AP1.8 CVD growth of single layer graphene on α-Al_2O_3 and multiscale analysis of MoS_2/Graphene/α-Al_2O_3 2D-layer stacks

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Introduction

Exploratory research on the utilization of the new class of 2D-materials for application in memristive devices and beyond von Neumann computing concepts has gained rising interest [1].
Key achievements towards this goal comprise:
(1) Industrial-compatible large-scale device manufacturing of the van der Waals-materials [2].
(2) Direct growth of functional and conductive 2D-material stacks on CMOS-compatible substrates.
(3) Large-scale transfer processes.

Metal organic chemical vapor deposition (MOCVD & CVD) of graphene, transition metal dichalcogenides (TMDC) and hexagonal boron nitride on CMOS-compatible substrates like α-Al_2O_3 is a promising approach to reach key factors (1) and (2). Further support comes availability of specialized commercial CVD reactors [3].
Direct growth of functional 2D-layer stacks enables control and design of interface properties. The aim is to maintain the high interface quality after transfer and integration of the stacks with CMOS-based circuits [4,5].

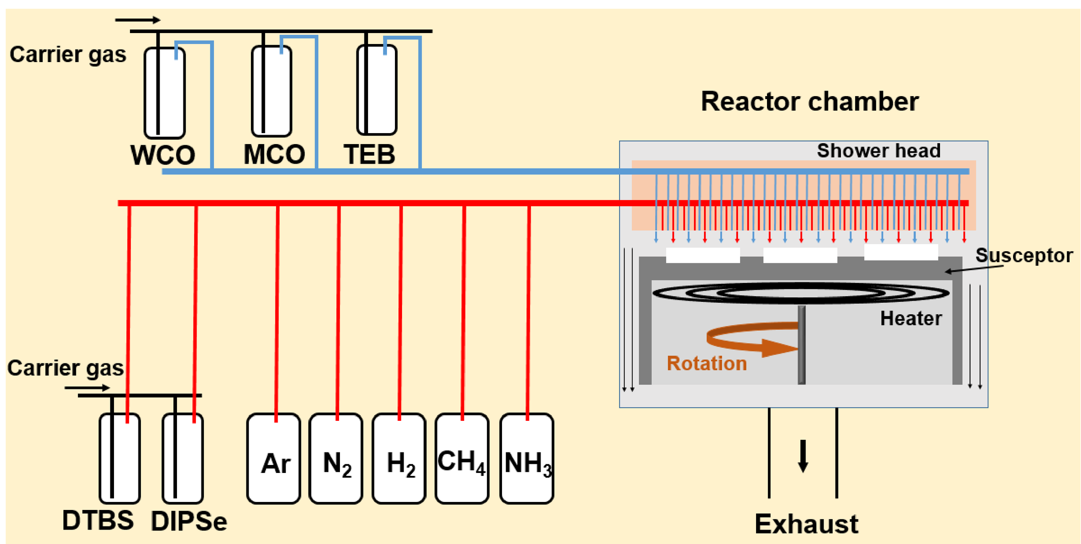
Here, we study CVD grown single layer graphene (SLG) on α-Al_2O_3 and MOCVD of MoS_2 thereon. SLG / α-Al_2O_3 was grown at AIXTRON SE and in the NEUROTEC MOCVD reactor JULE at FZJ. MoS_2 on SLG / α-Al_2O_3 was provided by CST at RWTH Aachen. A multiscale analysis of layers was performed to understand local and extended inter layer bindings and defects, their influence on wafer-scale performance and their impact on the local electronic device properties.

CVD of Graphene on Sapphire

JULE - JUelich advanced tool for 2D-Layer Epitaxy

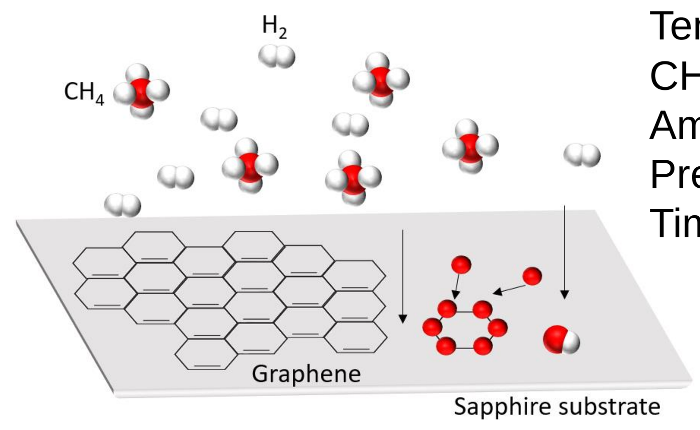
- 6x2'' – Closed Coupled Shower head MOCVD system with cold wall.
- Various wafer sizes: 10x10 mm² to 100 mm in diameter.

Schematic illustration



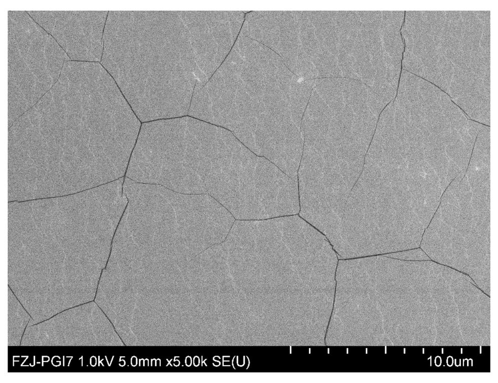
Different kinds of 2D materials can be fabricated: Graphene, WS_2, MoS_2, hBN…

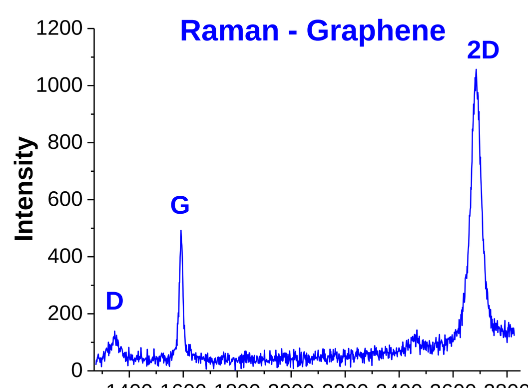
CVD process for SLG in JULE



Temperature 1400 °C
$CH_4 : H_2$ = 1: 13.3
Ambient gas – Argon
Pressure 500 mbar
Time 160 s

Characterization of SLG quality

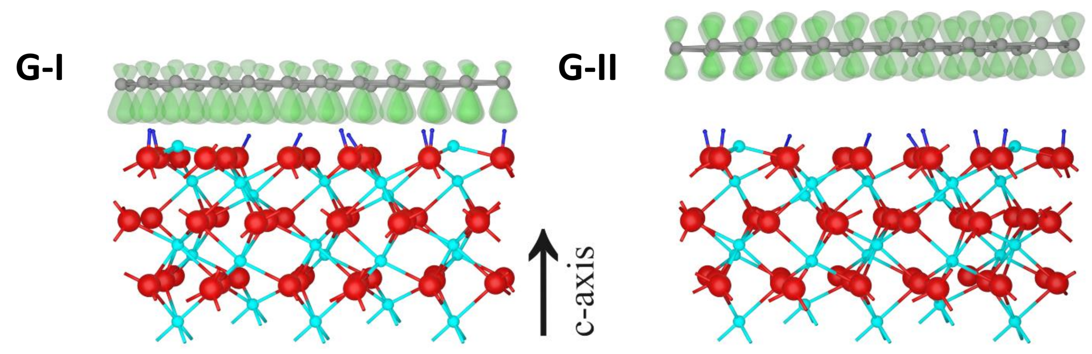




- Wrinkles or folds
- Detached graphene at sapphire steps

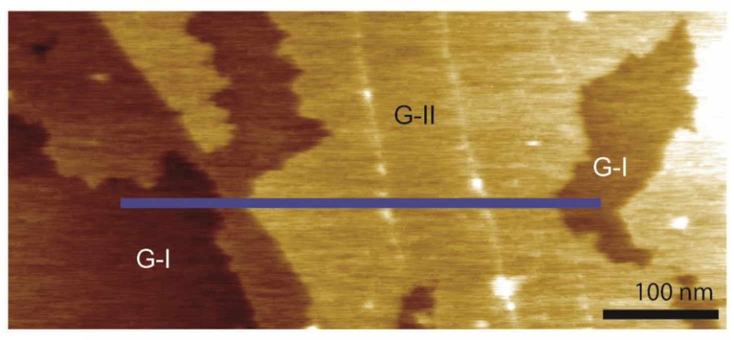
I_D/I_G = 0.16 – low defect density
I_{2D}/I_G = 2.2 – monolayer graphene

Graphene on Sapphire

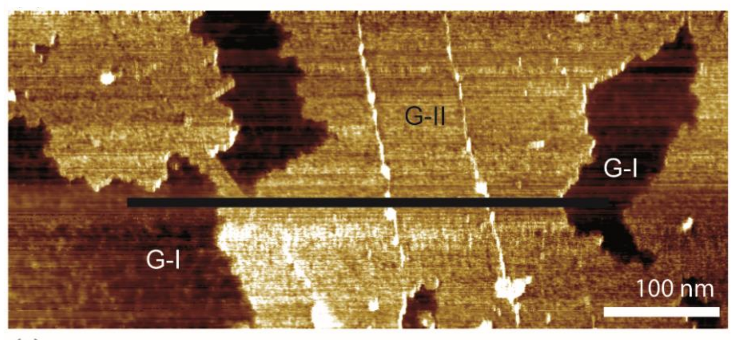


Two different binding regimes of SLG on α-Al_2O_3 could be identified, which have an influence on the atomic and macroscopic scale:
G-I: Weakly bonded graphene on the sapphire terrace
G-II: Nearly free standing SLG close to the step edges

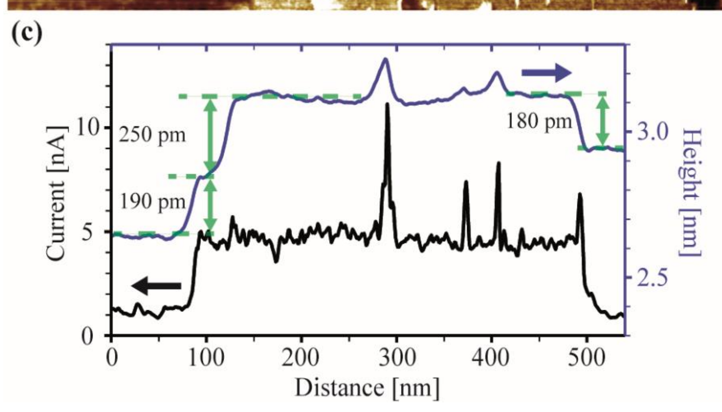
Conductive Atomic Force Microscopy (AFM)



AFM topography (contact mode)



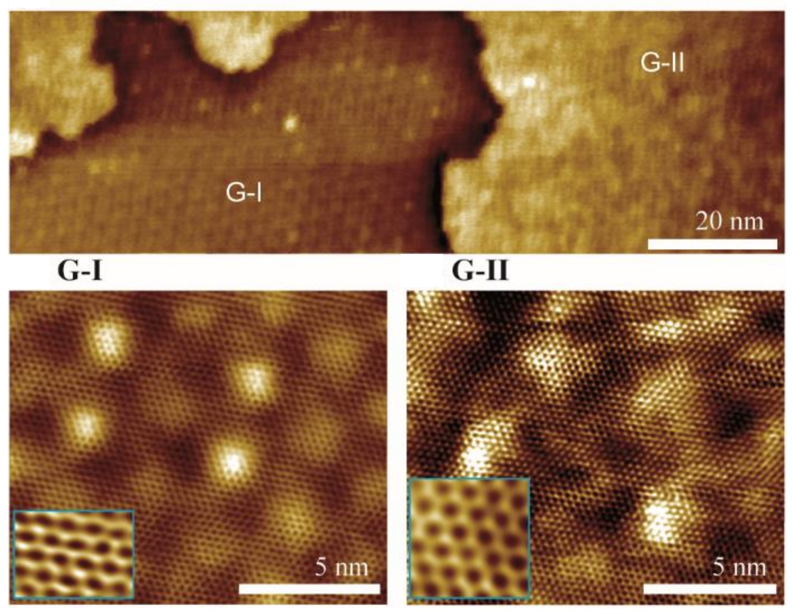
AFM conductivity



- Slight influence on the topography
- Difference in conductivity by a factor of 4.

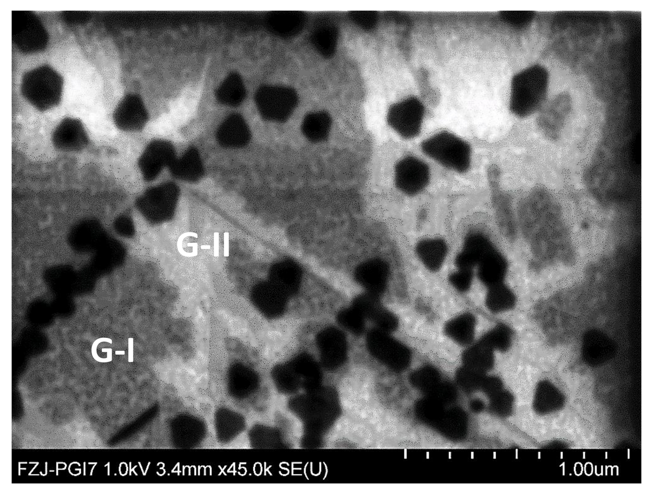
Scanning Tunneling Microscopy (STM)

Superstructure on the terraces and atomic structure of graphene on sapphire



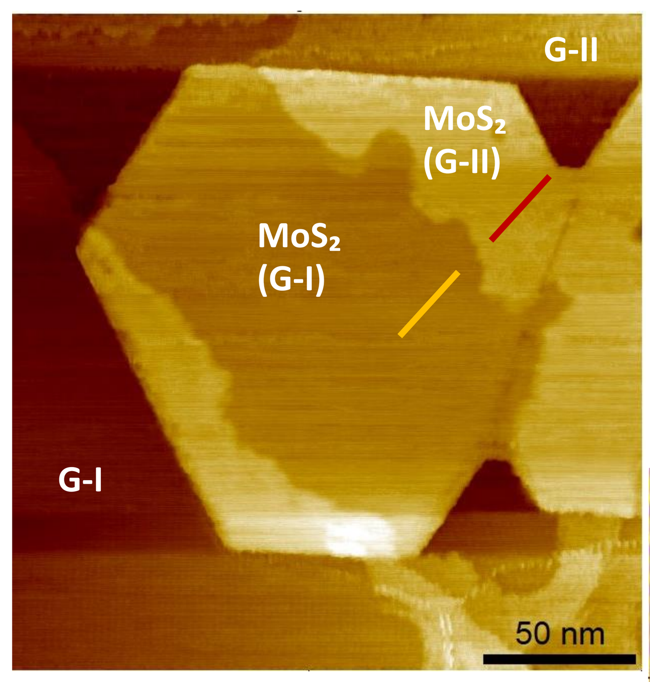
MoS_2 on SLG/ α-Al_2O_3

Scanning Electron Microscopy (SEM)

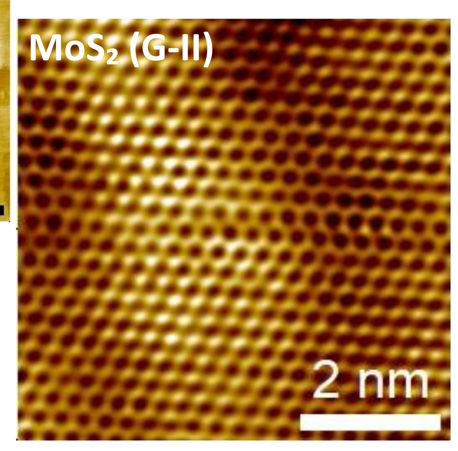


- MoS_2 crystals in the early stage of growth
- Hexagonal shapes
- Often multiple layers

Scanning Tunneling Microscopy (STM)

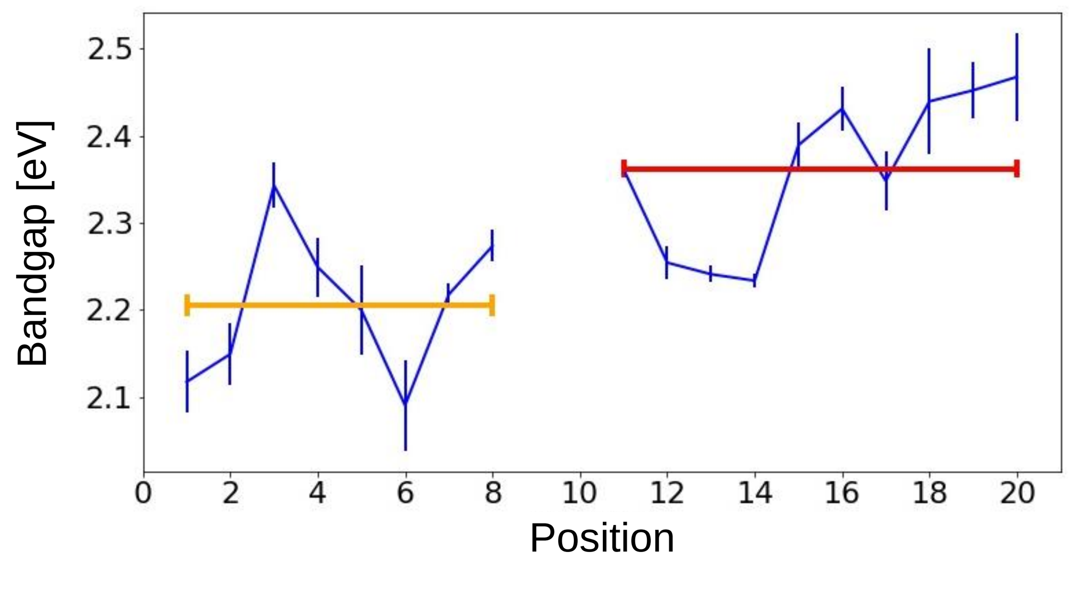


MoS_2 growth is almost independent of the underlying sapphire structure with the different graphene regions.



Single layer MoS_2 at the atomic scale doesn't show defects.

Bandgap analysis via STS



The different graphene regions have a measurable influence on the electric properties of the MoS_2 on top.

Internal Collaborations

AP1 Exchange of samples for characterization and growth.
Exchange of MOCVD process parameters and analysis results for an understanding of the substrate–film interactions.
Understanding of graphene properties on the MOCVD overgrowth of subsequent 2D-material.

AP2 Supply of CVD graphene for transfer.

AP3 AP4 Analysis of resistive switching properties of graphene/TMDC structures in STM and comparison with results obtained for macroscopic devices.
Exchange of characteristic switching parameters for device simulation.

Contribution to Milestone

Multiscale analysis of grown 2D-material layers and layer stacks for memristive device applications

- MOCVD growth of high quality graphene on sapphire in the MOCVD reactor JULE funded by NEUROTEC.
- Multiscale analyzes of graphene grown on sapphire with identification of two graphene regions which differ in binding and electronic properties.
- SLG / α-Al_2O_3 samples delivered to CST/RWTH for TMDC over growth.
- Multiscale analysis of MoS_2 / SLG / α-Al_2O_3 graphene with the focus on defects and electrical properties.

Further studies

- Localized switching behavior of the MoS_2 flakes.
- Comparison of $MoSe_2$, WSe_2, and MoS_2 in respect of growth and electrical properties.
- MOCVD of hBN in JULE.

References

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