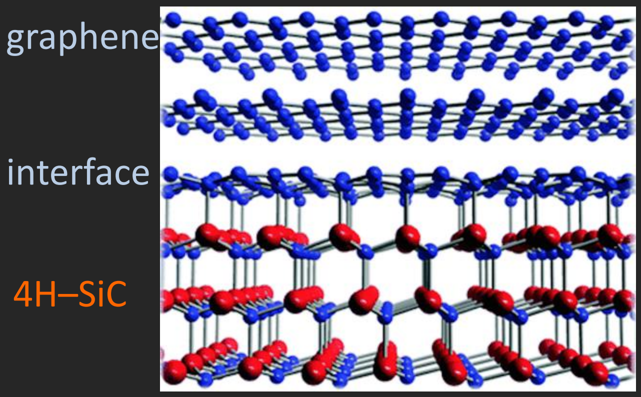
Multiband double junction photodiode and related manufacturing process, US 20170207360 A1, 2017, July the 20th



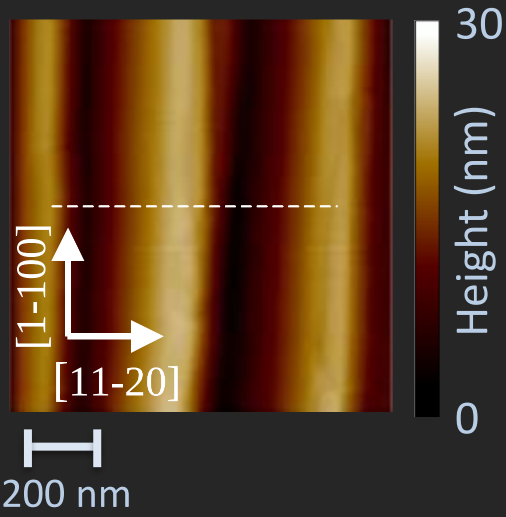
Graphene growth on mis–oriented Si–face of the SiC wafer

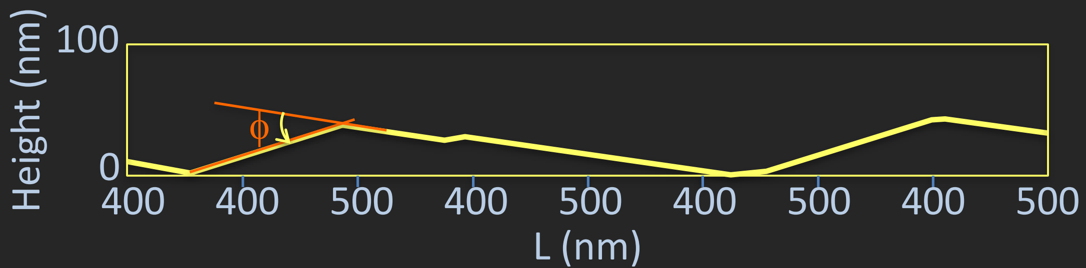


Si terminated 4H–SiC (0001) substrates 8° off–axis miscut angle in the [11$\bar{2}$0] direction



Epitaxial graphene: solution for integration of high power and high frequency functions on a SiC substrate

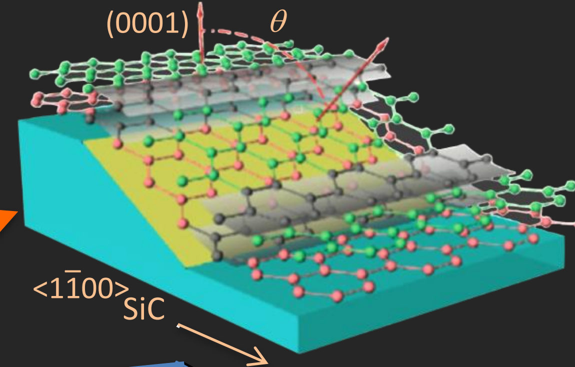




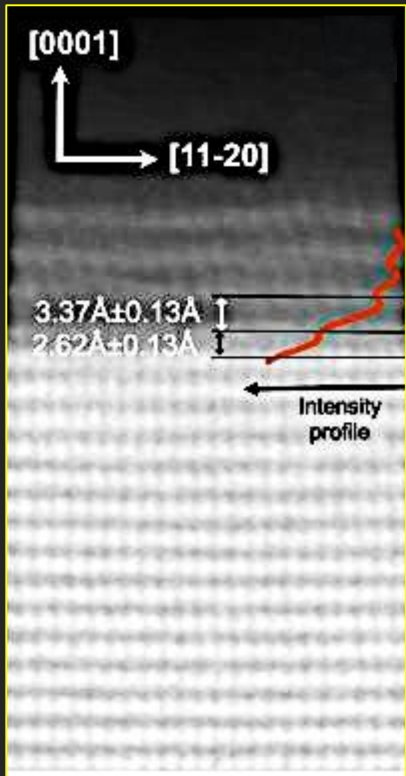
G. Nicotra et al., Phys. Rev. B 91(15), 155411 (2015)

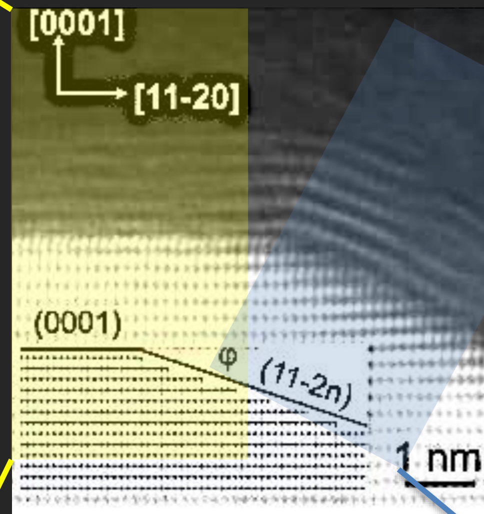
Atomic resolution HAADF–STEM

@ 60 keV primary electron beam

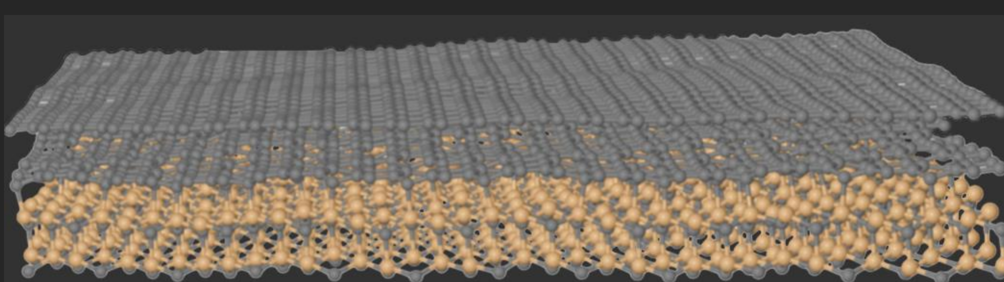


5th
4th
3rd
2nd
1st





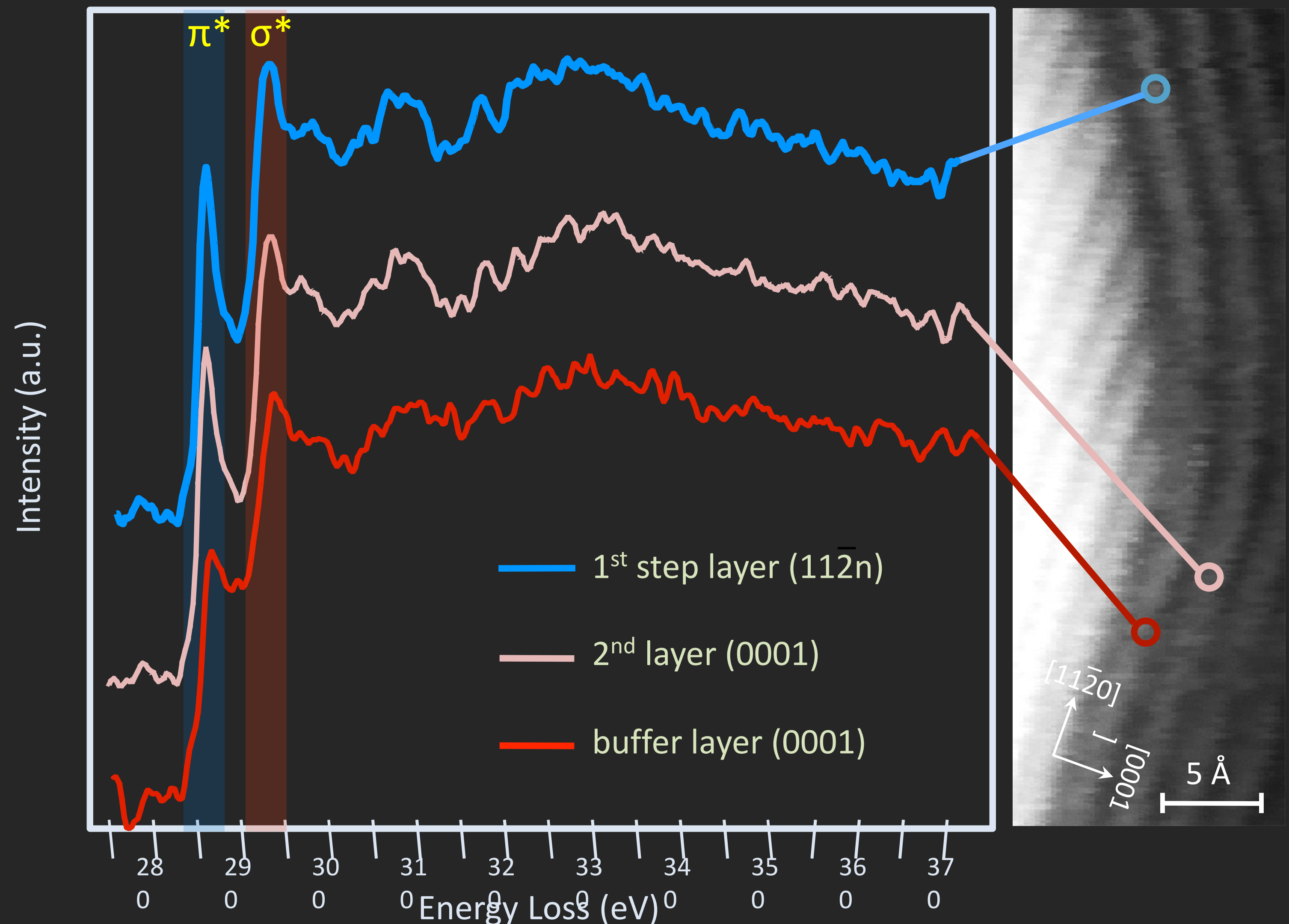
Cross section perpendicular to [0001] direction



3.35 Å
2.64 Å

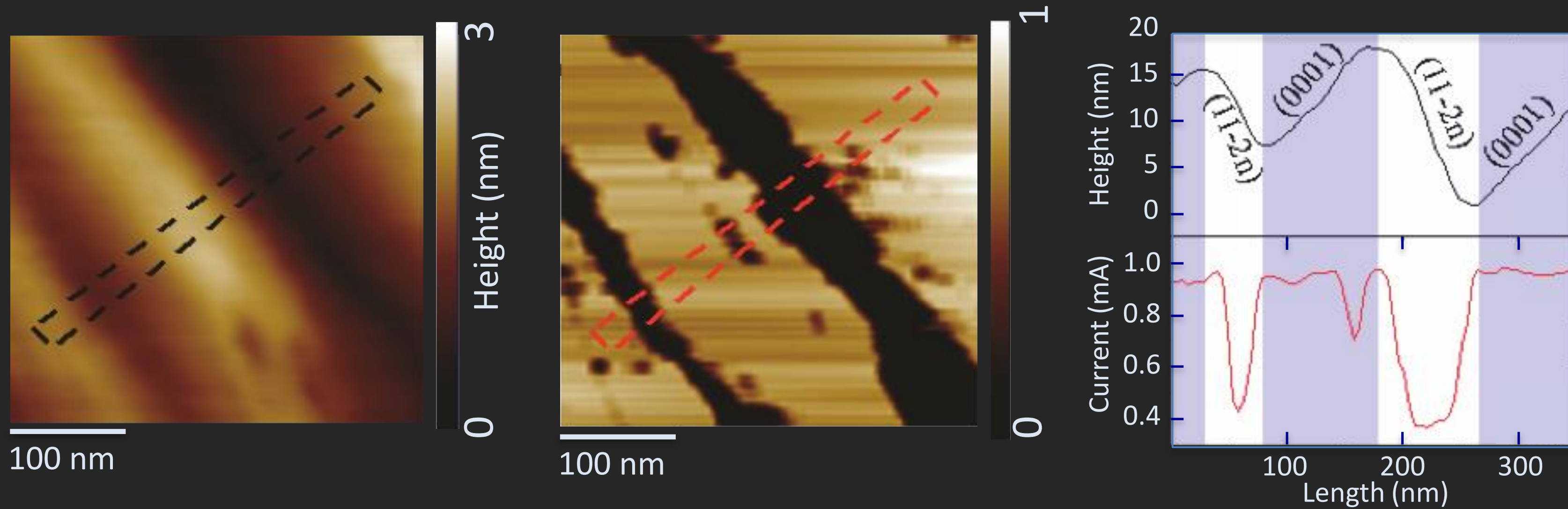
Ab initio simulations showing the equilibrium average atomic distances

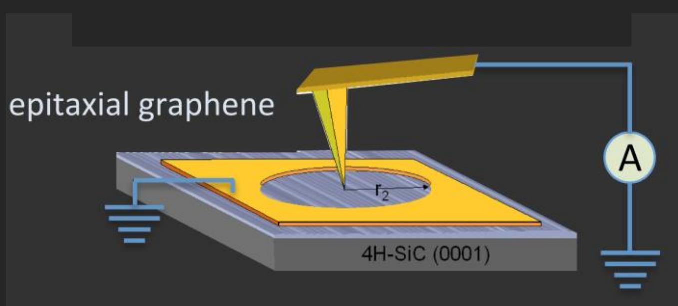
The buffer layer on the planar (0001) surface gets detached from the (11$\bar{2}$n) surface



The buffer layer present on the planar (0001) face gets detached from the substrate on the (11$\bar{2}$n) facets of the steps, turning into a quasi–freestanding graphene film

Conductive Atomic Force Microscopy





When synthesized on a silicon carbide (0001) surface, epitaxial graphene is subjected to a high electron–doping originating right from the interface carbon buffer layer that is covalently bonded to the substrate.

Distributed European Research infrastructure of advanced electron microscopy