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Ultra Low Energy SIMS Depth Profiling of 2D Materials

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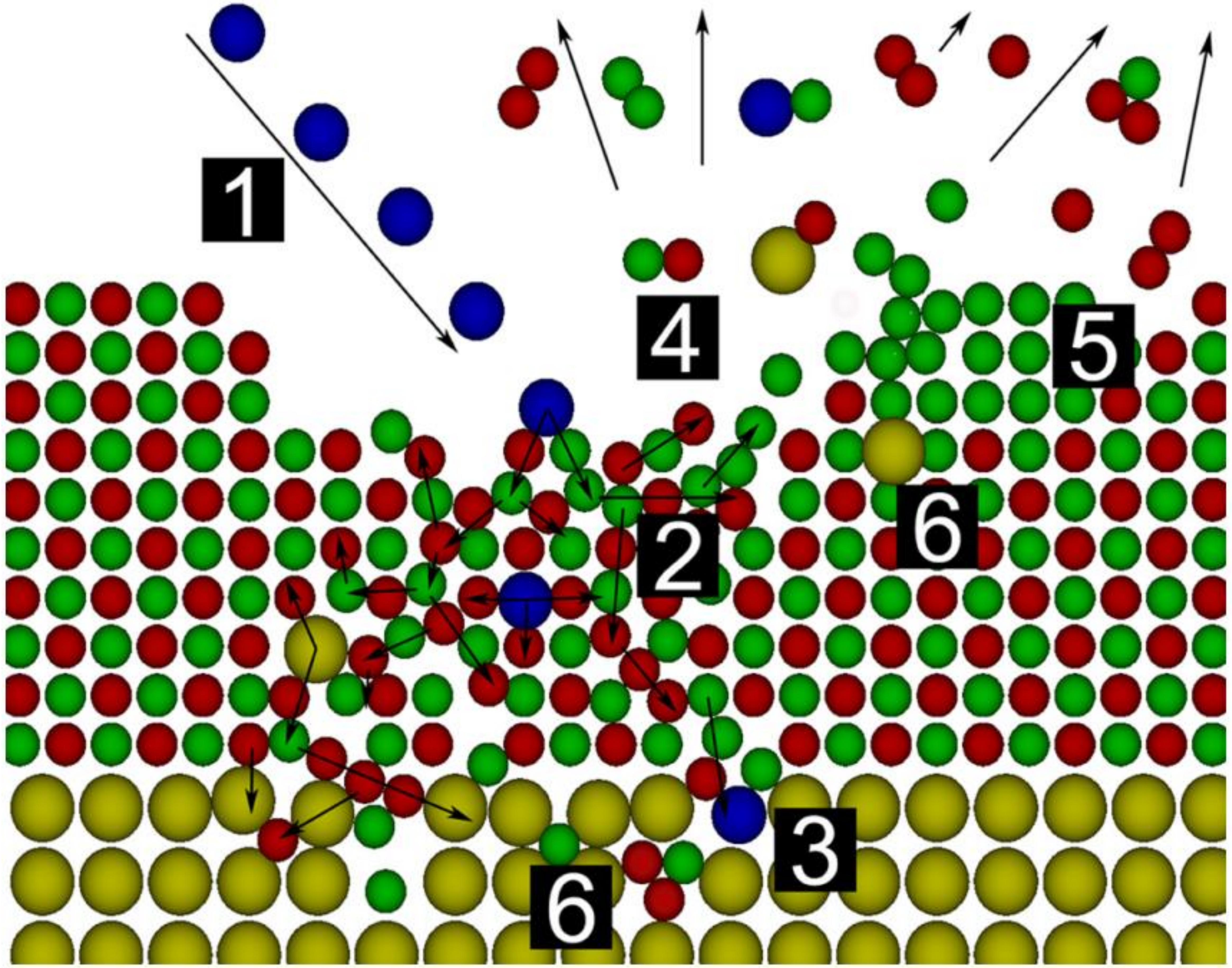
SIMS - principles



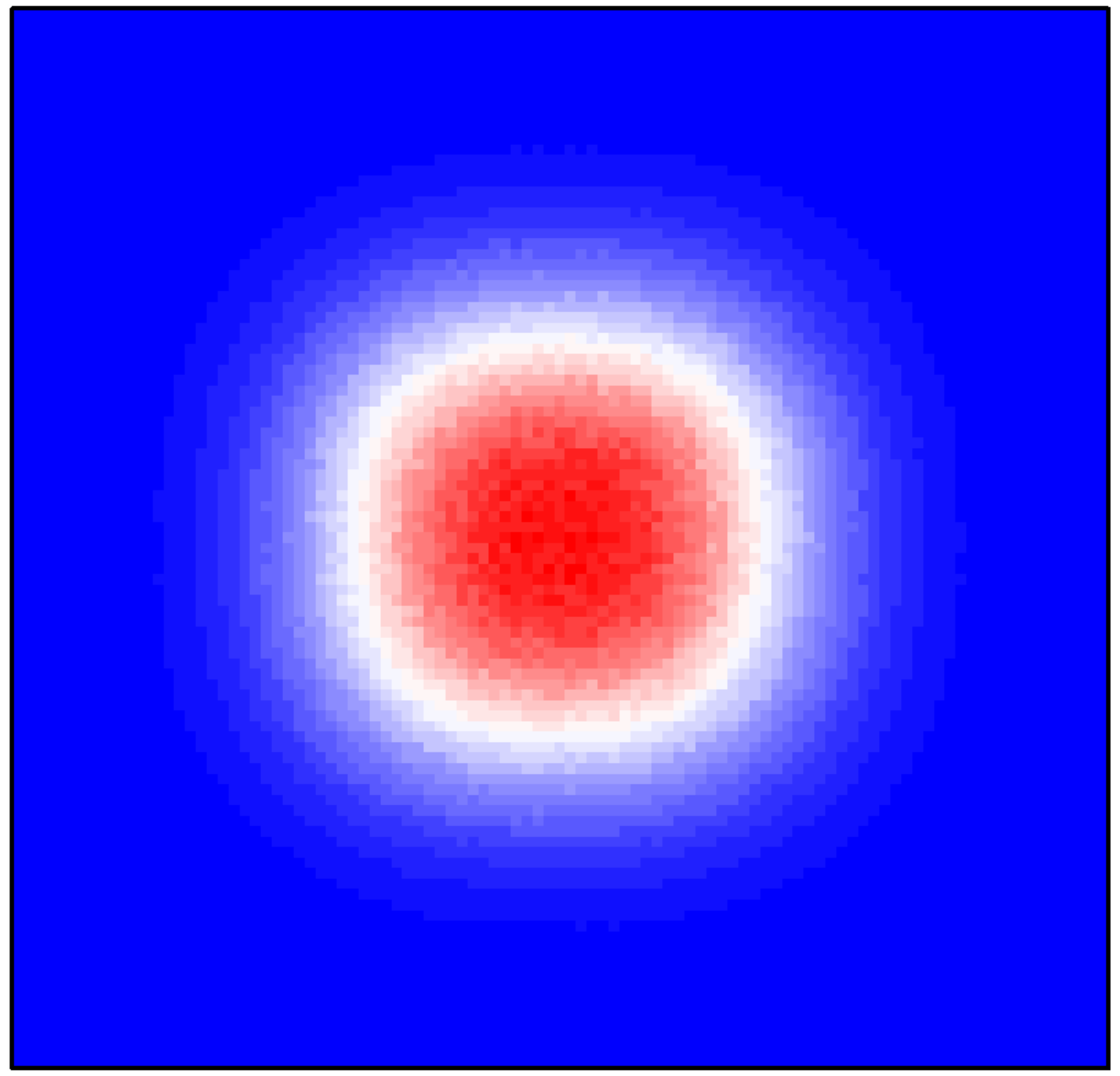
1. Primary beam
2. Collision cascade
3. Implantation
4. Sputtering and ionization
5. Preferential sputtering
6. Mixing

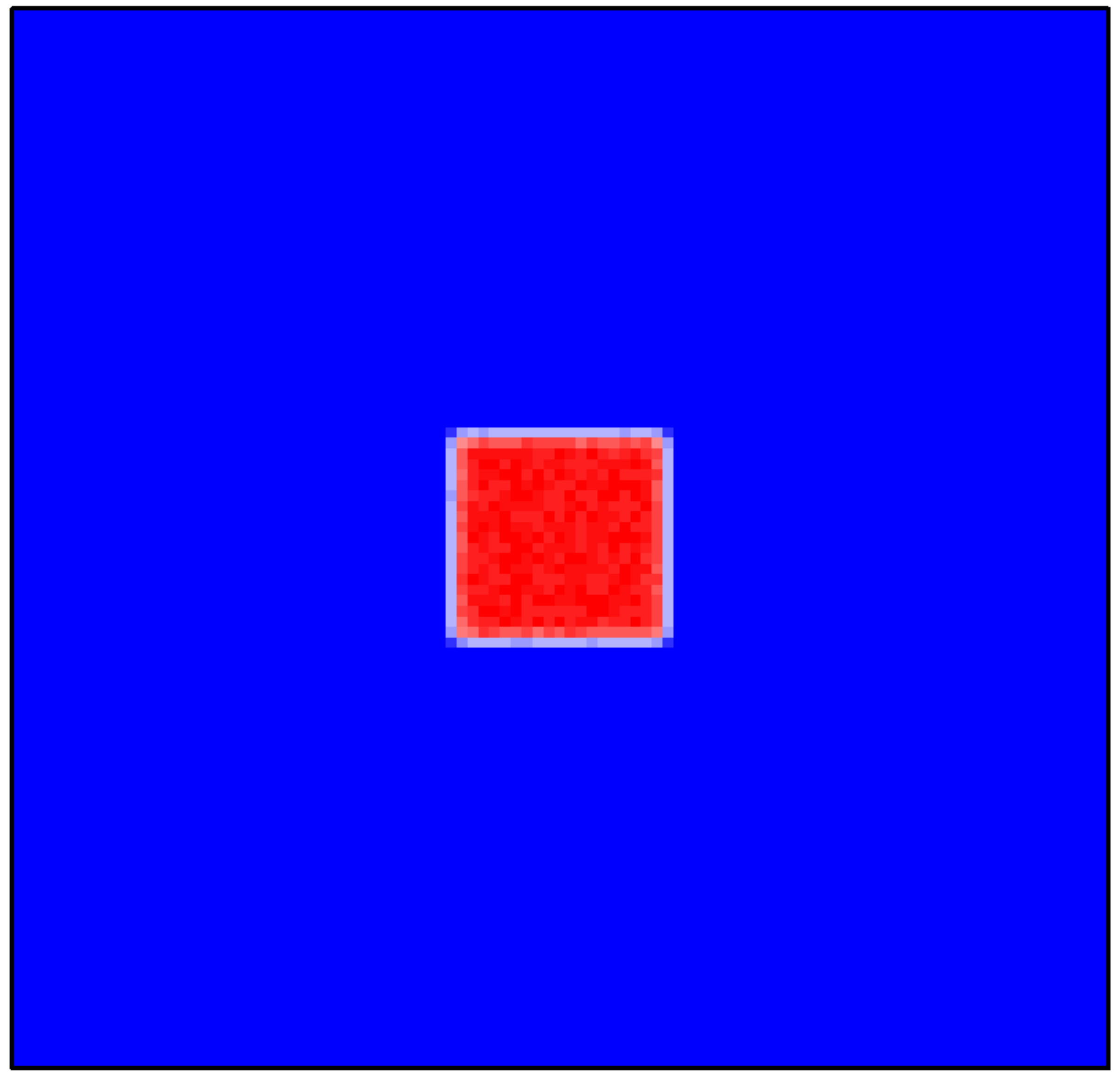
CAMECA IMS SC Ulra

EXLIE (EXtreme Low Impact Energy) technology

- RF Plasma for oxygen column – down to 60 eV
- Floating voltage for cesium column – down to 90 eV

Beam shape


Typical Gaussian-shaped beam

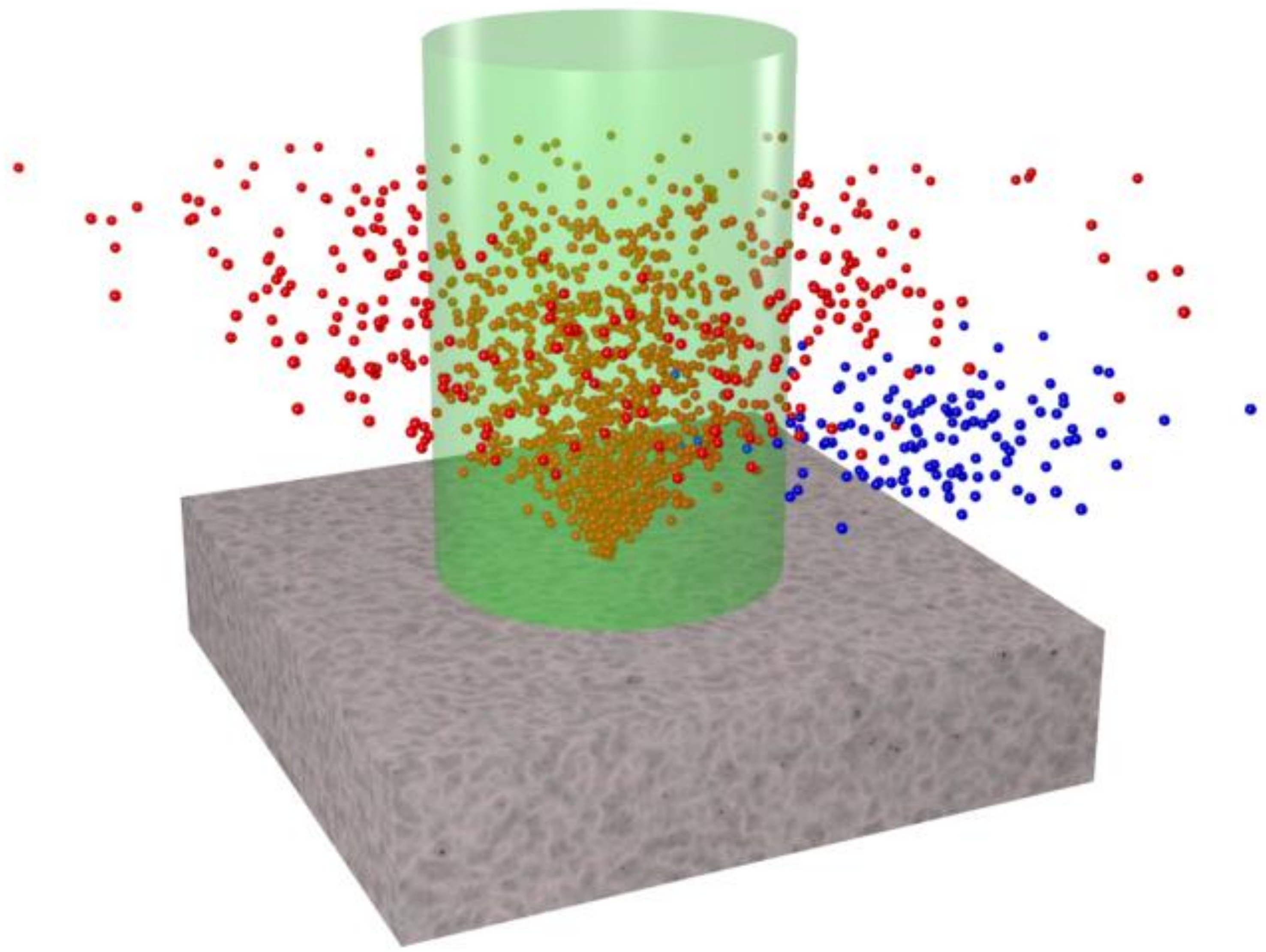

Projected on square stencil

Dedicated measurement procedures

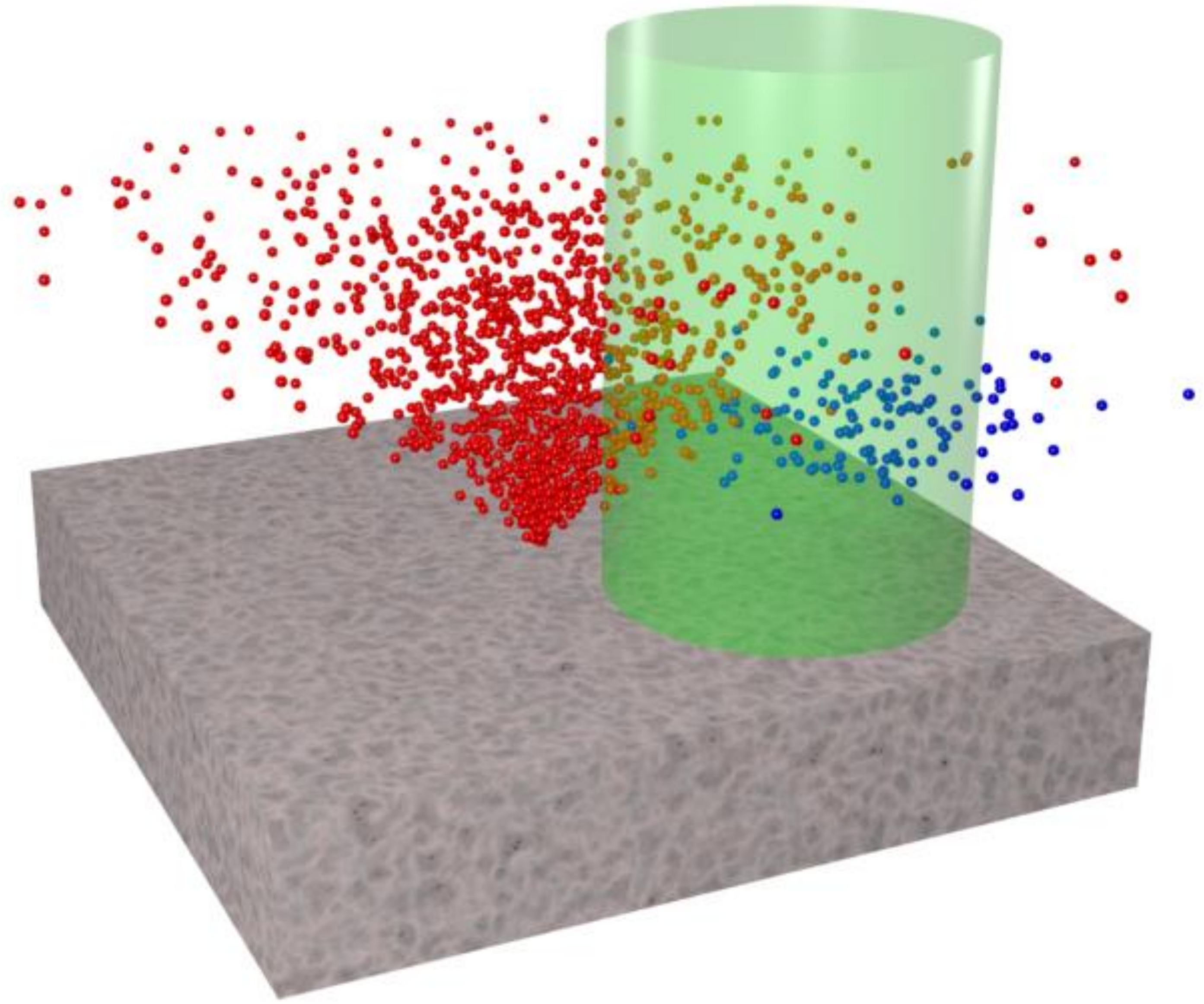
Type of procedures

- Standard/universal
- Dedicated

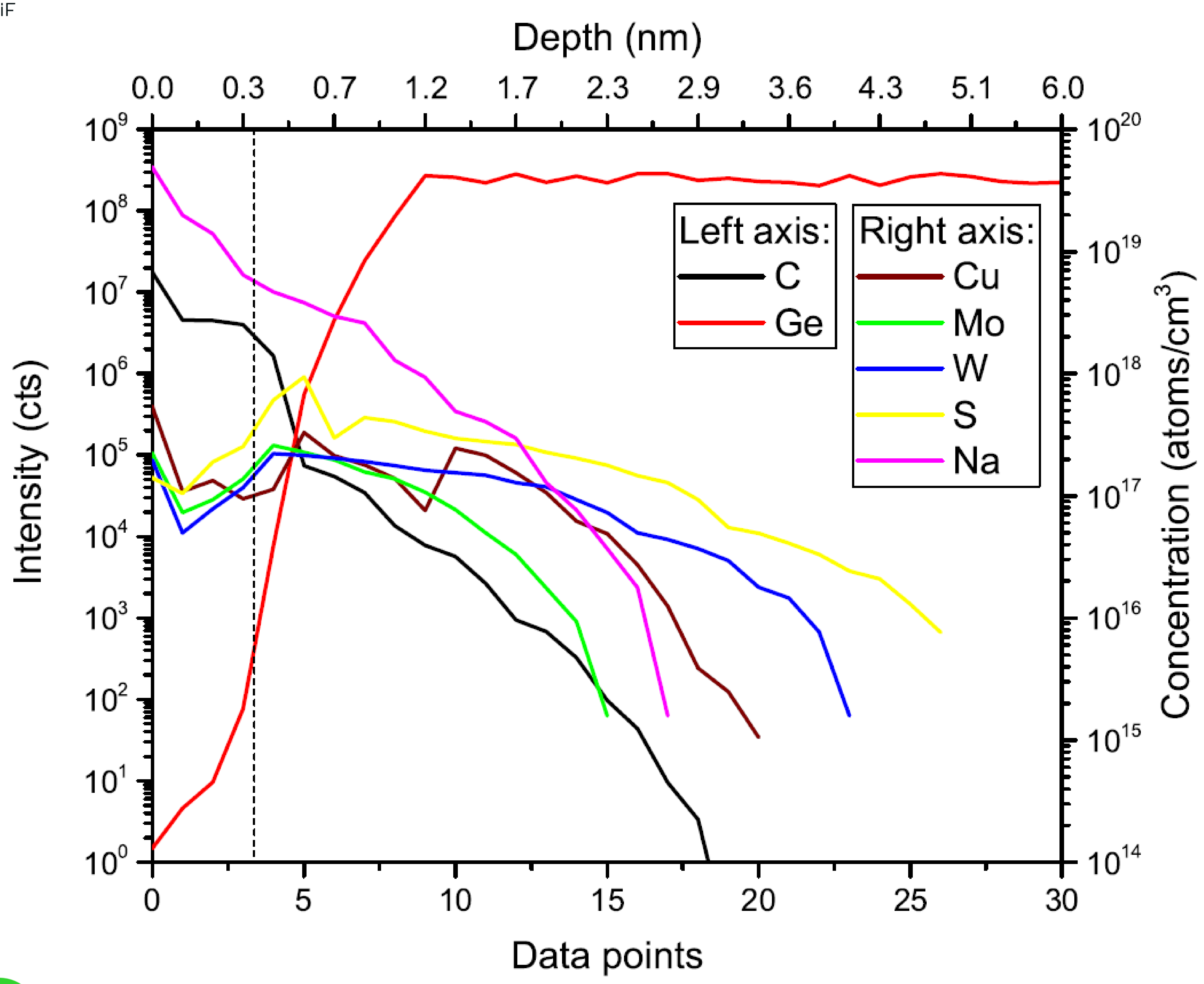
Standard



Dedicated



How clean is Graphene?



Remarks

- 250 eV impact energy
- 45º incident angle

- Detection
- Localization?

Measurement **187**, 110308 (2022)

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Solution

PROBLEMS AND POTENTIAL SOLUTIONS

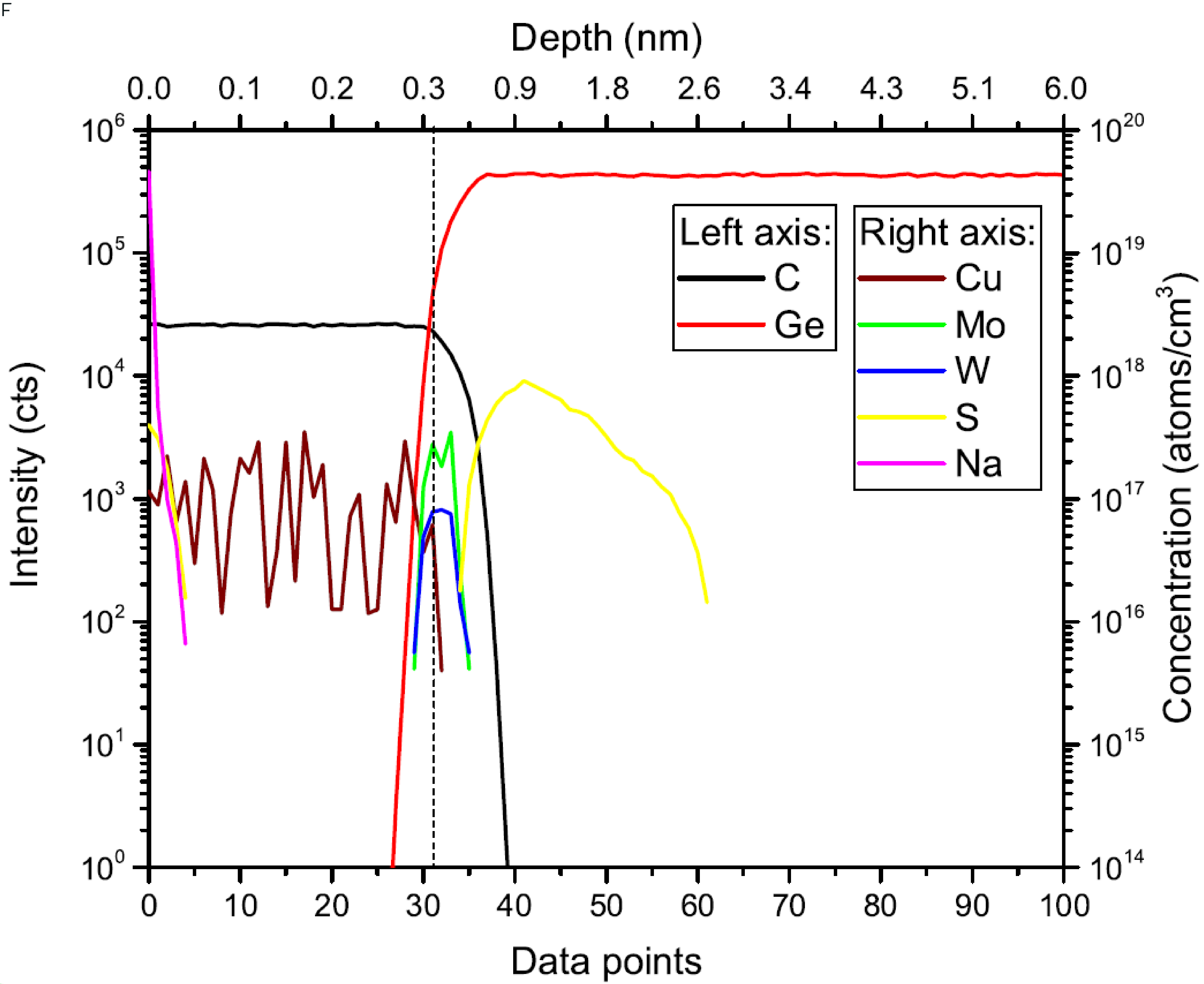
Problem	Potential solution	Resulting problems	Potential solution	Conclusion
Transition layer	Lower beam density	Signals intensity reduction	Higher integration time	Still a few data points per graphene
Ion mixing	Lower impact energy	Signals intensity reduction	Higher integration time	Still a few data points per graphene
Preferential sputtering	Higher impact energy	Bigger ion mixing	?	Not feasible

REALISTIC SOLUTION – HIGH INCIDENT ANGEL

Angle	Data points	Transition layer	Ion mixing	Preferential sputtering	Acquisition time	Detection limits (ppm)
45°	4 for graphene	Severe	Severe	Severe	5 minutes	0.2 – 1.5
75°	30 for graphene	Negligible	Negligible	Negligible	3 hours	0.8 – 2.9

Measurement **187**, 110308 (2022)

Enhanced procedure



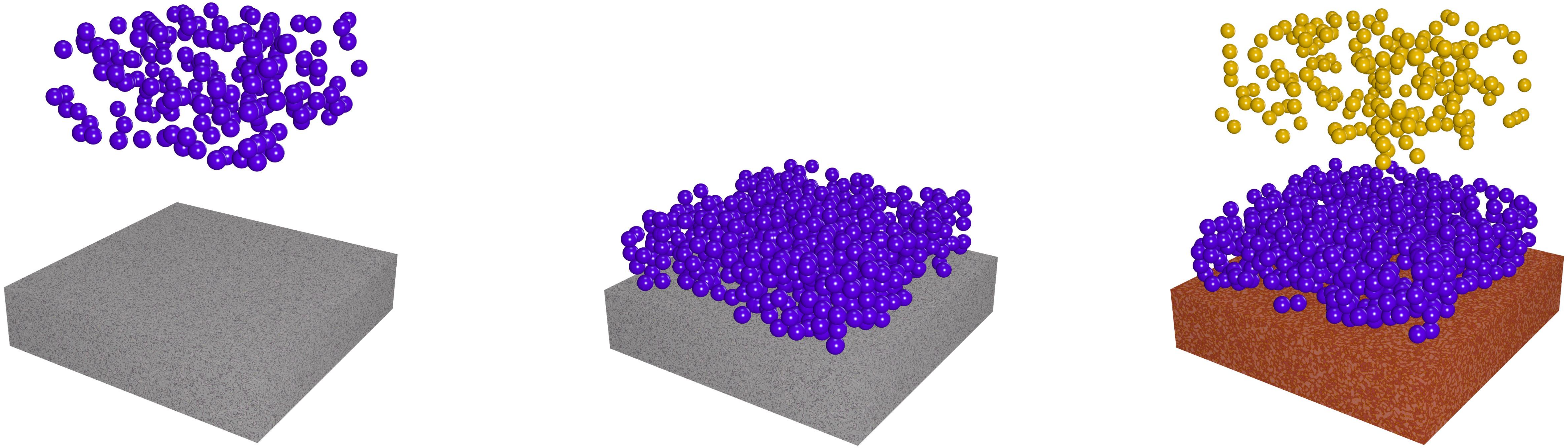
Remarks

- 250 eV impact energy
- 75º incident angle

- Detection
- Localization!

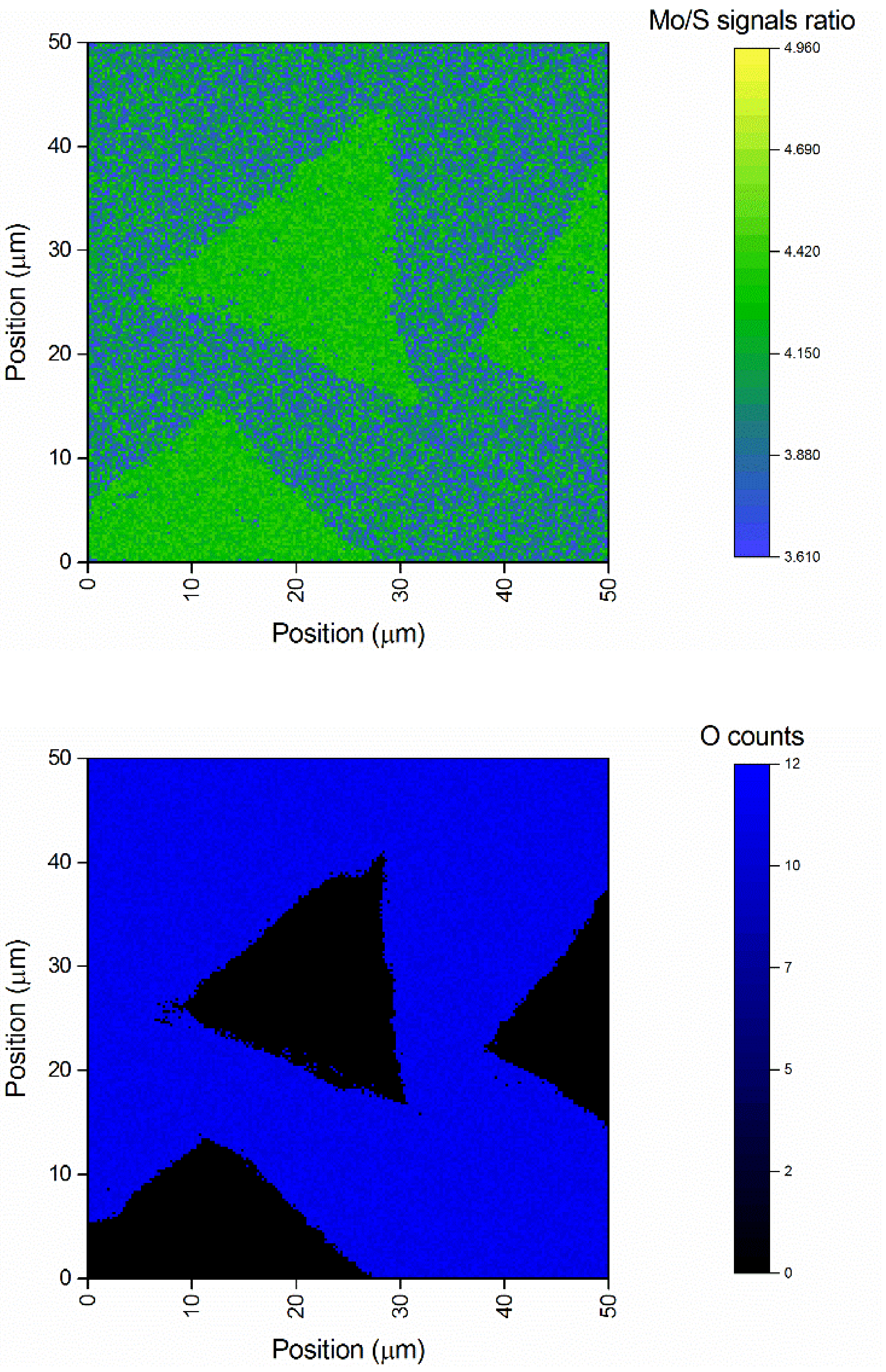
Measurement **187**, 110308 (2022)

Molybdenum disulfide

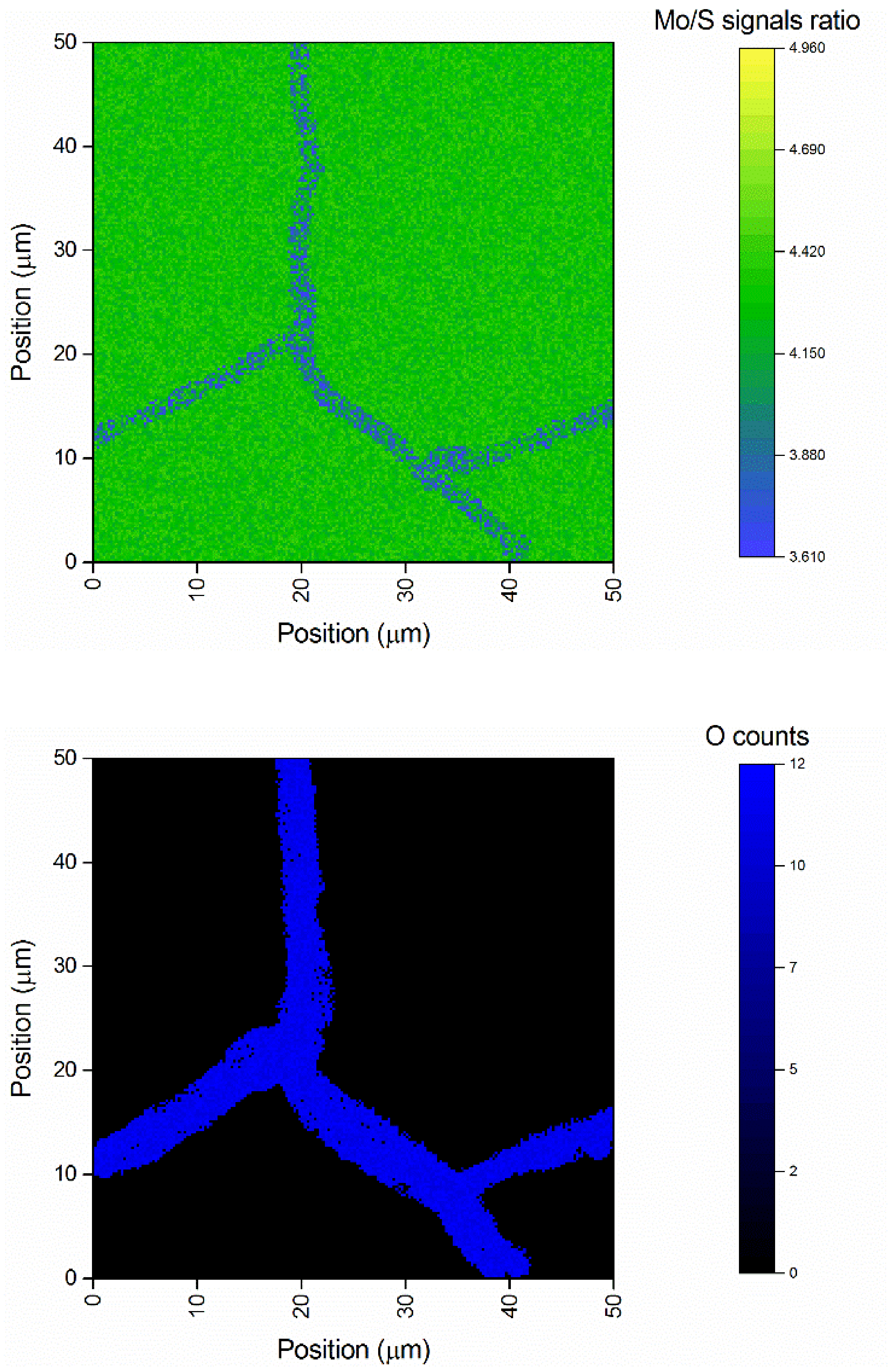


Physical Chemistry Chemical Physics **21**, 8837-8842 (2019)

SiO_2

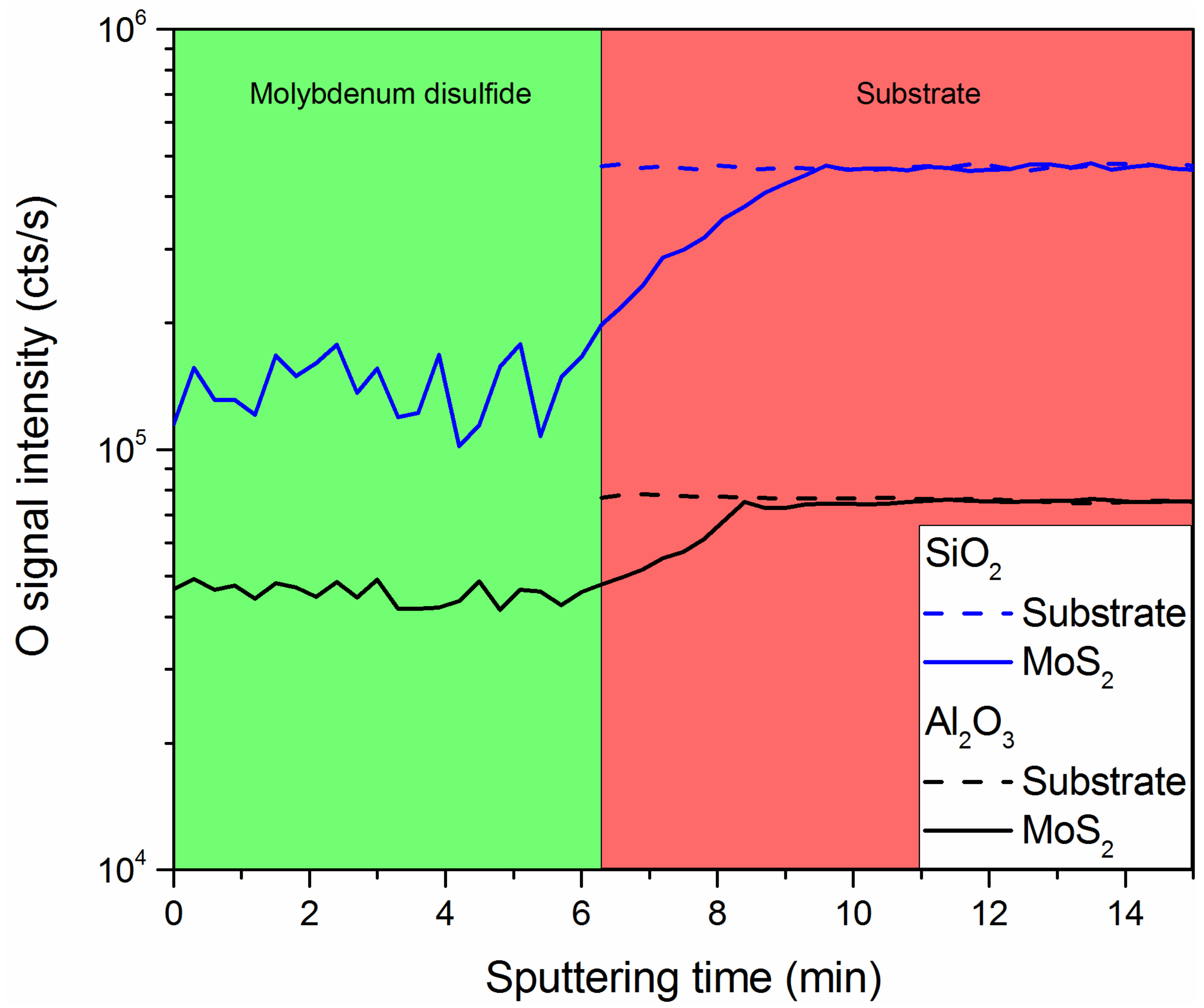


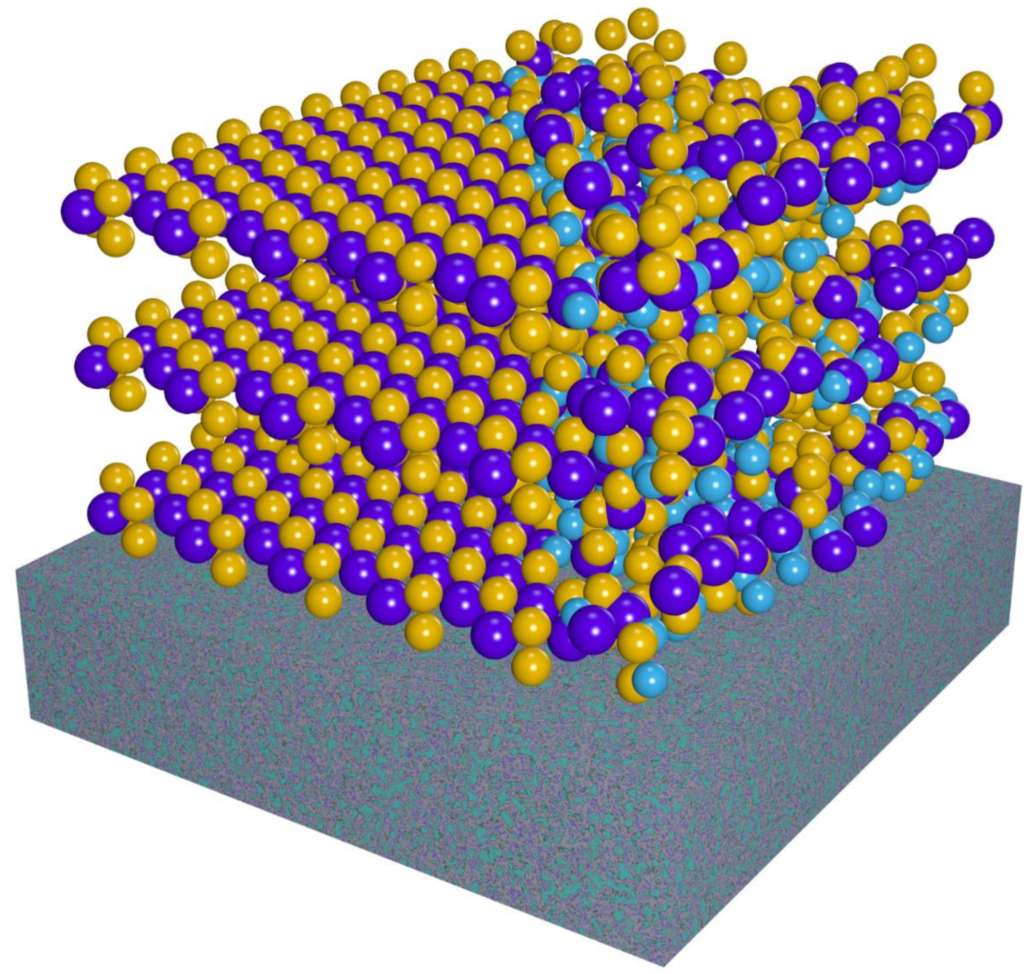
Al_2O_3

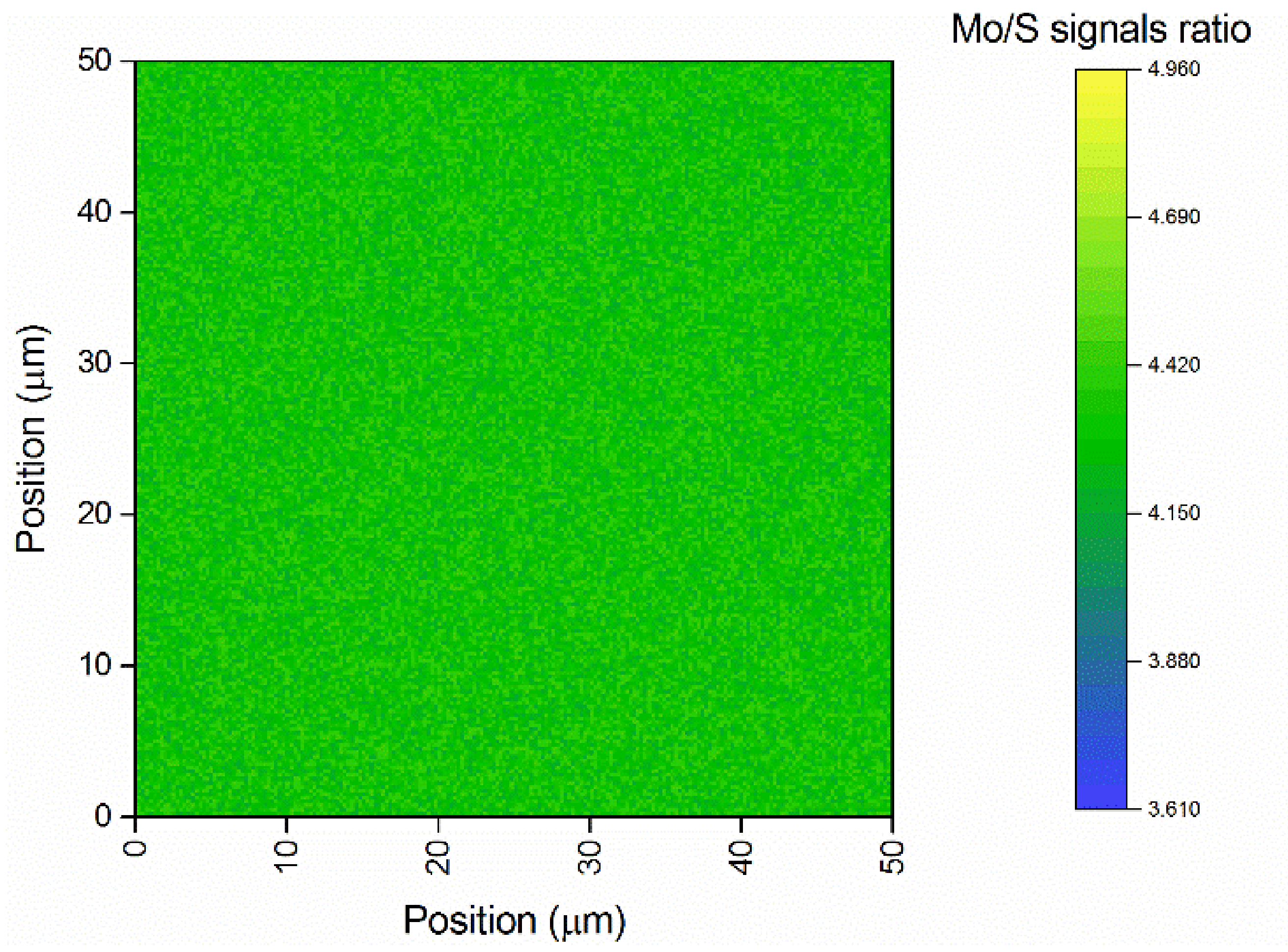


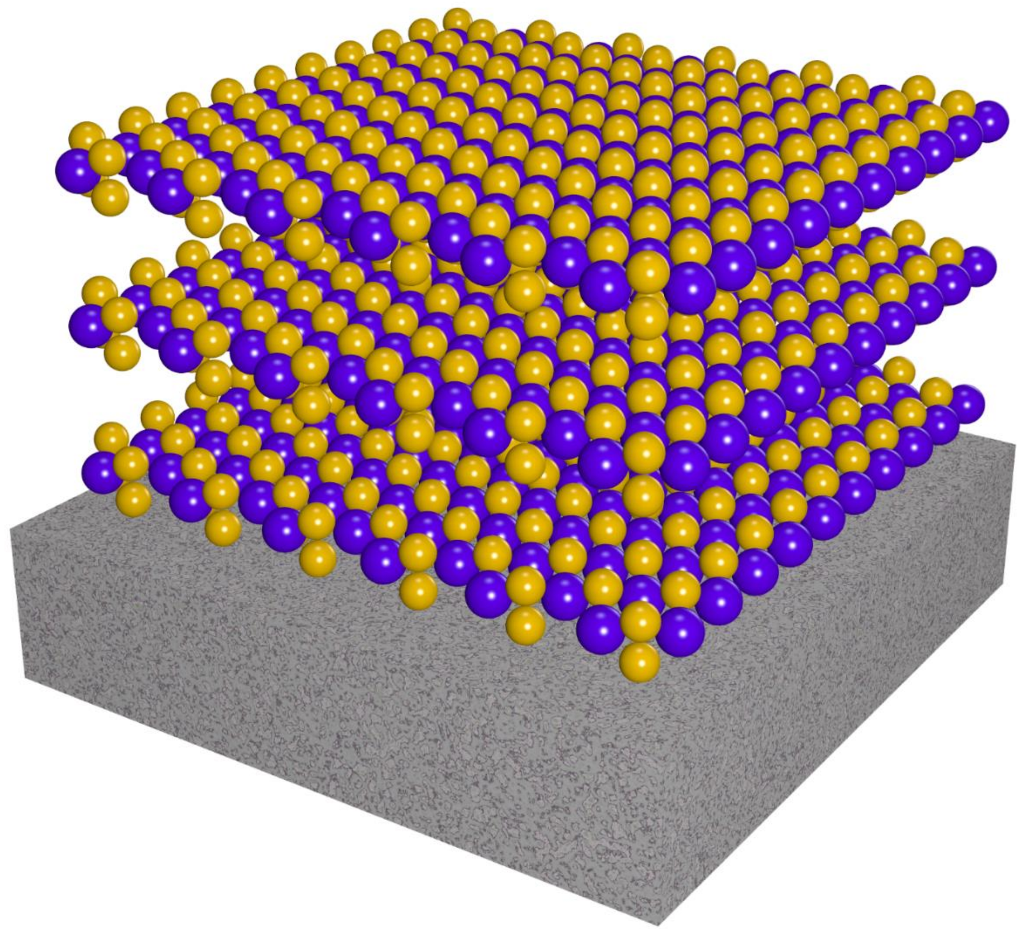
Physical Chemistry Chemical Physics **21**, 8837-8842 (2019)

Substrate type / procedure optimization



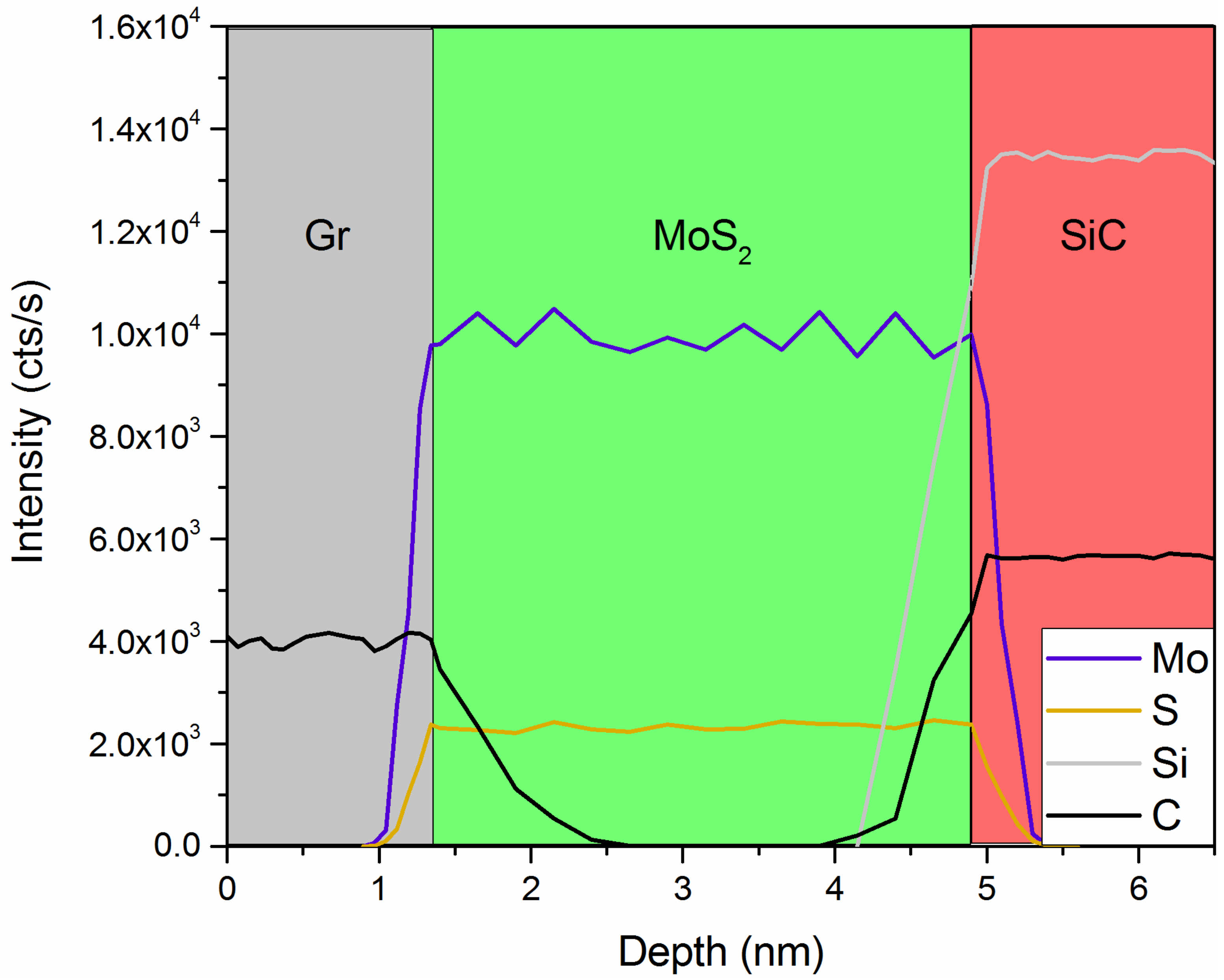


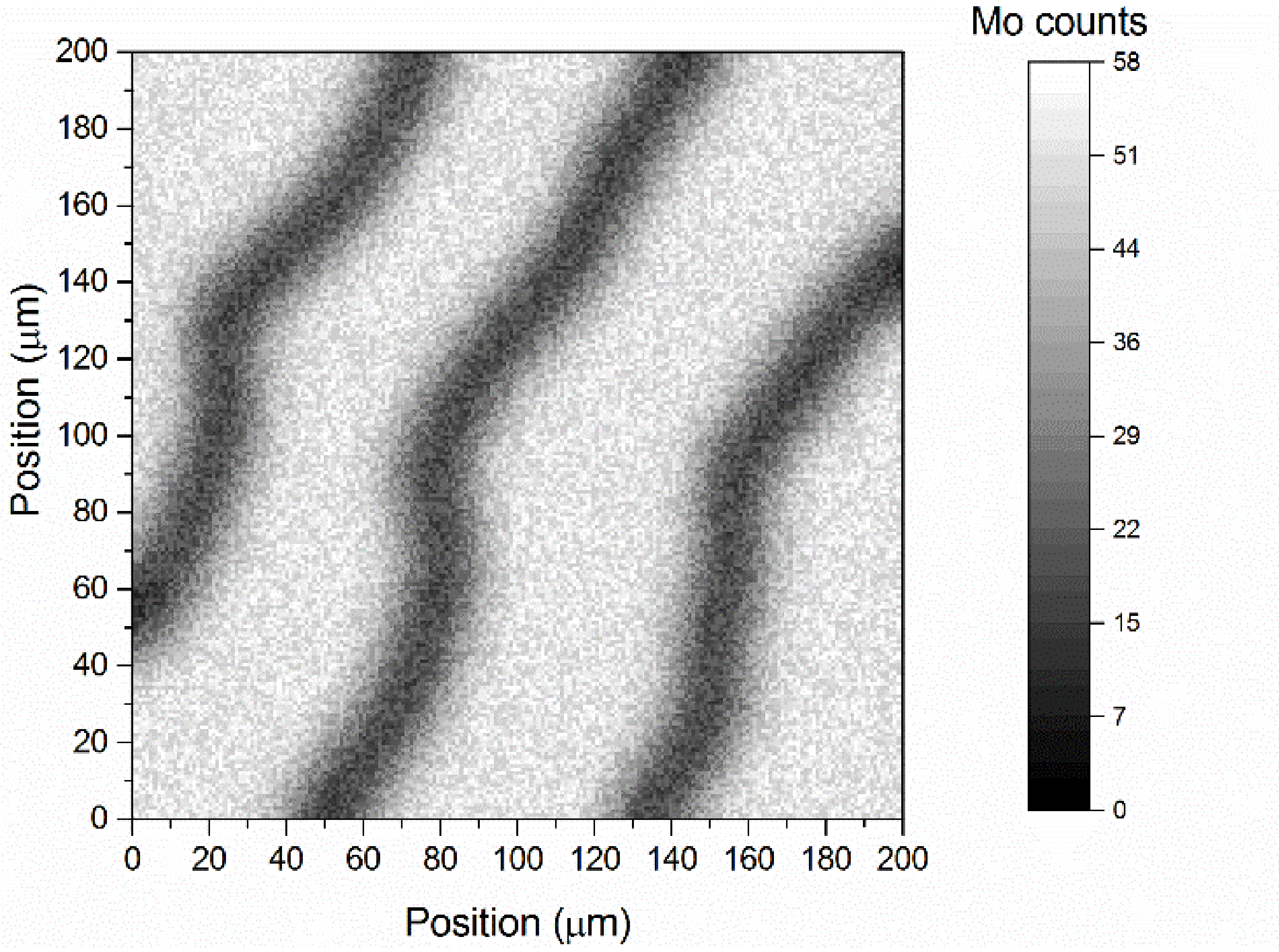


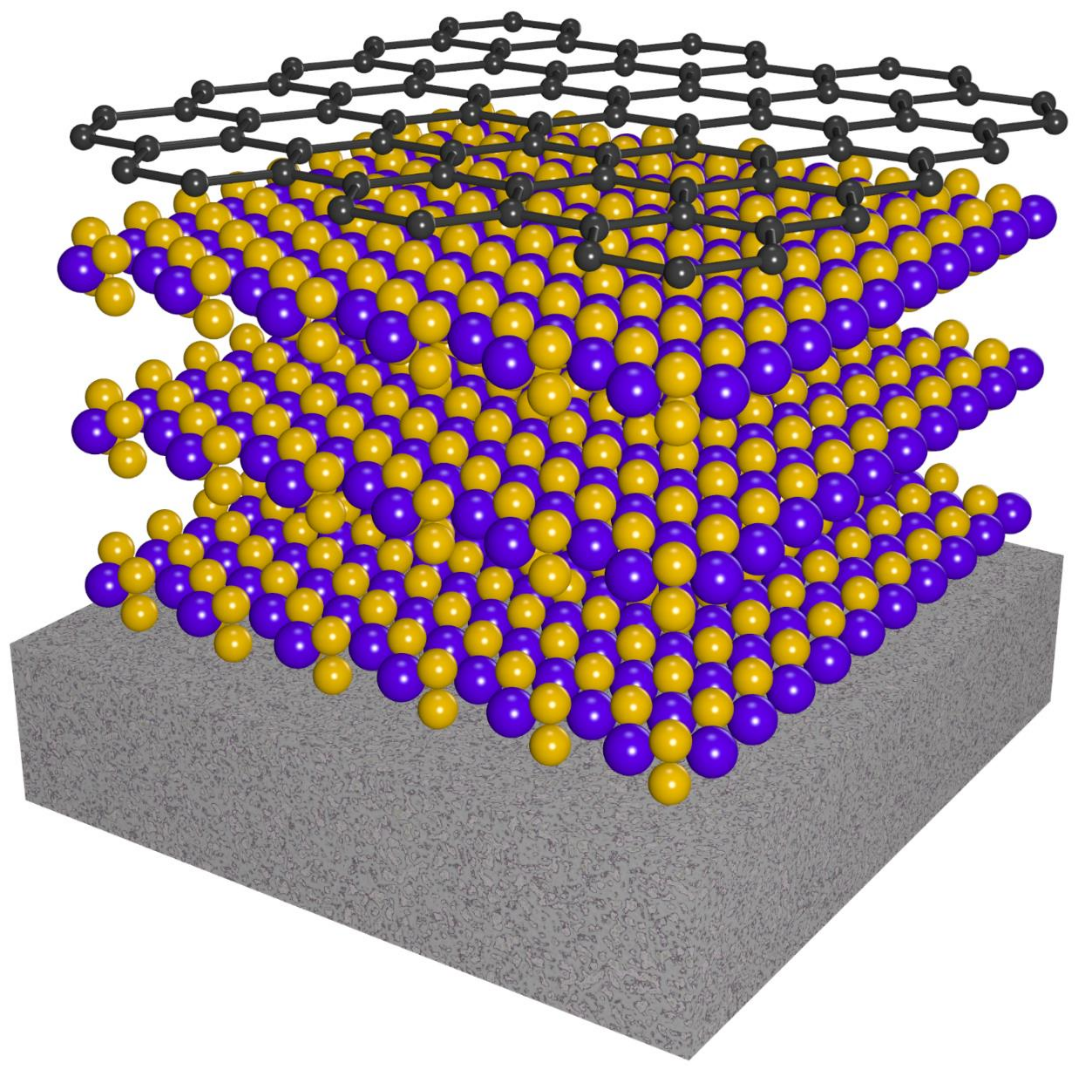


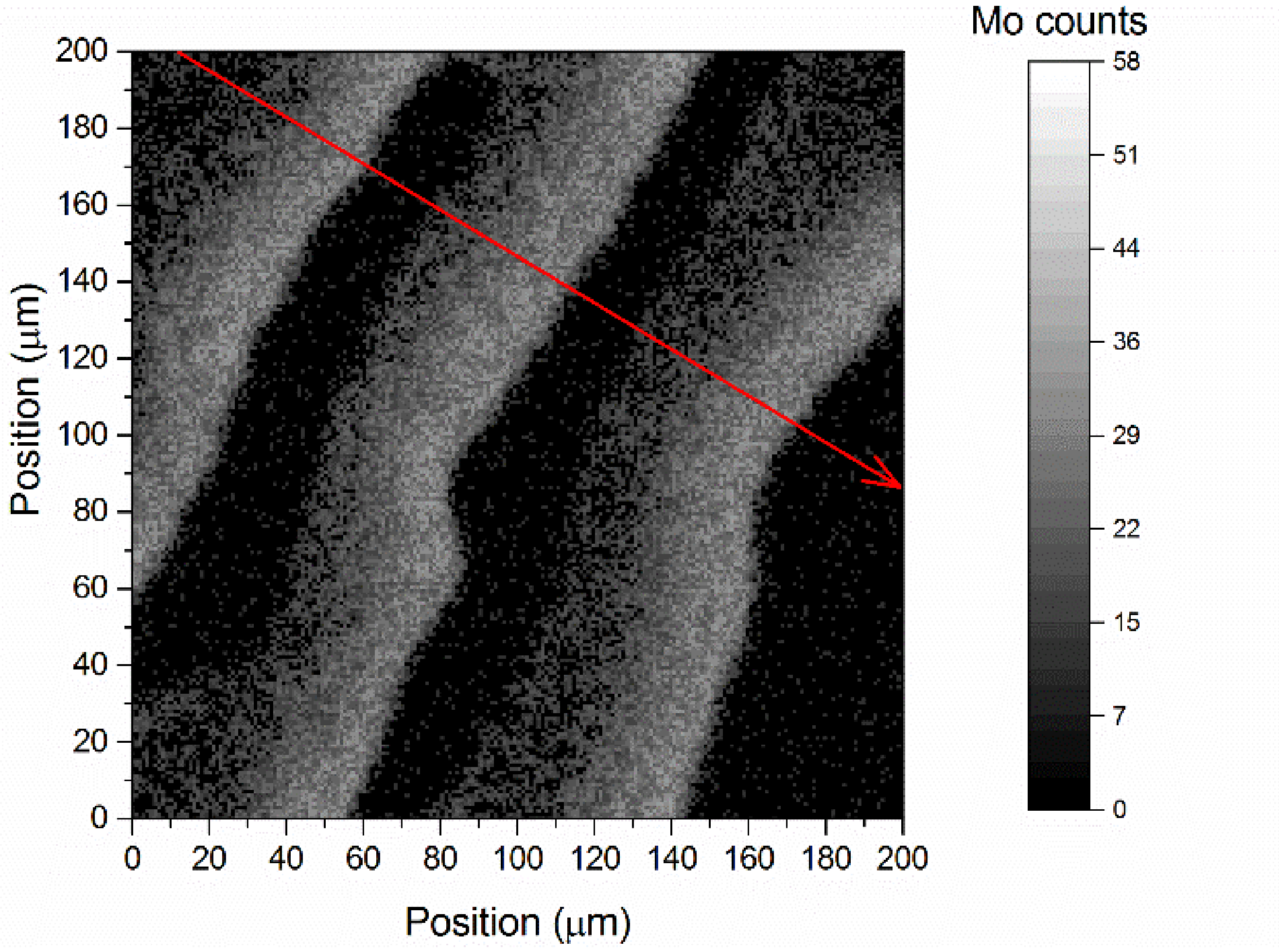
Physical Chemistry Chemical Physics **21**, 8837-8842 (2019)

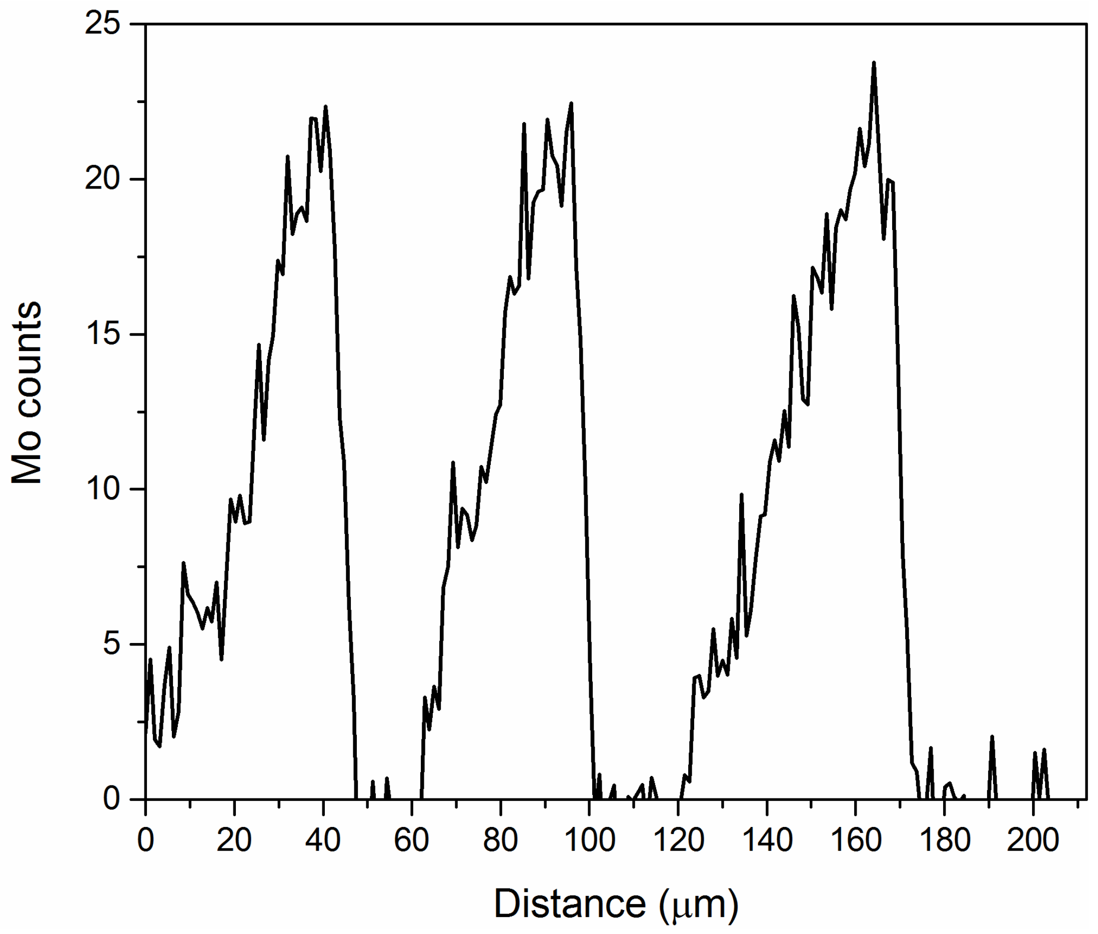
Graphene/SiC case











Physical Chemistry Chemical Physics **21**, 20641-20646 (2019)

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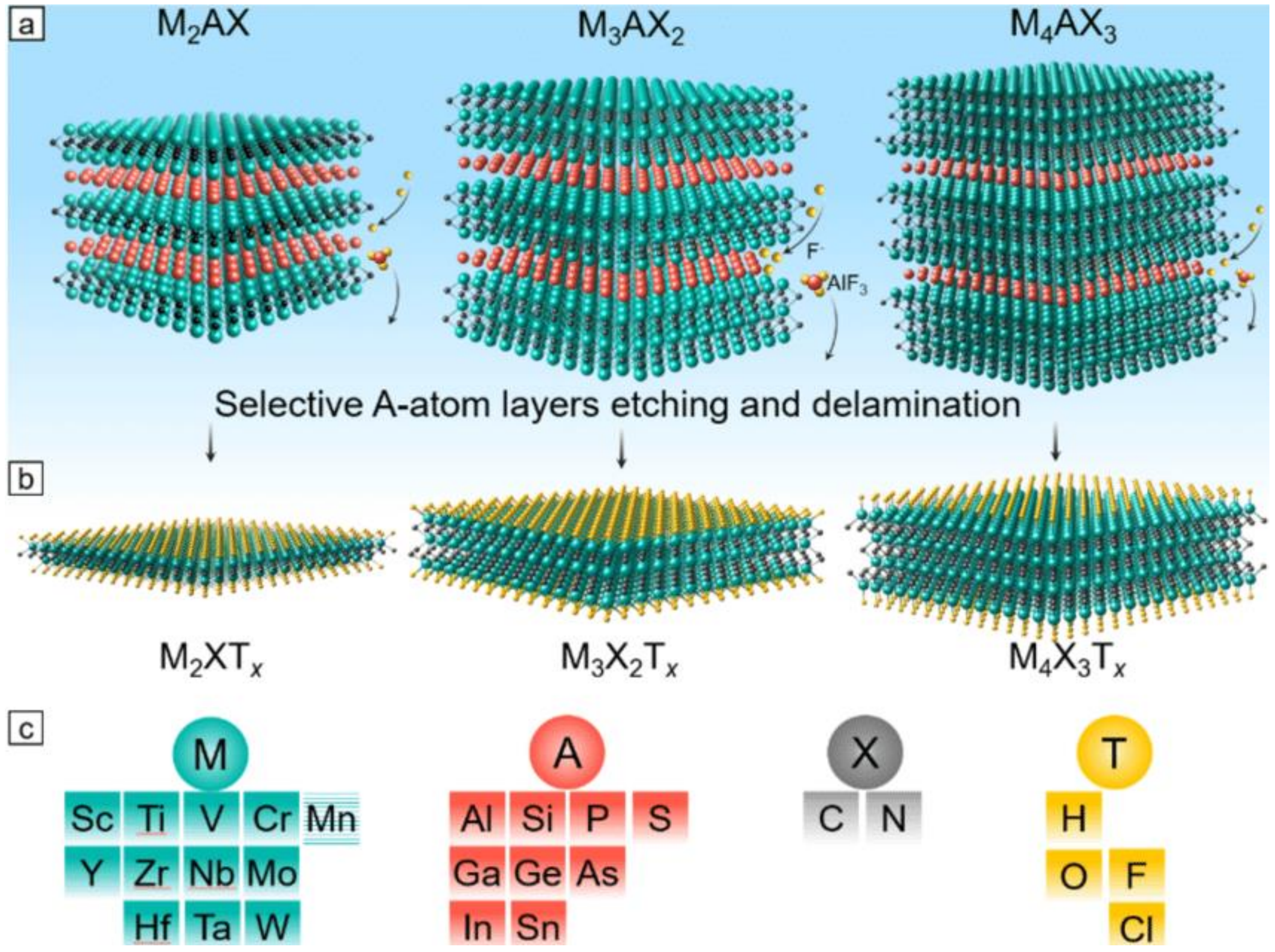
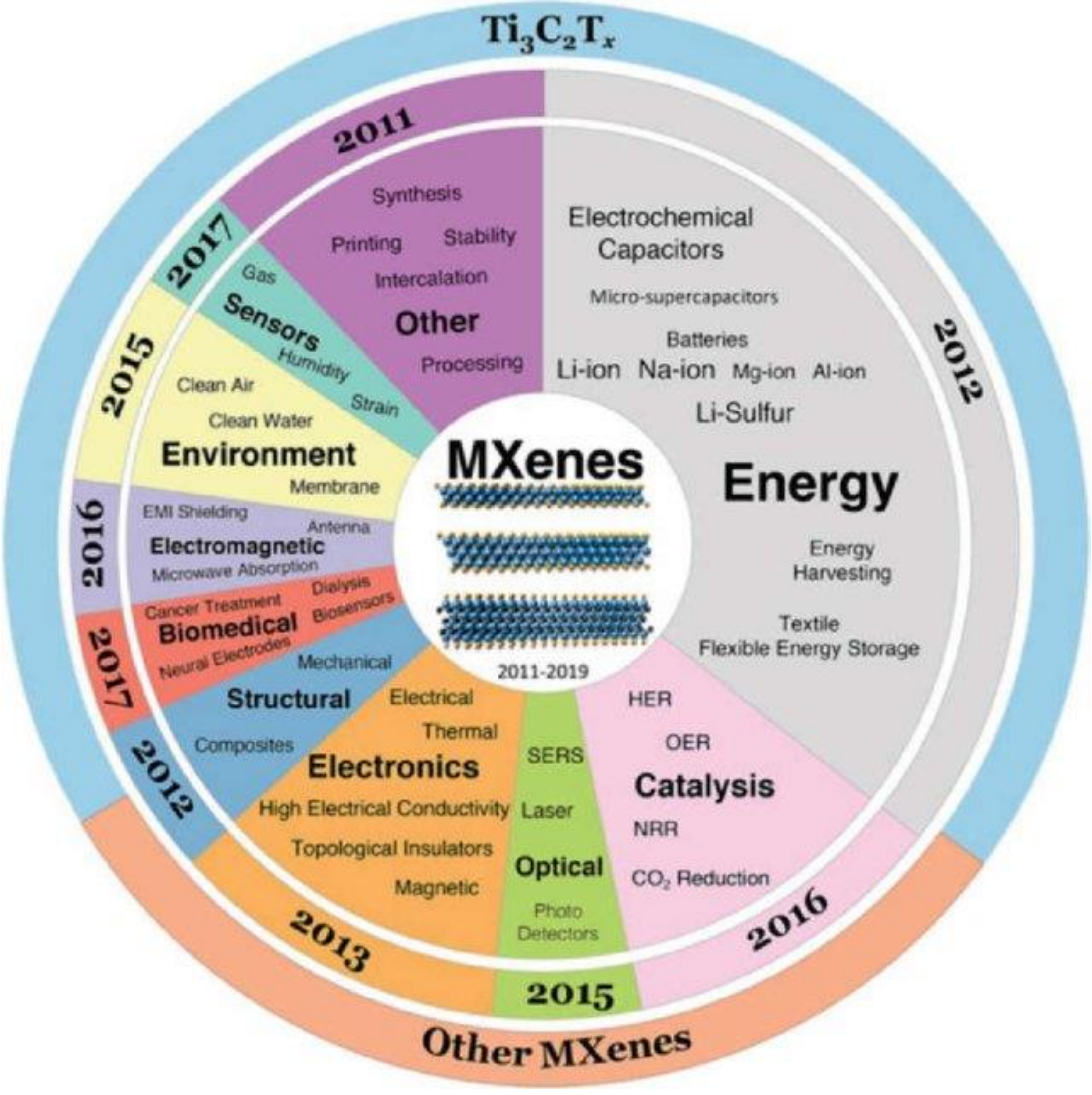
MXenes

- MXenes: a new family of two-dimensional (2D) transition metal carbides, carbonitrides and nitrides
- Synthesized from a MAX phase



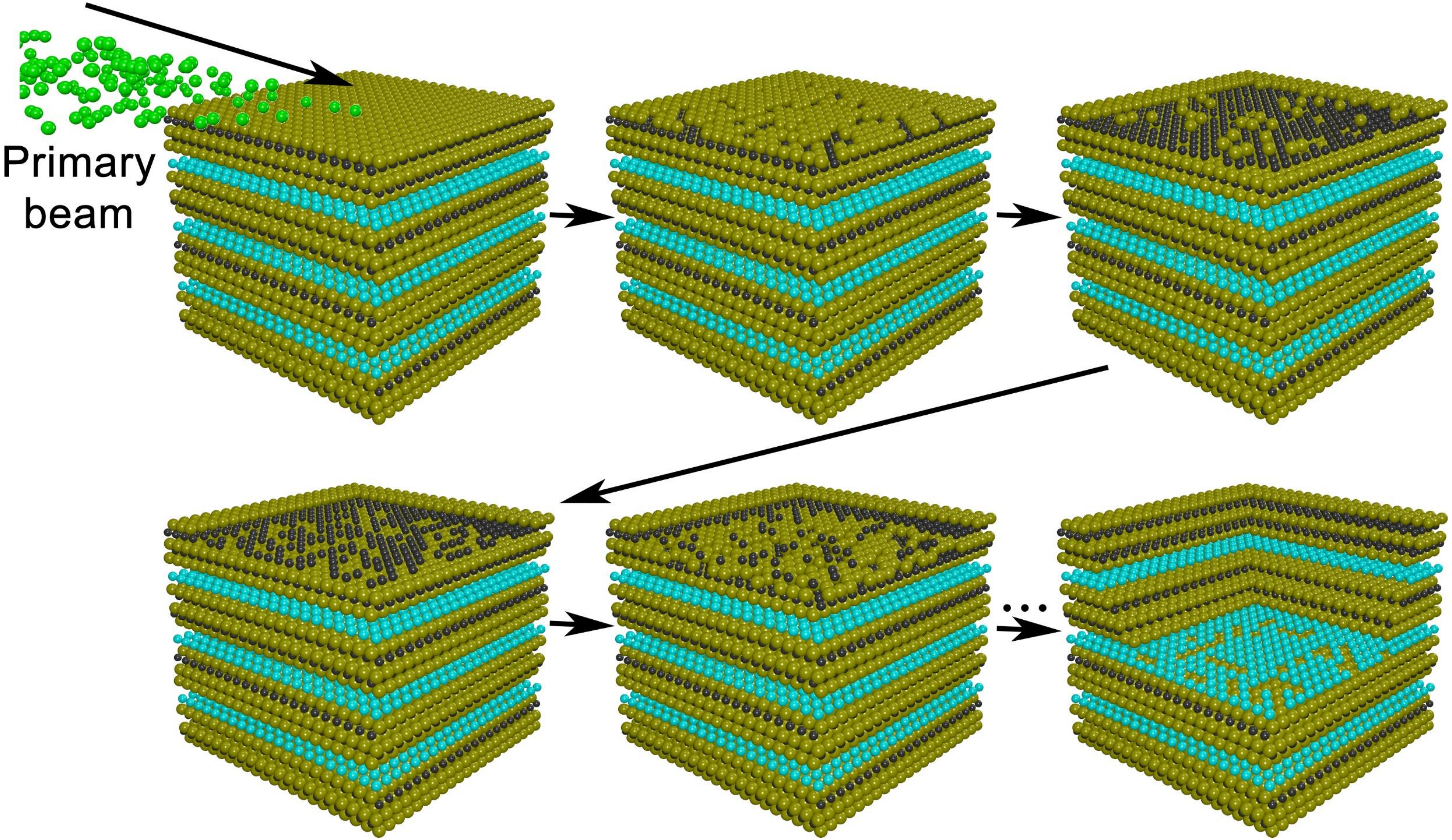
Hong, W. *et al. MRS Bulletin* **45,** 850–861 (2020).

Prof. Yury Gogotsi



https://nano.materials.drexel.edu/research/synthesis-of-nanomaterials/mxenes/

How to make such measurements?



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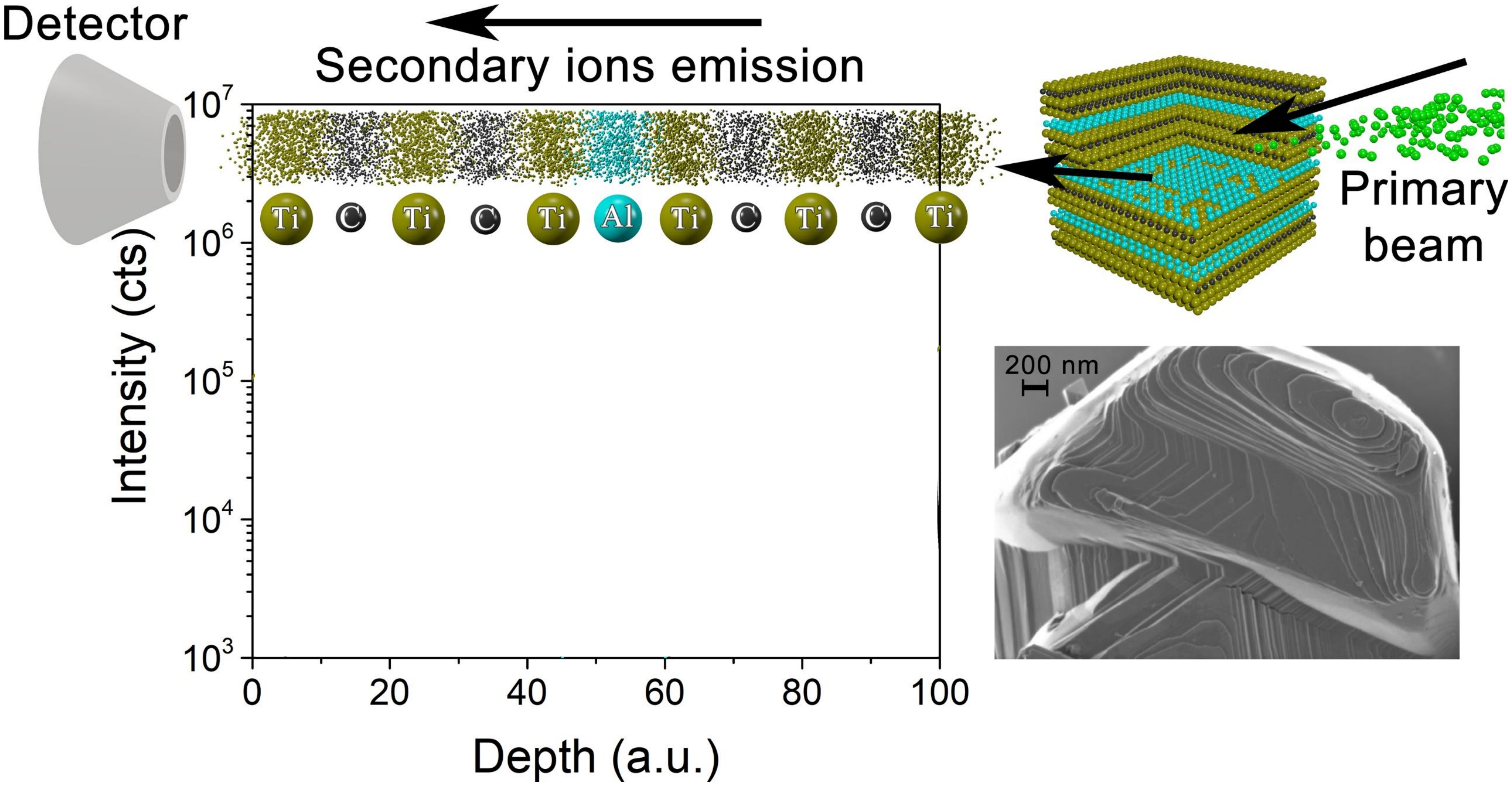
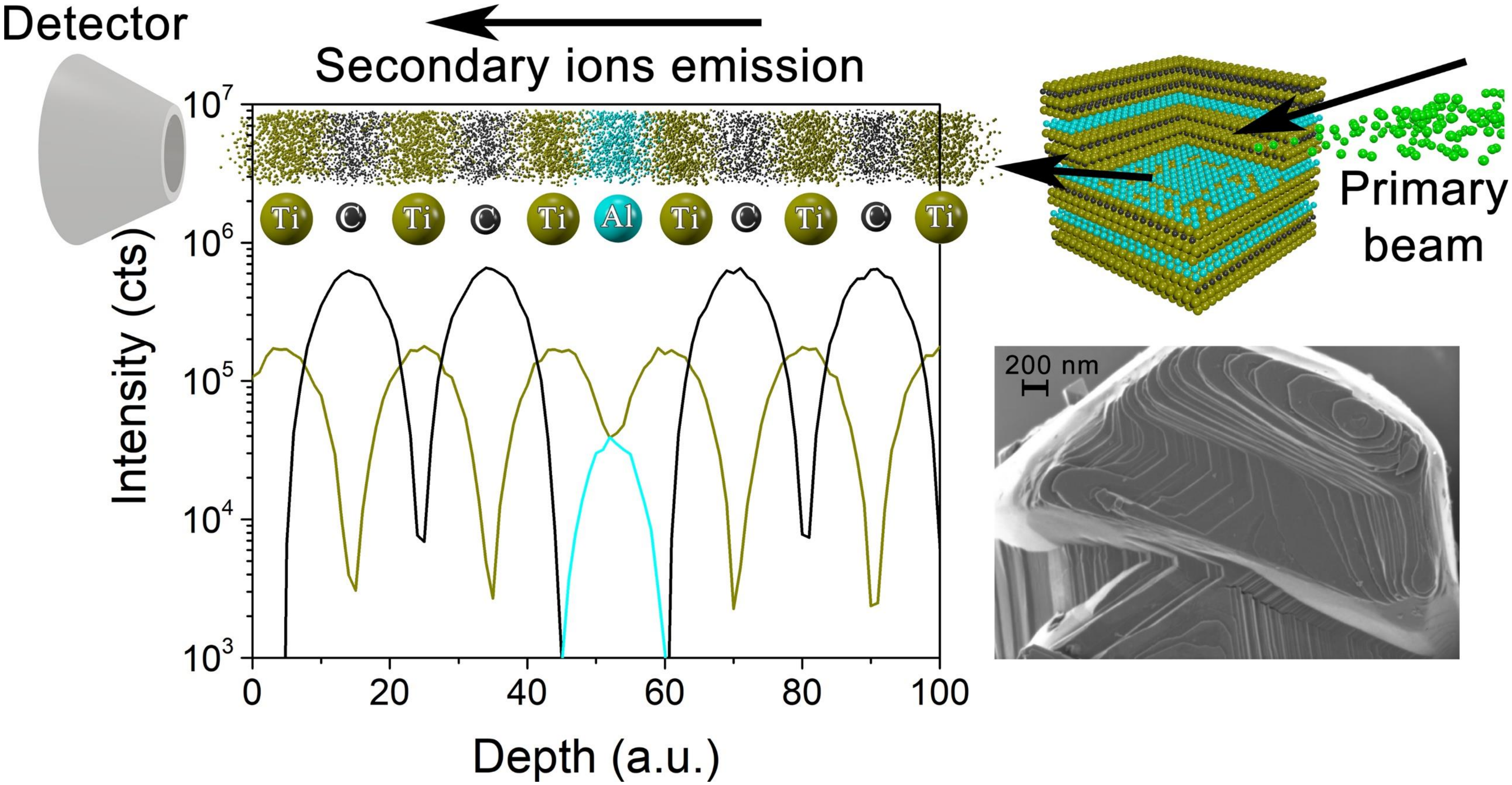
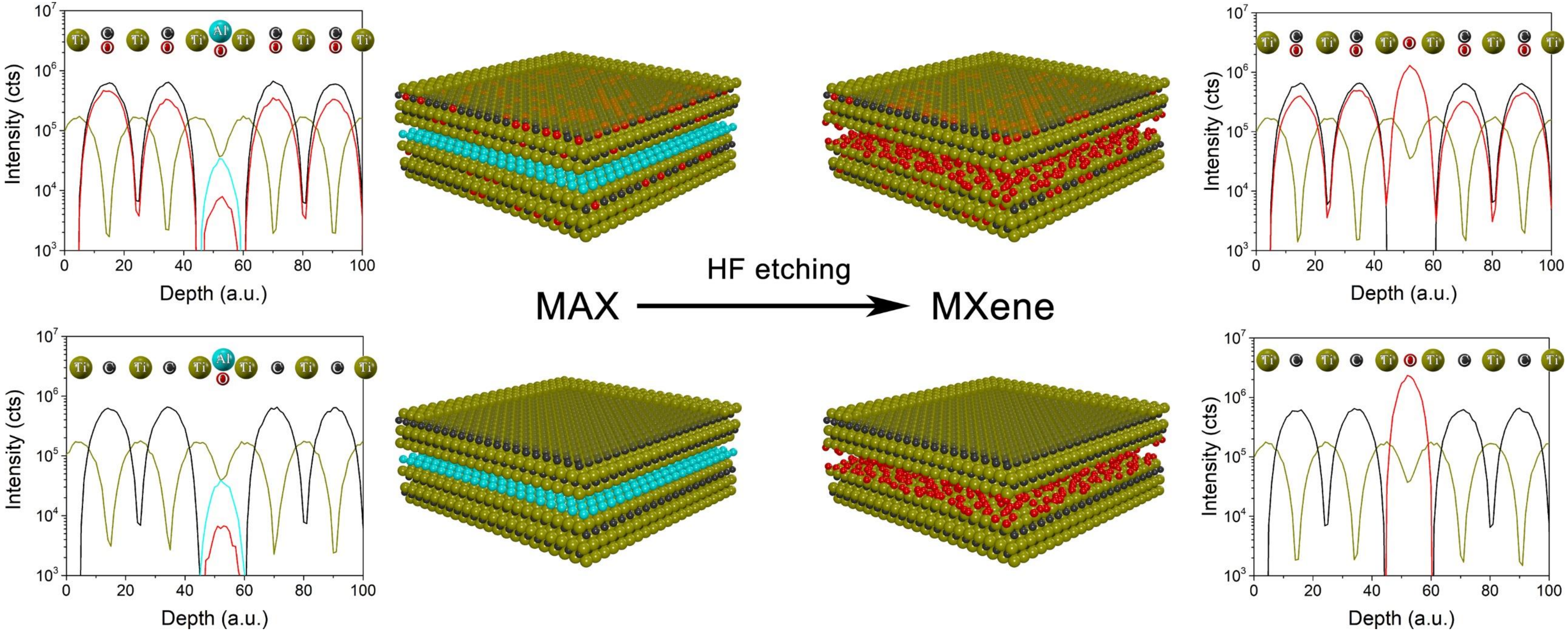
A depth profile of Ti_3AlC_2 MAX phase



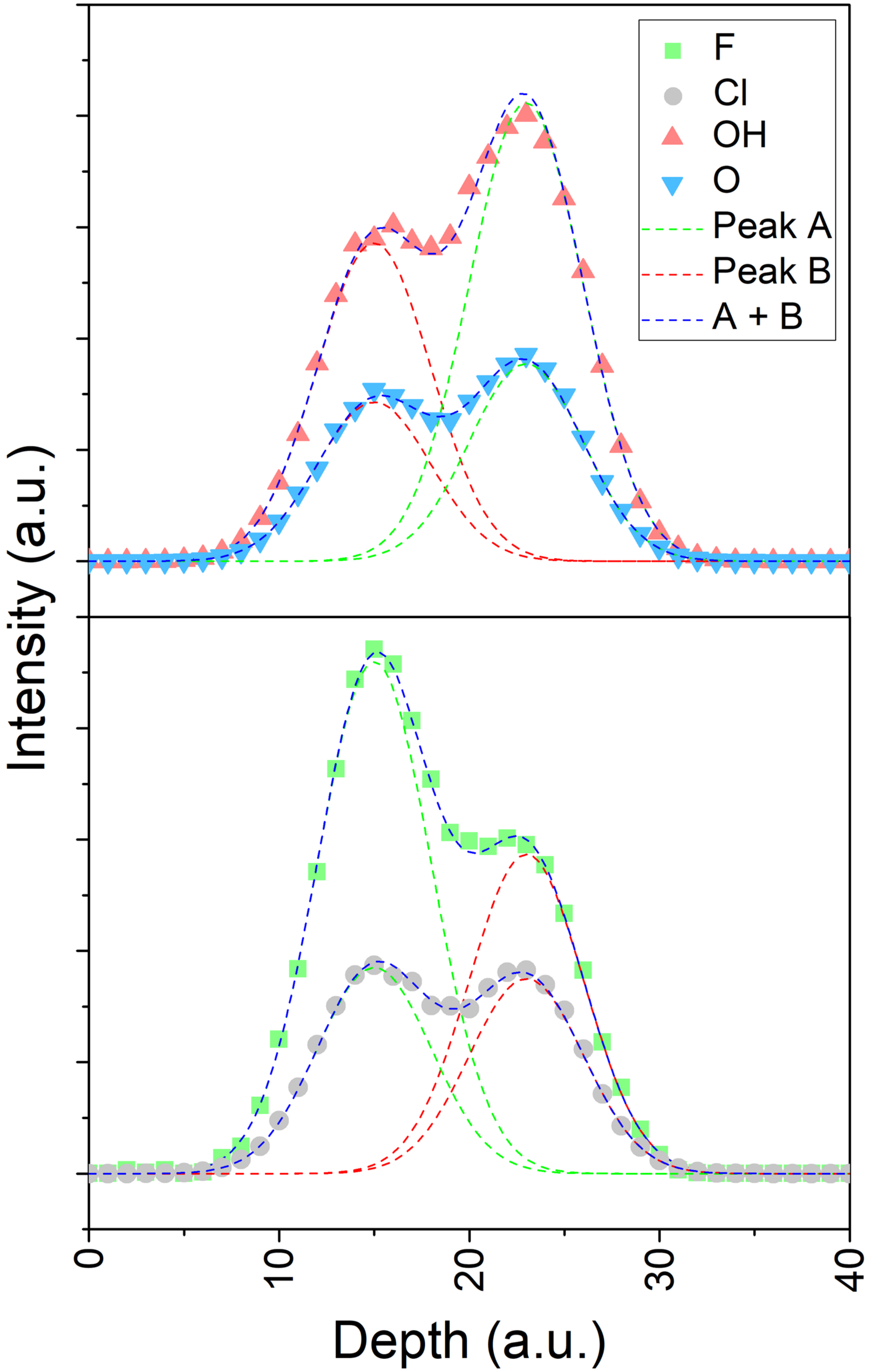
A depth profile of Ti_3AlC_2 MAX phase

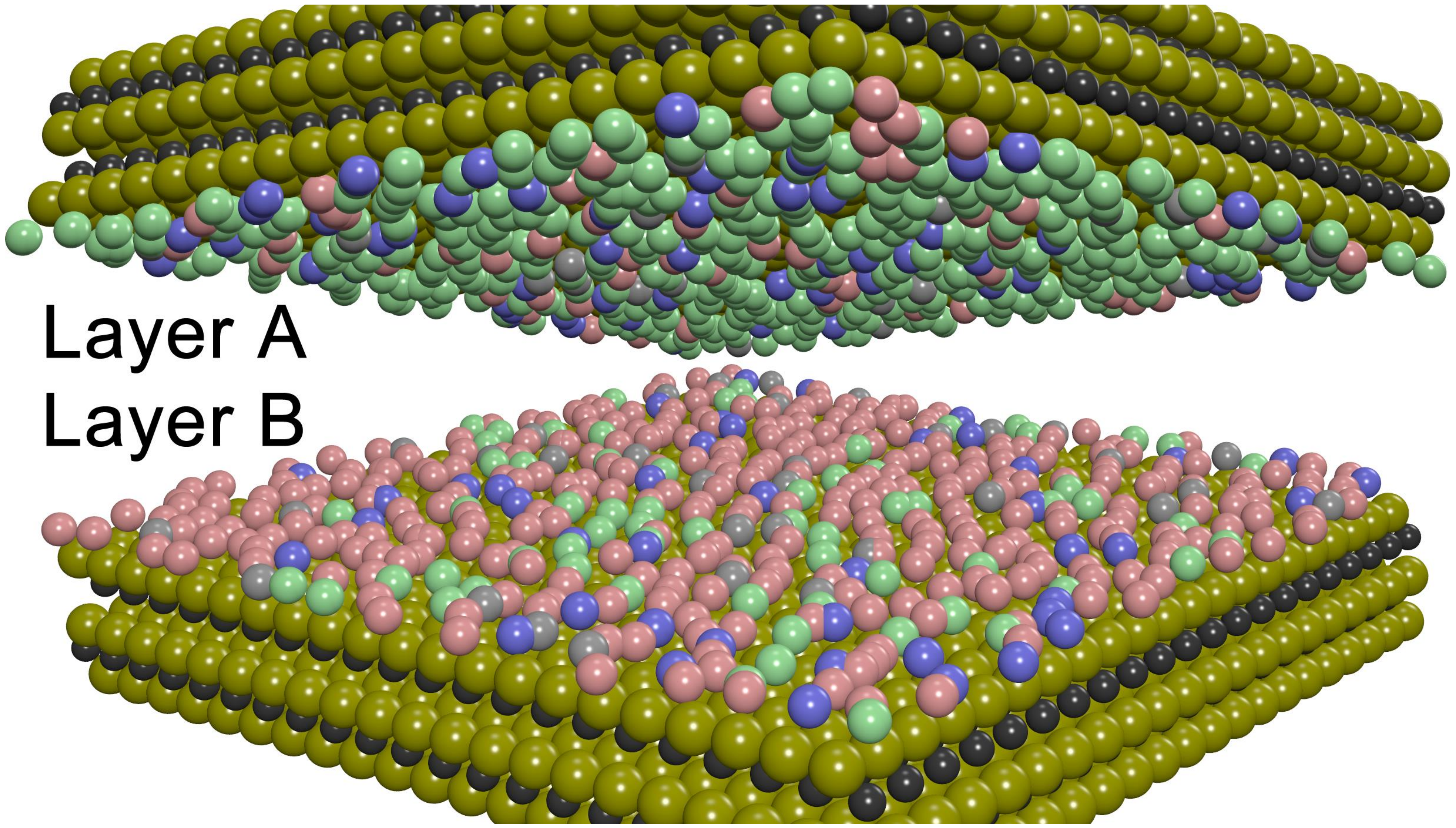


Carbides? Or oxycarbides?



Termination layers





Conclusions

- State-of-the-art instrument
- Dedicated procedures (time-consuming but worth it!)
- Superior depth resolution (even atomic!)
- Only slightly worse detection limits

SIMS can be used for 2D materials!

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