Non-invasive Raman tomography for 2D-material applications

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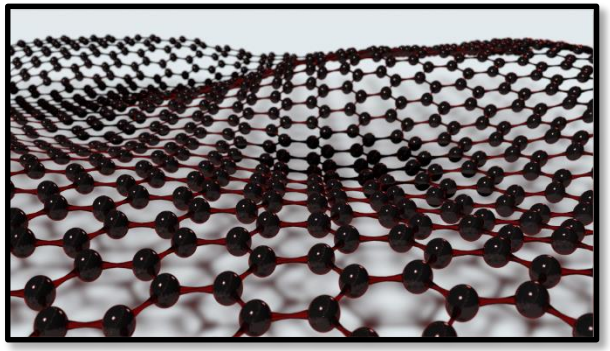
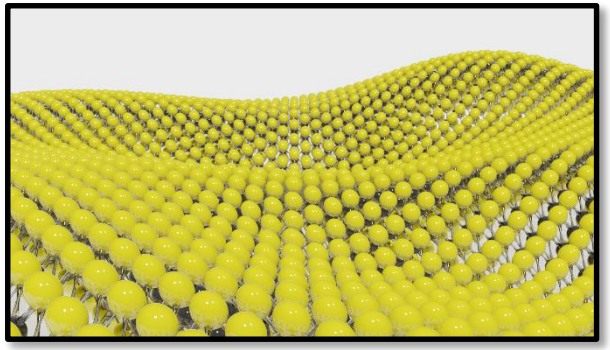
Graphene 2017 March 28-31 Barcelona (Spain)

Outline

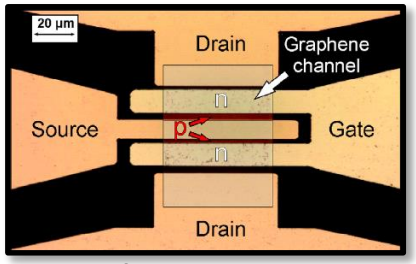
1. Introduction
2. Device fabrication
3. Raman tomography
4. Other applications
5. Conclusions

2D material device oriented research



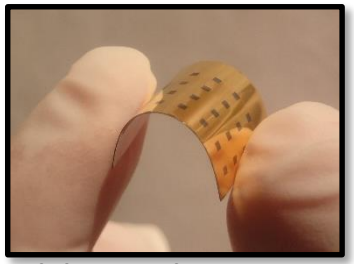


Electronics



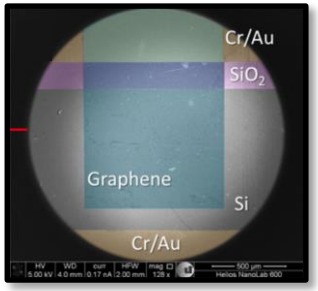
RF graphene transistor [5]

Flexible electronics



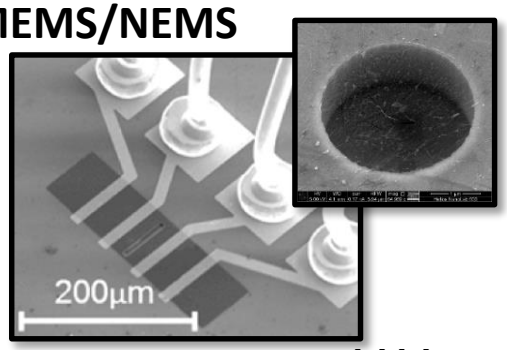
Flexible multispectral photodetector [6]

Opticoelectronics



2D material/Si photodetector [7]

MEMS/NEMS



Pressure sensor [8],[9]

→ Applications require non-invasive analytics

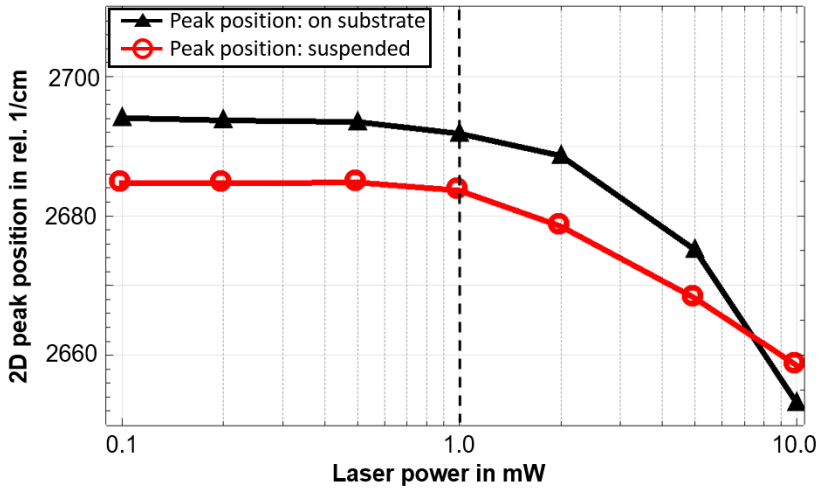
[1] Schneider, D. et al., accepted for oral presentation, DRC Conference 2016
[2] Riazimehr, Sarah, et al. *Solid-State Electronics,* Selected papers from the EUROSOI-ULIS conference, 115, Part B (January 2016)
[3] Wagner, S., et al. *Microelectronic Engineering*. March, 2016
[4] Pandey, H., et al. In *2016 Joint International EUROSOI-ULIS*, 143–46, 2016.
[5] Smith, A. D., et al. *Nano Letters* 13, no. 7 (July 10, 2013)

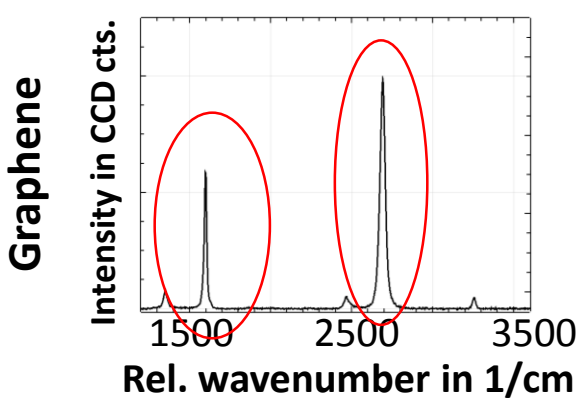
Raman spectroscopy

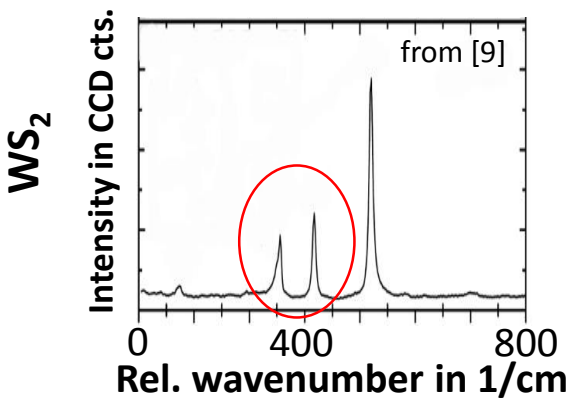
2D materials

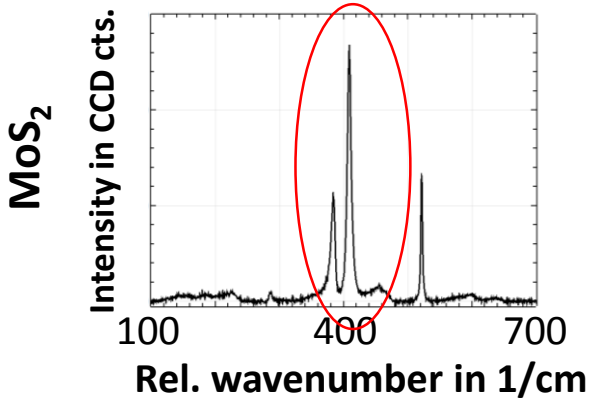
- Large-area scan possible (step motor and/or piezo stage: from µm up to cm size areas)
- non-invasive
- 2D material spectrum
  - high intensity
  - distinct fingerprint

Graphene laser dependency measurement





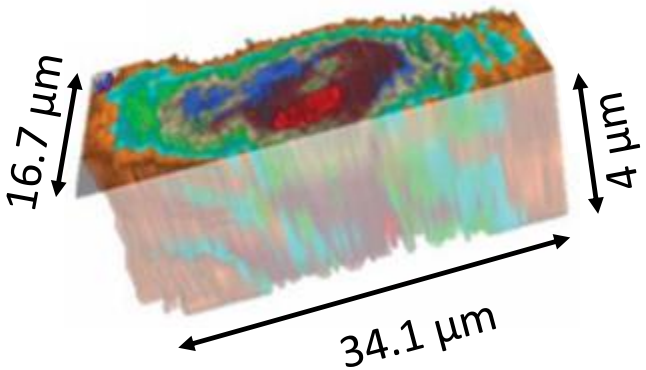




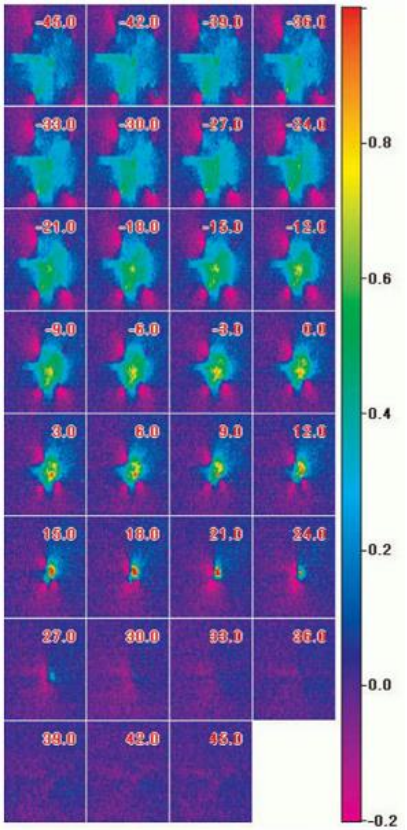
[9] A. Berkdemir *et al.*, *Sci Rep*, vol. 3, Apr. 2013.

Raman spectroscopy 3D-imaging

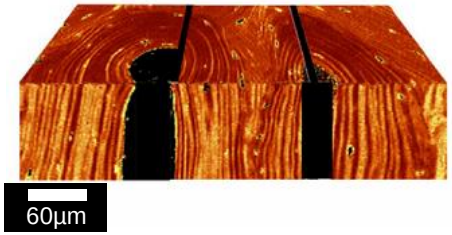
Biology:
Endothelial cells and vascular wall [6]



Material science:
Residual strain in diamond single crystals [8]



Biology:
Cortical bones[7]



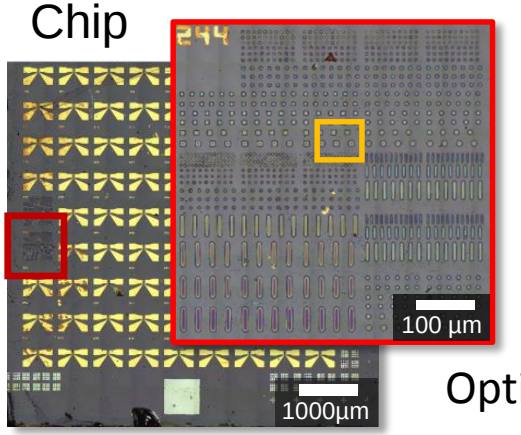
→ So far not done for semiconductor devices

[6]K. Majzner, A. Kaczor, N. Kachamakova-Trojanowska, A. Fedorowicz, S. Chlopicki, and M. Baranska, Analyst, vol. 138, no. 2, pp. 603–610, Dec. 2012.
[7]M. Kazanci *et al.*, *Bone*, vol. 41, no. 3, pp. 456–461, Sep. 2007.
[8] A. Crisci, F. Baillet, M. Mermoux, G. Bogdan, M. Nesládek, and K. Haenen, Phys. Status Solidi A, vol. 208, no. 9, pp. 2038–2044, Sep. 2011.

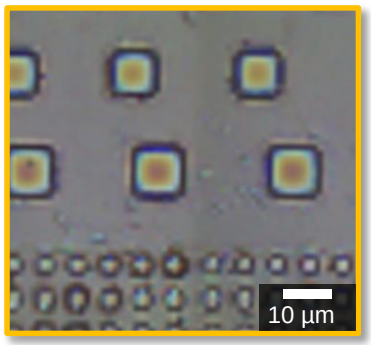
Device fabrication

Test structures

Chip

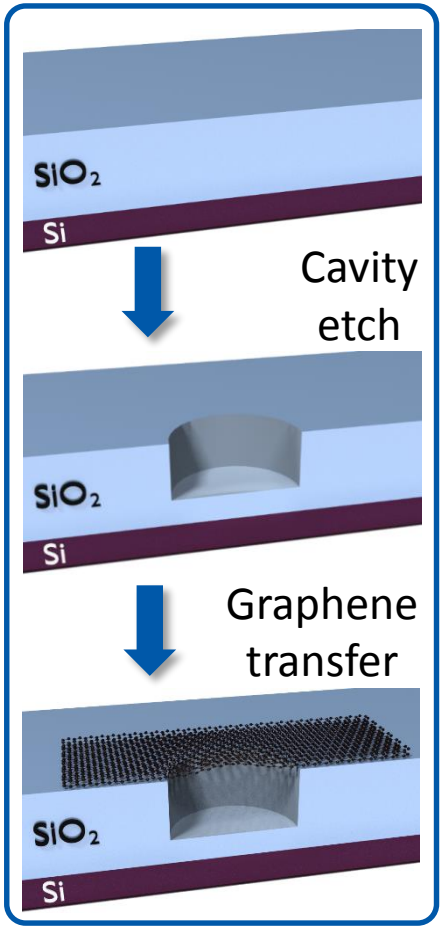


Optical micrograph



Optical micrograph

Cross-section of the test structure substrate



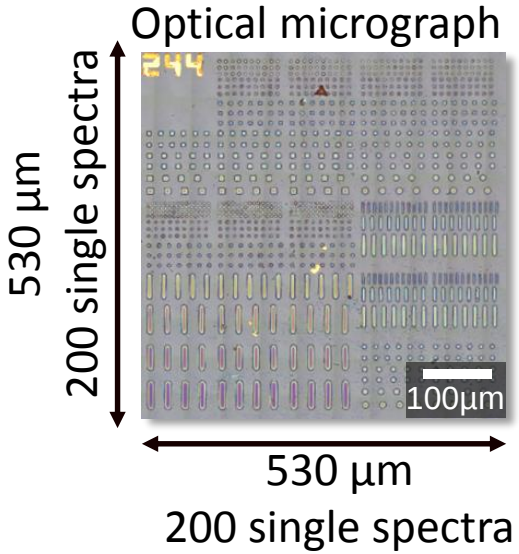
Chip:

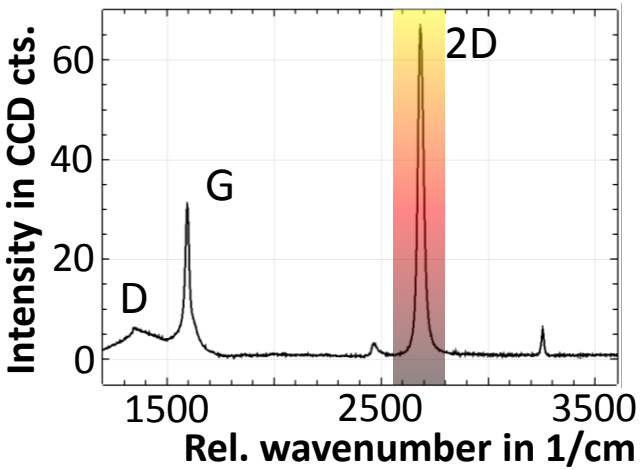
- Dimensions: 530 µm x 530 µm (Chip: 7 mm x 7 mm)
- 2x Test structures (+ 79x devices)

Test structures:

- Geometry: round, square and rectangular cavities
- Dimensions: 3µm – 20 µm diameter / edge length

Identification of intact membranes



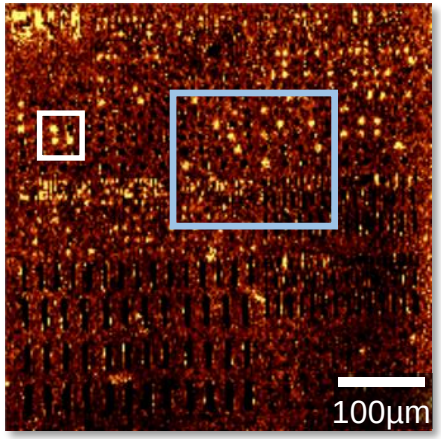


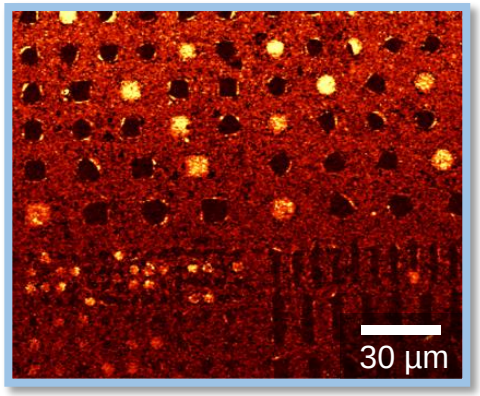
Single Raman spectrum of graphene from the device.

Area scan:

- Scan time: 13 min
- Filtered by the 2D-peak

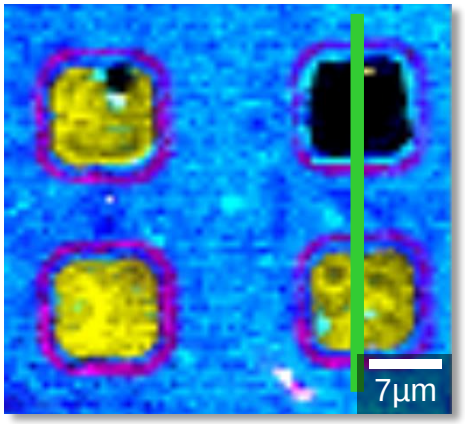
→ Highest intensity
→ Easy to identify
→ Higher intensity if suspended

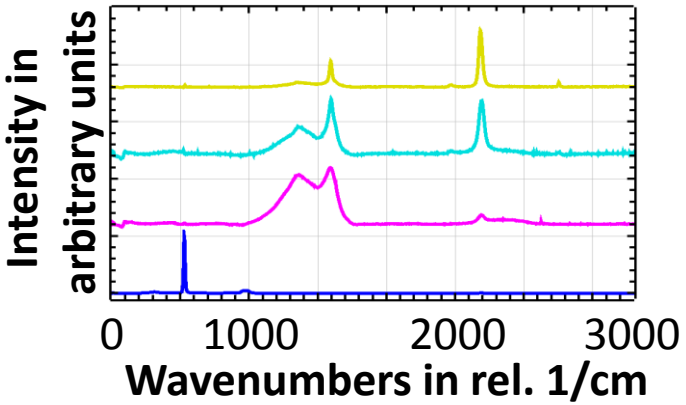




2D – peak filtered area maps

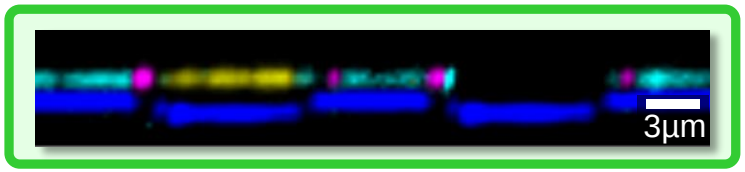
Raman tomography





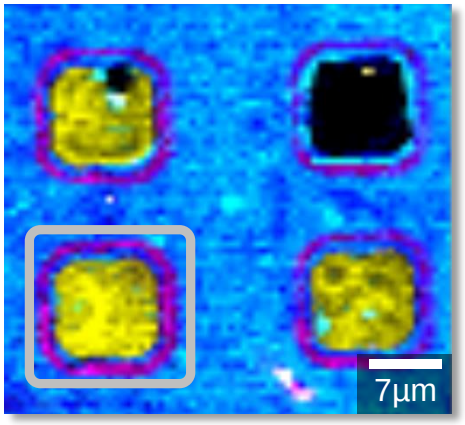
- Suspended graphene
- Graphene on SiO_2
- Amorphous carbon
- Silicon

Cross-sectional view



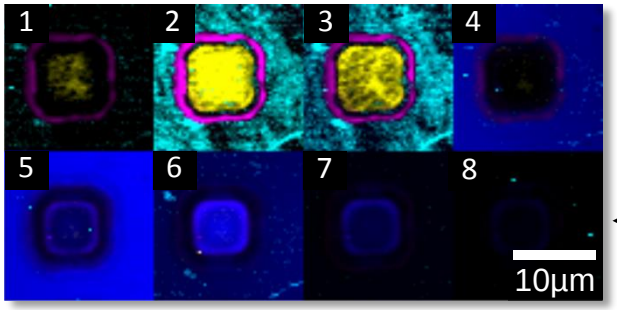
- Resolution: 300 nm lateral, 900 nm vertical
- Scan in z-direction:
  - Start with focus above the sample
  - Focus lowered step by step in z
  - Ending with focus in the sample
- Total 24 x 30 µm line scans

Raman tomography



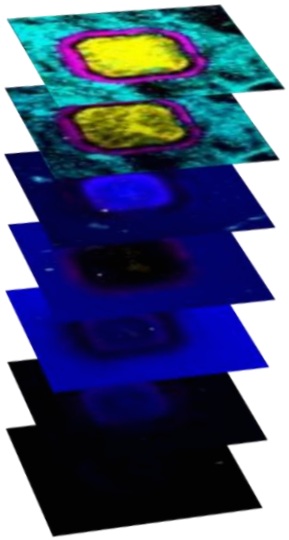
Images sequence at different z-height

Above membrane

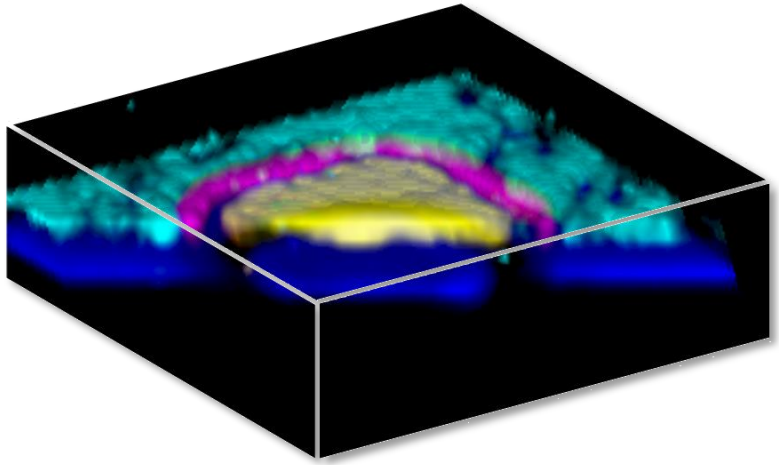


In the device

- Resolution: 300 nm lateral, 900 nm vertical
- 8 area scans at different z-height

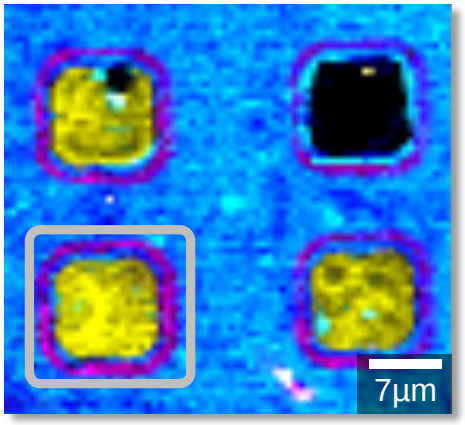


3D Raman tomography image



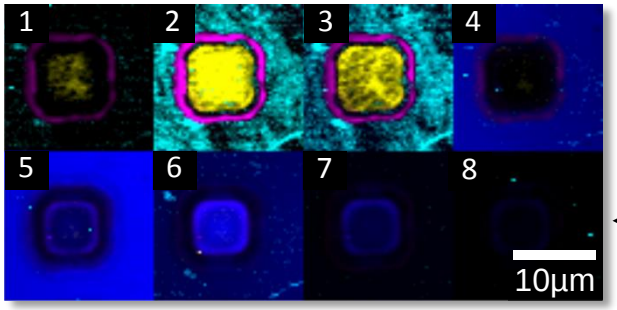
S. Wagner et al., Nano Lett., Jan. 2017.

Raman tomography

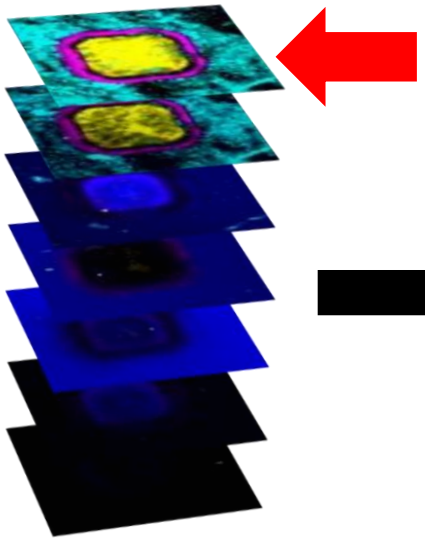


Images sequence at different z-height

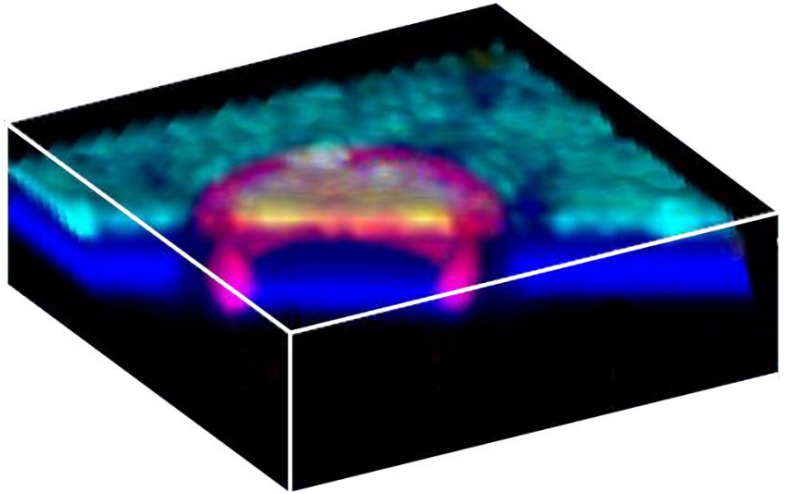
Above membrane →



← In the device



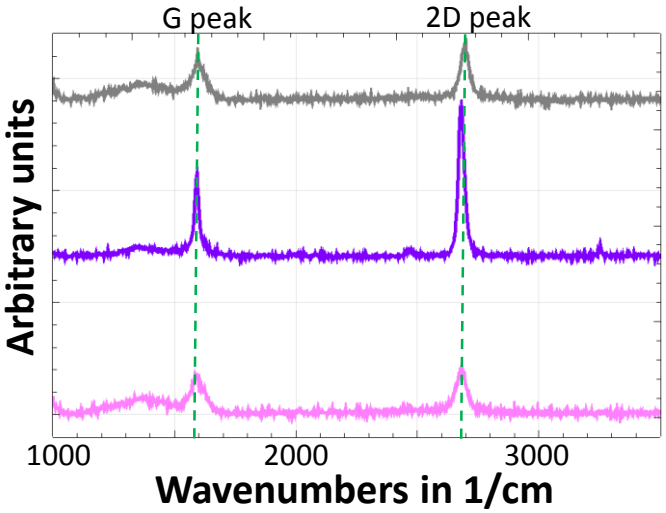
3D Raman tomography image



- Resolution: 300 nm lateral, 900 nm vertical
- 8 area scans at different z-height

S. Wagner et al., Nano Lett., Jan. 2017.

Depth dependent analysis

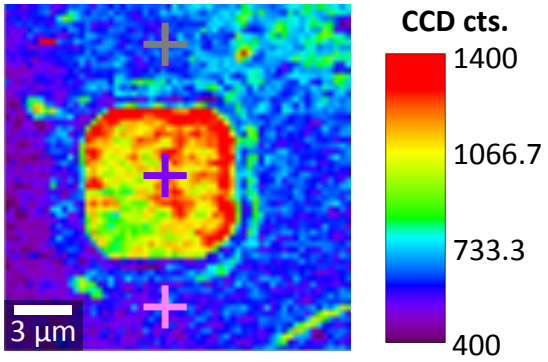


Each layers can be analyzed separately for:

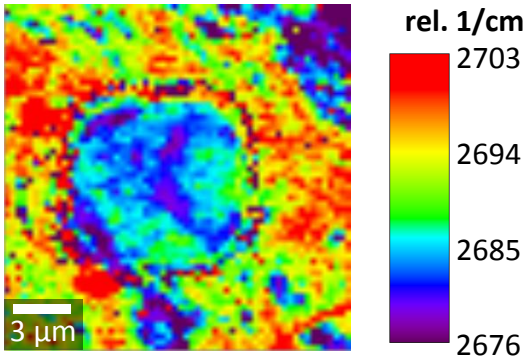
→ Strain variations

→ Doping variations

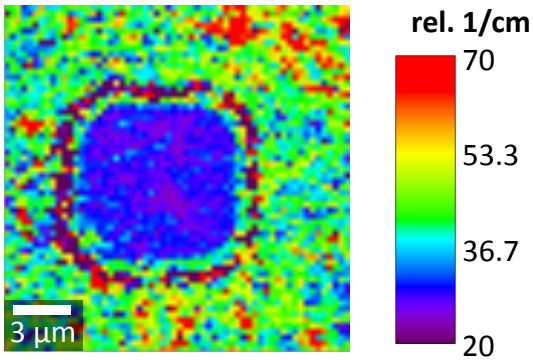
2D Intensity



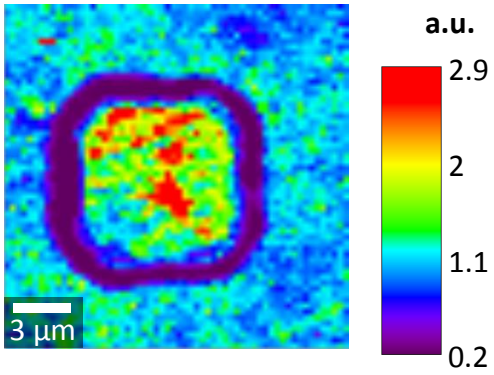
2D Peak position



2D FWHM

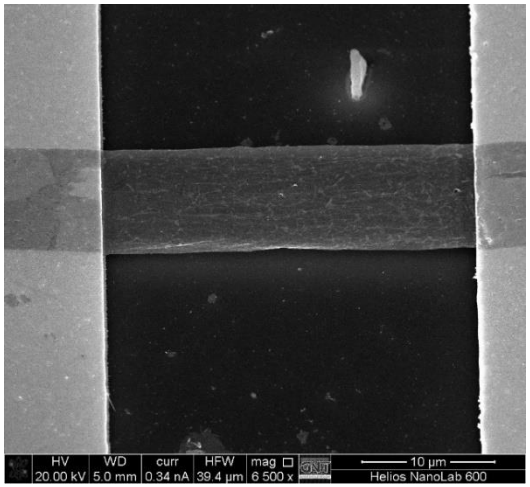


I(2D)/I(G) ratio



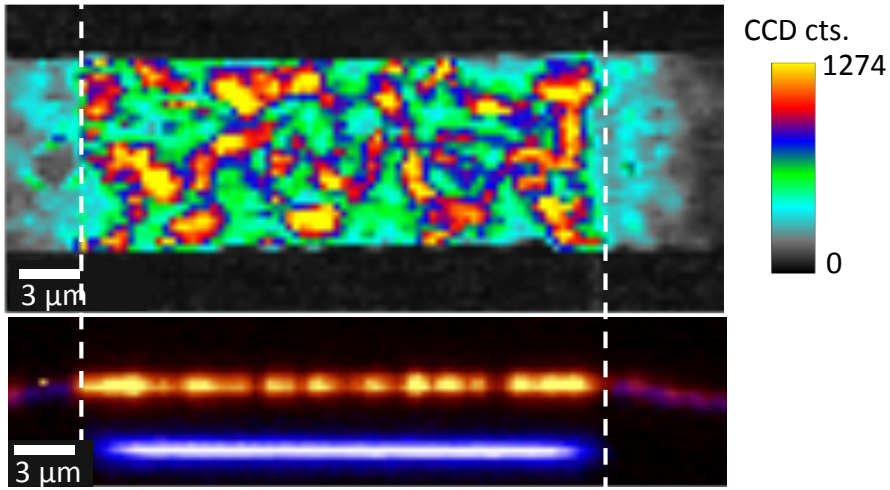
Other applications

Suspended 3 layer graphene over a trench



SEM image (45° tilt angle)

Area map: 2D-band intensity



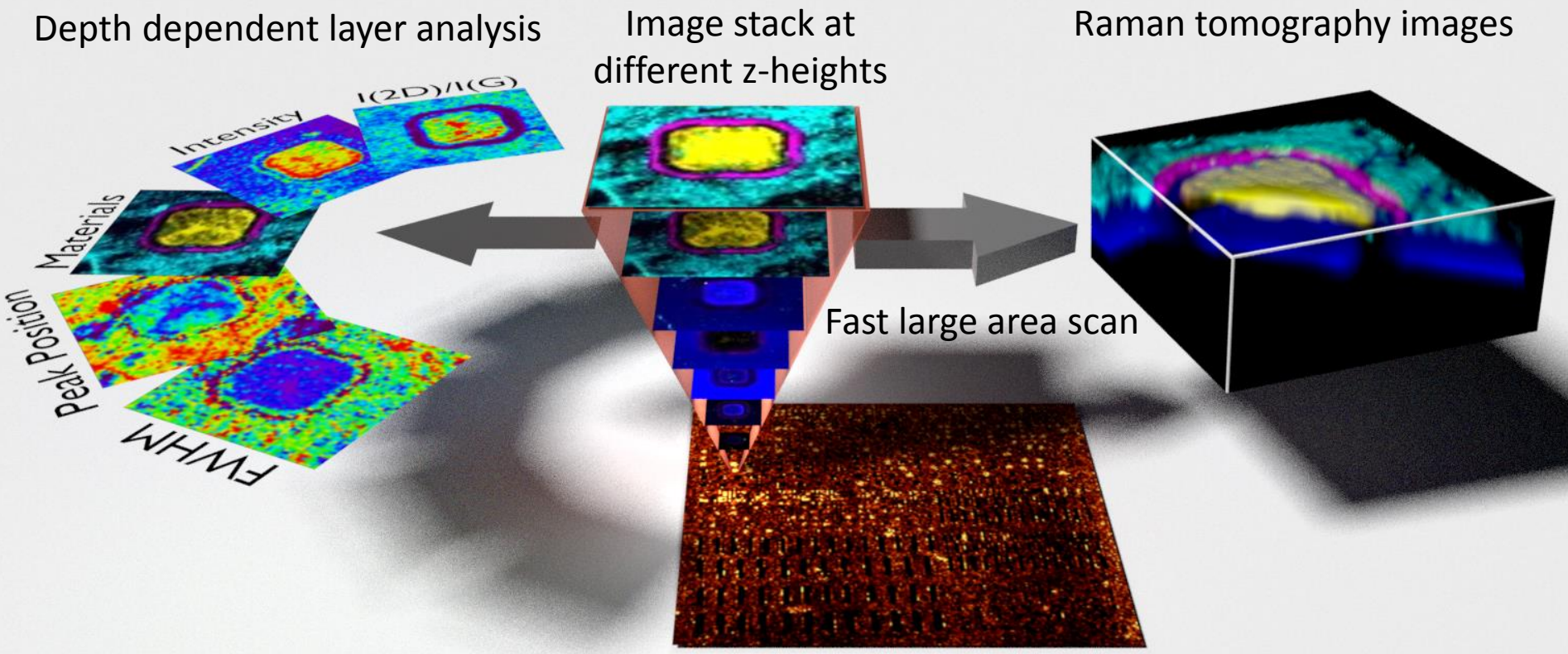
Cross-section:
2D-band (red/yellow) and Si (blue) intensity

Futher applications:

- Burried 2D materials (GBT[10], devices with dielectric layer covering, burried strained layers,...)
- Layer stacks (identify the materials and check for intact layers after fabrication)
- Graphene nano reactors[11]

[10] S. Vaziri *et al.*, *Nano Lett.*, vol. 13, no. 4, pp. 1435–1439, Apr. 2013.
[11] B. Ding *et al.*, *Chem. A*, vol. 1, no. 4, pp. 1096–1101, Dec. 2012.

Conclusion



- System dependent resolution not high enough for layer thickness measurement
- non-invasive
- Detection to different materials
- Depth dependent analysis

Acknowledgement

WITec: Thomas Dieing
Graphenea: Alba Centeno, Amaia Zurutuza

erc
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Bundesministerium für Bildung und Forschung

GNT GRAPHENE BASED NANOTECHNOLOGY

Thank you very much for your attention