

Growth Study for CVD of Single Layer Graphene on c-Plane Sapphire

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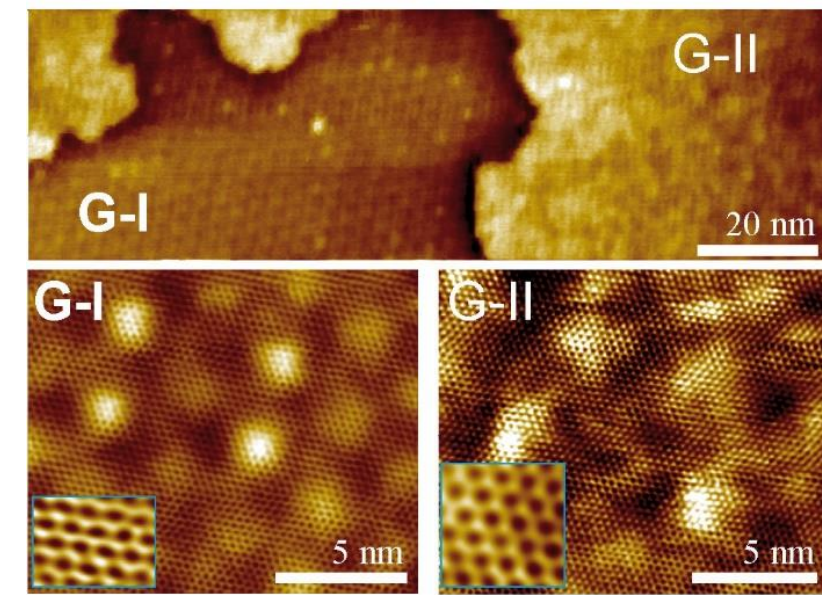
Standard Graphene Process – SPM results

Process parameters

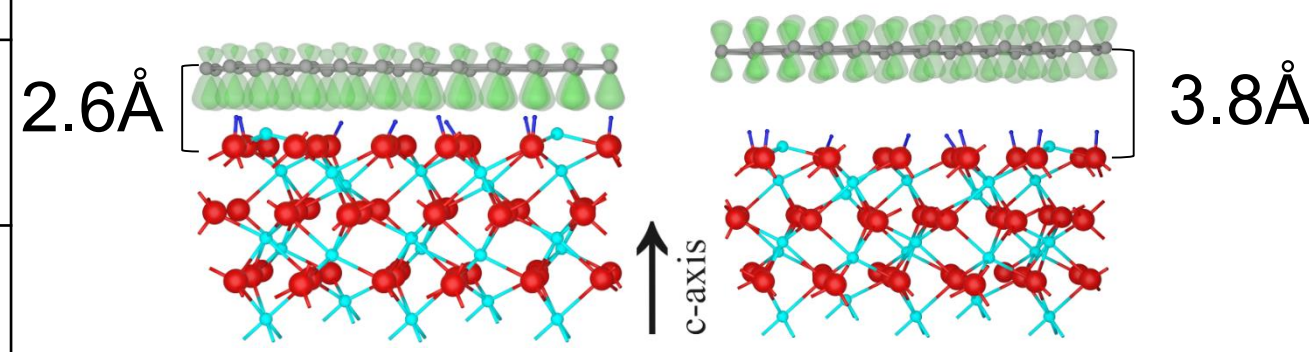
Desorption		
Zone	Gas	t (s)
TTC (°C)		
1400	H ₂	600

Growth			
Zone	CH ₄ : H ₂	Gas	t (s)
TTC (°C)			
1400	1 : 13.3	Argon	160

SPM [3]



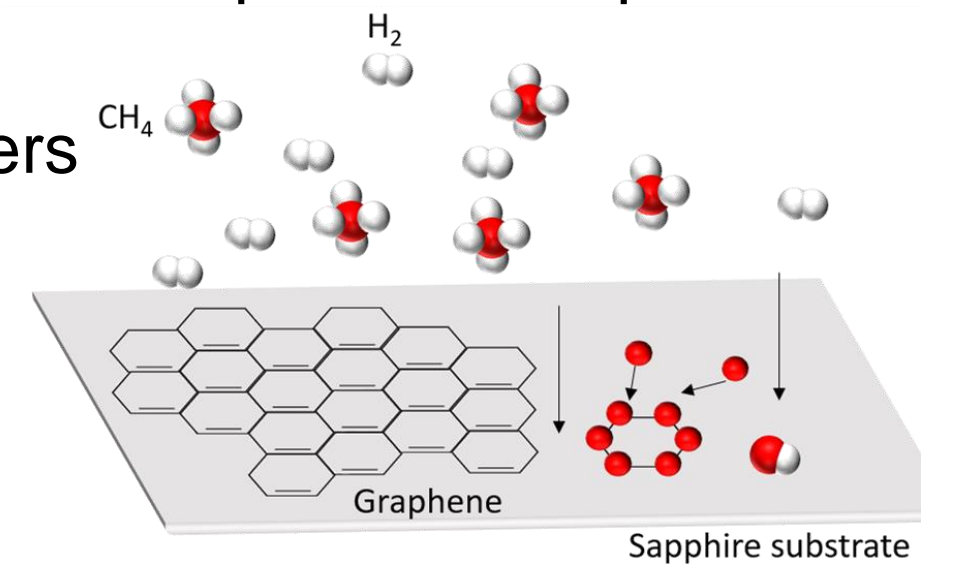
G-I: Weakly bonded graphene on the sapphire terrace
G-II: Nearly free standing SLG close to the step edges



Motivation & Background

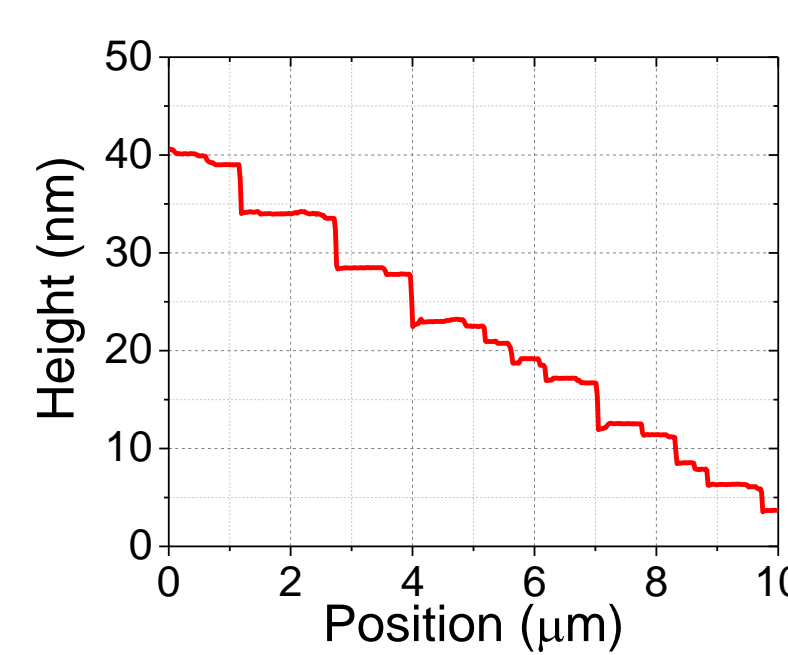
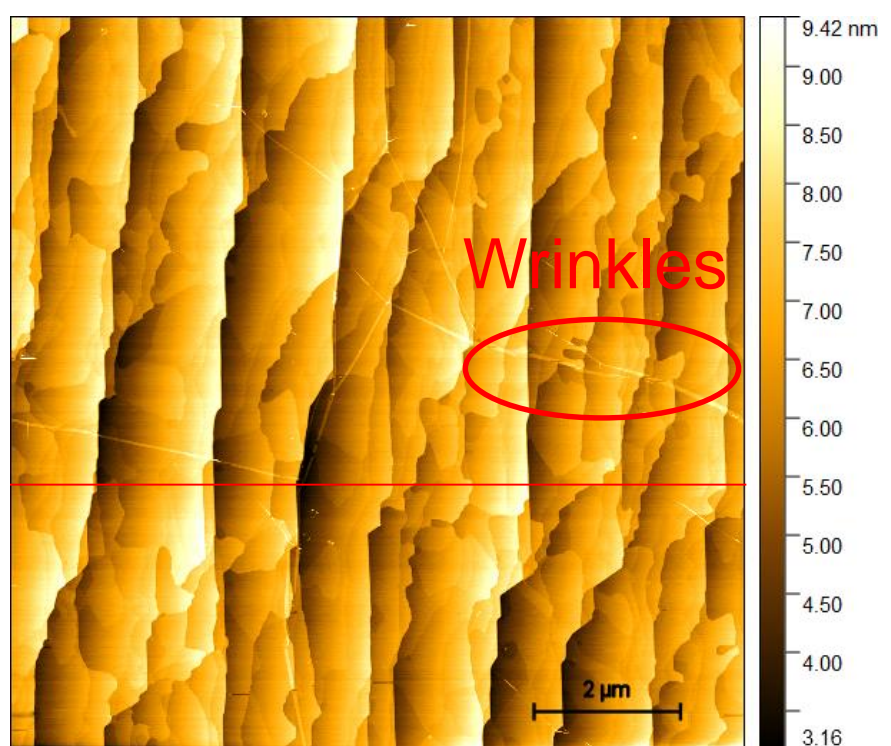
Chemical vapor deposition (CVD) provides the growth of large scale uniform and high quality 2D materials [1], which are interesting for new applications in flexible electronics, photonics and neuromorphic computing [2]. The growth of high quality single layer graphene (SLG) on sapphire is typically performed at high temperature of about 1400 °C, which demands for the use of graphite as susceptor material. In contrast, for MOCVD of transition metal dichalcogenides (TMDCs) SiC coated susceptors are used at temperatures below 1250 °C. Thus, a reduction of the SLG deposition temperature would allow consecutive MOCVD of SLG/TMDC heterostructures without switching between process chambers.

In this work, SLG was deposited on α -Al₂O₃ (0001) at 0.2° off-cut in an AIXTRON CCS 6x2" cold-wall reactor. A systematic study of the effect of the growth temperature is performed by detailed analysis of the SLG quality.

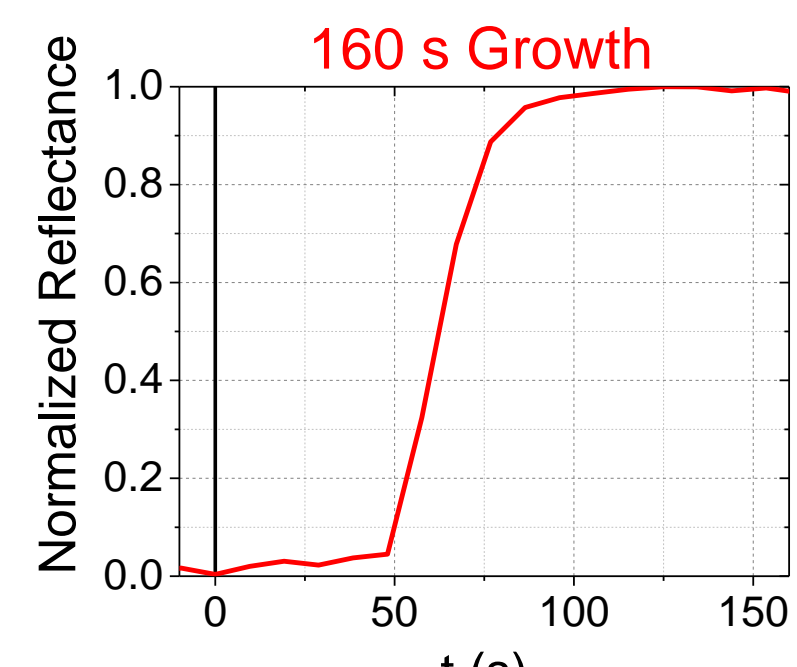
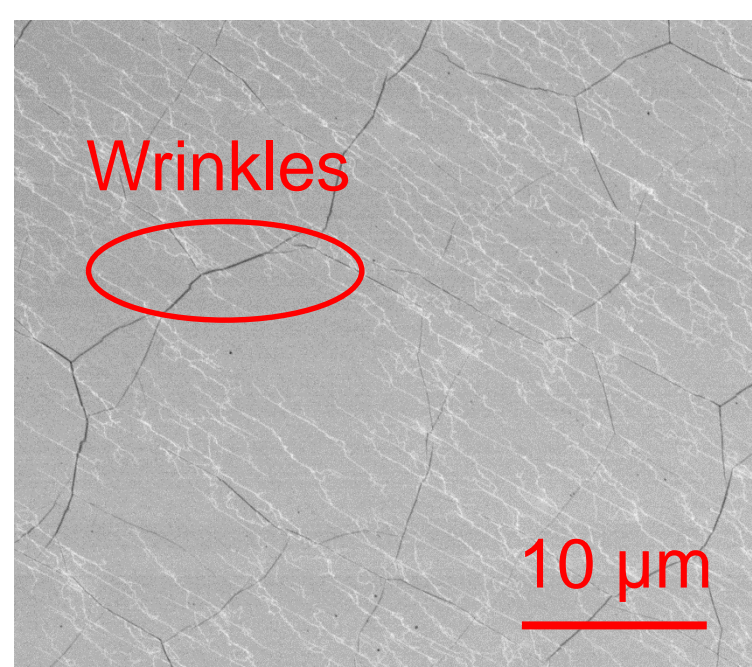


Desorption & Growth at 1400 °C

Morphology

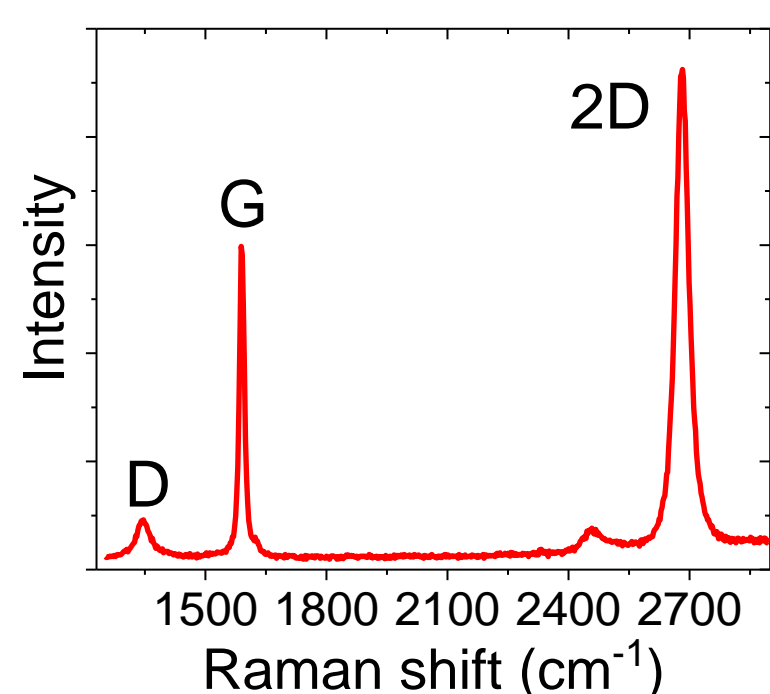


- 10x10 μm² AFM scan
- RMS 1.056 nm
 - Sapphire surface shows continuous terraces
 - Terrace width avg. 670 nm
 - Terrace height avg. 2.4 nm
 - Graphene wrinkles are revealed at a scale of about 10 μm.

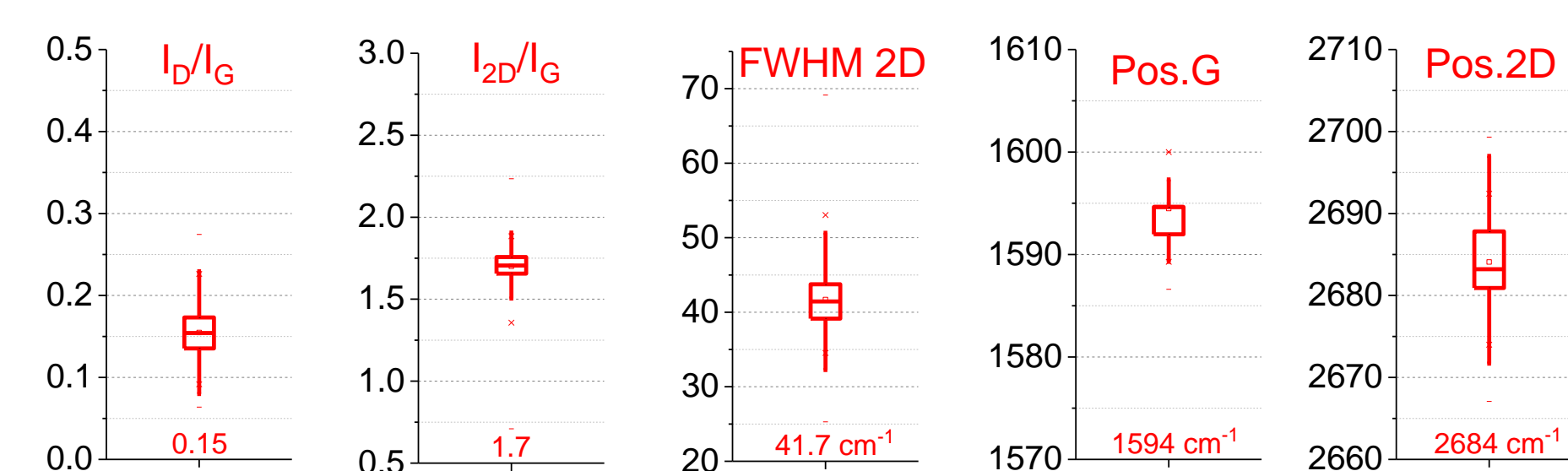


- 40x40 μm² SEM
- Wrinkles (black lines)
 - Detached graphene (white lines) at sapphire terrace edges
 - The growth time for SLG is about 160 s.

Raman characterization



532 nm laser, 8 mW, spot size 0.5 μm



Layer quality:

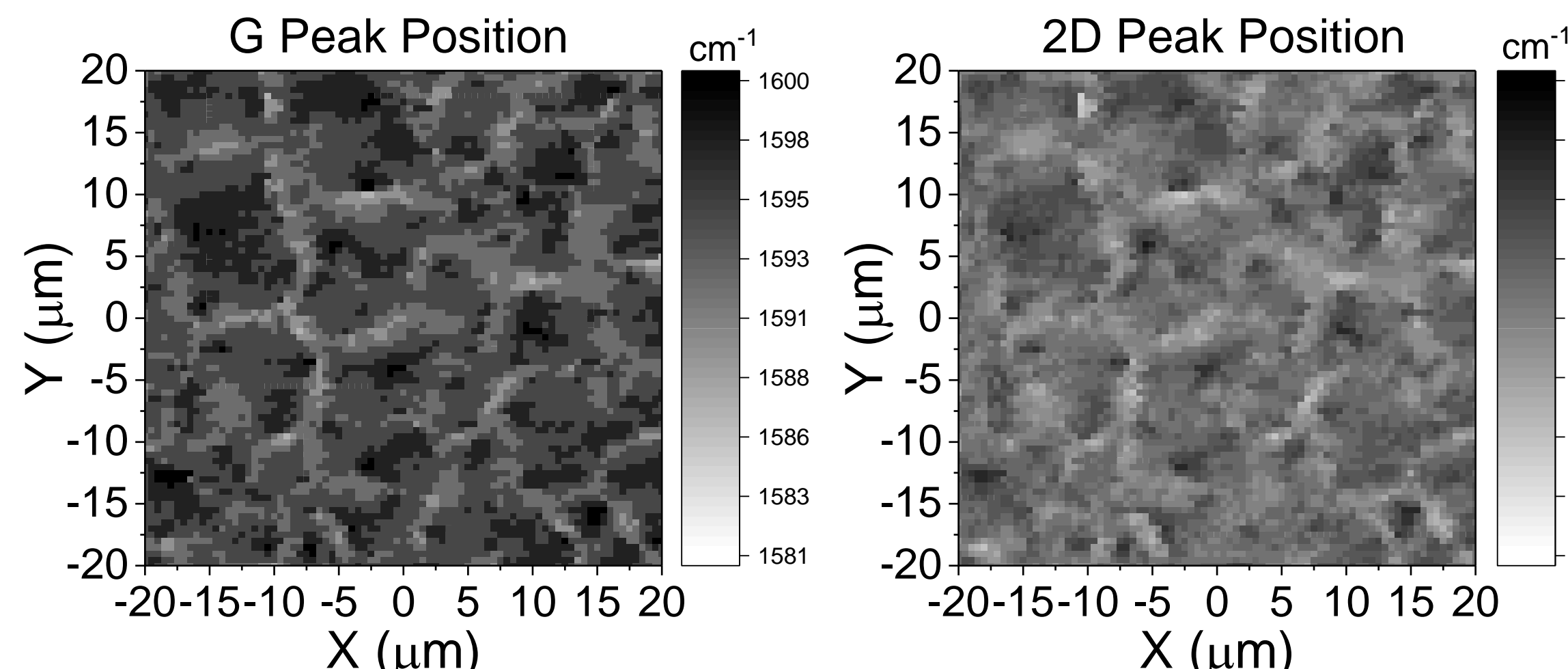
- Single layer graphene
- Low defect density
- Blue shift of the peak position w.r.t. free standing graphene [4] indicates compressive strain.

Electrical properties

Susceptor	Mobility (cm ² /V·s)	Sheet carrier density (1/cm ²)	Sheet resistance (kΩ/□)
Graphite	1670	1.65 × 10 ¹²	2.27

Hall measurement data taken for as-deposited SLG on sapphire in vdP geometry at room temperature.

Local structure

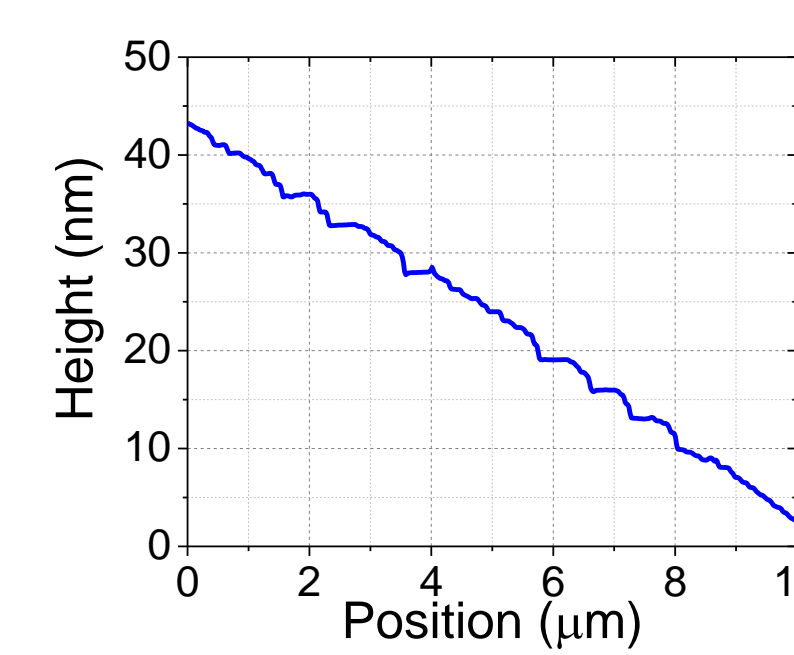
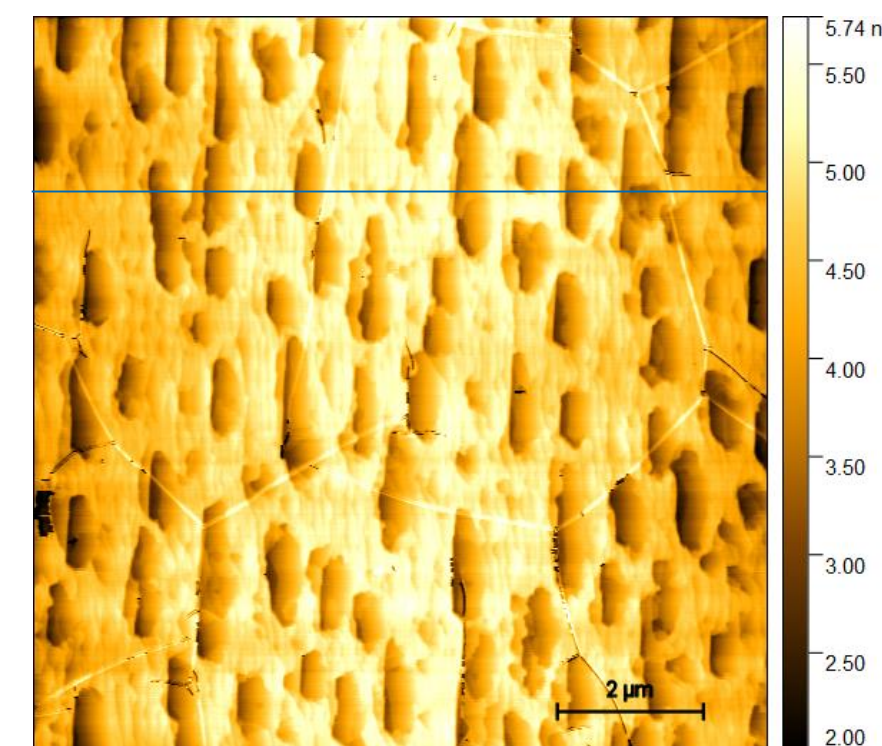


Raman mapping of 20 x 20 μm² region, 81 x 81 spots

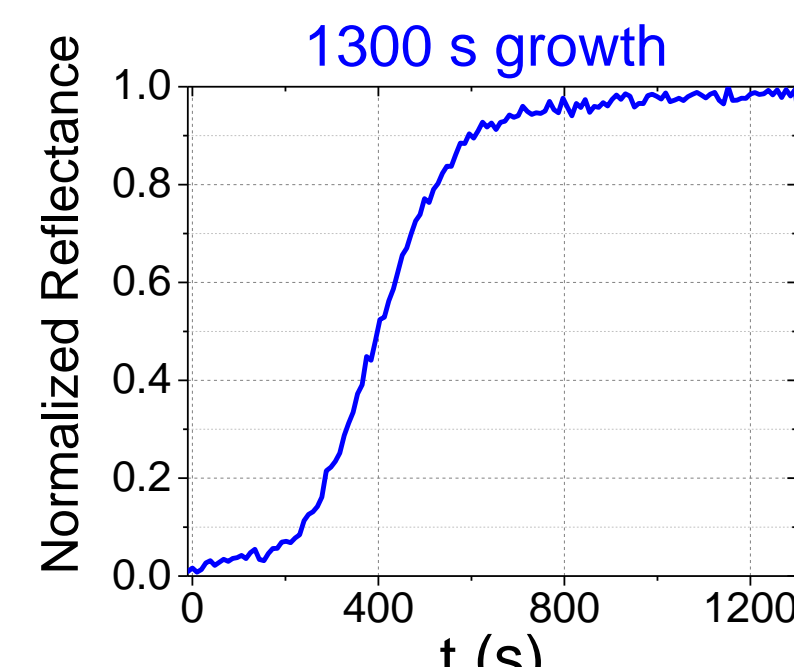
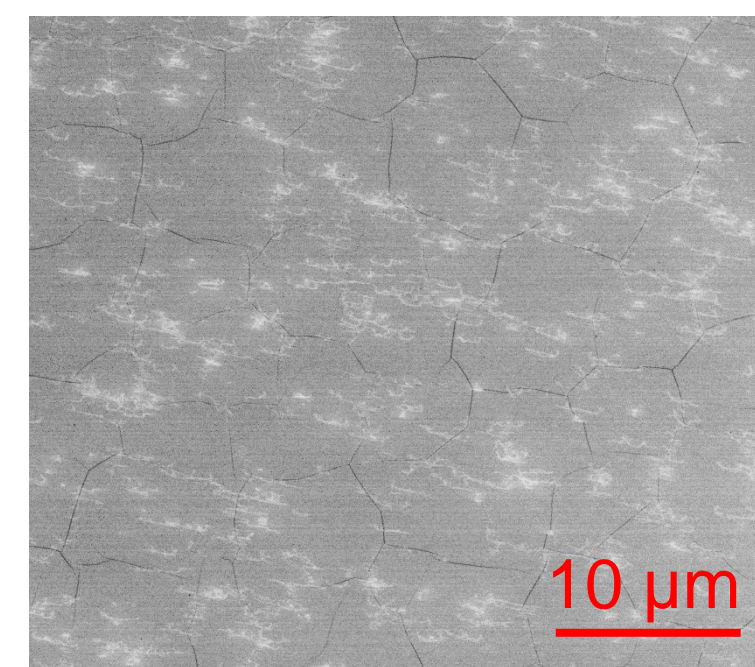
- Compressive strain distributed all over the SLG layer
- Graphene on wrinkles is close to free standing graphene [4] Pos(G) = 1579 cm⁻¹, Pos(2D) = 2673 cm⁻¹.

Desorption & Growth at 1250 °C

Morphology

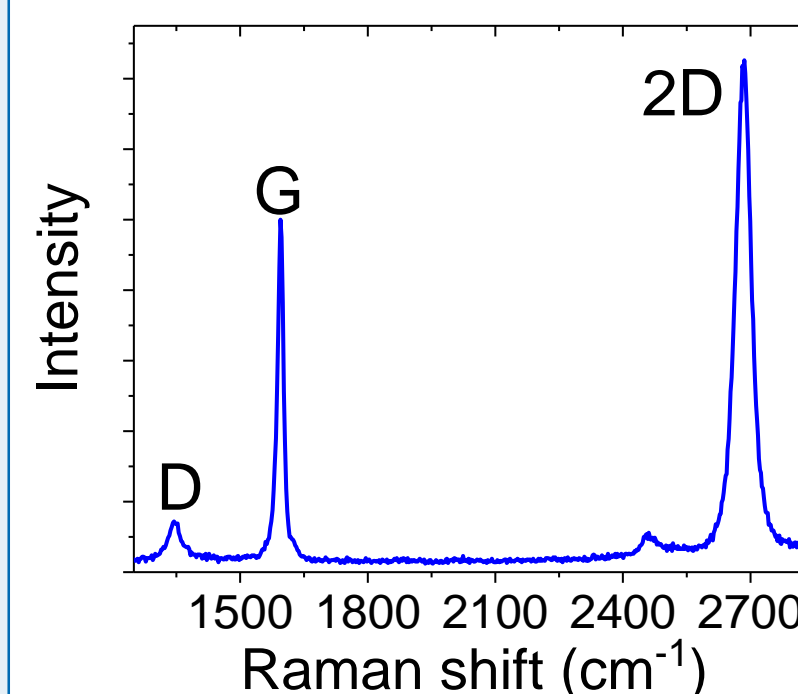


- 10x10 μm² AFM scan
- RMS 0.655 nm
 - Sapphire surface shows non-continuous terraces.
 - Terrace width avg. 220 nm
 - Terrace height avg. 0.9 nm



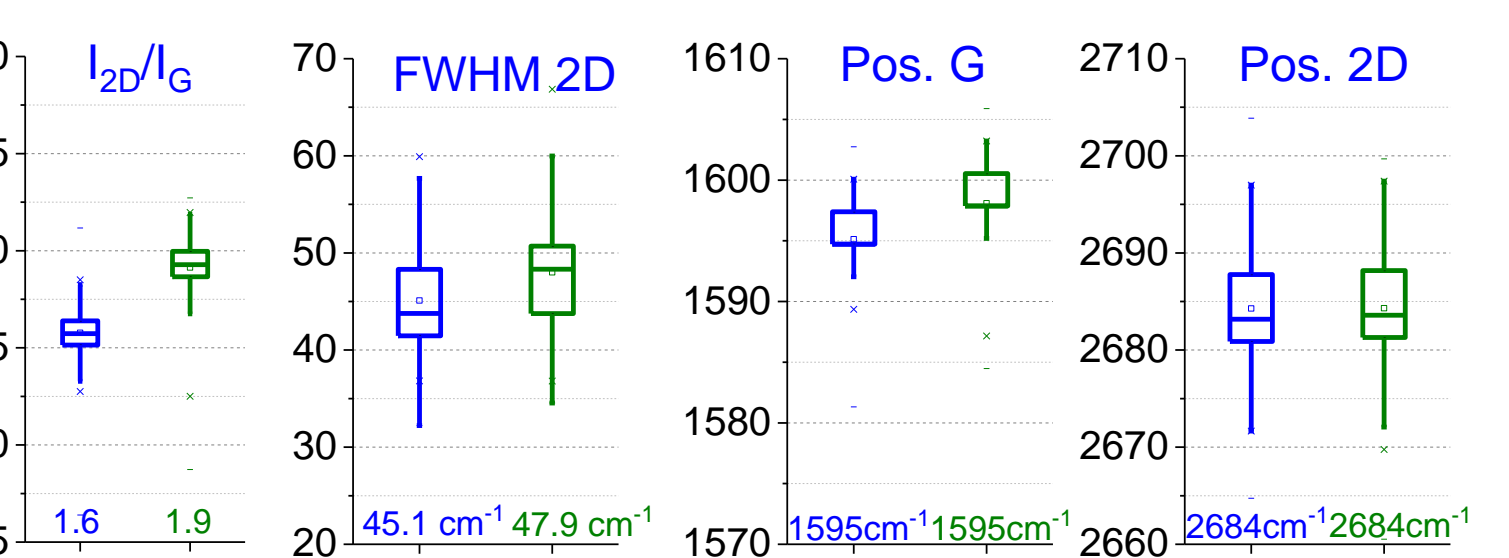
- 40x40 μm² SEM
- Detached graphene mostly shown at the edge of the big terraces
 - Growth time for layer closing is about 1300 s.

Raman characterization



Comparison of SLG quality for growth on sapphire at 1250°C utilizing

- Graphite susceptor
- SiC-coated susceptor



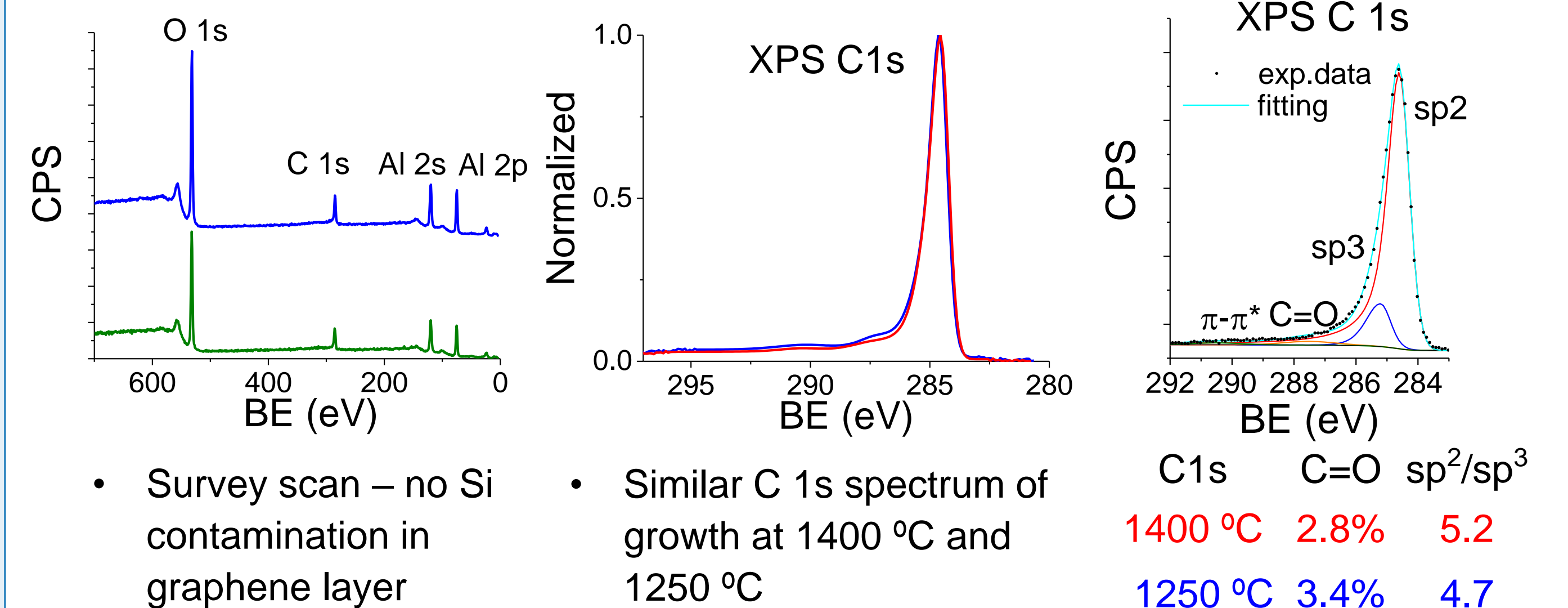
Layer quality:

- Single layer graphene
- Low defect density for graphite susceptor
- Increase of defect density for SiC susceptor
- Compressive strain

Electrical properties

Susceptor	Mobility (cm ² /V·s)	Sheet carrier density (1/cm ²)	Sheet resistance (kΩ/□)
Graphite	1500	0.68 × 10 ¹²	6.12
SiC	1320	1.05 × 10 ¹²	4.51

XPS – surface chemical state confirmation



- Survey scan – no Si contamination in graphene layer
- Similar C 1s spectrum of growth at 1400 °C and 1250 °C

Summary

- Closed SLG layer on sapphire with high quality has been obtained in an CVD process at 1400 °C susceptor temperature – low defect density, high carrier mobility, clean surface.
- Reduction of the susceptor temperature to 1250 °C still provides high quality SLG for a roughly 10 times increased growth time.
- SLG grown on sapphire is under moderate compressive strain with negligible effect of the growth temperature.
- The amount of amorphous carbon is slightly increased for decrease growth temperature.

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References

- [1] Mishra, N., et al., *SMALL* 2019,15, 1904906.
- [2] Zhang, D., et al., *IEEE TRANSACTIONS ON ELECTRON DEVICES* 2021, 68, 2033-2040.
- [3] Wördenweber, H., et al, under review.
- [4] Berciaud, S., et al, *Nano Letters* 2009, 9, 346-352.