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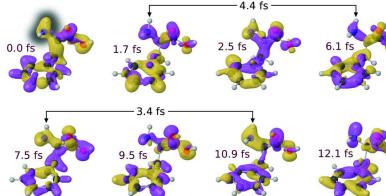
EXPLORING MATTER AT THE ATOMIC LEVEL



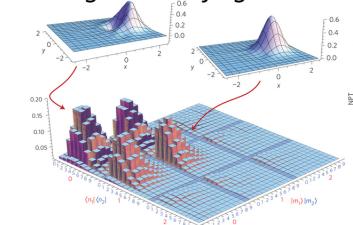
The approach

From fundamental science to device prototyping

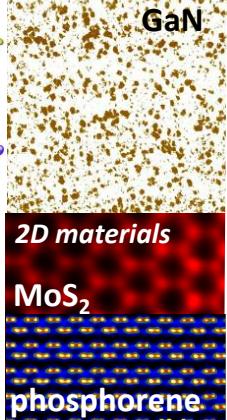
*Electron dynamics in molecules
by attosecond laser*



Entanglement of light



*High performance
microelectronics*

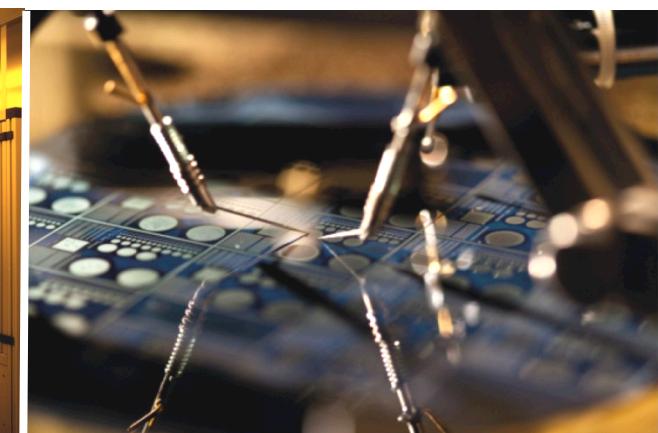


*Fundamental science on light
and matter*

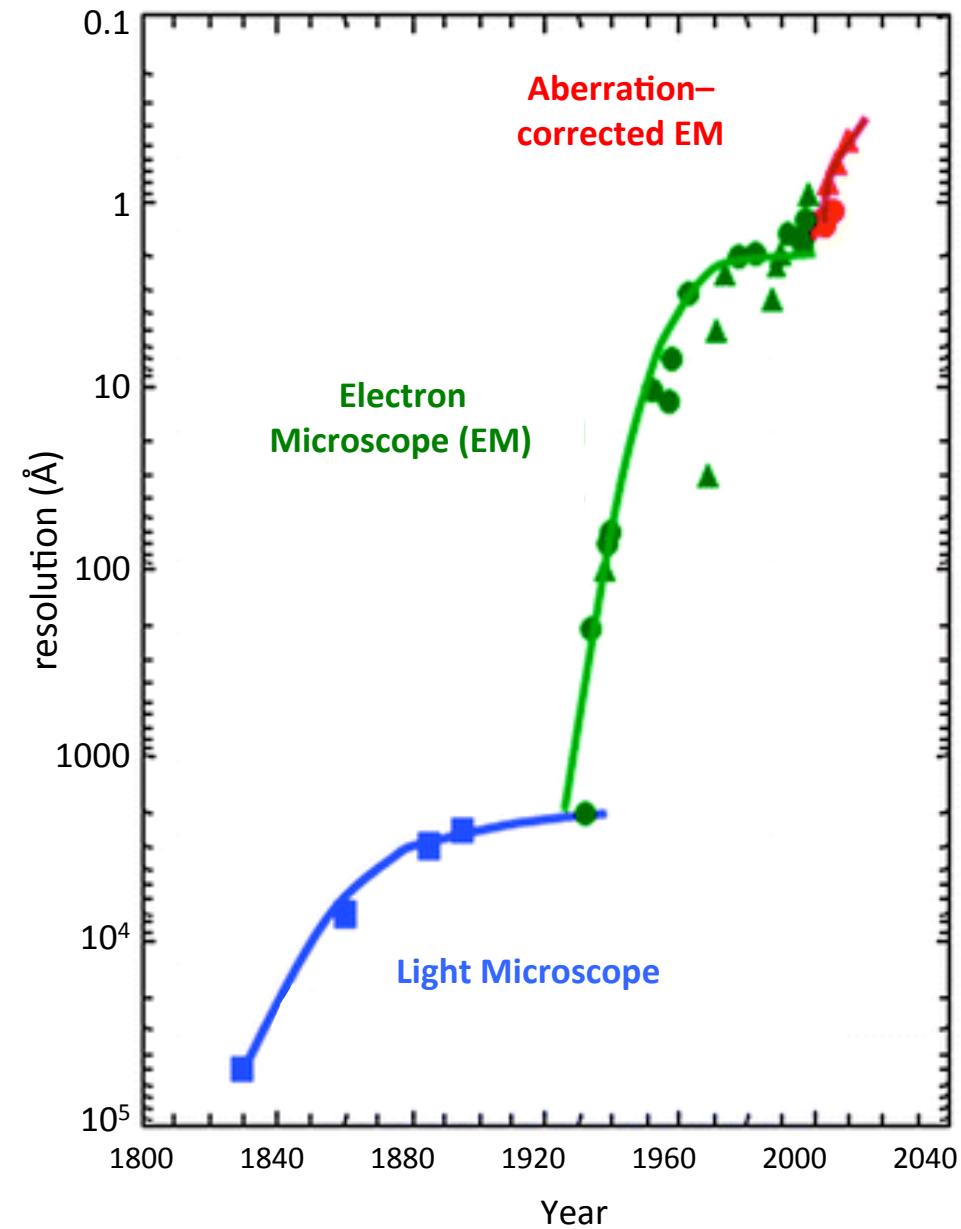
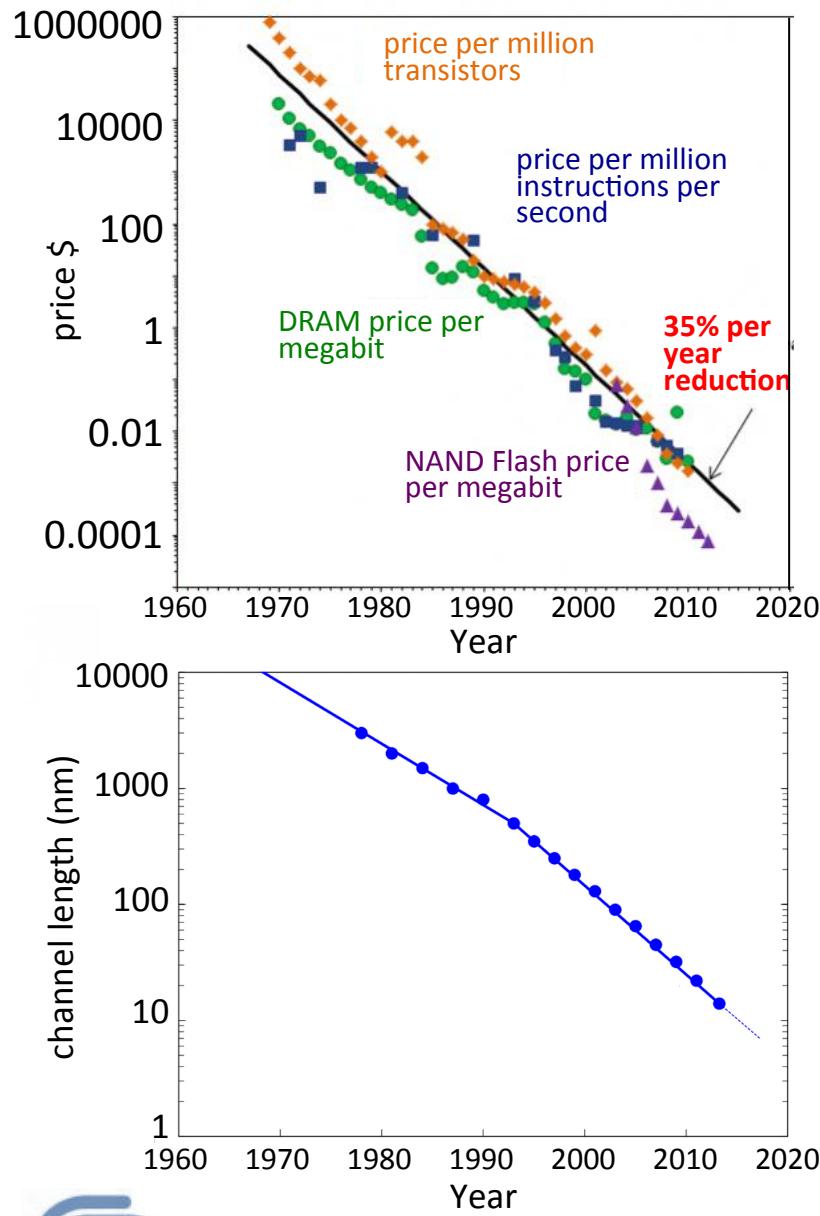
Nanofabrication processes

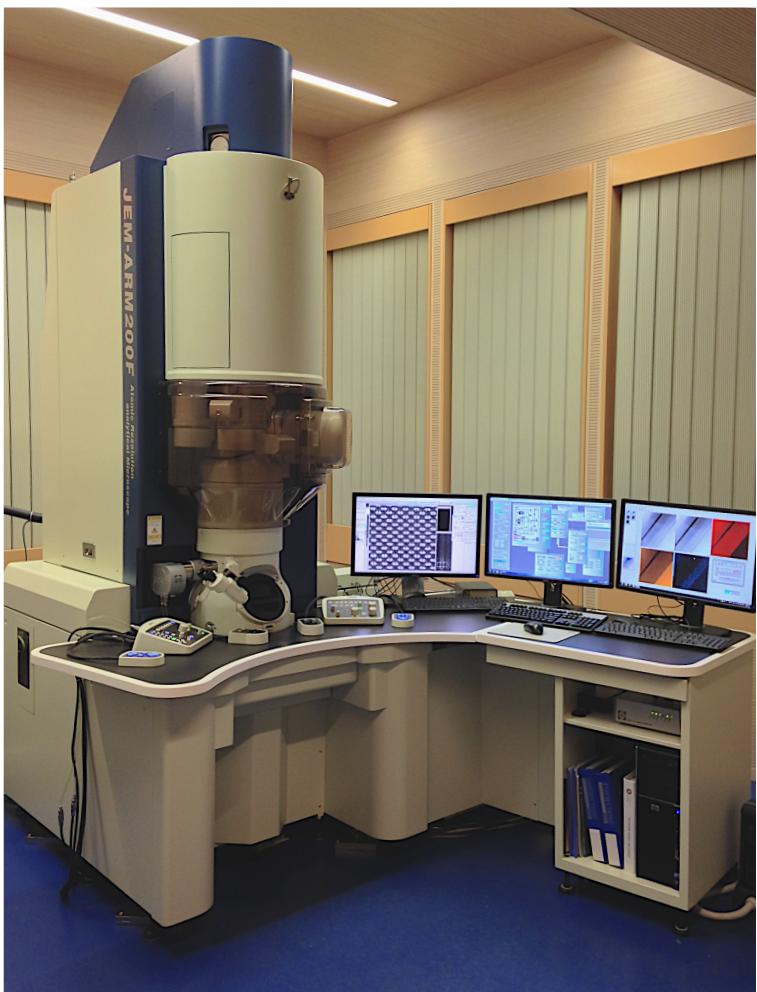


*Materials and process
integration in complex devices*

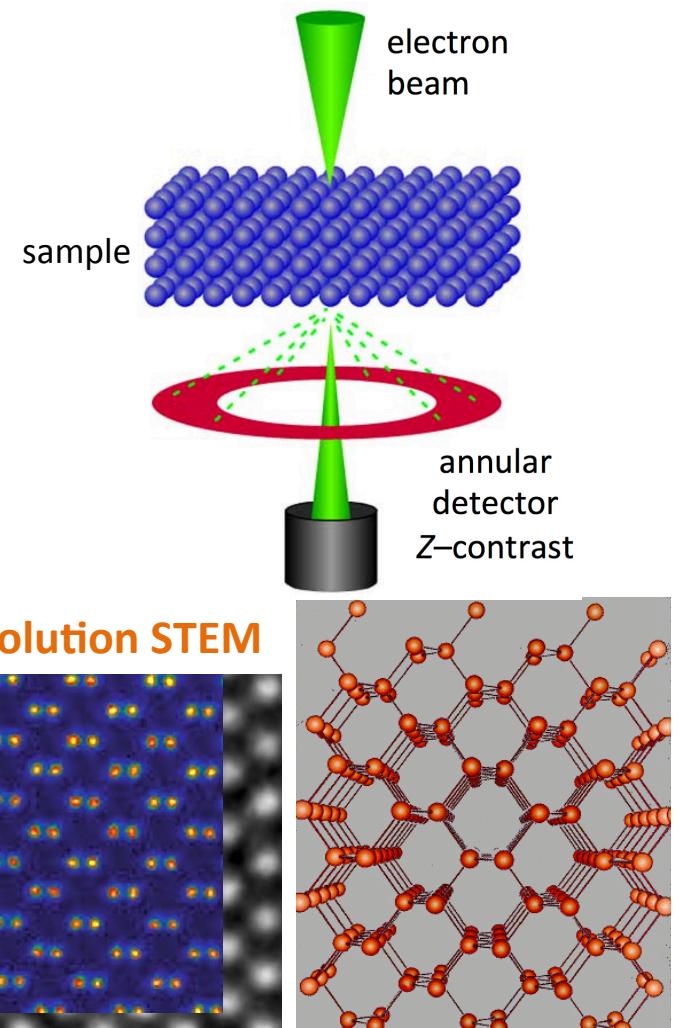


The Moore's law





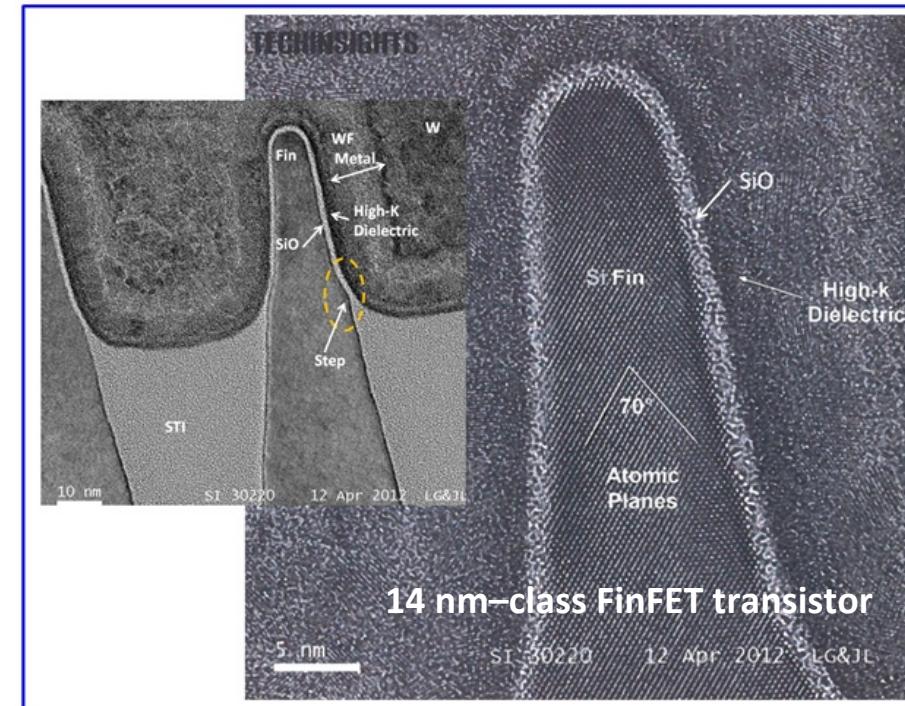
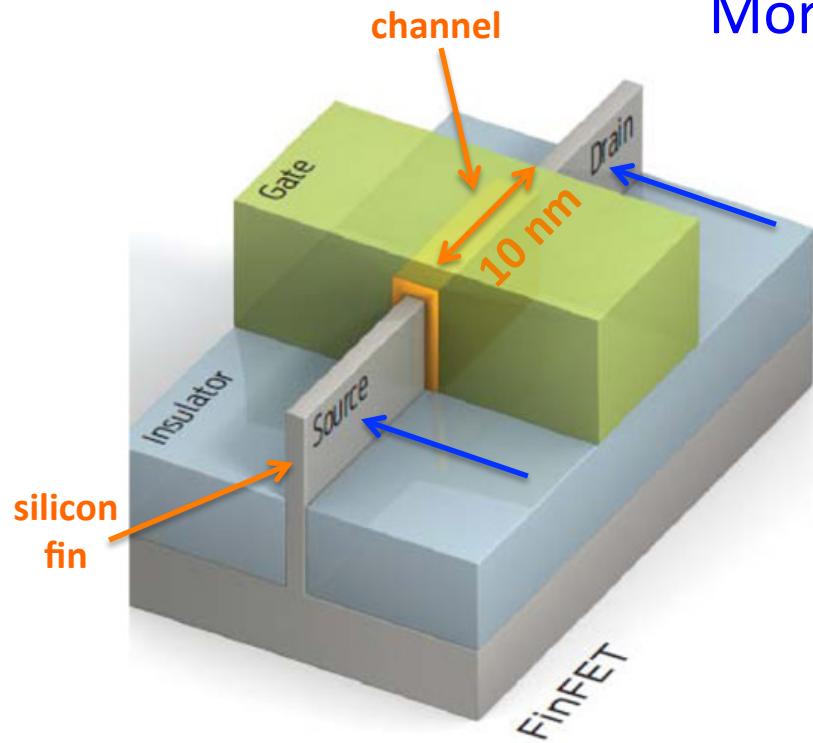
| Beam Energy (KeV) | STEM resolution (Å) |
|-------------------|---------------------|
| 200 | 0.68 |
| 100 | 0.83 |
| 60 | 1.1 |
| 40 | 1.36 |



Comparison to conventional TEM

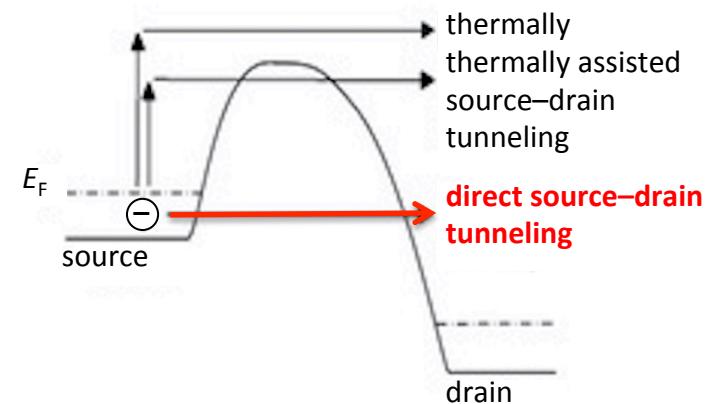


More Moore: 3-D silicon-based architecture



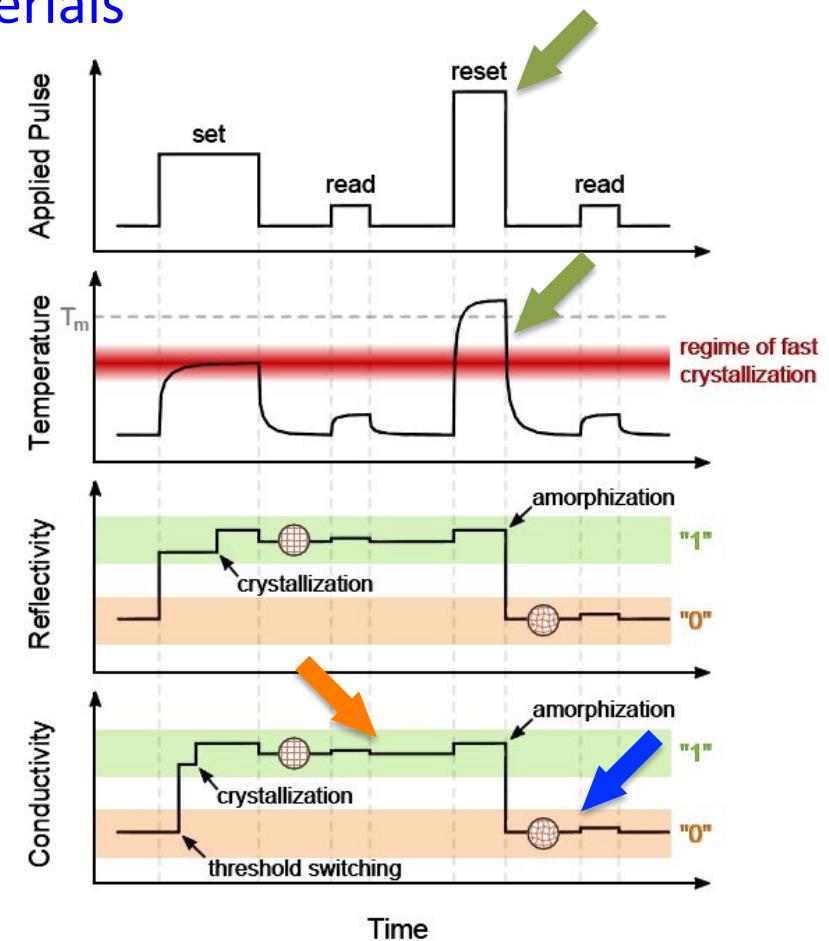
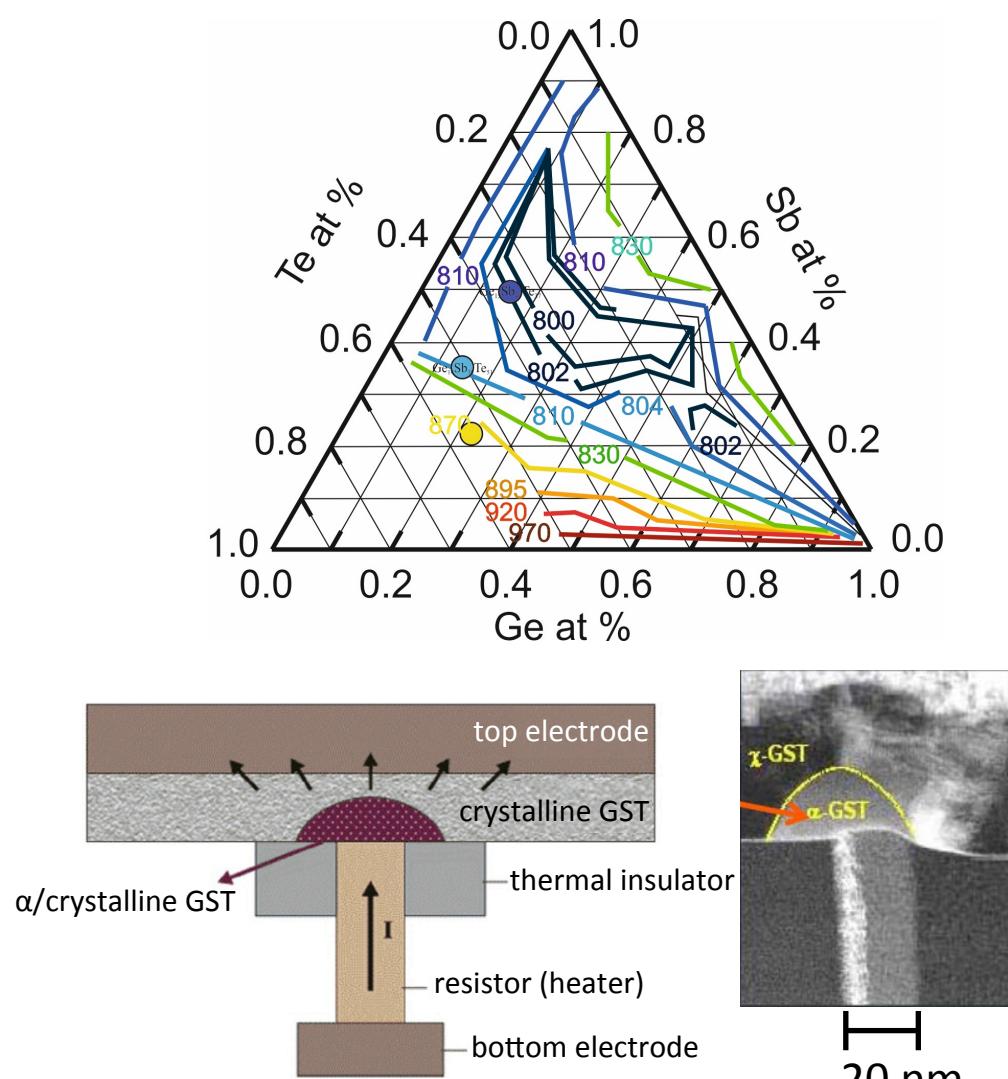
Traditional 2-D planar MOS transistors have been replaced with gates that straddle **narrow silicon fins** rising vertically from the silicon substrate.

Quantum mechanical tunneling of carriers from the source to the drain is believed to be the major determinant of the ultimate transistor scaling limits



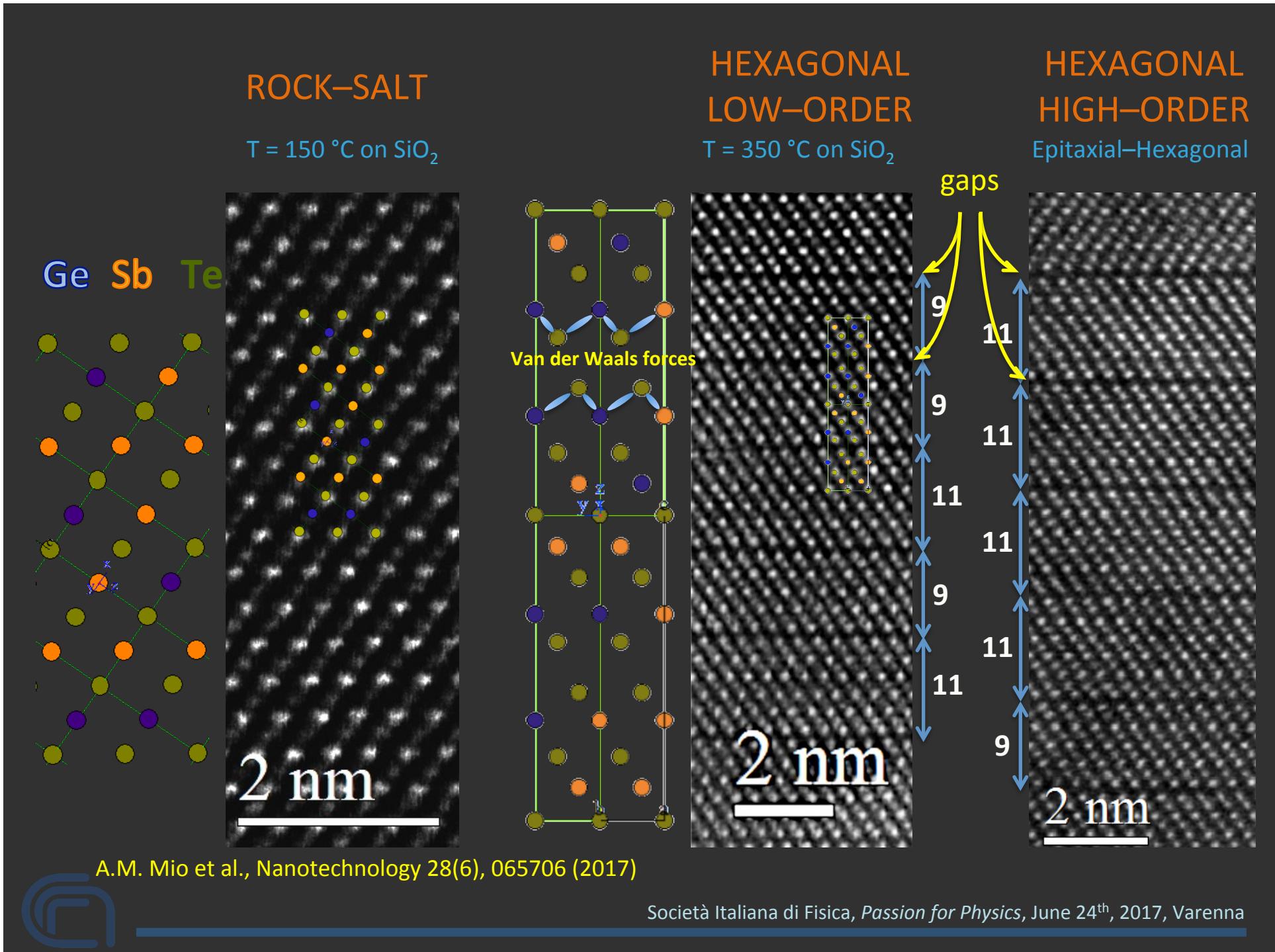
More Moore: beyond-silicon, novel materials

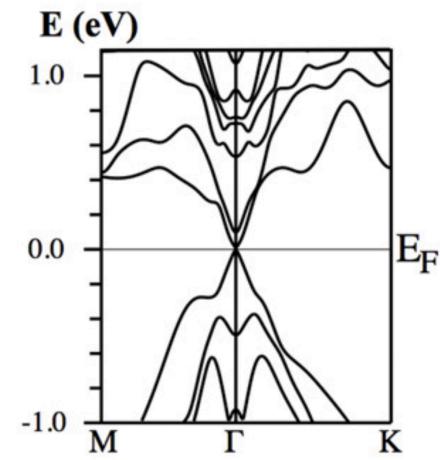
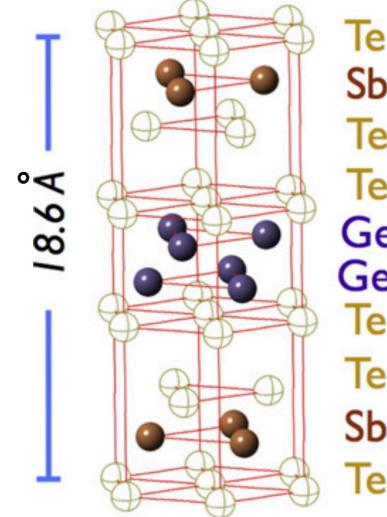
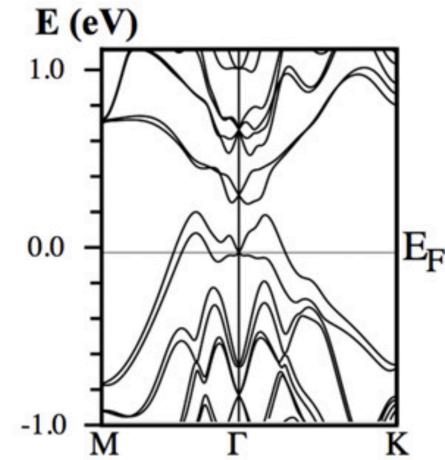
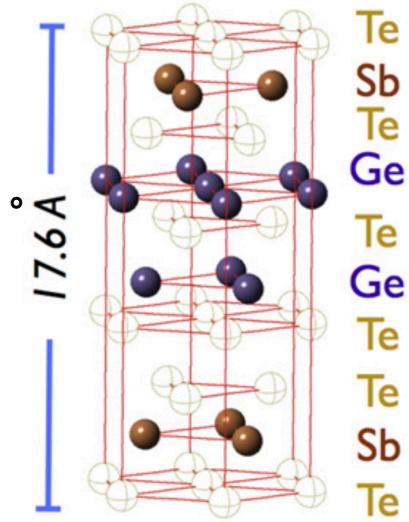
Phase Change Memories based on chalcogenides



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





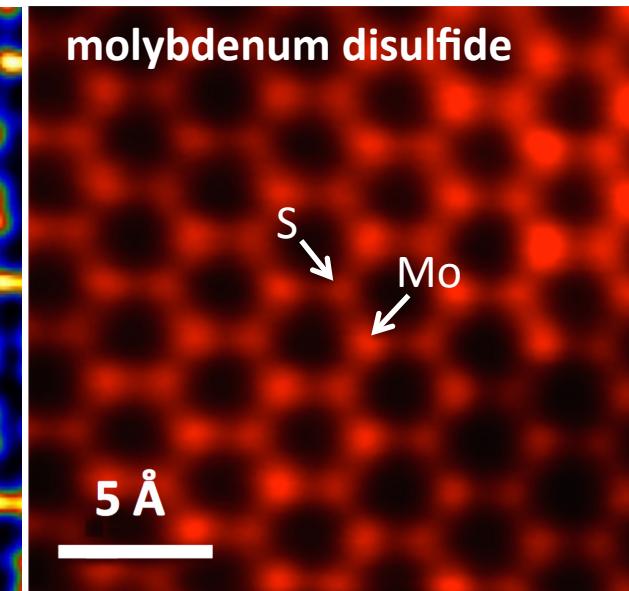
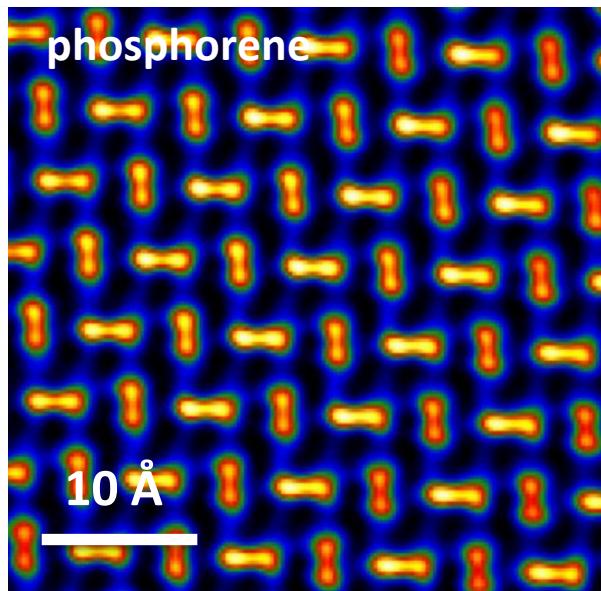
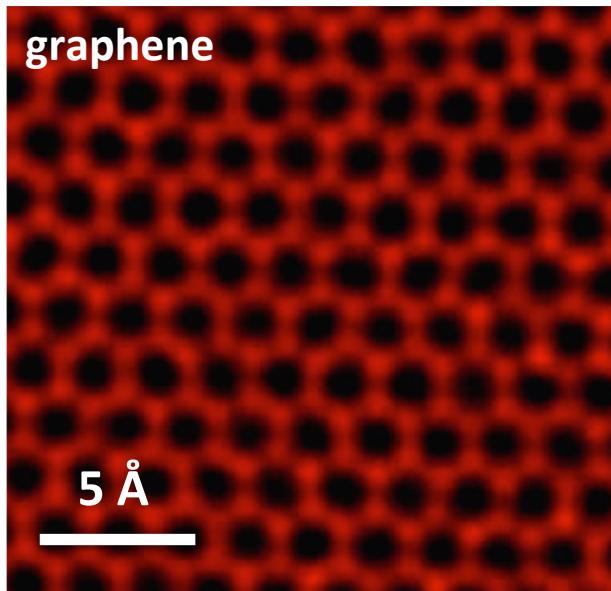


In thin films the local atomic order of chalcogenides is extremely important in determining their electrical properties.



The graphene and the 2–D companions

MoS₂ promising material for next generation post-Si CMOS technology

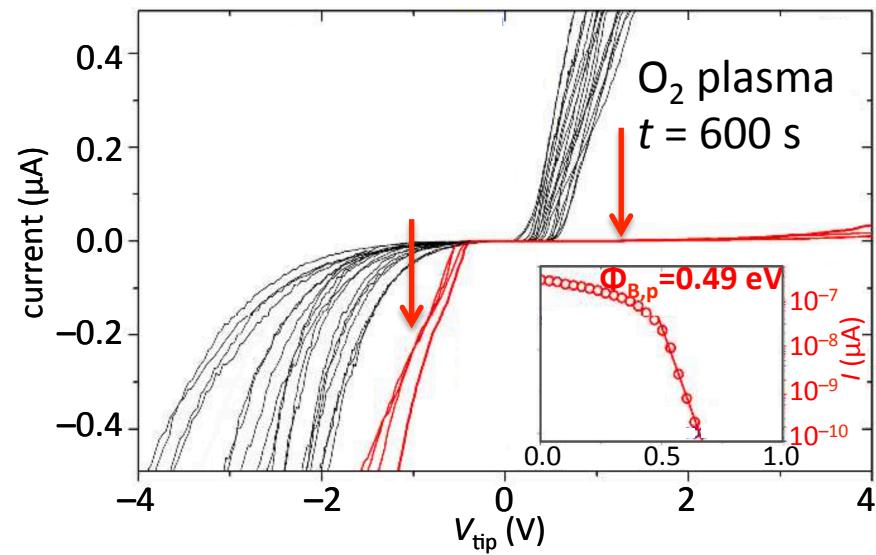
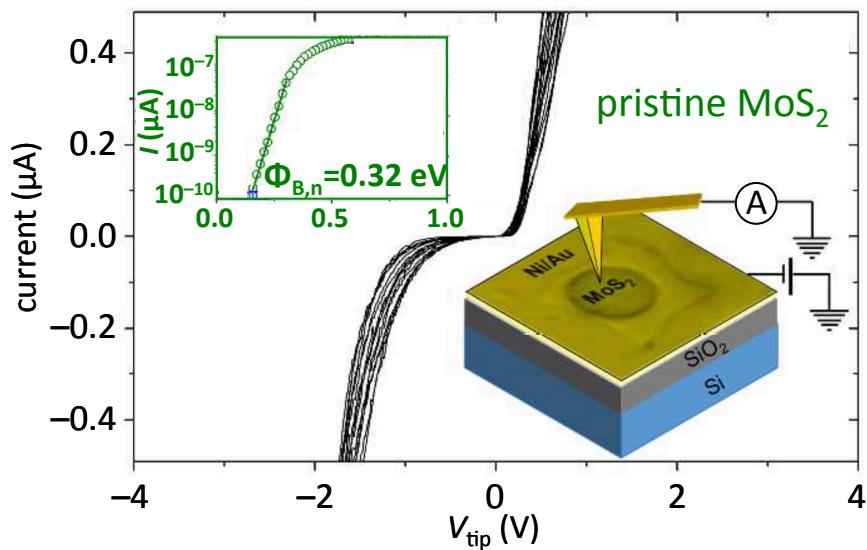


Graphene: the material with many superlatives
The highest electron mobility ($10^5 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$)
Optically transparent
High mechanical resistance (10^3 Pa)
Exceptional thermal conductivity ($5 \times 10^3 \text{ Wm}^{-1} \text{K}^{-1}$)

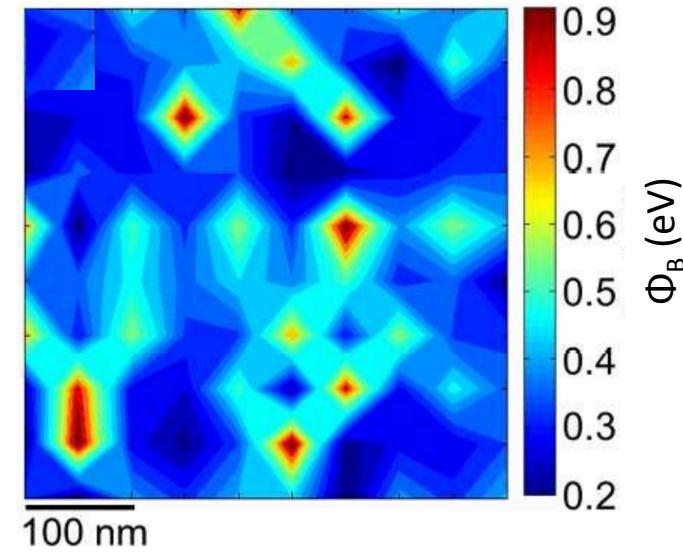
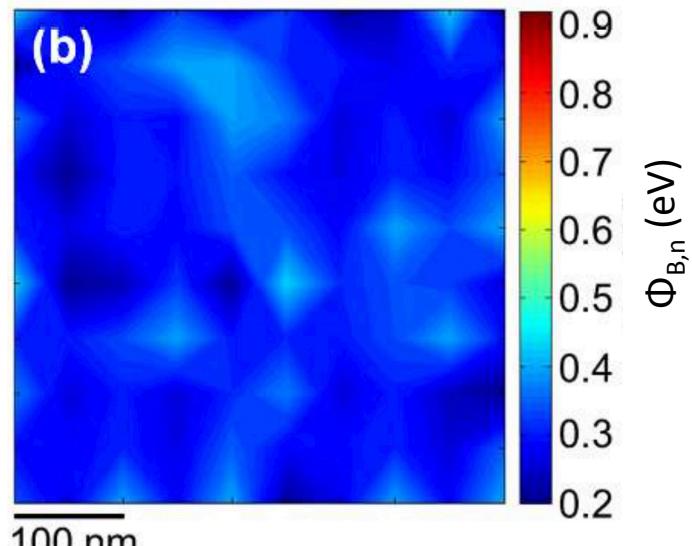
The high effective mass and large bandgap of MoS₂ minimize direct source–drain tunneling, while its atomically thin body maximizes the gate modulation efficiency in ultrashort–channel transistors.

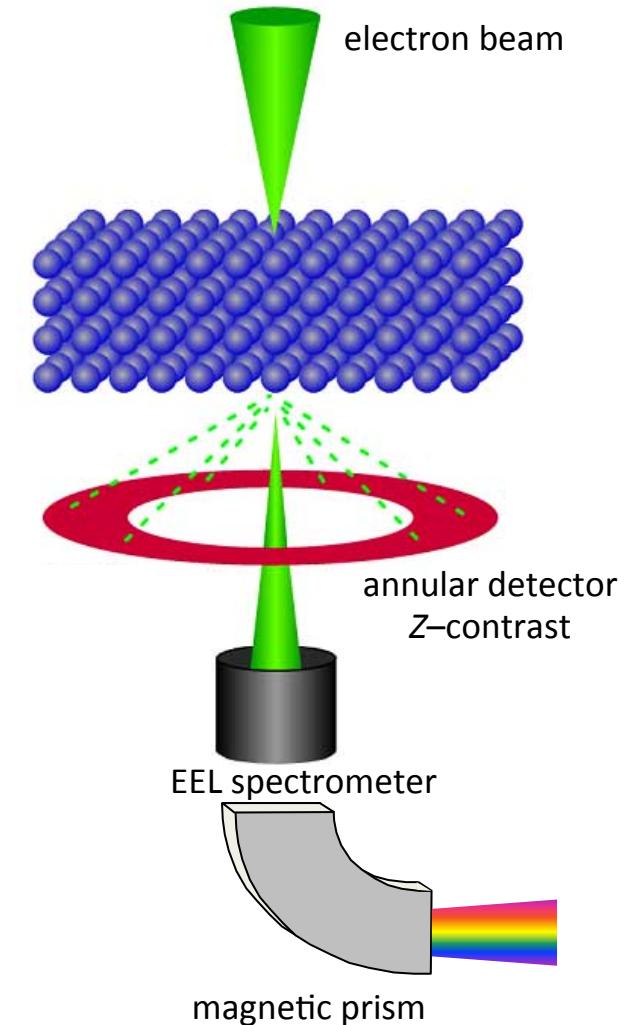
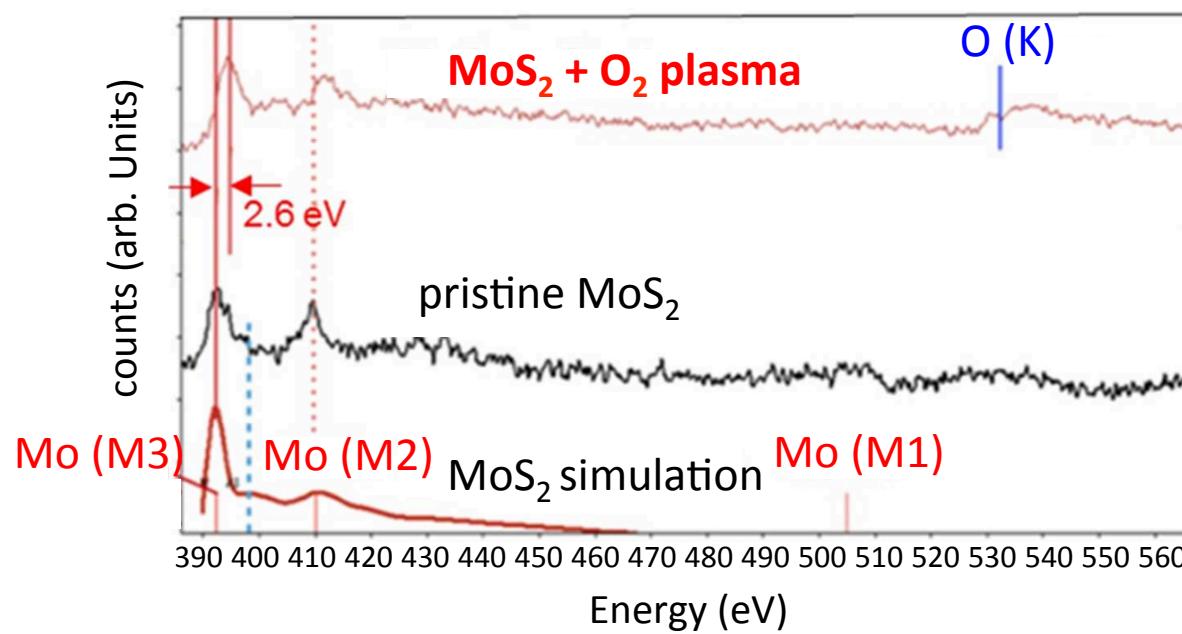
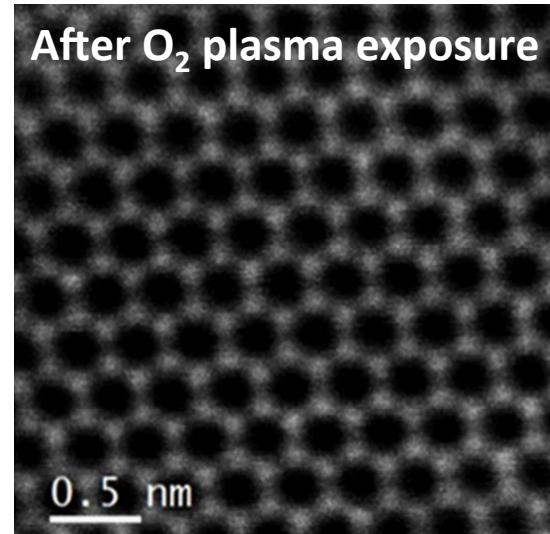
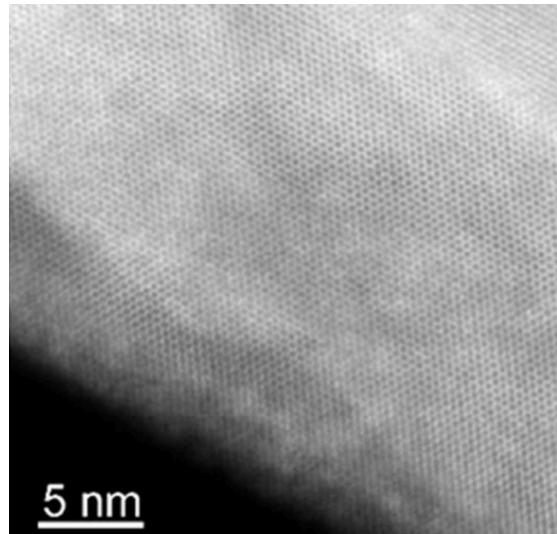


Nanoscale tailoring of Schottky metal/MoS₂ barrier by oxygen plasma functionalization

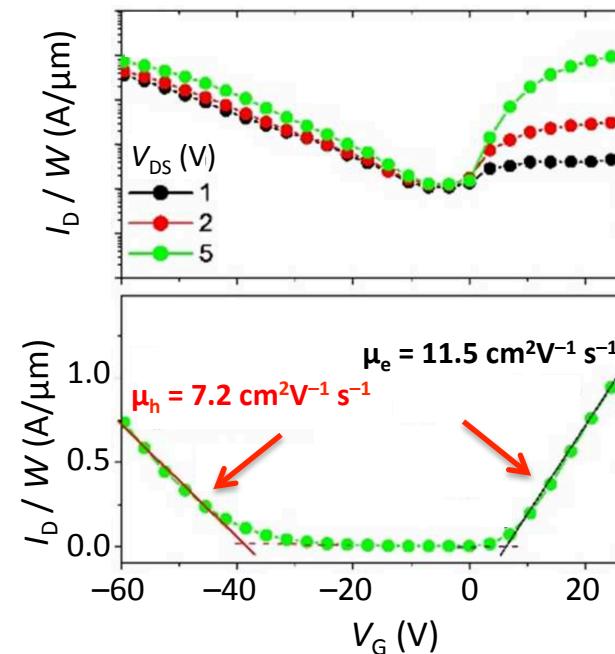
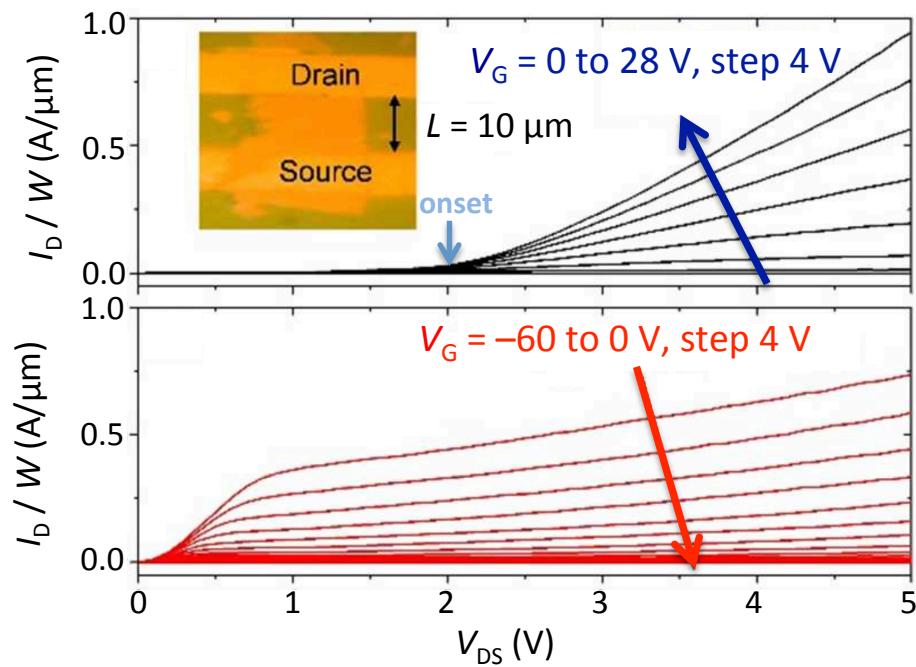
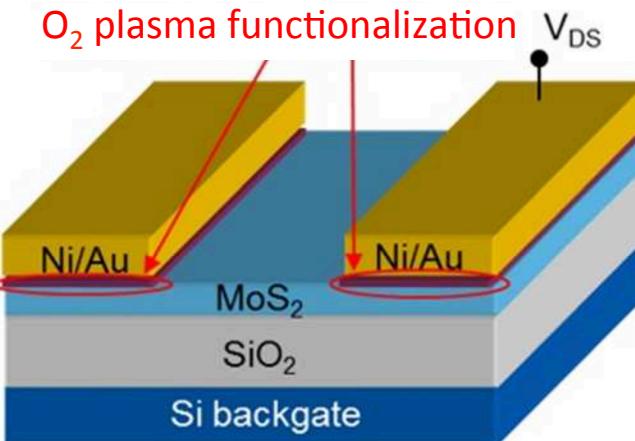


$$I \propto e^{-\Phi_{B,n}/kT} e^{q/mkT}$$

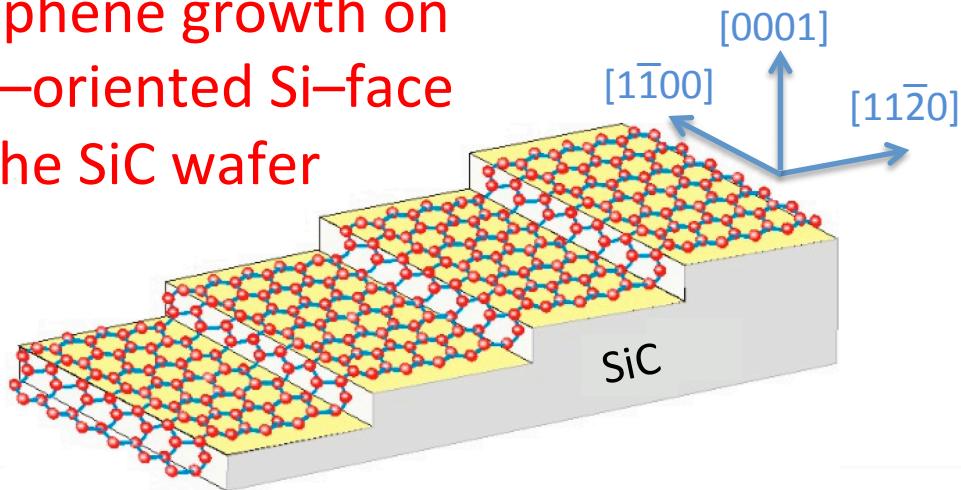




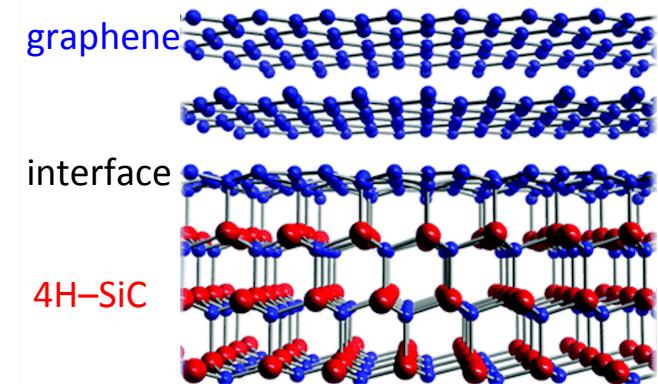
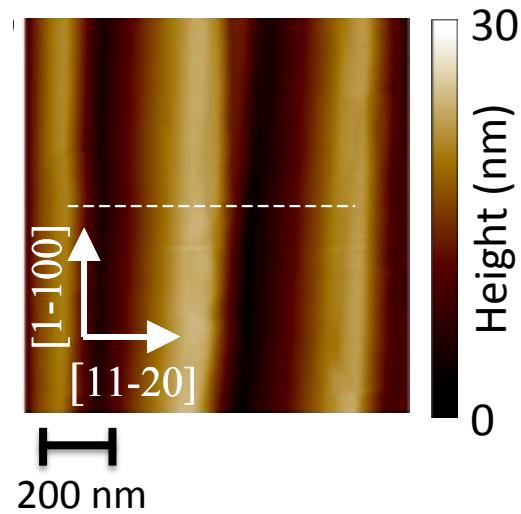
Ambipolar MoS₂ transistor



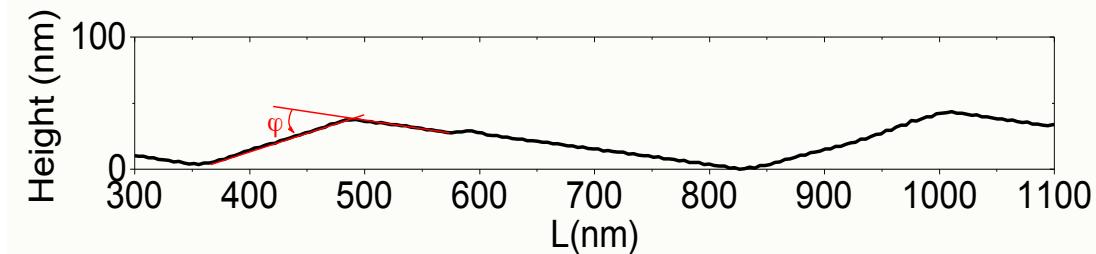
Graphene growth on mis-oriented Si-face of the SiC wafer



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



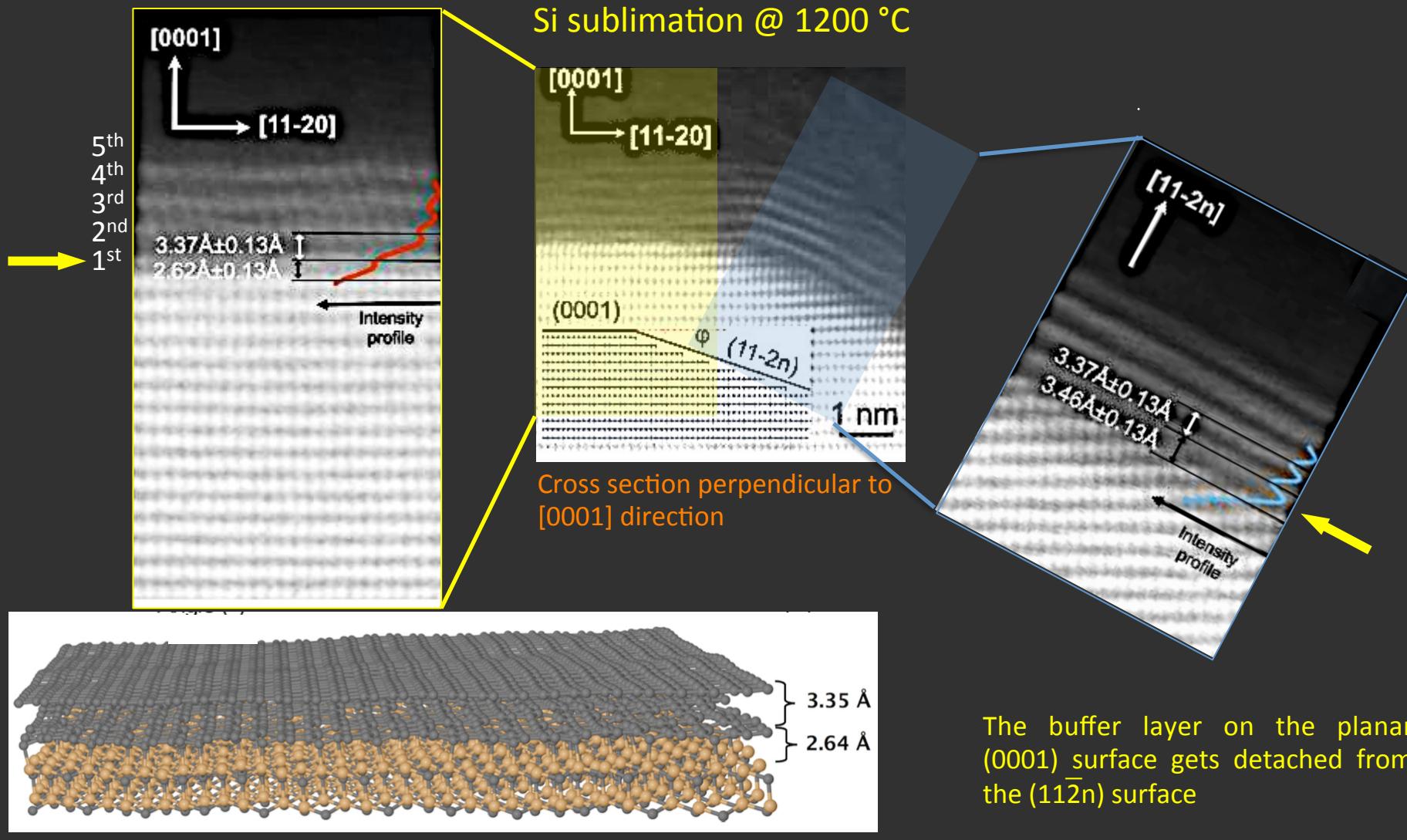
Epitaxial graphene: solution for integration of high power and high frequency functions on a SiC substrate



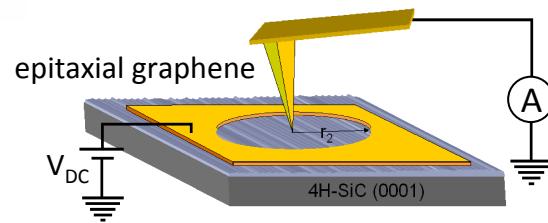
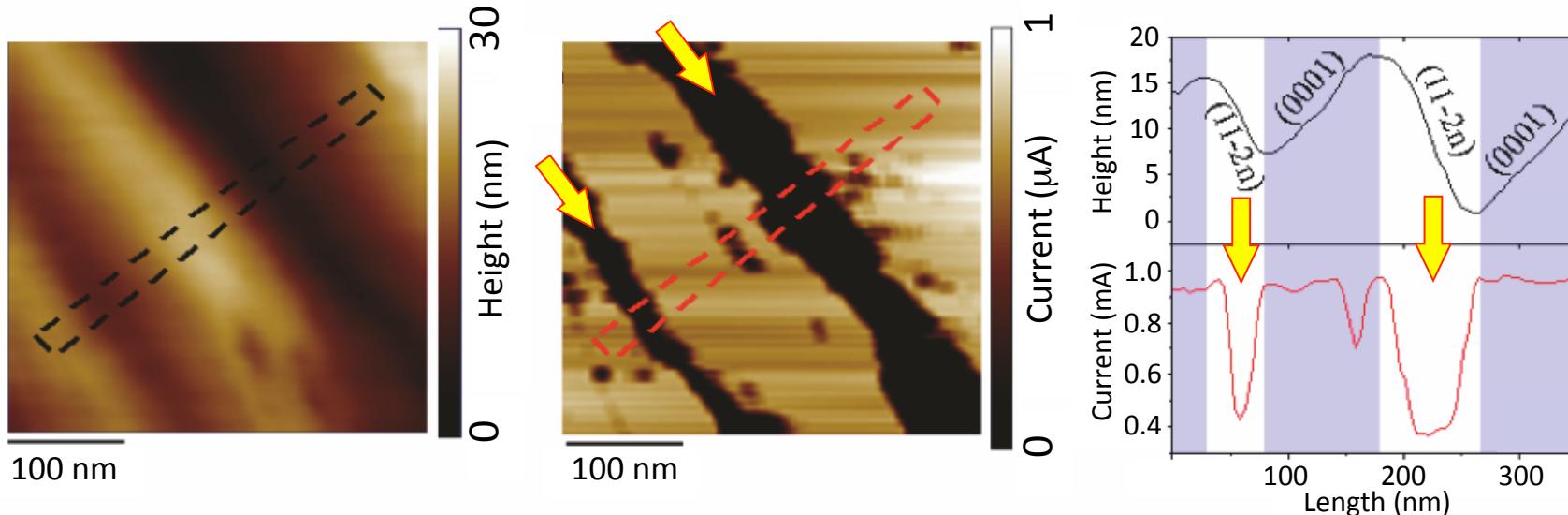
G. Nicotra et al., Phys. Rev. B 91(15), 155411 (2015)

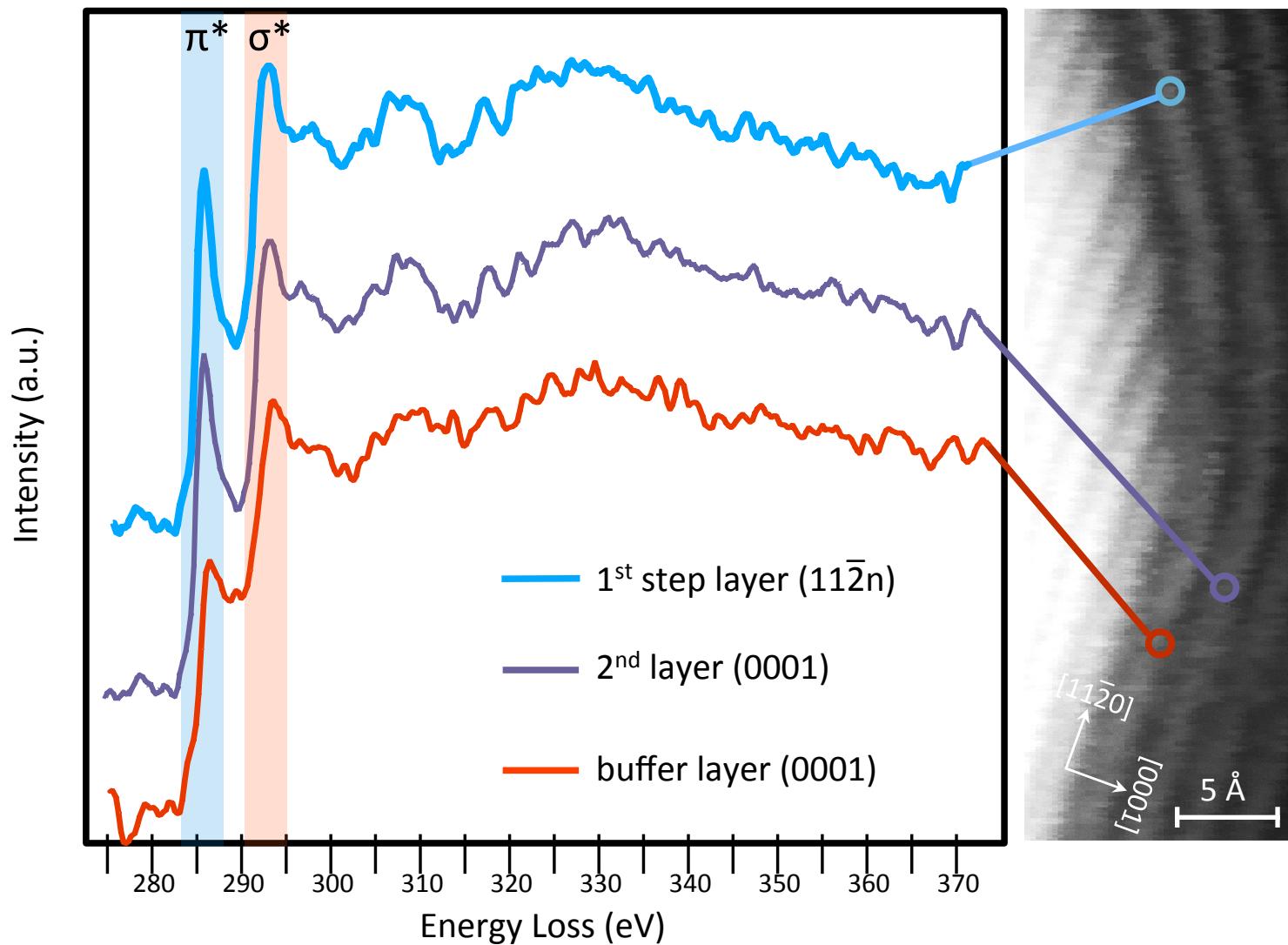


Atomic resolution HAADF-STEM @ 60 keV primary electron beam



Conductive Atomic Force Microscopy





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



Conclusions

Fulfilling Feynman's Dream



*... I would like to try and impress upon you while I am talking about all of these things on a small scale, **the importance of improving the electron microscope by a hundred times**. It is not impossible; it is not against the laws of diffraction of the electron ... **What good would it be to see individual atoms distinctly?***

December 29th 1959 at the annual meeting of the American Physical Society at California Institute of Technology

