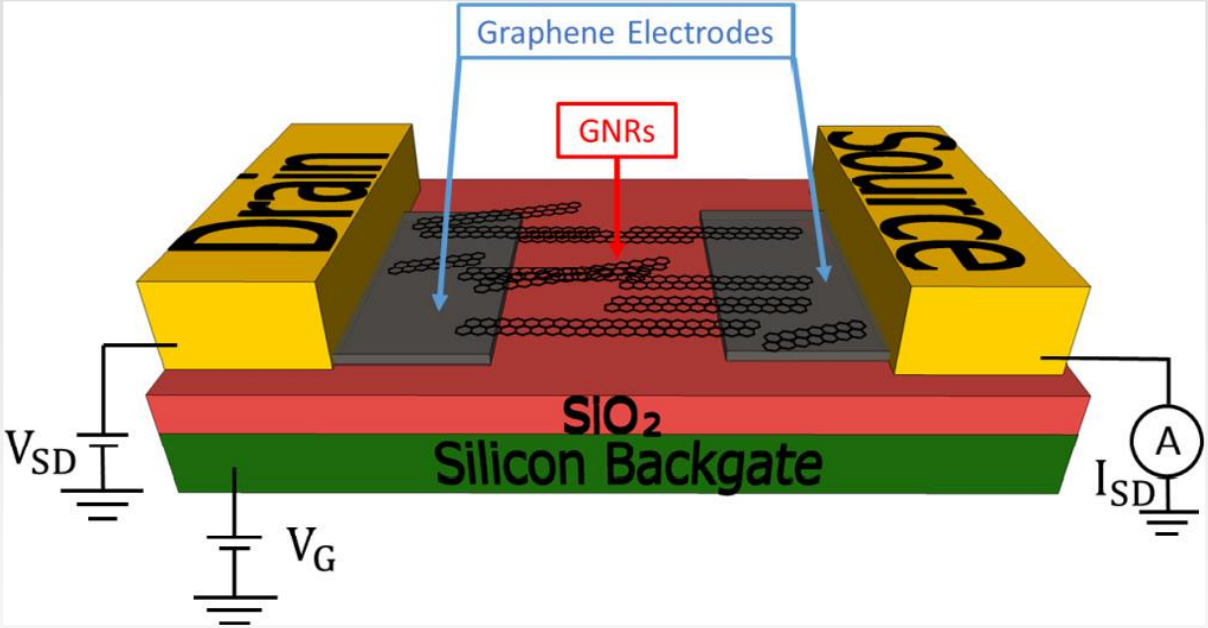
Graphene-based electrodes for graphene nanoribbons devices



Andrea Candini

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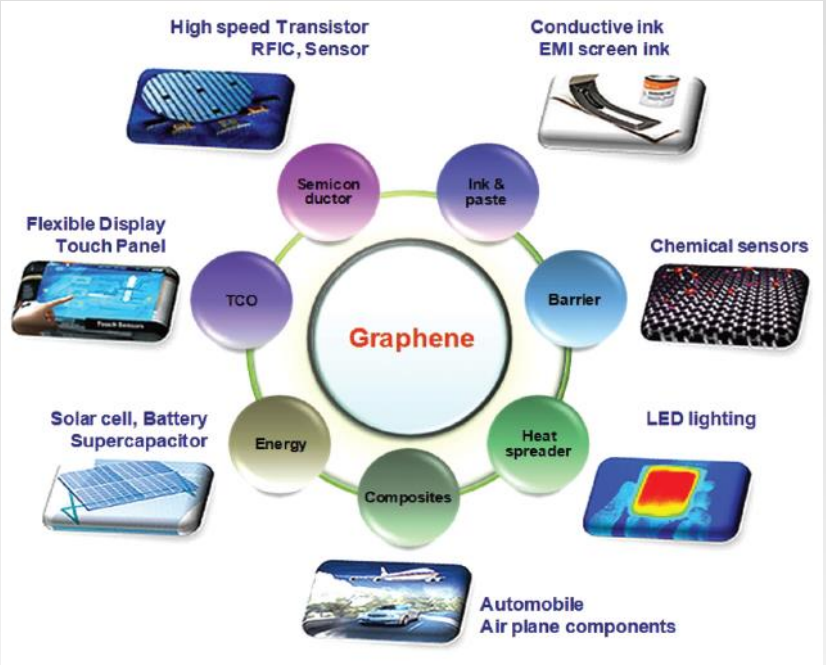
Via Gobetti 101, 40129 Bologna

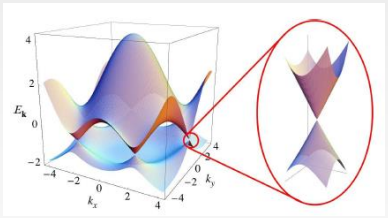
ISTITUTO PER LA SINTESI ORGANICA E LA FOTOREATTIVITA'

andrea.candini@isof.cnr.it

Motivations

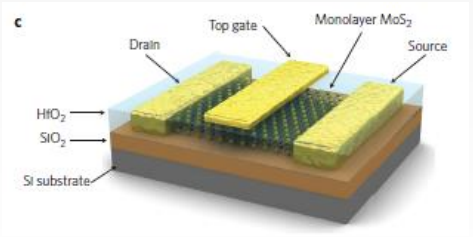
Nanoscale 2015, **7,** 4598





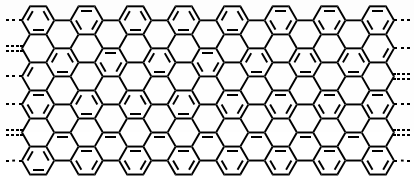
***… however…* NO Bandgap**

Other materials (2D TMD)



Nature Nanotech. **6,** 147-150 (2011)

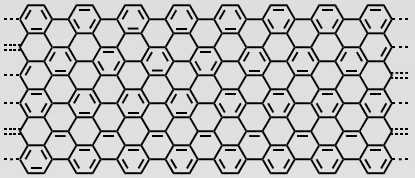
Open a bandgap by structural confinement



see *Rev. Mod. Phys.* ***81,*** *109-162 (2009)*

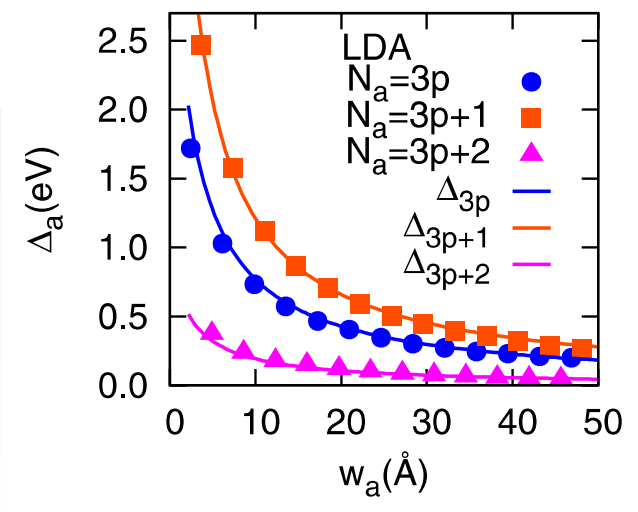
Graphene Nanoribbons (GNRs)

High mobility of graphene + Bandgap
FET and opto-electronic devices



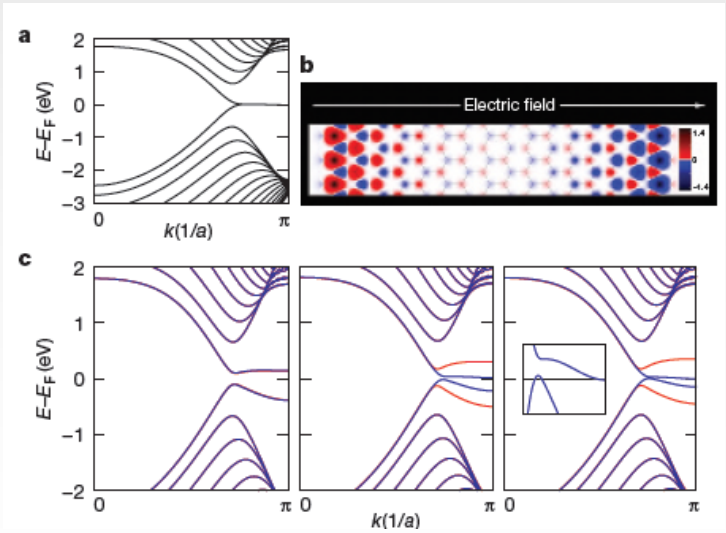
Opto-electrical properties determined by structure

Width-dependend bandgap



Phys. Rev. Lett. **97,** 216803 (2006)

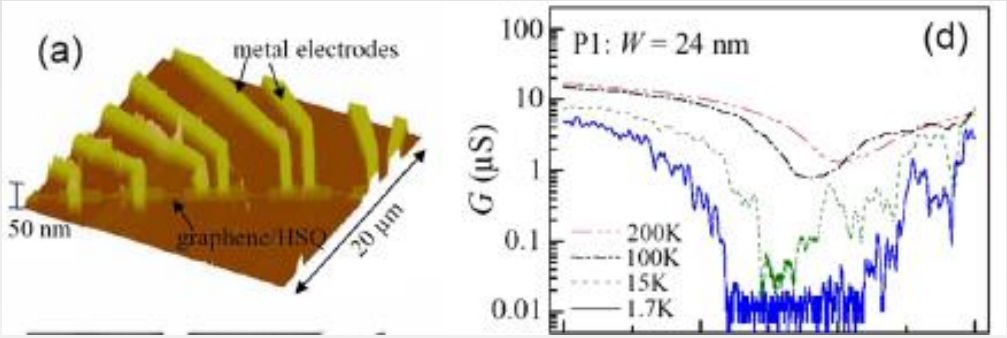
Half-metallic edge states in zGNRs



Nature **444,** 347-349 (2006)

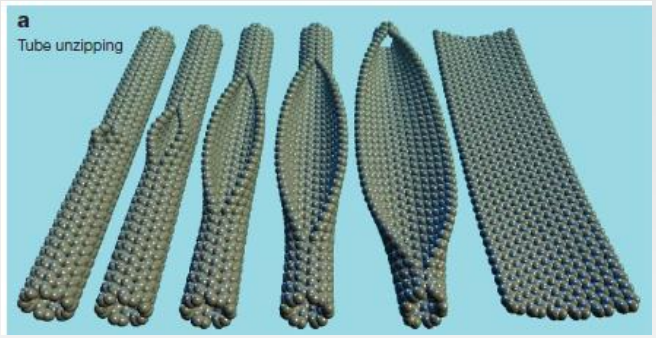
GNRs production: Top-Down approaches

Lithography patterning



Phys. Rev. Lett. **98,** 206805 (2007)

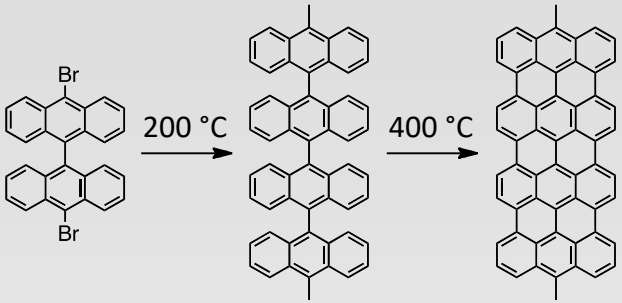
Carbon nanotube unzipping



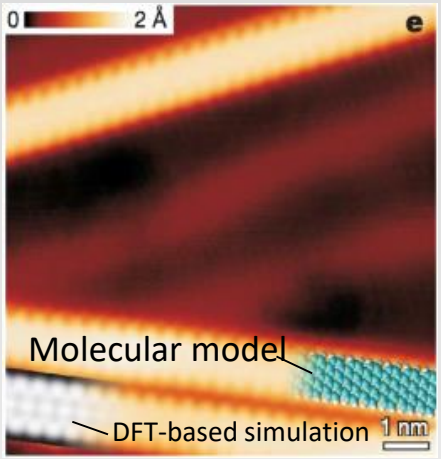
Nature **458,** 872 (2009); 877 (2009)

NO control on width and edge structure

GNRs production: Surface assisted synthesis

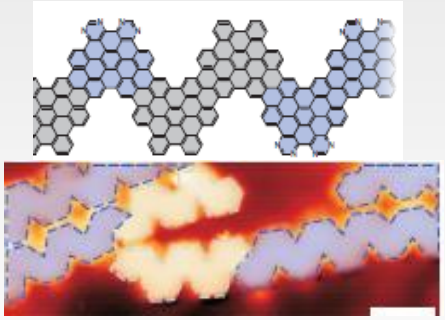


UHV, Au(111) surface



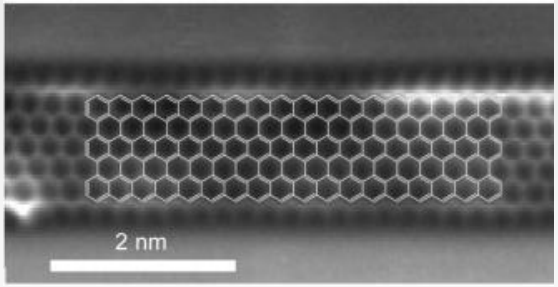
R. Fasel group
K. Müllen group
Nature **466,** 470 (2010)

Heterojunctions



Nature Nanotech. **9,** 896 (2014);
10, 156 (2015)

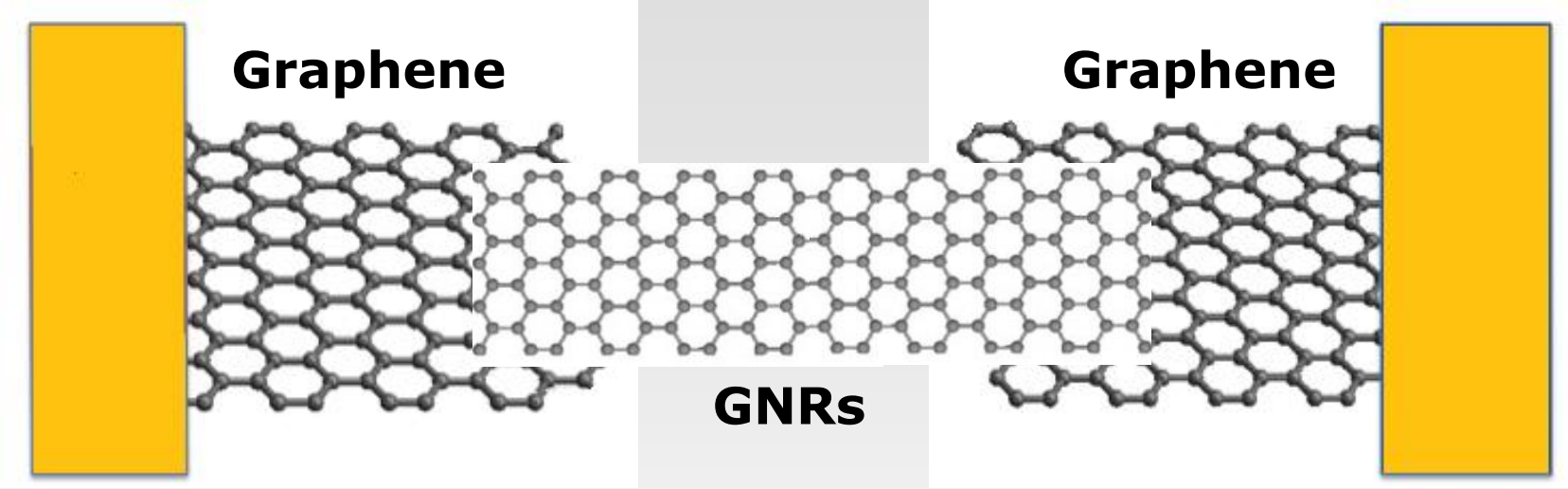
Zigzag edges



Nature **489,** 531 (2016)

Challenge: how to make high-quality devices

All-Graphene Devices



Graphene electrodes - GNRs channel

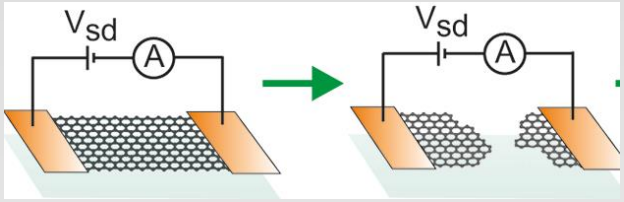
Key points

- Planar and "nano"
- Very stable
- Gatable (no screening)
- Exploit π-stacking

see also E. Lörtscher Nature Nanotechnology **8,** 381 (2013)

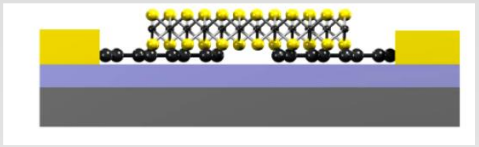
Use of graphene-based electrodes

Single Molecule



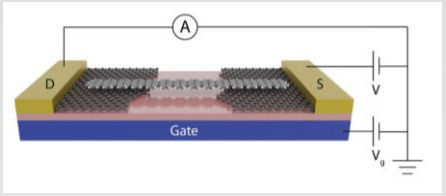
F. Prins et al., Nano Lett 2011
C. Jia et al., Science 2016

other 2D materials



Y. Liu et al.,
Nano Lett. 2015

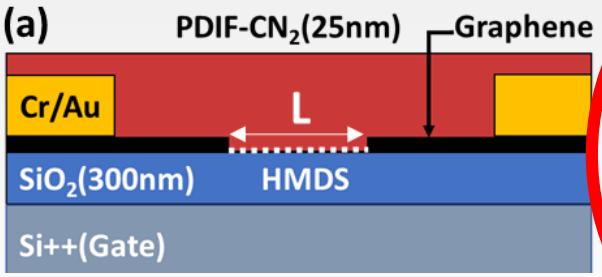
GNRs



M. El Alabassi et al.,
Nano Lett. 2015

Delft group
…also Basel, Oxford, Erlangen etc…

… our group

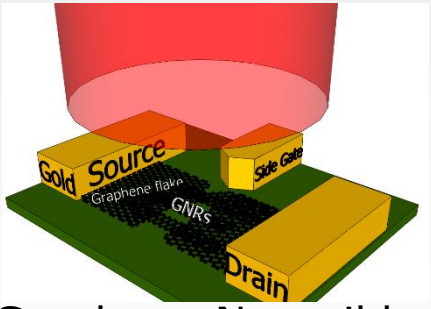


Organic Semiconductor

F. Chianese et al. Appl. Phys. Lett. 112, 213301 (2018)

F. Chianese et al. J. Mat Chem C 8, 8145-8154 (2020)

F. Chianese et al. Synthetic Metals 273, 116683 (2021)

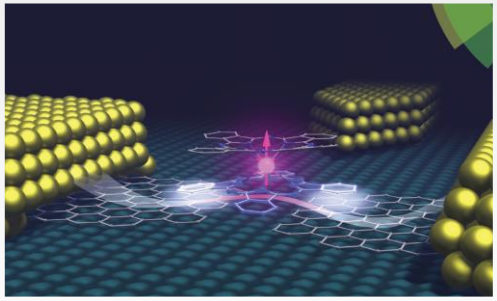


Graphene Nanoribbon

Z. Chen et al, J. Am. Chem. Soc. **2016**, *138,* 15488-15496

A. Candini et al, J. Phys. Chem. C **2017,** *121,* 10620-10625

L. Martini et al, Carbon **2019,** *146,* 36-43



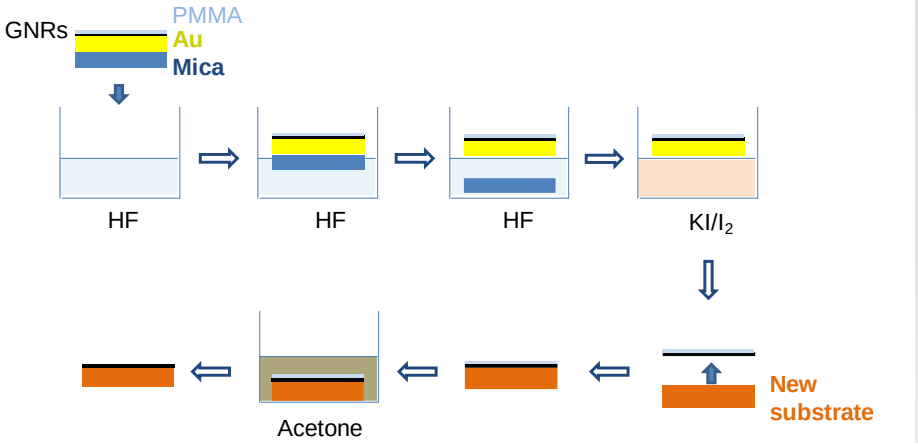
Single (magnetic) molecule

A. Candini et al., Beilstein J. Nanotech. **6,** 711 (2015)

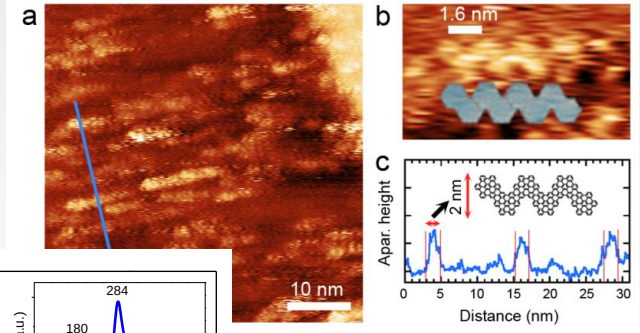
S. Lumetti *et al.*, Dalton Trans. 2016, **45** 16570-16574

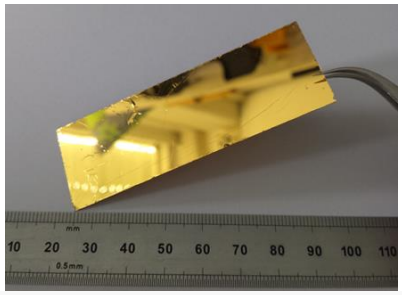
GNR growth by CVD

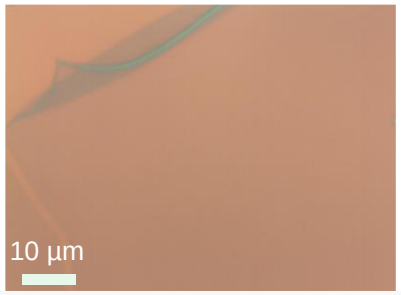
A. Narita, X. Feng, K. Muellen, MPI Mainz and TU Dresden



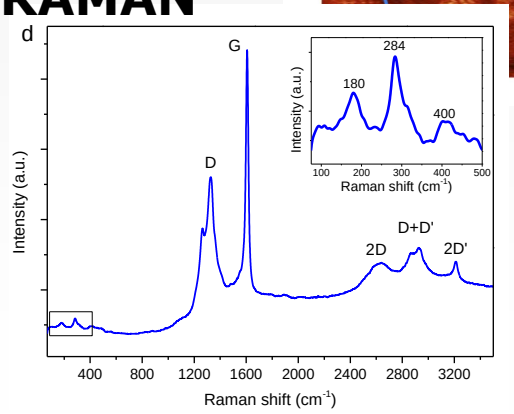
STM







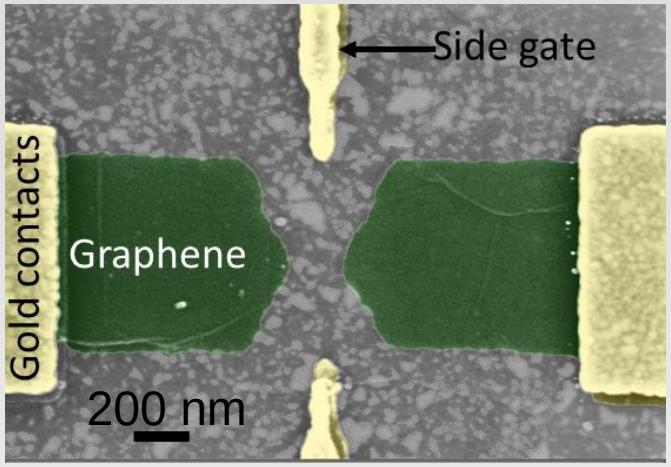
RAMAN

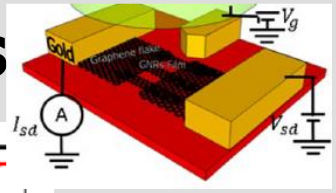


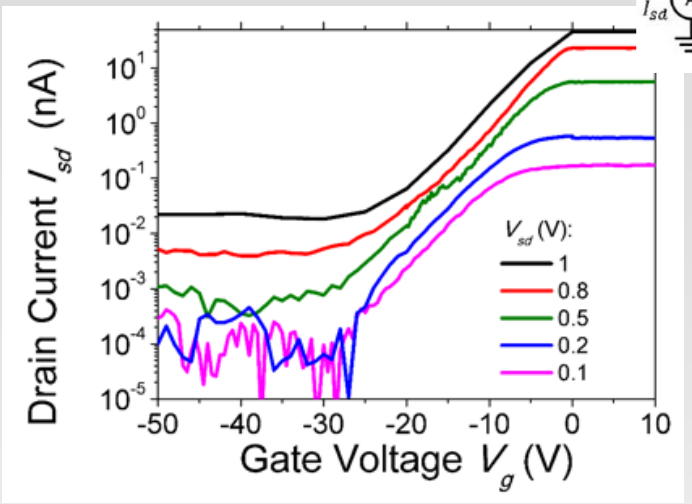
GNRs layer transferred directly on graphene electrodes

Z. Chen et al, *J. Am. Chem. Soc.* **2016,** *138,* 15488-15496

GNR devices: thin film optolectronics



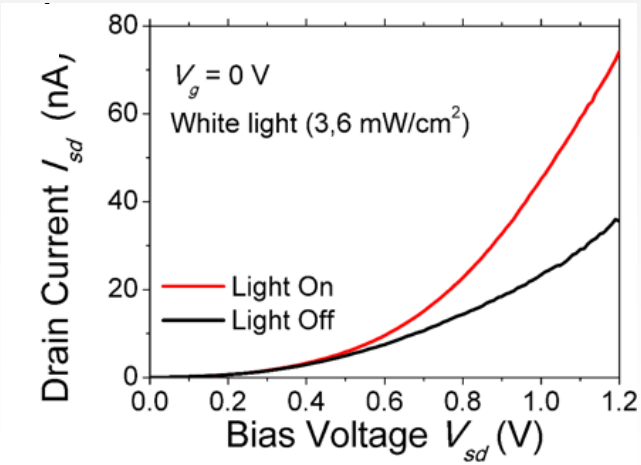


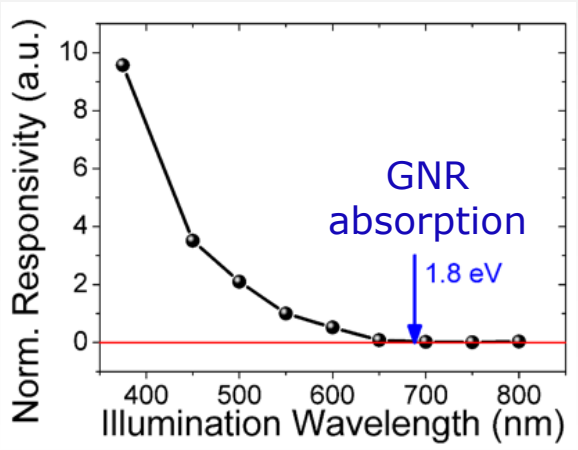


C. Coletti group, IIT Pisa

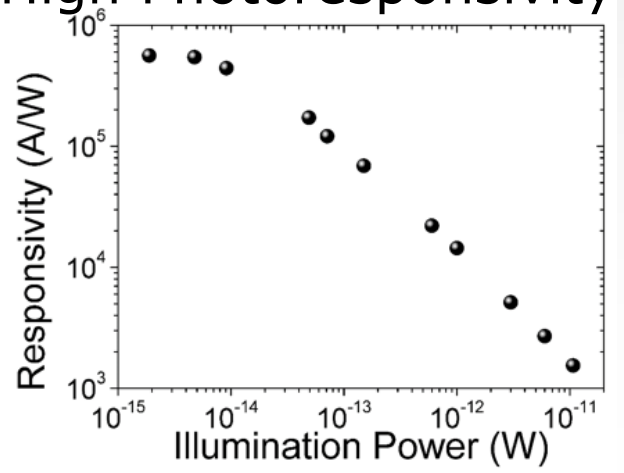
FET behavior Ion/Ioff ~10^4

Photocurrent



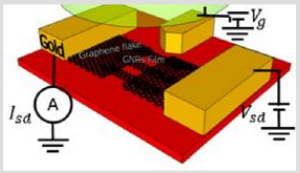


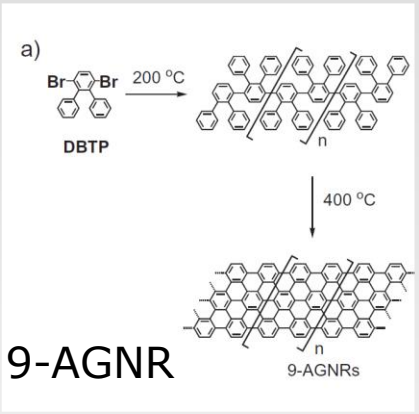
High Photoresponsivity

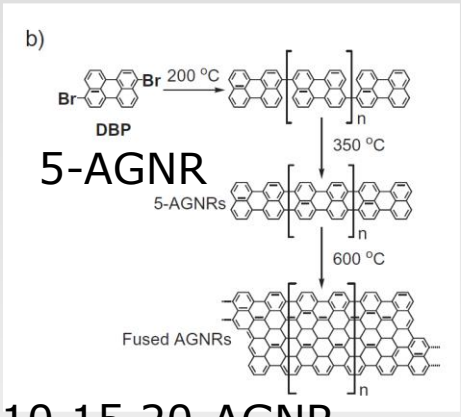


A. Candini et al, *J. Phys. Chem. C* **2017,** *121,* 10620-10625

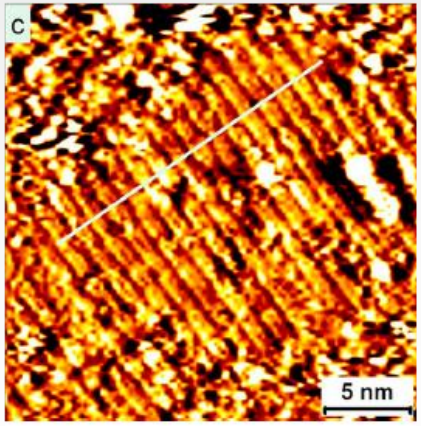
GNR devices:
Structure ↔ Electrical Properties

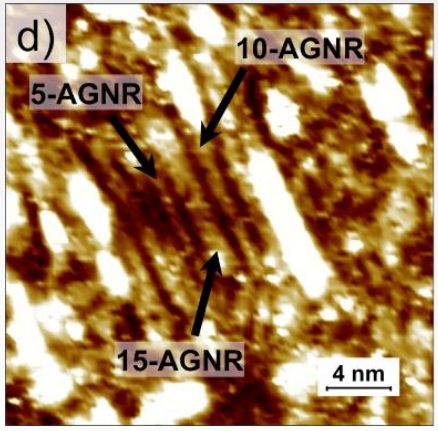




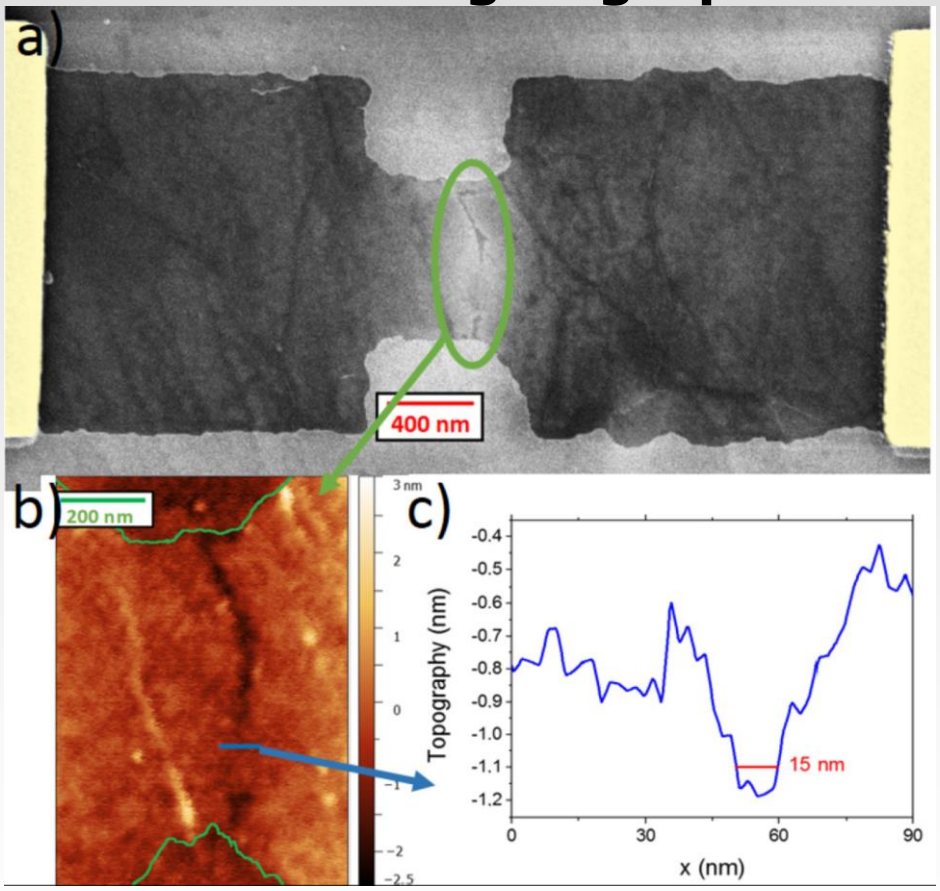


10,15,20-AGNR





Electroburning of graphene



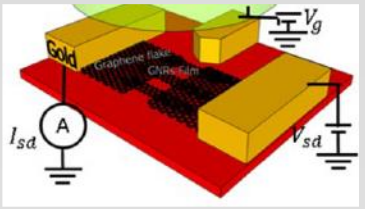
electrode separation ~ 10-20 nm

Z. Chen et al JACS **2017,** 139, 3635

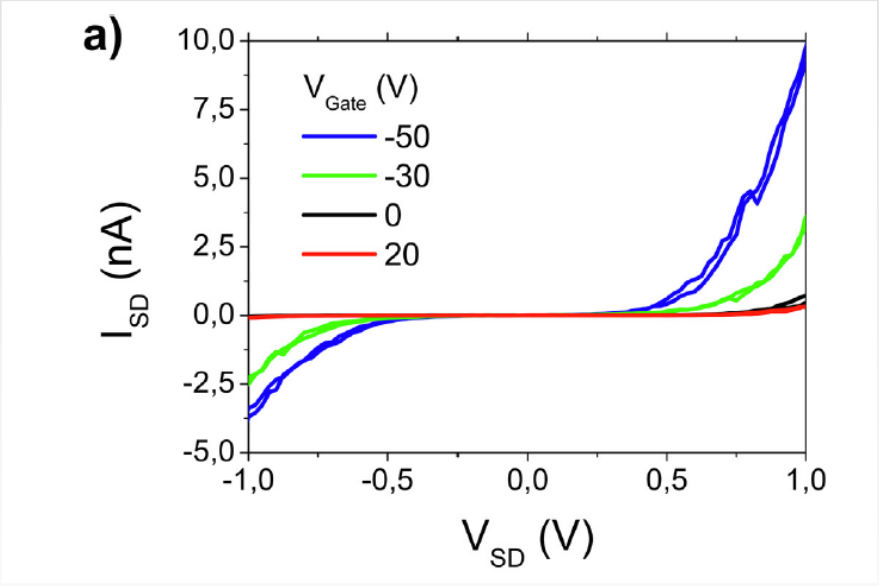
Z. Chen et al JACS **2017,** 139, 9483

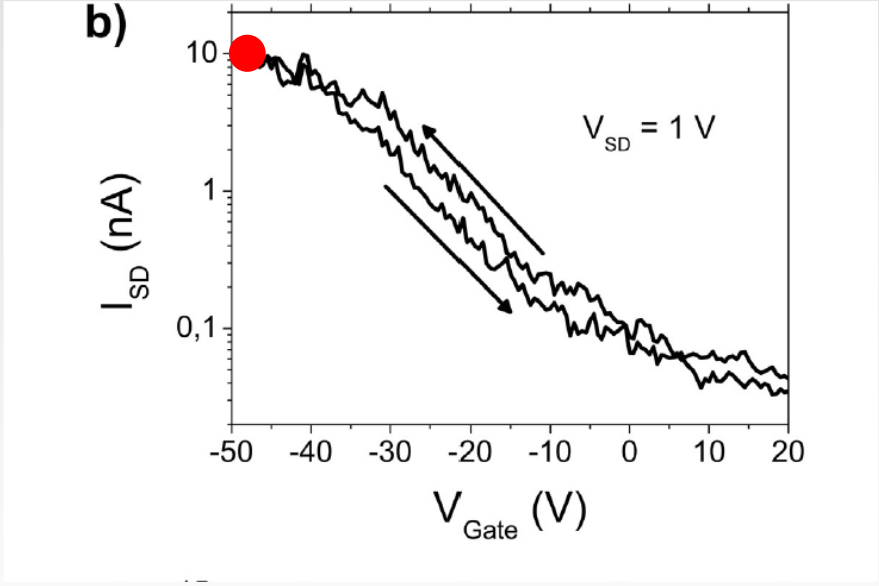
L. Martini et al, Carbon **2019,** *146,* 36-43

GNR devices:
Structure ↔ Electrical Properties



Typical device characteristics

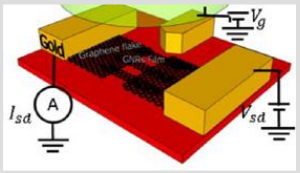


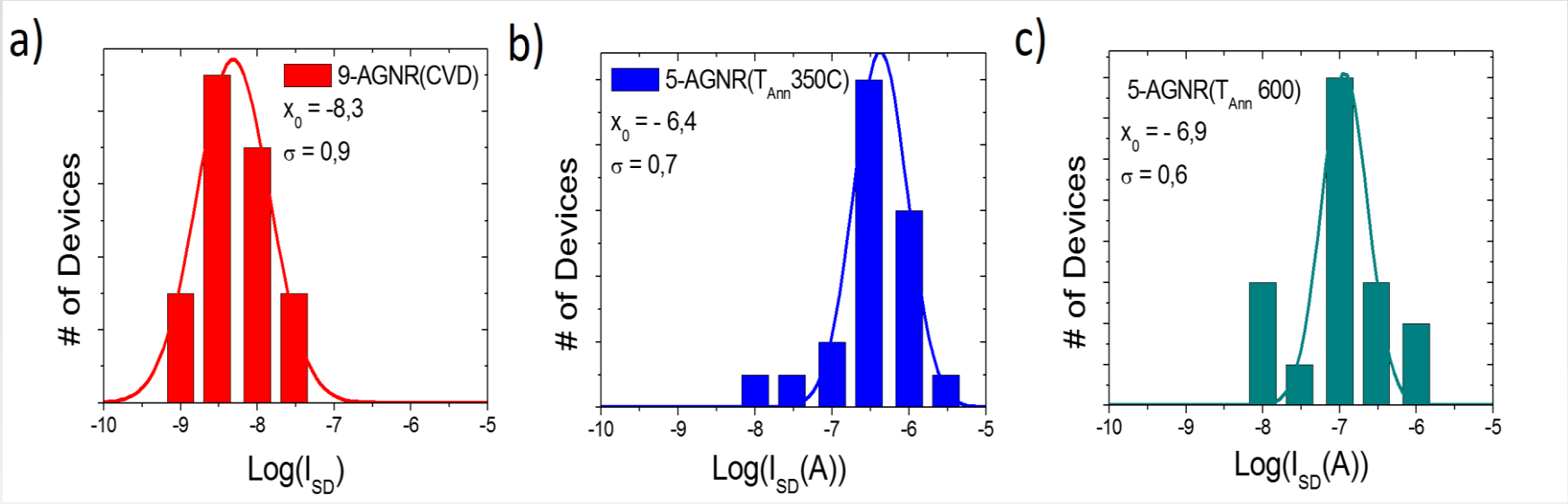


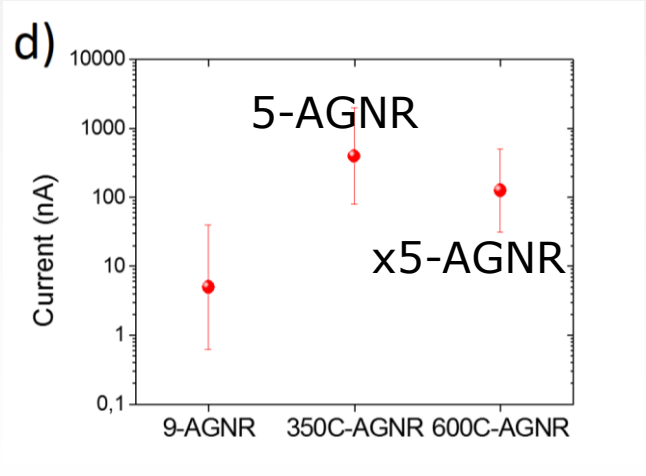
FET behavior, non-linear I-V

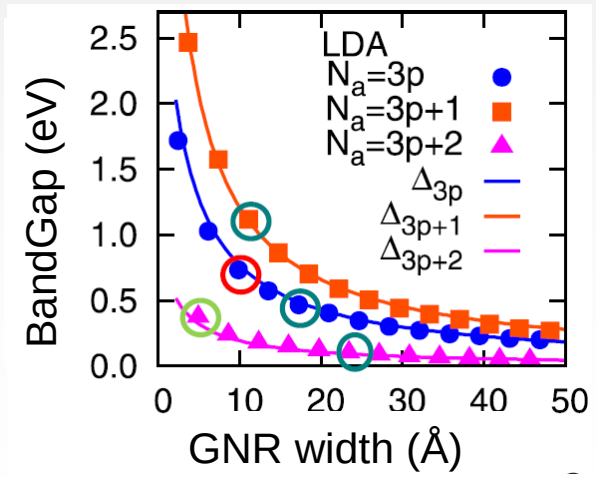
L. Martini et al, Carbon **2019,** *146,* 36-43

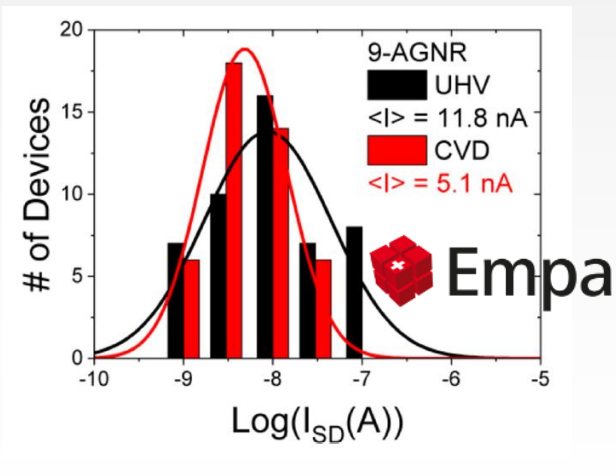
GNR devices:
Structure ↔ Electrical Properties











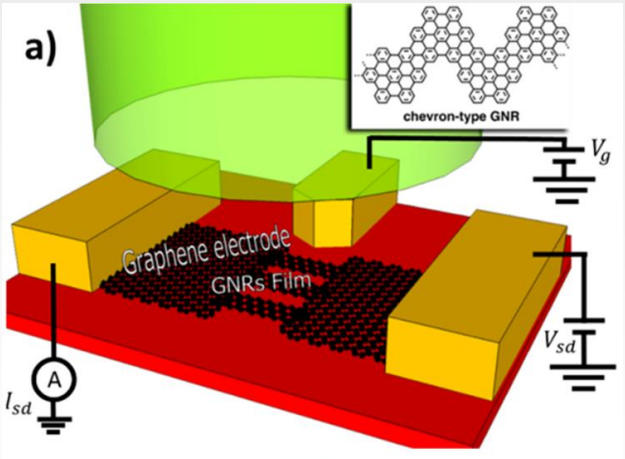
Structure-Properties relation on a device

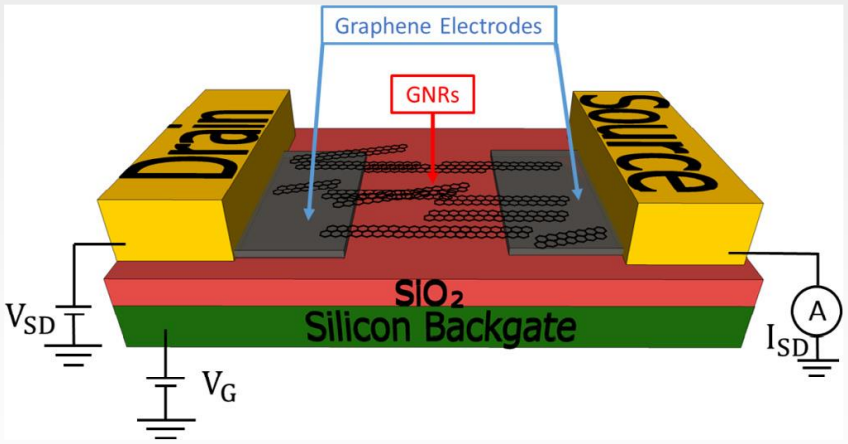
L. Martini et al, Carbon **2019,** *146,* 36-43

Conclusions

- All graphene devices (G+GNRs): nanoelectronics and optoelectronics

- Relation between the GNR structure and the device electrical properties





Z. Chen et al, *J. Am. Chem. Soc.* **2016,** *138,* 15488-15496
A. Candini et al, *J. Phys. Chem. C* **2017,** *121,* 10620-10625
L. Martini et al, Carbon **2019,** *146,* 36-43

Thanks to

S3, Istituto Nanoscienze – CNR
UniMORE Italy

Leonardo Martini
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Akimitsu Narita

IIT @NEST, Pisa, Italy

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