Towards Graphene-based heterojunction devices for microelectronic applications

IHP GmbH Leibniz Institute for Innovative Microelectronics
TU-Dresden/IHM (Institute of Semiconductors and Microsystems)

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Member of Leibniz Association

TECHNISCHE UNIVERSITÄT DRESDEN

DFG BA 2009/6-1 & WE 3594/5-1

DFG ME 4117/1

FFLexCom High Frequency Flexible Bendable Electronics for Wireless Communication Systems
DFG PRIORITY PROGRAMME (SCHWERPUNKTPROGRAMM) 1796

Deutsche Forschungsgemeinschaft DFG

20.04.2016

Graphene2016

IHM Leibniz Association

Agenda

1. Motivation
2. Graphene Synthesis on Germanium (200 mm wafer size)
3. Deposition of amorphous Silicon on transferred Graphene
4. Deposition of dielectrics on transferred Graphene

Graphene Base High-Frequency Transistor

GRADE

SEVENTH FRAMEWORK PROGRAMME

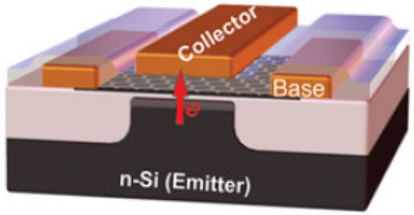
DFG

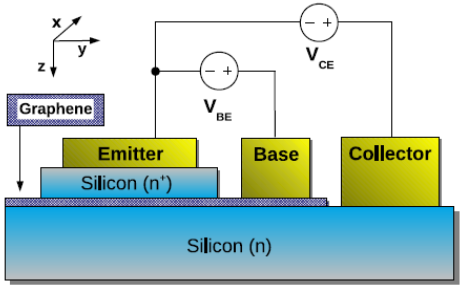
FFLexCom

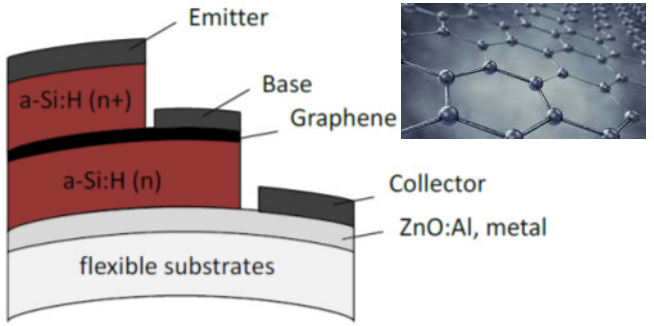
2012 Proof of concept

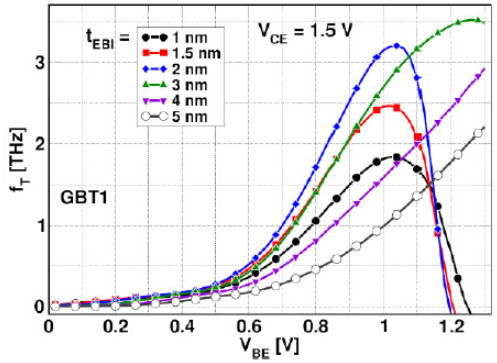
2013 Simulation

2016 New flexible concept

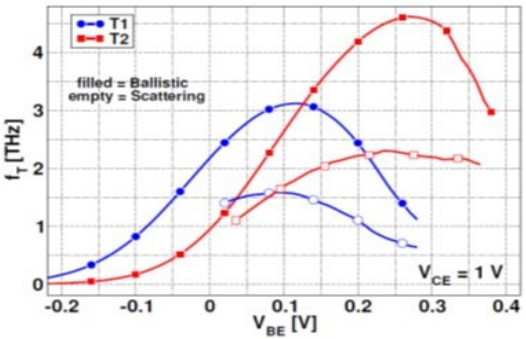




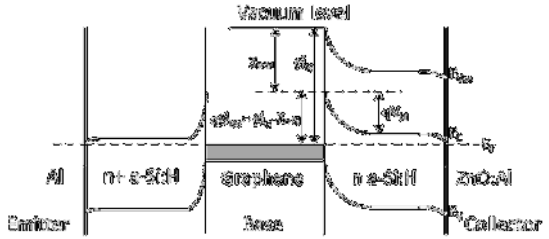




S. Vaziri, Nano Lett. 13, 1435 (2013)

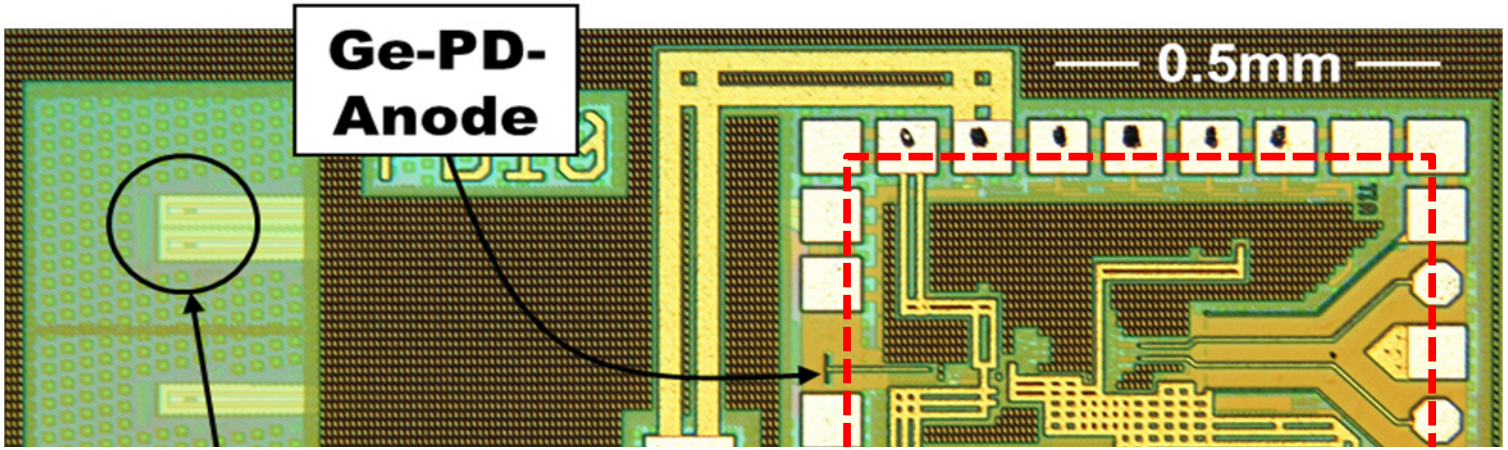


V. Di Lecce, Trans. Electron Dev., 60, 4263 (2013)

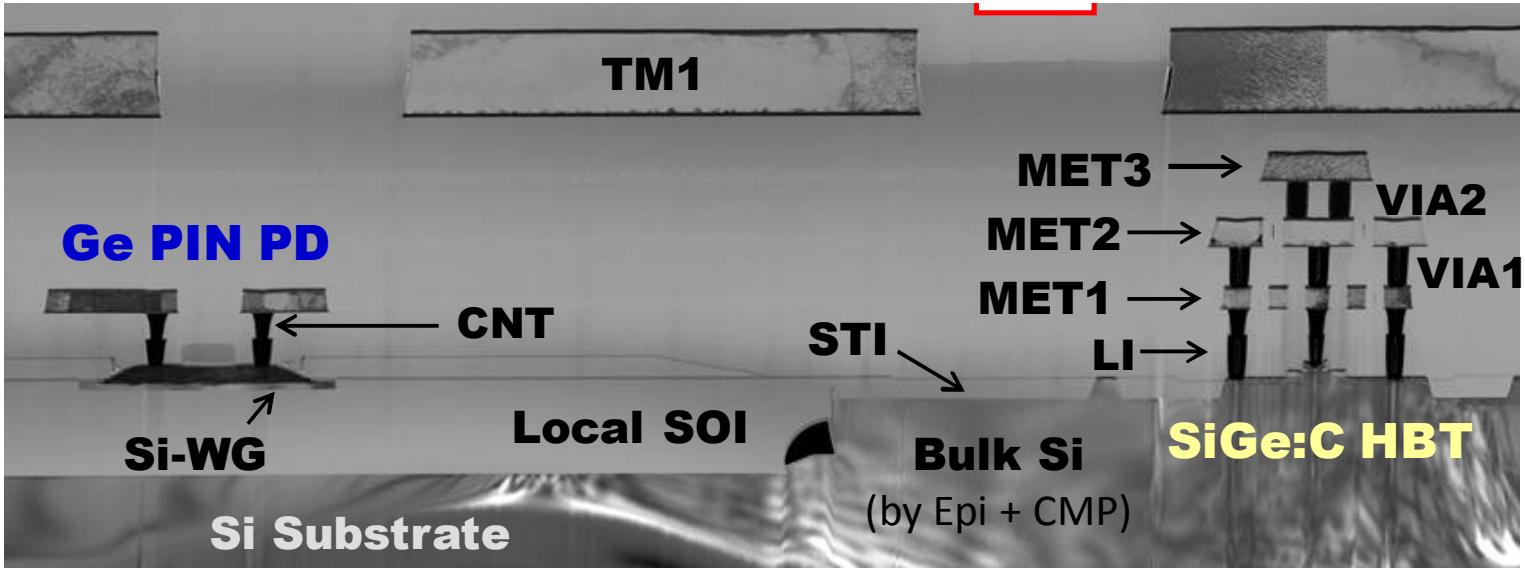


Goal: f_T > 100 GHz

Main challenge: Manufacturability of Graphene devices

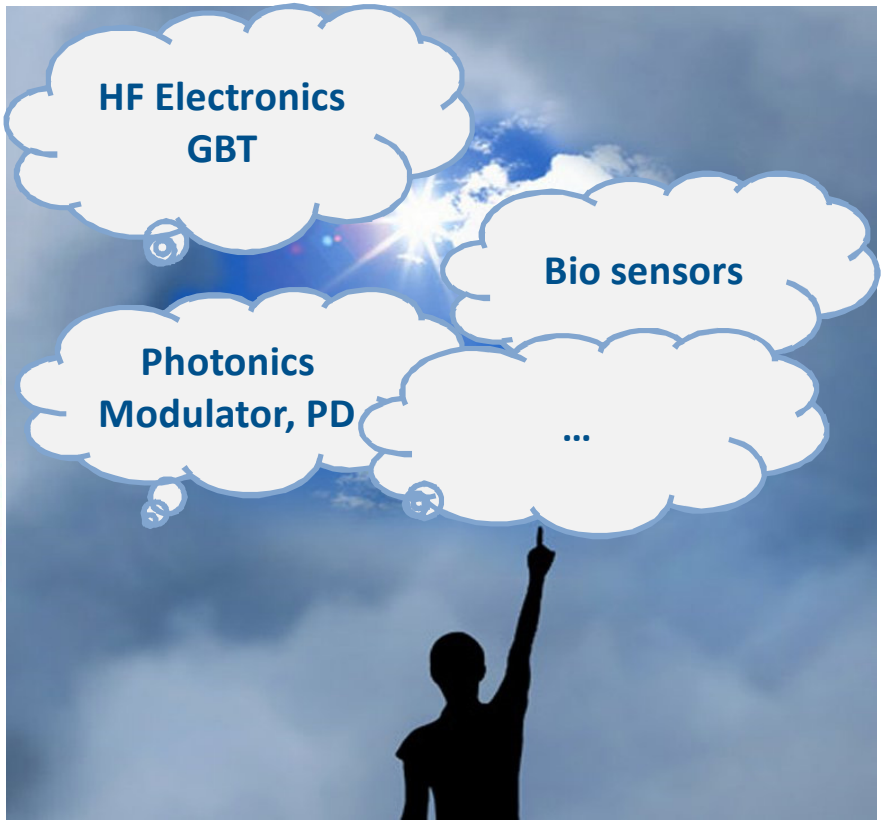


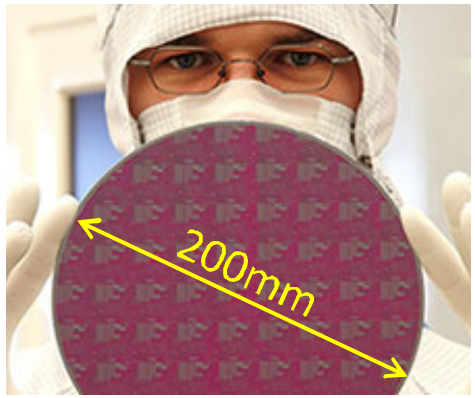
Where to integrate Graphene?



Intermediate goal: Graphene toolbox

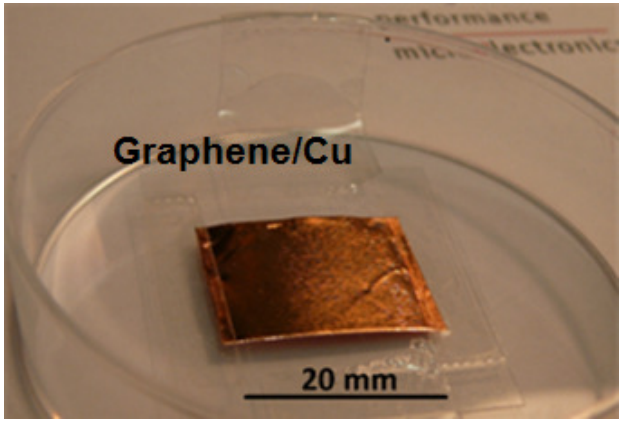
- Universal toolbox of process and metrology tools enabling fabrication of a variety of graphene-based devices on 200 mm wafers in a CMOS pilot line
- In collaboration with universities and industrial partners

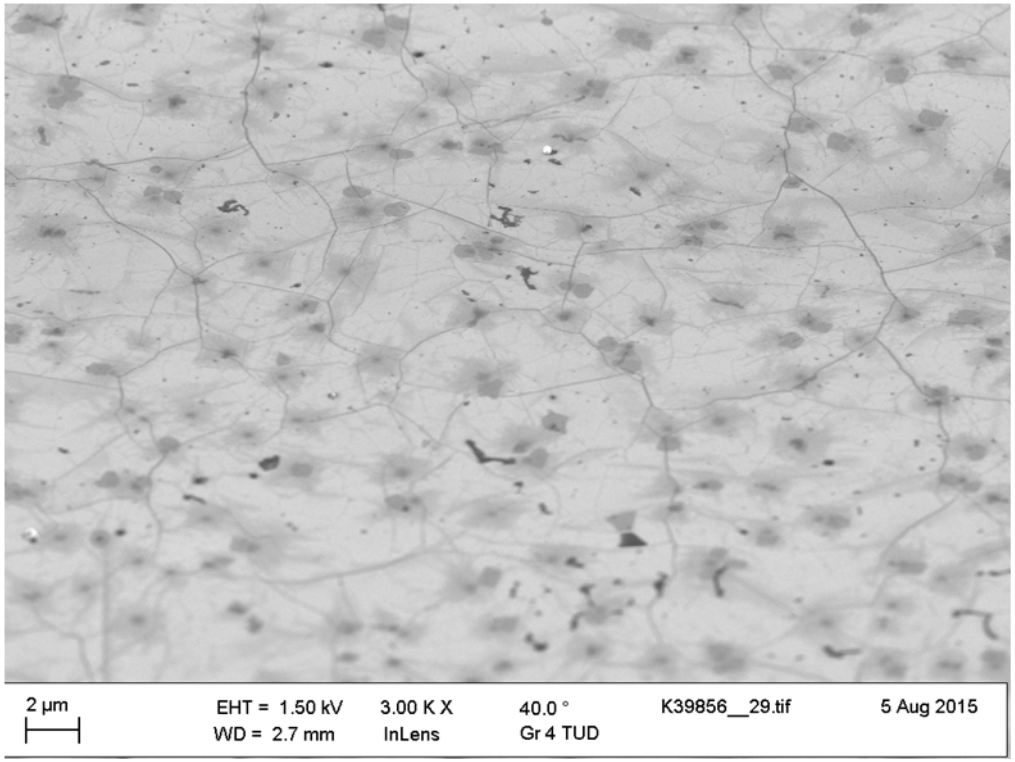


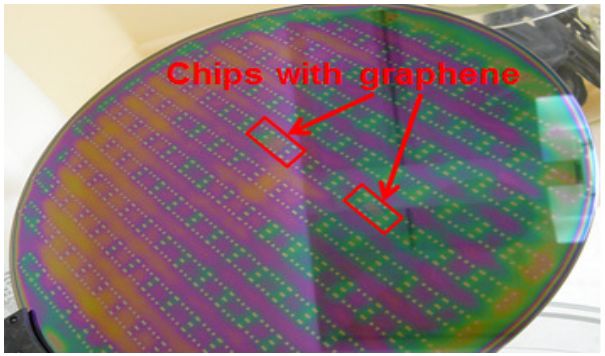


Transferred Graphene on 200 mm Silicon wafers

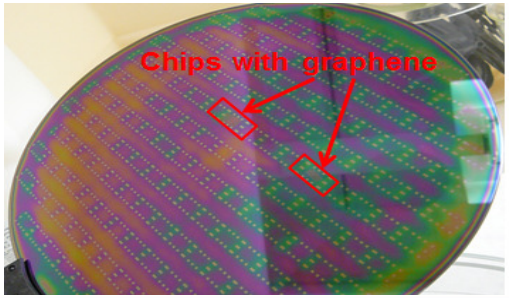
SEM investigation of transferred CVD graphene on SiO_2/Si wafer

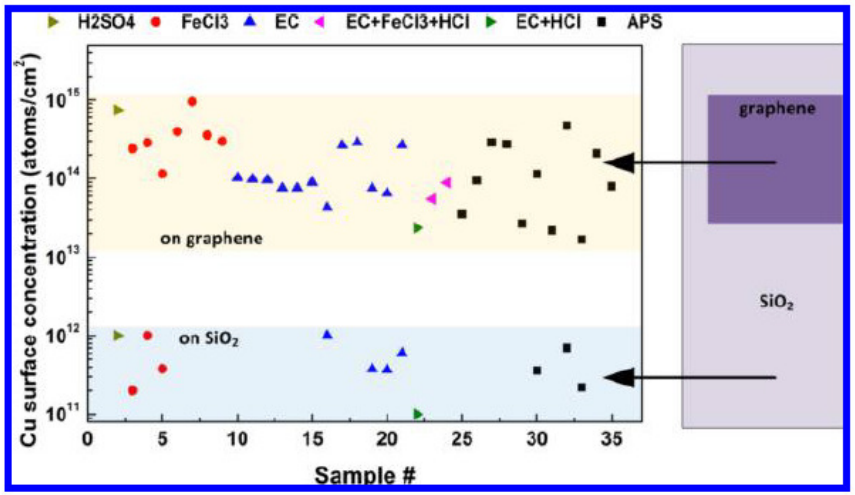






Residual contamination of transferred Graphene





Residual Metallic Contamination of Transferred Chemical Vapor Deposited Graphene

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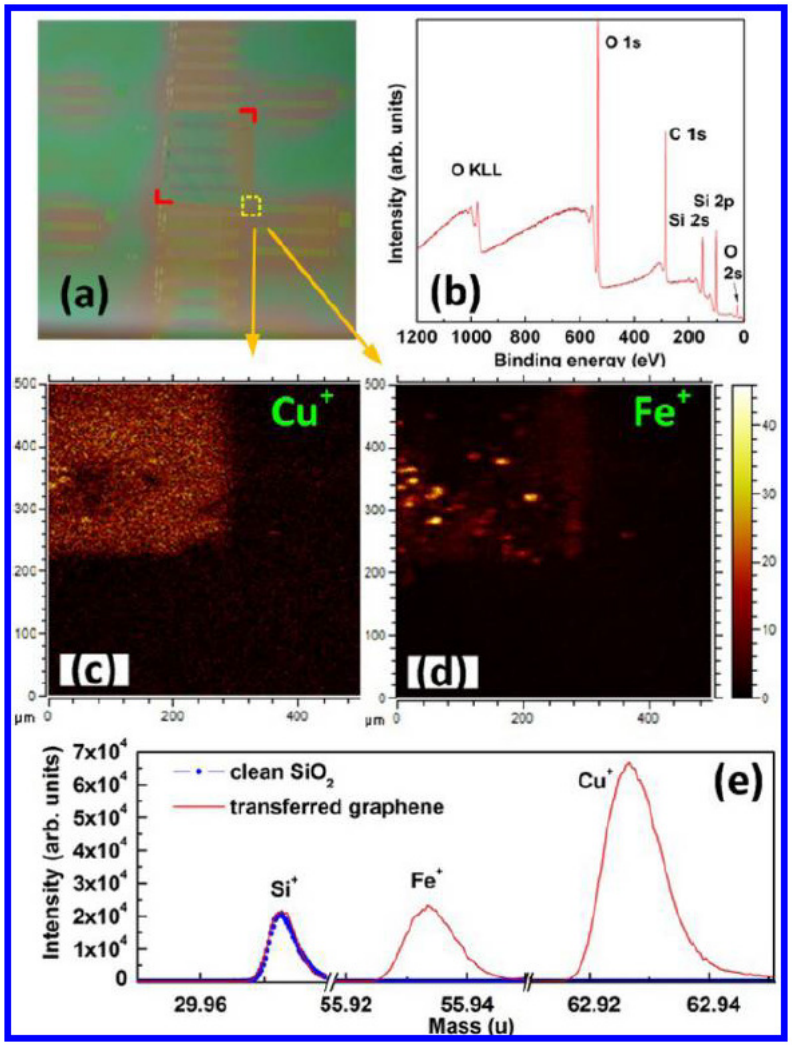
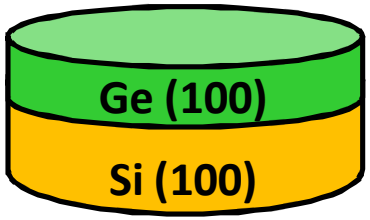
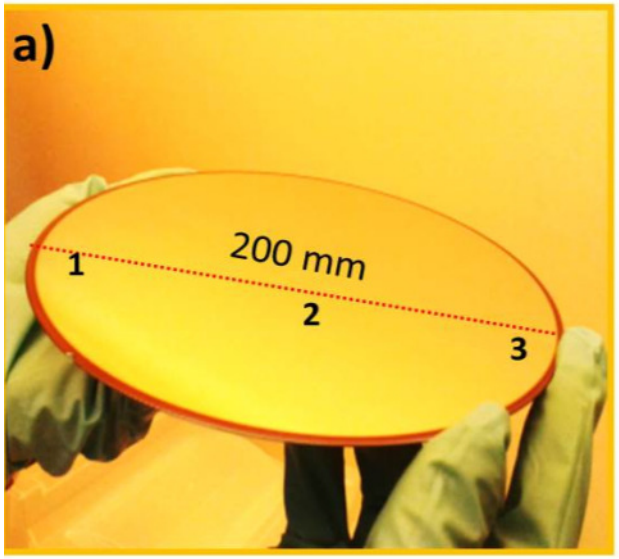


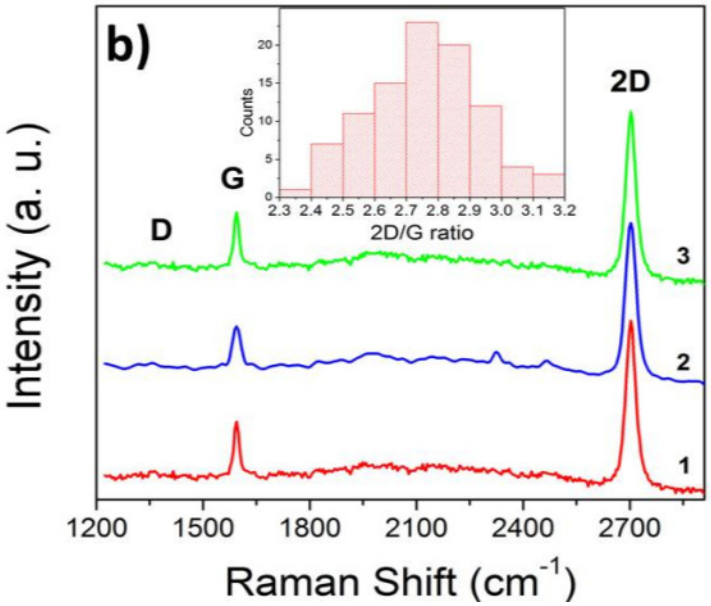
Graphene synthesis @ IHP

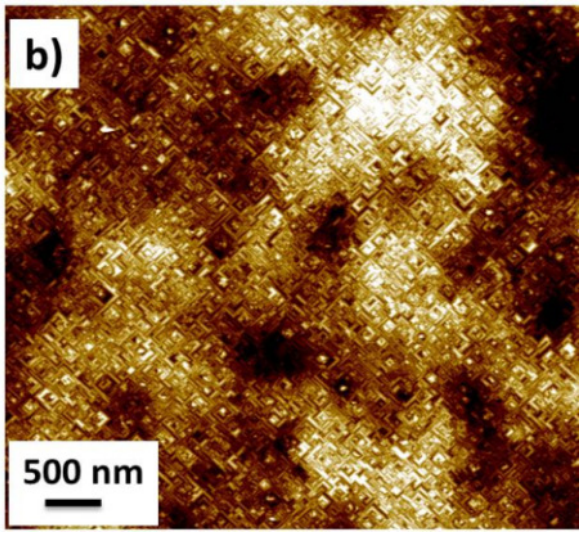
- Tool integrated into the cleanroom toolset
- 200 mm Graphene available on Ge and Ni

Graphene on Ge









	Rs [kOhm/sq]	μ [cm²/Vs]
Gr on SiO2/Si(100) **Ge100/Si100**, Hall	1.3±0.1	440±20

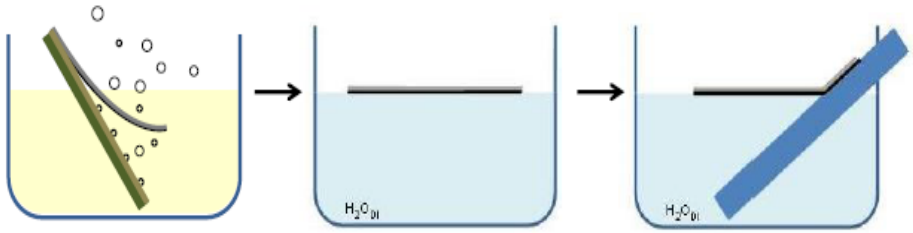
	Rs [kOhm/sq]	μ [cm²/Vs]
Gr on SiO2/Si(100) **Cu growth**, Hall	0.95±0.2	1200±20

Ge/Si – Transfer by Electrochemical Delamination

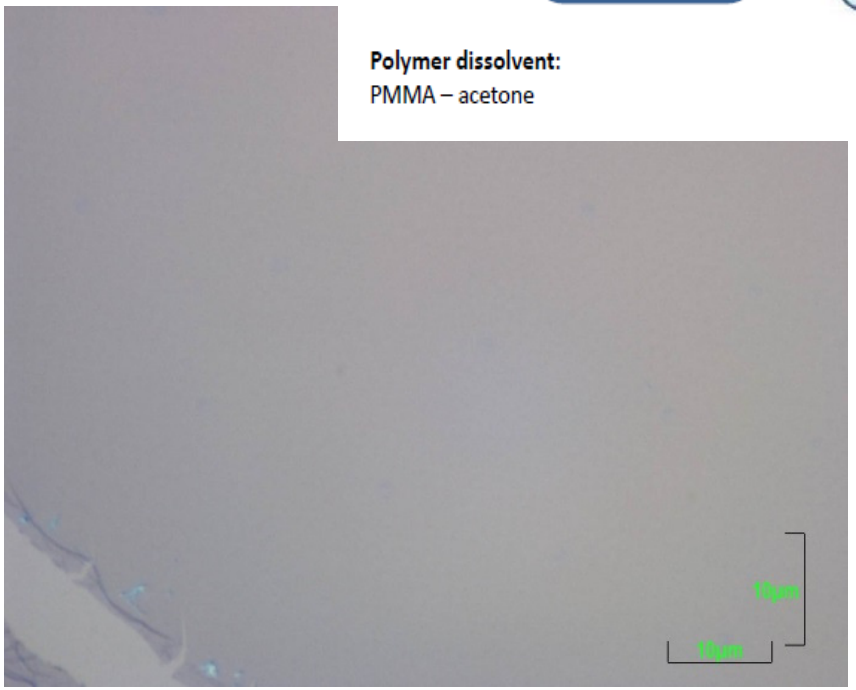
Polymer:
PMMA (4% anisole)

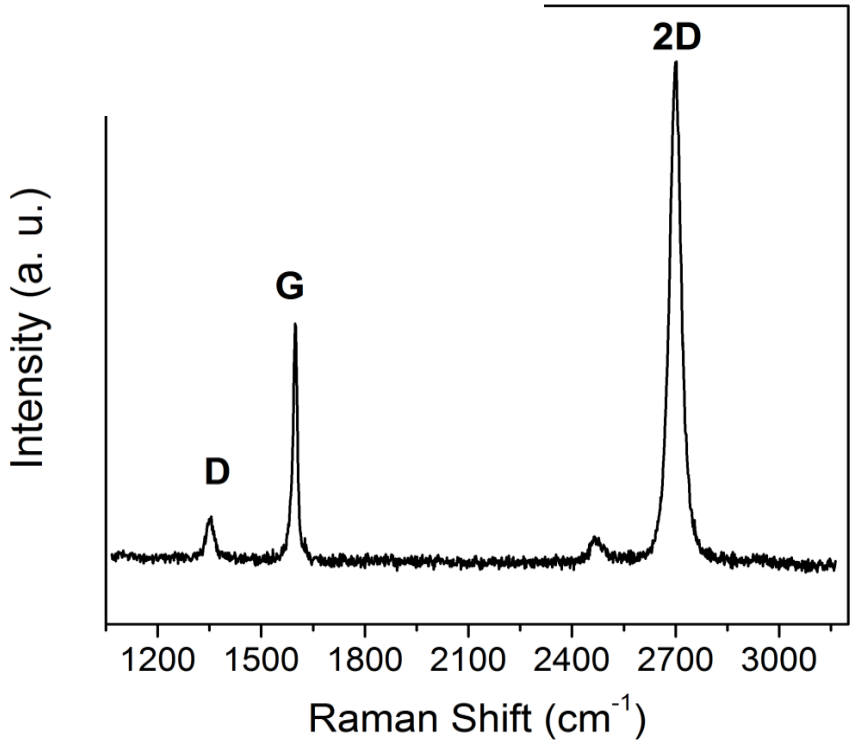
Covering with polymer

Electrolyte:
KCl
Voltage: 5V
Time: ~30s



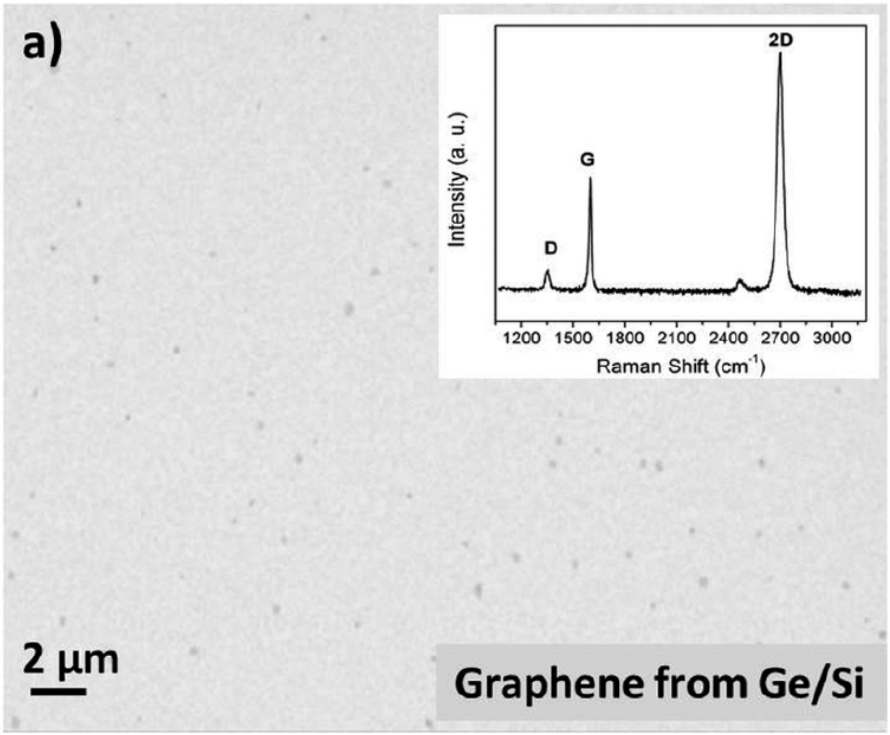
Polymer dissolvent:
PMMA – acetone

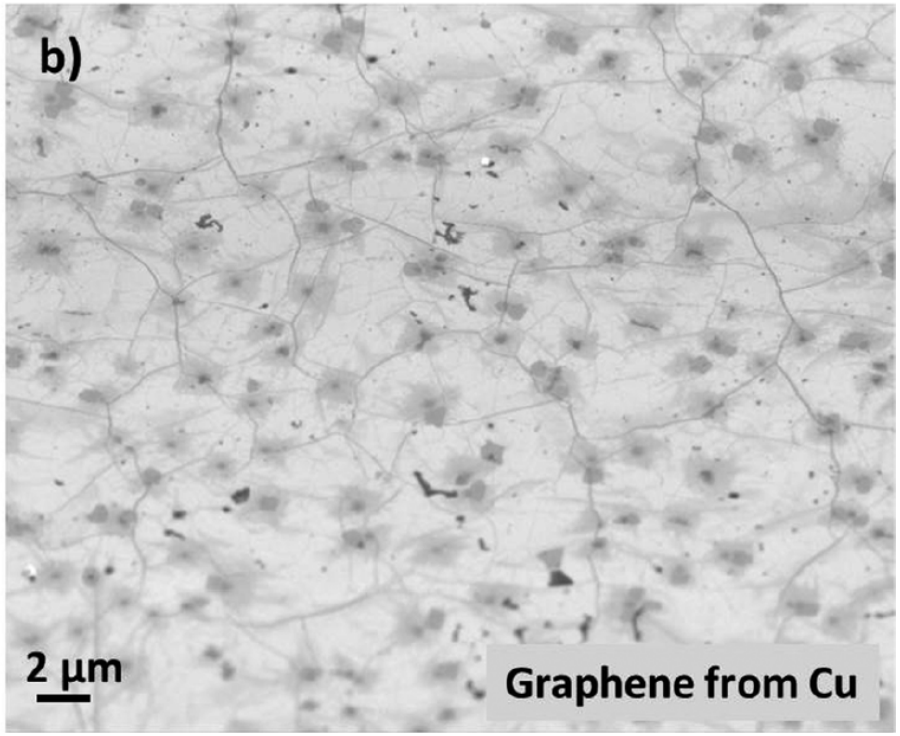




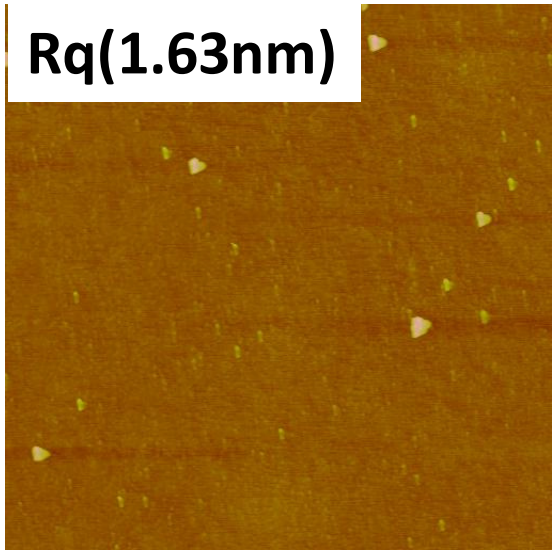
Large area transferring possible

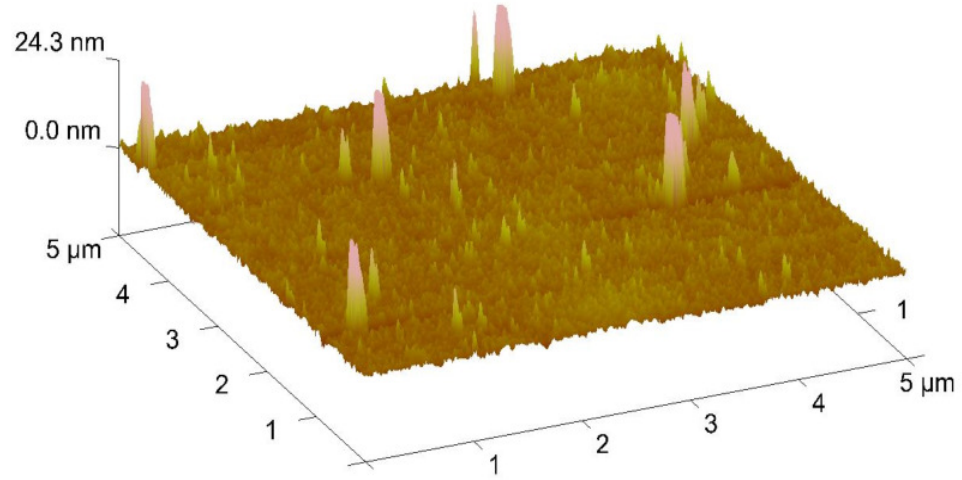
Ge/Si – Transfer by Electrochemical Delamination

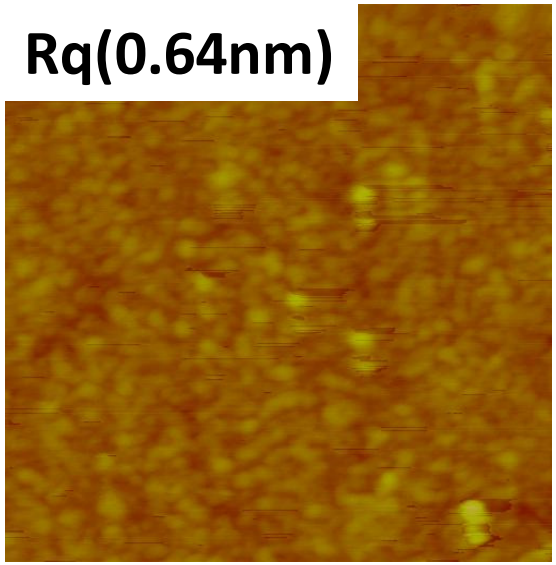


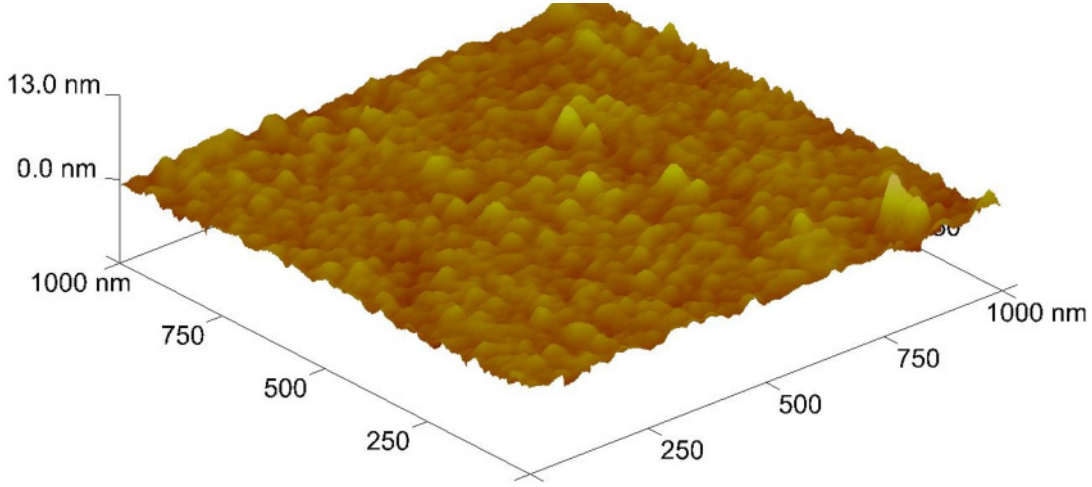


Quality of Ge/Graphene after transfer









Modified CVD of amorphous Silicon on Graphene

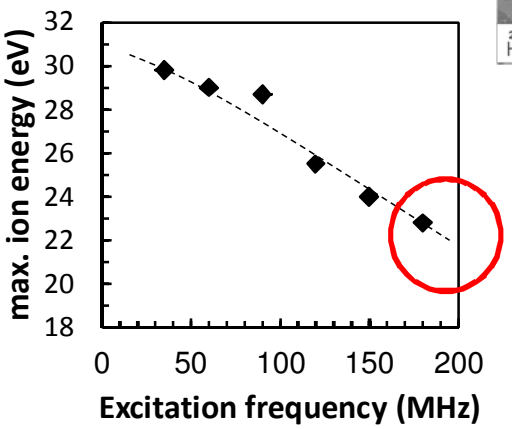
Deposition technique for n-type silicon on graphene

- Without damaging the electronic structure of graphene
- VHF PEVCD – extremly „soft“ deposition technique

Frequencies

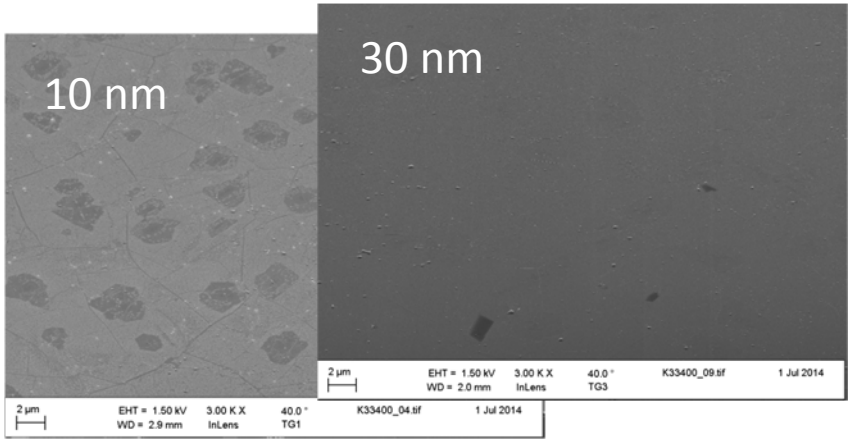
up to 200 MHz

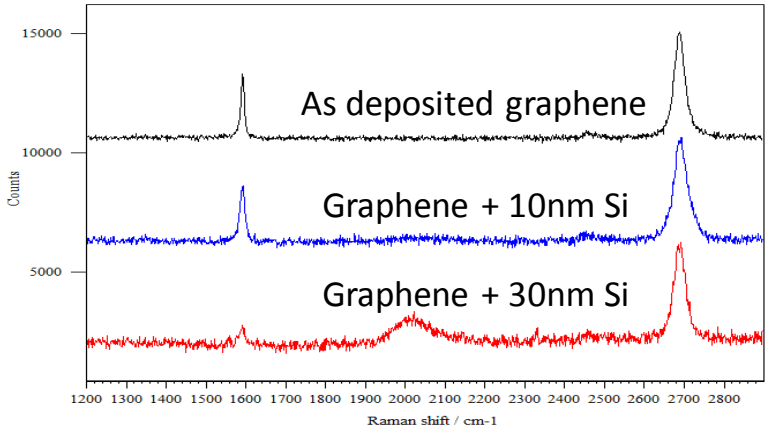
„Soft“ deposition



M.Heintze, R.Zedlitz, Journal of Non-Cryst. Solids 198-200 (1996) 1038-1041

SEM of Si on graphene:

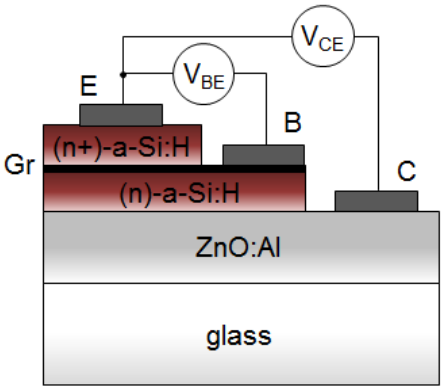




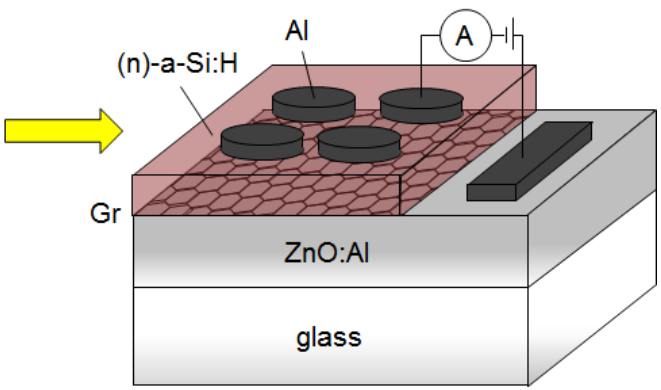
Electrical characterization of graphene/(n)-a-Si:H junctions

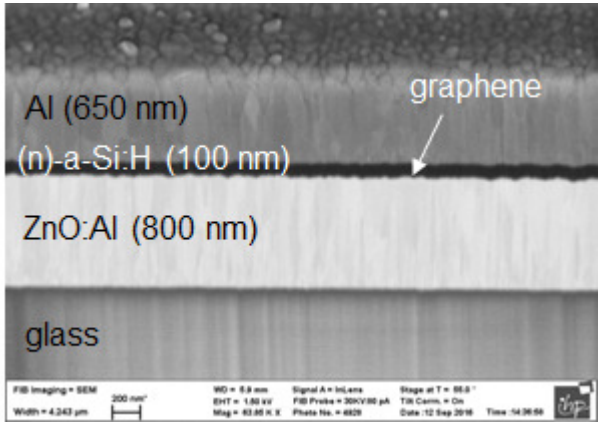
- **Device simplification:**

GBHT-Transistor



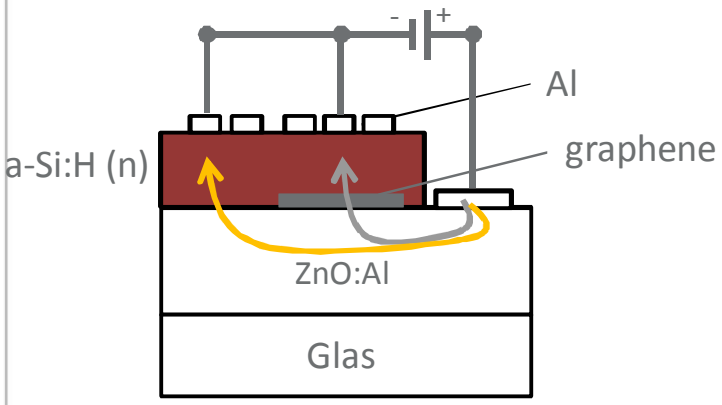
Diode

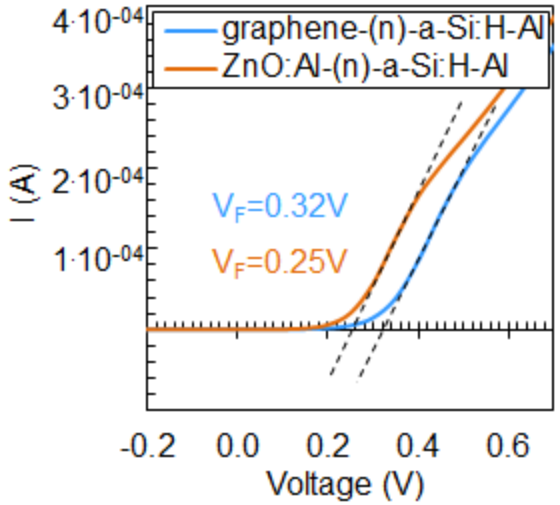




- Graphene/(n)-a-Si:H diode as core element of the GBHT
- diode characterization by means of temperature dependent IV-measurements and CV-measurements
- CVD-grown graphene on Cu transferred to ZnO:Al using standard wet chemical transfer techniques
- a-Si:H n-layers deposited with VHF-PECVD (140 MHz)
- all contacts except the graphene/(n)-a-Si:H junction are ohmic contacts

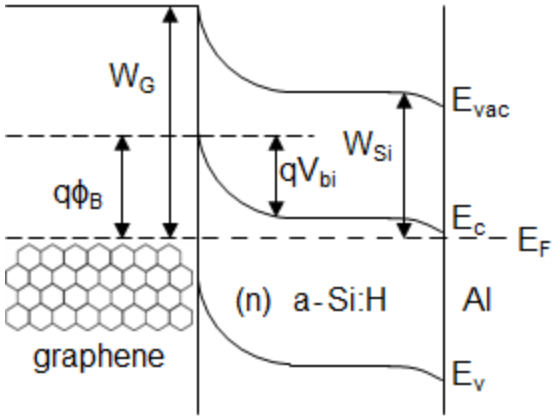
Electrical properties of graphene/(n)-a-Si:H junctions





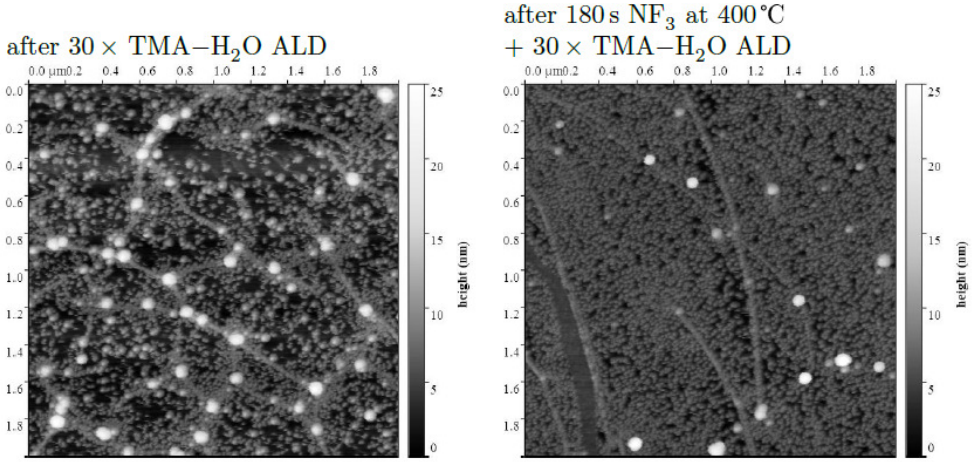
threshold voltage (V_F) of the graphene/(n)-a-Si:H junction increased compared to the reference ZnO:Al/(n)-a-Si:H junction

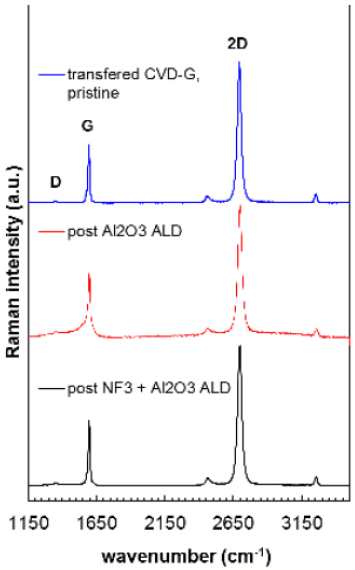
rectification ratio 1.6×10^4 (± 1 V)



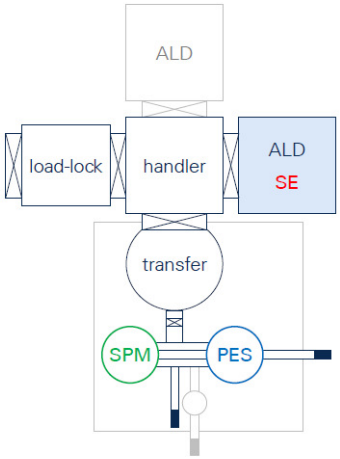
$q\Phi_B$ → I (V,T)

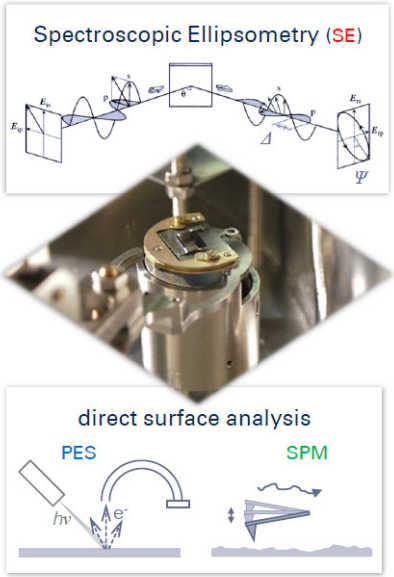
Improving nucleation on graphene by NF_3 pre-treatment





EXPERIMENTAL METHODOLOGY





Atomic Layer Deposition of Al_2O_3 on NF_3-pre-treated graphene

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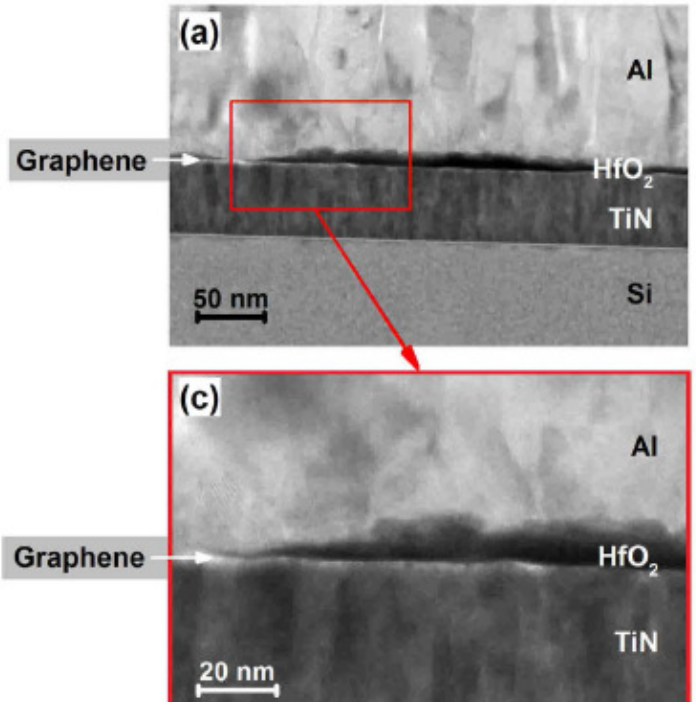
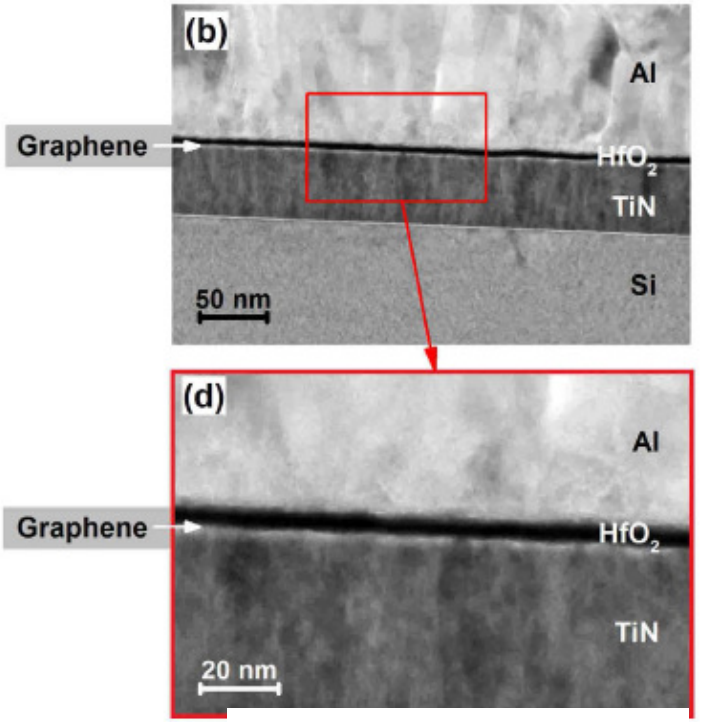
Proc. of SPIE Vol. 9519 951915-1

Improving nucleation on graphene by FDTS pre-treatment

Without FDTS pre-coating



With FDTS pre-coating



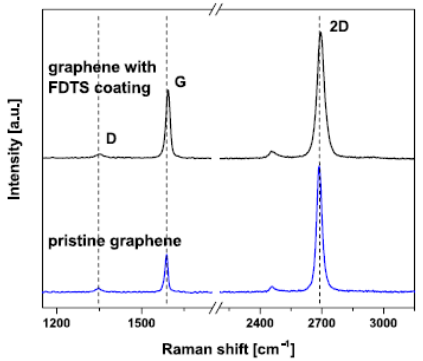
SCIENTIFIC REPORTS

OPEN

Perfluorodecyltrichlorosilane-based seed-layer for improved chemical vapour deposition of ultrathin hafnium dioxide films on graphene

Received: 21 April 2016
Accepted: 14 June 2016
Published: 06 July 2016

Julia Kitzmann, Alexander Göritz, Mirko Fraschke, Mindaugas Lukosius, Christian Wenger, Andre Wolff & Grzegorz Lupina



Summary

- IHP and IHM develop processing modules for graphene electronic devices
- With a vision of integrating them with the backbone BiCMOS technology
- Current activities focused on the development of a baseline graphene technology
    - graphene synthesis on Germanium
    - deposition of silicon and dielectrics on graphene
- Graphene/(n)-a-Si:H diodes as core element of the high-frequency graphene-base heterojunction transistor (GBHT) were investigated

This work is dedicated to the memory of Prof. Wolfgang Mehr, the inventor and the pioneer of research on graphene base transistors.

Thank you for your attention!

Christian Wenger

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innovations
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Graphene Base High-Frequency Transistor

Objectives:

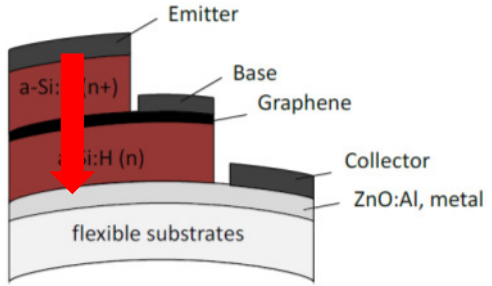
High frequency graphene based transistor on flexible substrates

Unipolar silicon to graphene heterojunction device technology

Ballistic transport across the base (Graphene)
Extremely short transit times (vertical structure)

↓

High cut-off frequencies (> 100 GHz)
Improved Strain limit (> 10 %)



f_T [GHz]	Strain limit [%]	Substrate	Reference
11	2	polyethylene naphthalate (PEN)	N. Petrone et al., Nano Letters, 13 , 121 (2013)
25	8	polyimide (PI)	J. Lee et al., ACS Nano 7, 7744 (2013)
32	>3	polyethylene terephthalate (PET)	C.-H. Yeh et al., ACS Nano, DOI: 10.1021 (2014)