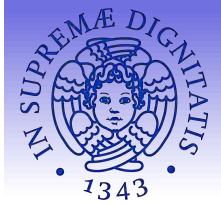


Graphene and two-dimensional materials

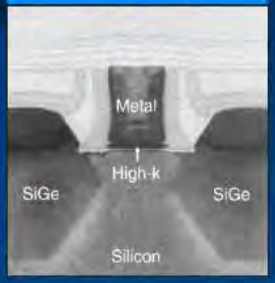
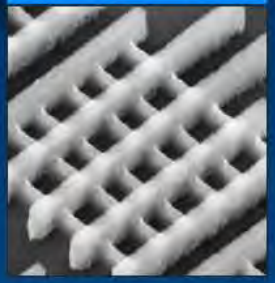
Gianluca Fiori, Giuseppe Iannaccone,

Dipartimento di Ingegneria dell'Informazione

Università di Pisa

The scaling context

Transistor Innovations Enable Technology Cadence

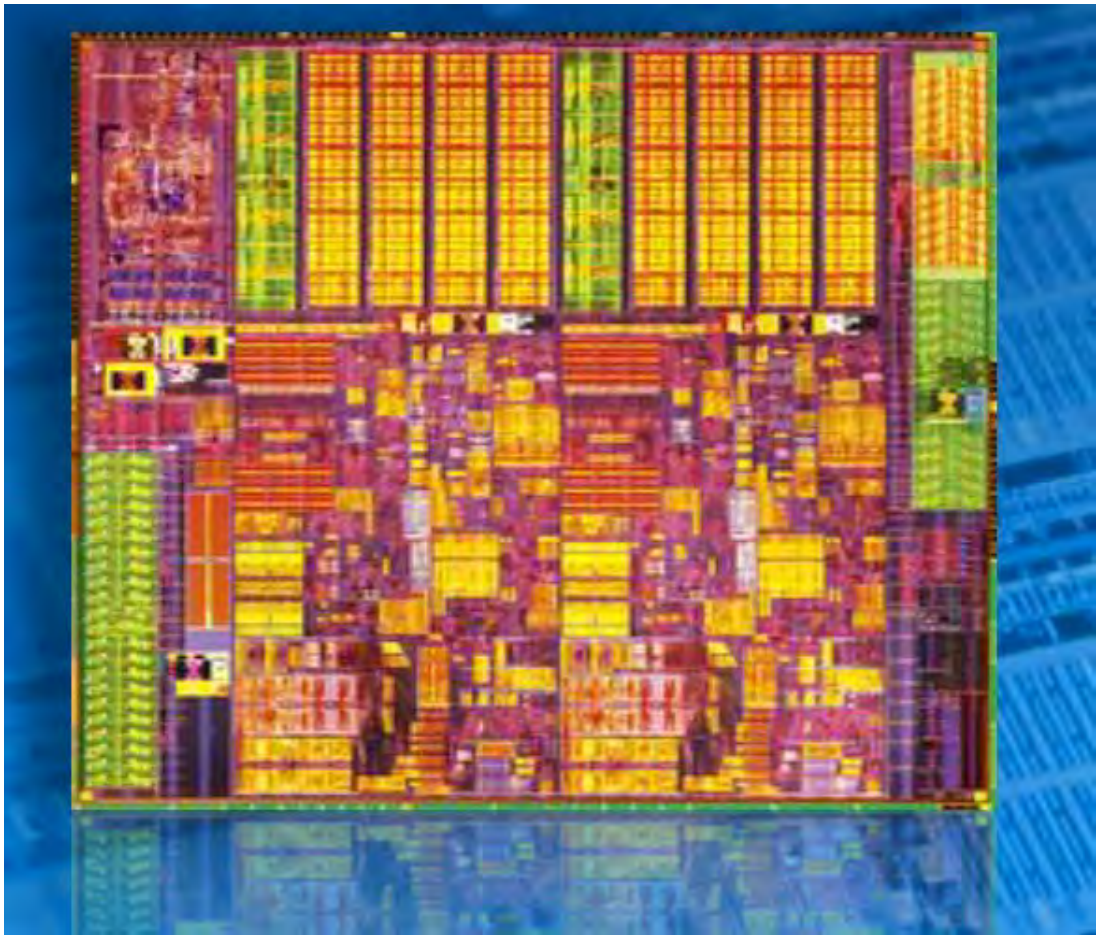
2003	2005	2007	2009	2011
90 nm	65 nm	45 nm	32 nm	22 nm
				
Invented SiGe Strained Silicon	2nd Gen. SiGe Strained Silicon	Invented Gate-Last High-k Metal Gate	2nd Gen. Gate-Last High-k Metal Gate	First to Implement Tri-Gate

Strained Silicon

High k Metal gate

Tri-Gate

And now?



2013

22 nm process

1B transistor

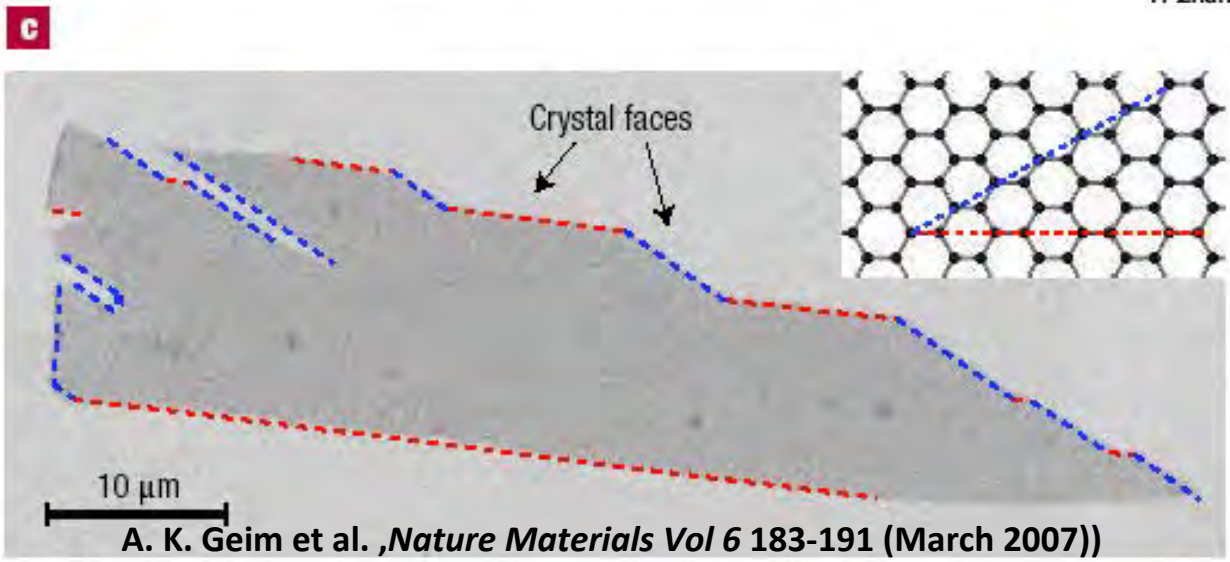
Graphene

2D Allotrope: N.S. Novoselov 2004 [K.S. Novoselo et al., Science, 306, 5696,2004].

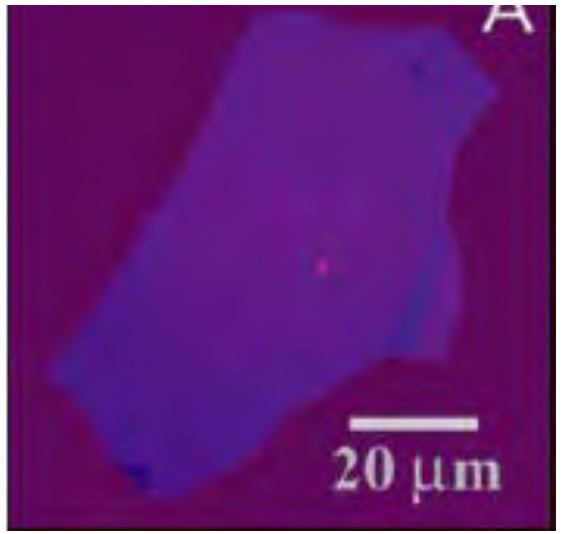
22 OCTOBER 2004 VOL 306 SCIENCE www.sciencemag.org

Electric Field Effect in Atomically Thin Carbon Films

K. S. Novoselov,[1] A. K. Geim,[1*] S. V. Morozov,[2] D. Jiang,[1] Y. Zhang,[1] S. V. Dubonos,[2] I. V. Grigorieva,[1] A. A. Firsov[2]



A. K. Geim et al. ,*Nature Materials Vol 6* 183-191 (March 2007))



- K. Novoselov et al.,Science 306, 666, 2004.
- K. Novoselov et al., Nature 438, 197, 2005.
- K. Novoselov et al., Nature Physics 2, 177, 2006.

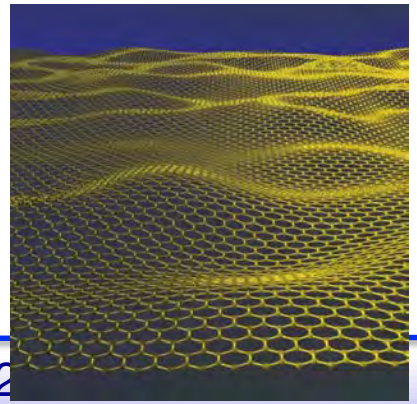
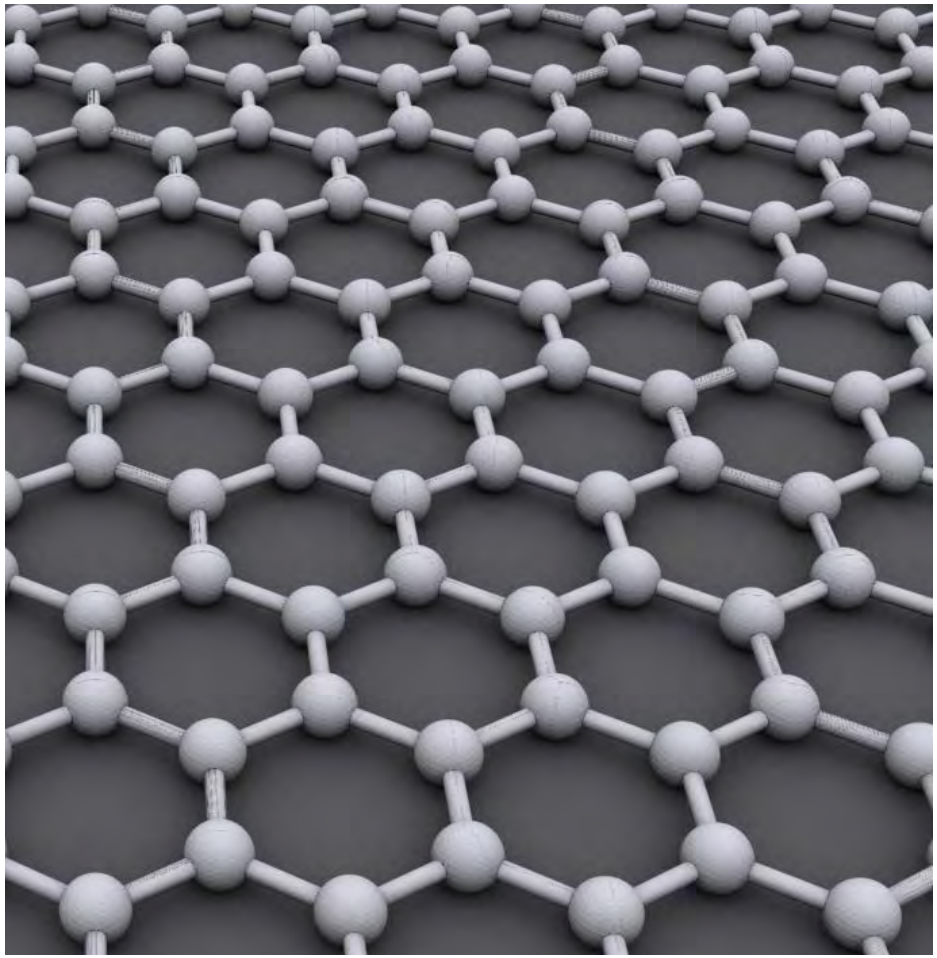


Image: Jannik Meyer
http://faraday.fc.up.pt/.../admin/copy_of_teste/image

Graphene as a material for electronics



- High mobility at room temperature (>10^4 cm^2/Vs)
- Symmetric properties for electrons and holes
- One-atom thin -> promising for scaling
- Cheap and CMOS compatible

….but ….

… the zero energy gap is a showstopper for use in (digital) electronics ….

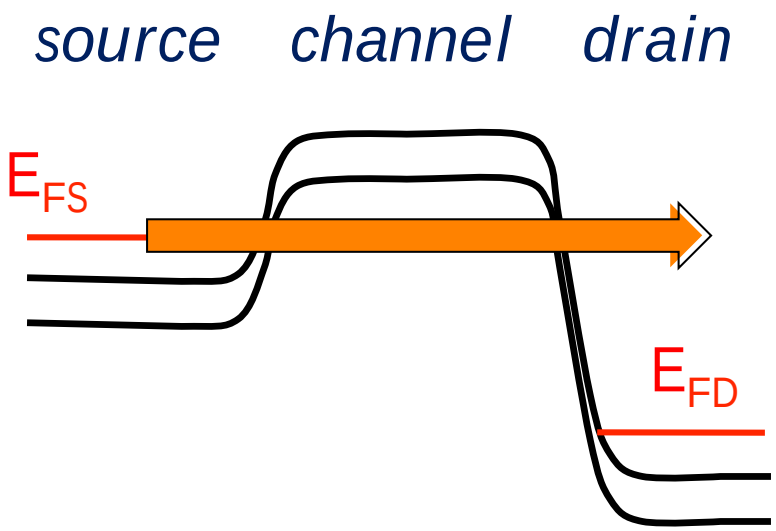
Rules of the game

Increase gap, fabricate device, but

keep mobility high, keep reproducibility high

Energy gap and the Off state

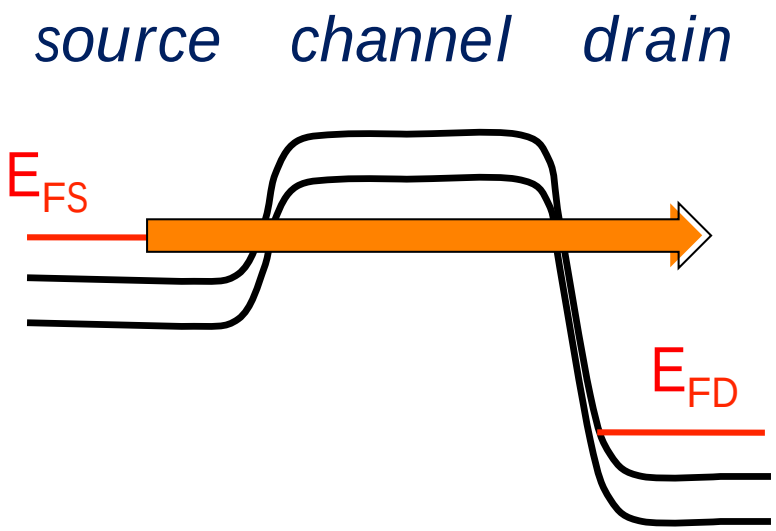
Poor off state



Small energy gap enables interband leakage => high I_{off}

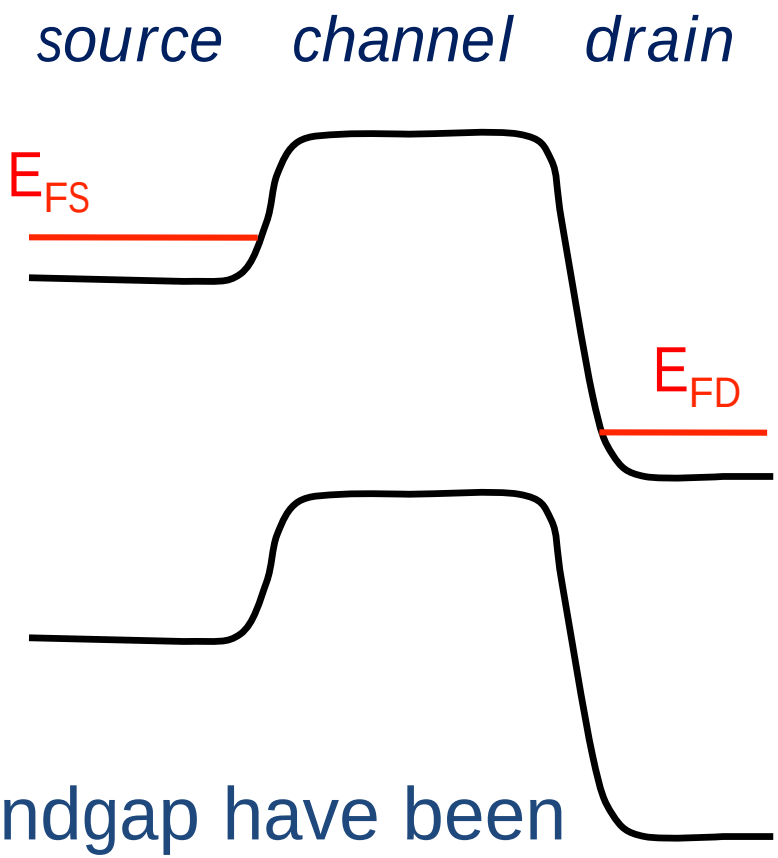
Energy gap and the Off state

Poor off state



Small energy gap enables interband leakage => high I_{off}

Good off state



Several options to induce a bandgap have been pursued → manufacturability challenges

Device modeling tool: NanoTCAD VIDES

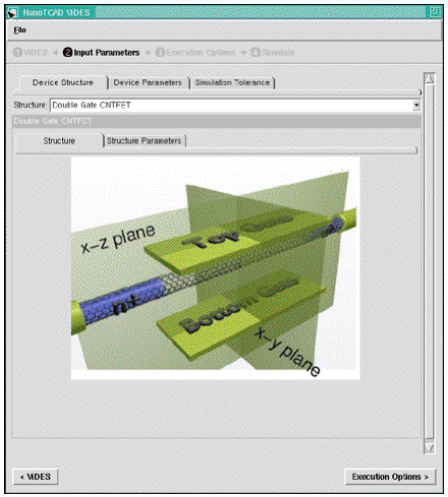
3D Non-Equilibrium Green's Functions (NEGF) solver

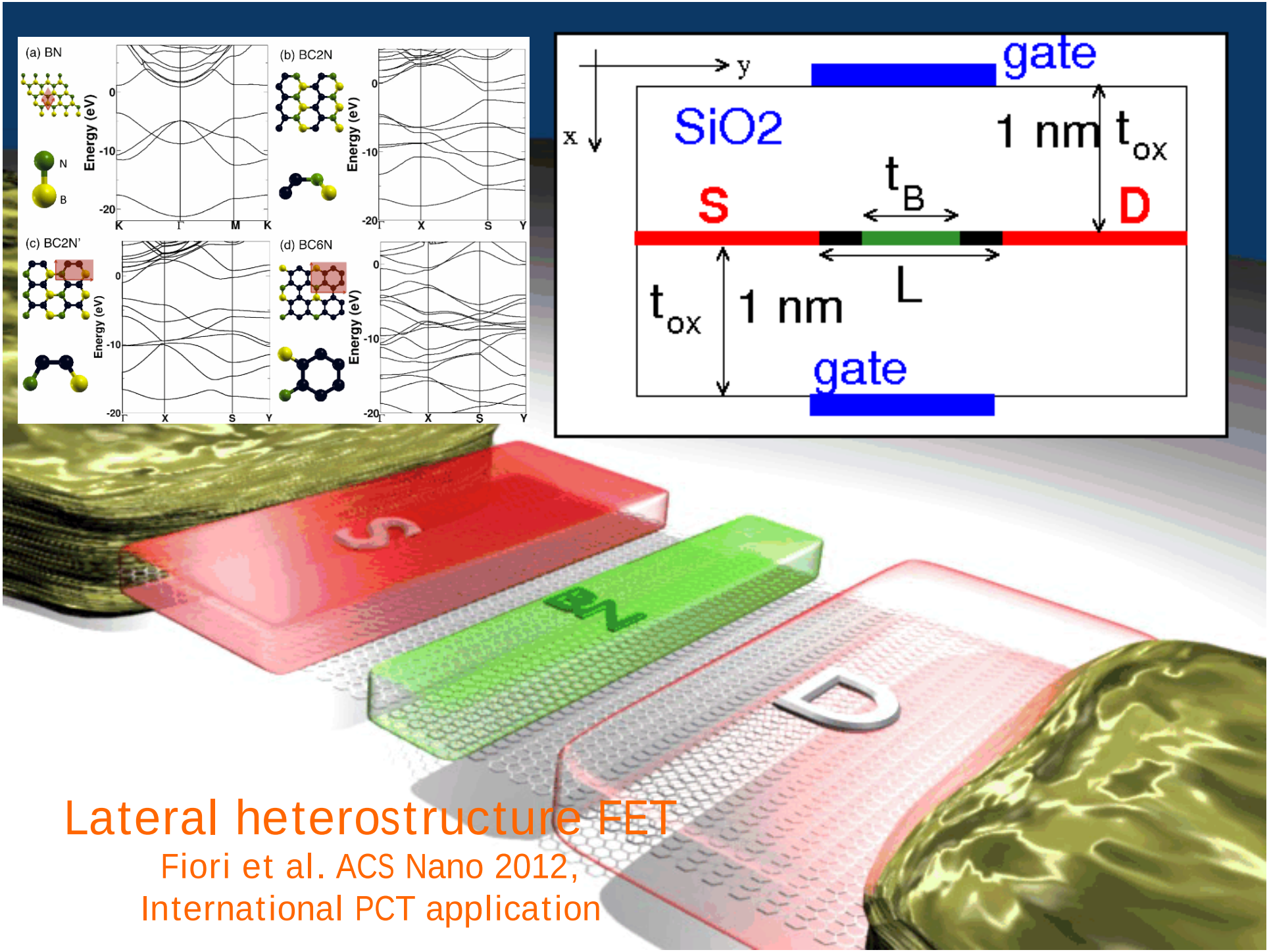
Fully coherent transport

Generic 3D structures

- CNT and GNR FETs (TB atomistic)
- Bilayer graphene FETs (TB atomistic)
- Semiconductor NW Transistors (EMA + TB atomistic)
- hBCN

New version of the code as a python module – all documentation and code at: http://vides.nanotcad.com and on the nanohub.org → More than 300 downloads



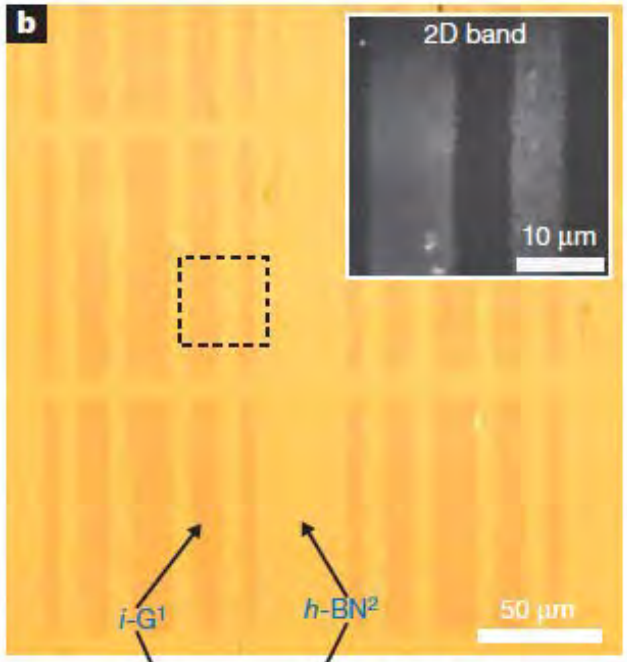


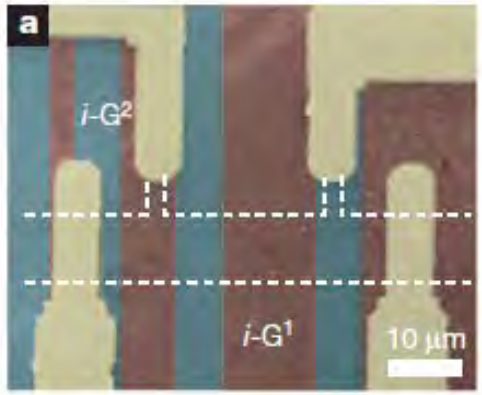
Lateral heterostructure FET

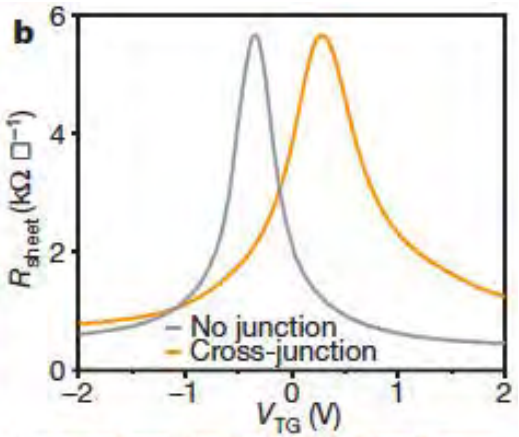
Fiori et al. ACS Nano 2012,
International PCT application

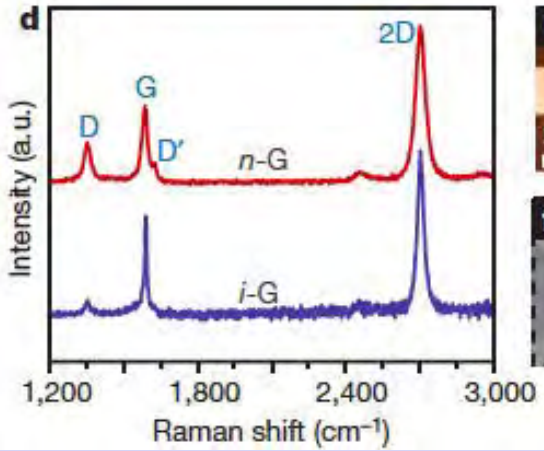
ures

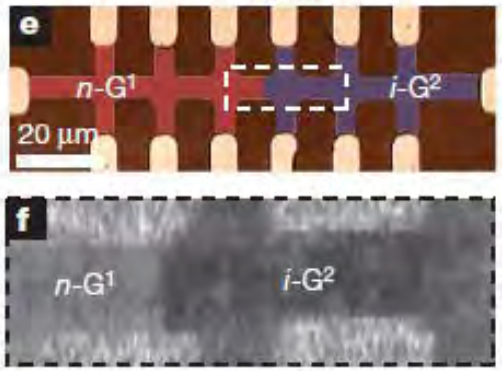
M.P. Levendorf
Nature 2012
(Cornell)



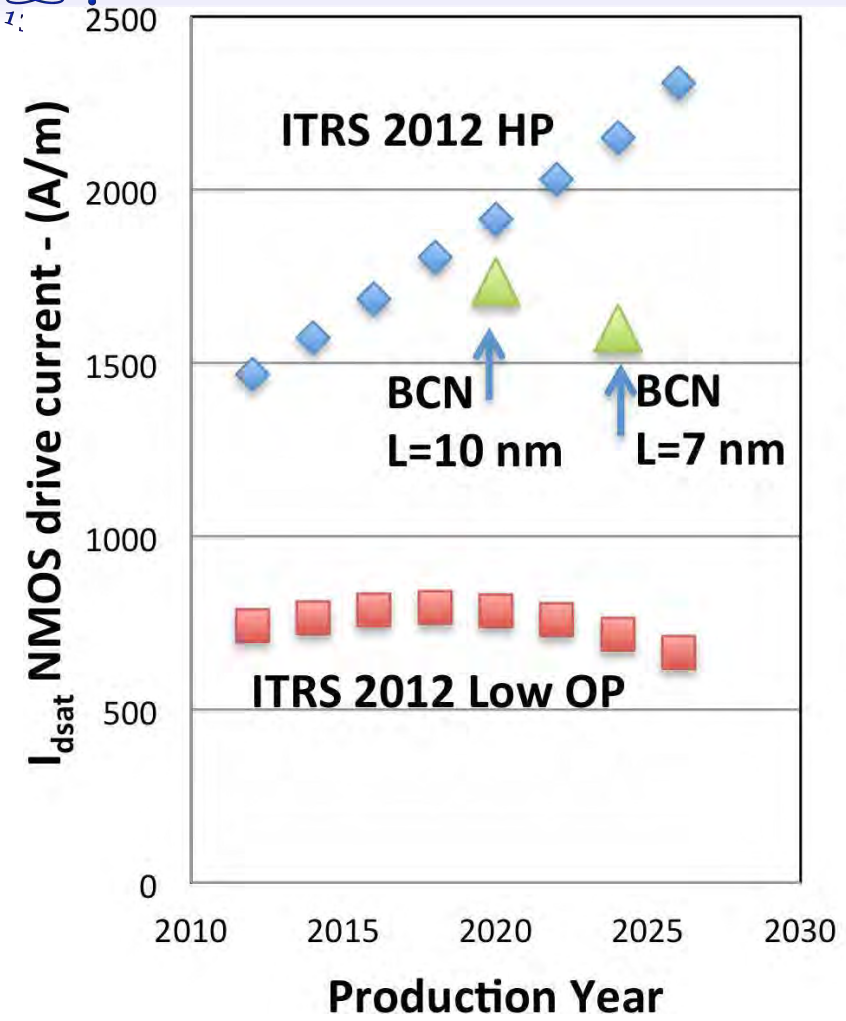


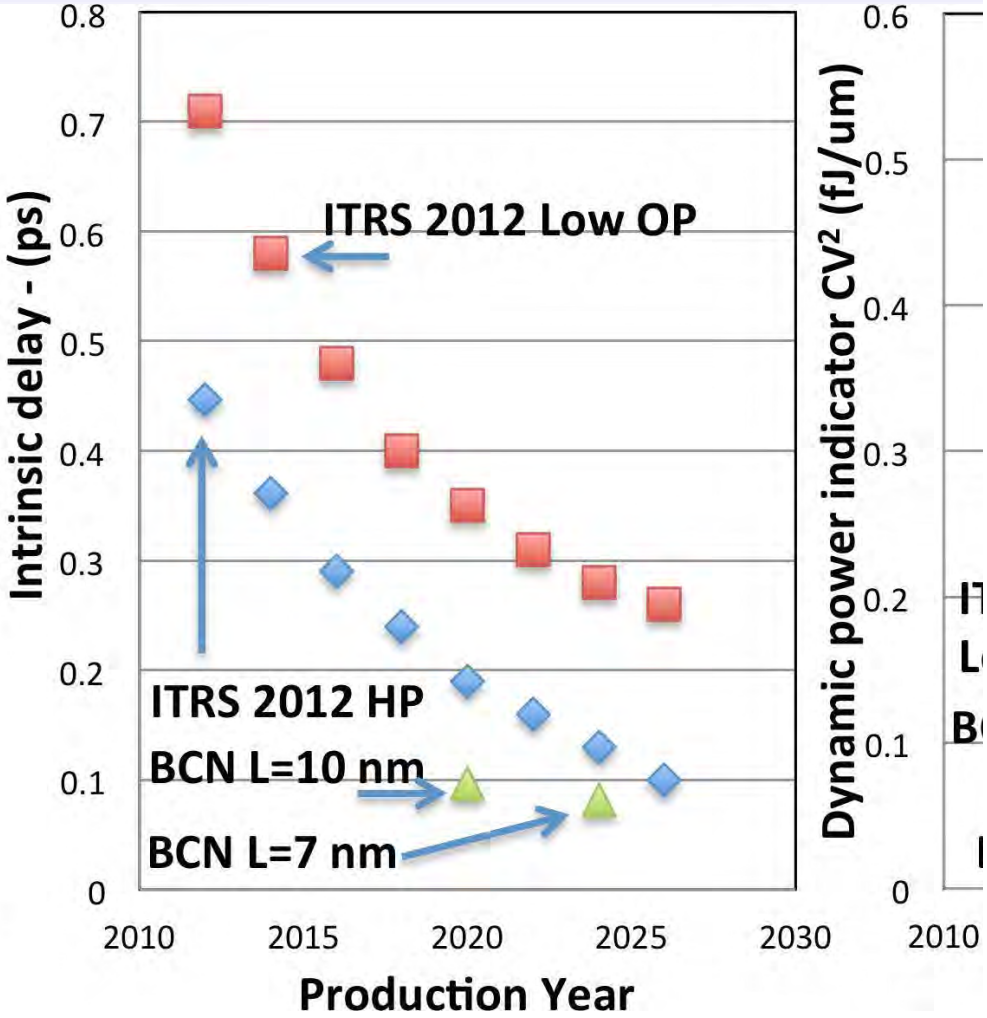






Graphene LHFET - Comparison with ITRS 2012





I_{off} fixed at 100 nA/μm (as for HP) [Low OP has I_{off} 5 nA/μm]

Thank you

Acknowledgments

GRAND FP7

NANOSIL FP7

DEWINT European Science Foundation

GONEXTS FP7

GRADE FP7