Location-Selective CVD Synthesis of Circular MoS_2 Flakes with Ultrahigh Field-Effect Mobility

Presenter:

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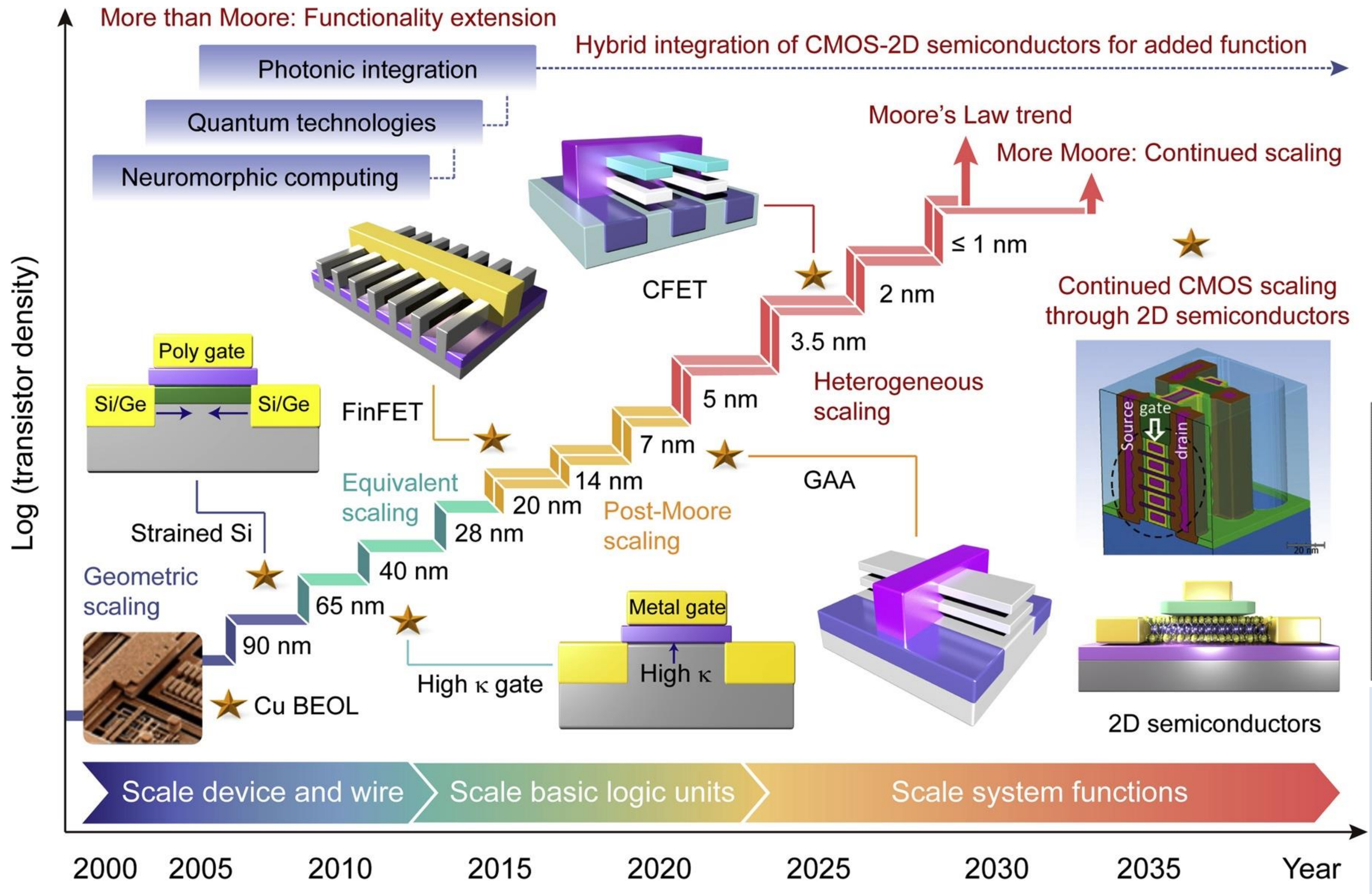
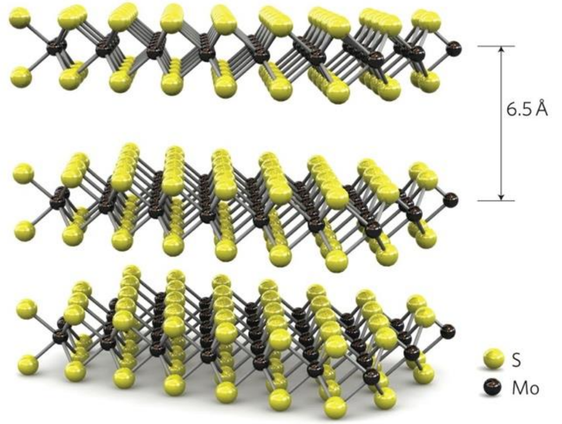
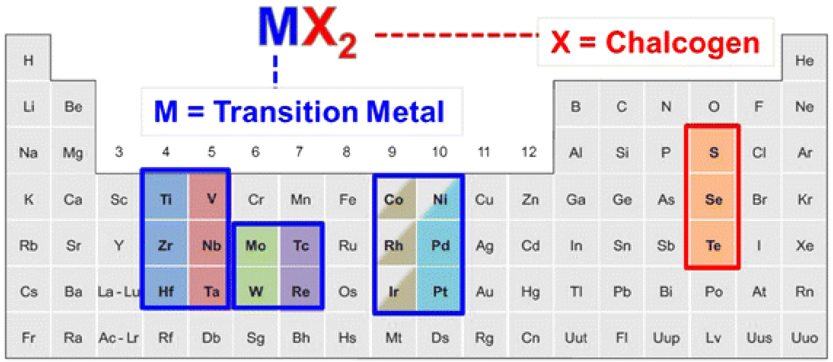
The rise of 2D TMDs

Introductions | Materials and methods | Results and discussion | Conclusion and highlights



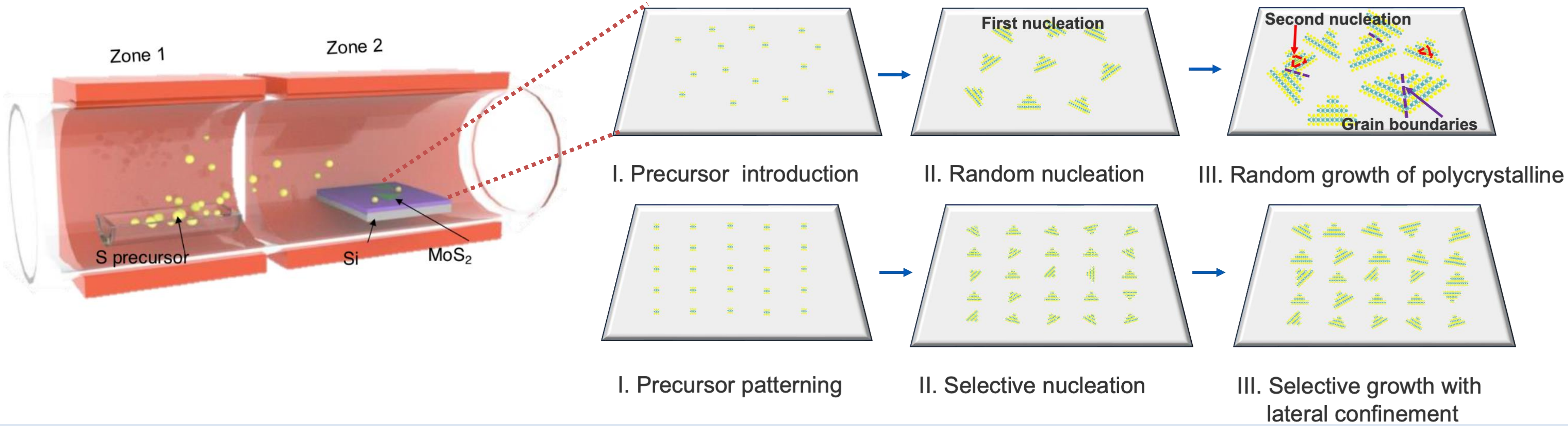




- Two-dimensional (2D) transition metal dichalcogenides (TMDs) have been extensively explored as channel materials for electronic devices.

1. iScience Volume 25, Issue 10, 21 October 2022, 105160
2. Nature Nanotechnology volume 6, pages147–150 (2011)
3. Nano Convergence volume 2, Article number: 17 (2015)

Site-specific synthesis



➢ **Challenges for nanoelectronics:**

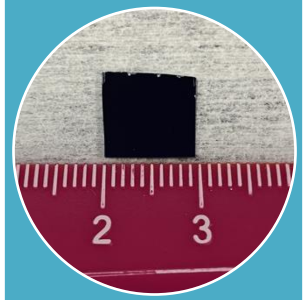
Despite initial achievements in fundamental scientific research and device demonstrations, the growth of wafer-scale, single crystalline (SC) TMD films is a major obstacle to the advancement of commercially feasible TMD-based nanoelectronics.

➢ **Solutions:**

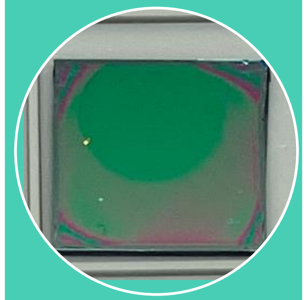
Site-specific growth → allows micrometer scale controlled growth at selected locations which can be directly used as channel material for electronic devices.

1. Nature 614, 88–94 (2023)

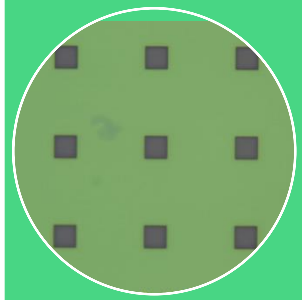
Experiment process



Substrate preparation



E-beam resists spin coating



E-beam lithography patterning

Mo precursor loading

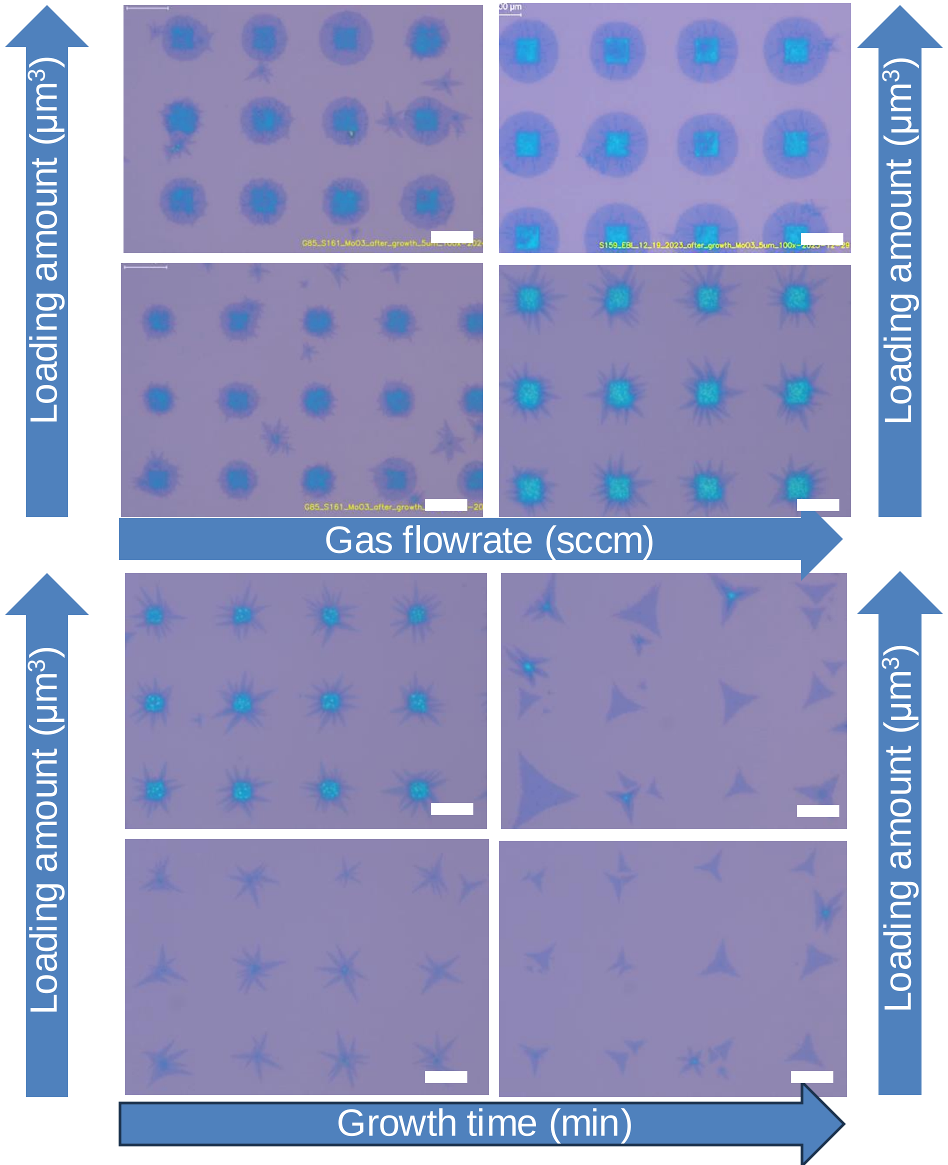
Acetone liftoff E-beam resists

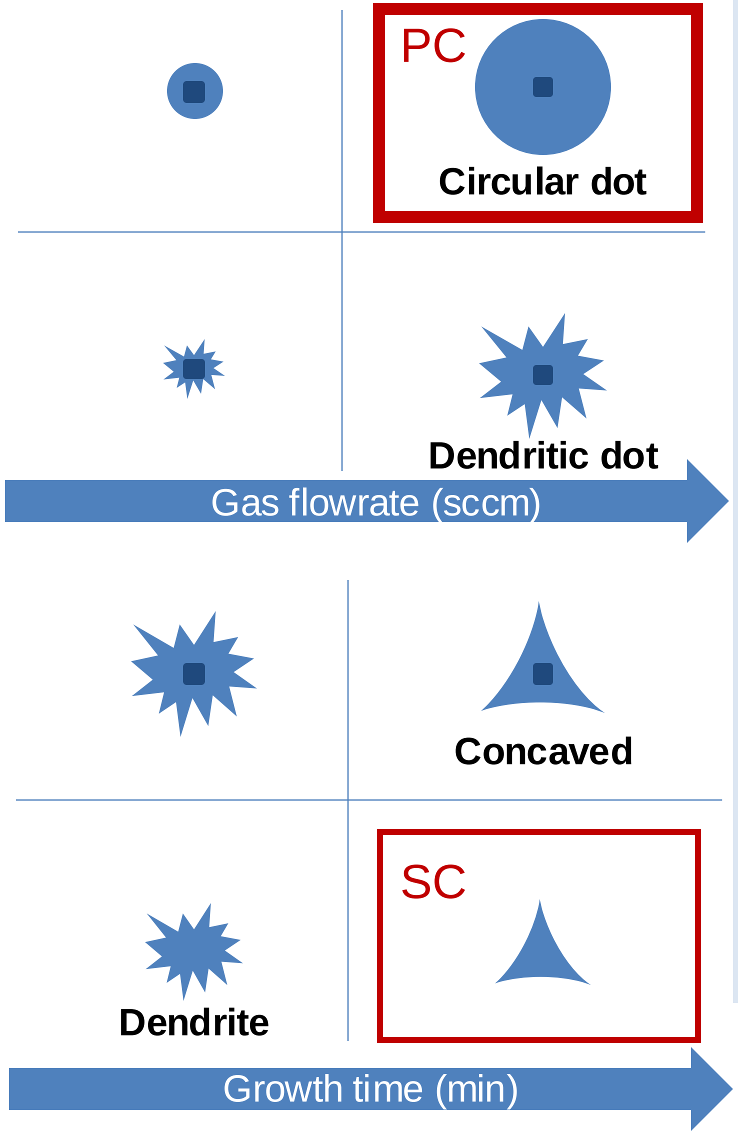
Selective MoS_2 CVD synthesis

Materials Characterization

Device fabrication and performance measurement

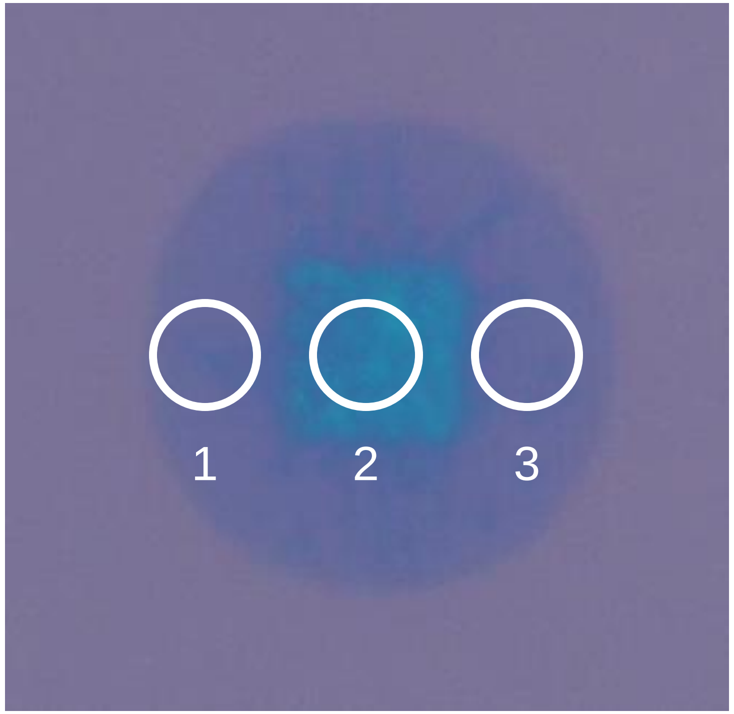
CVD parameter space exploration

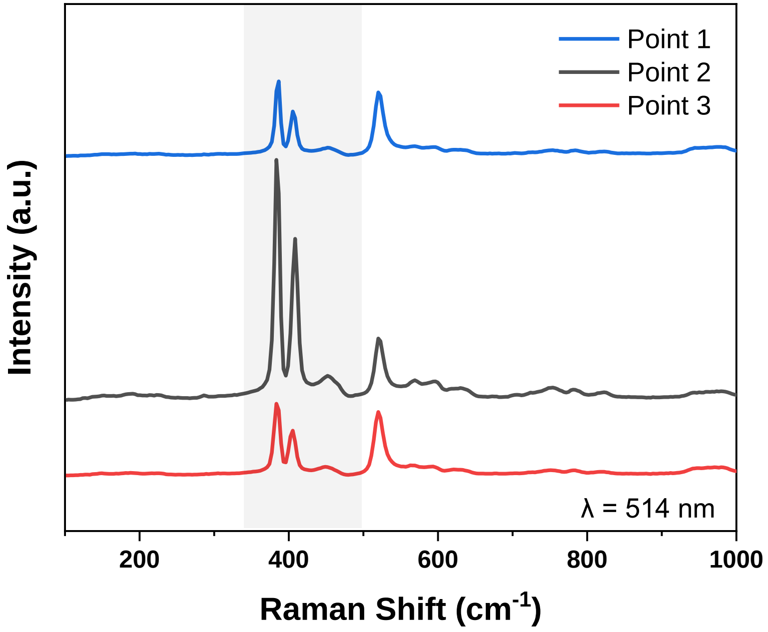


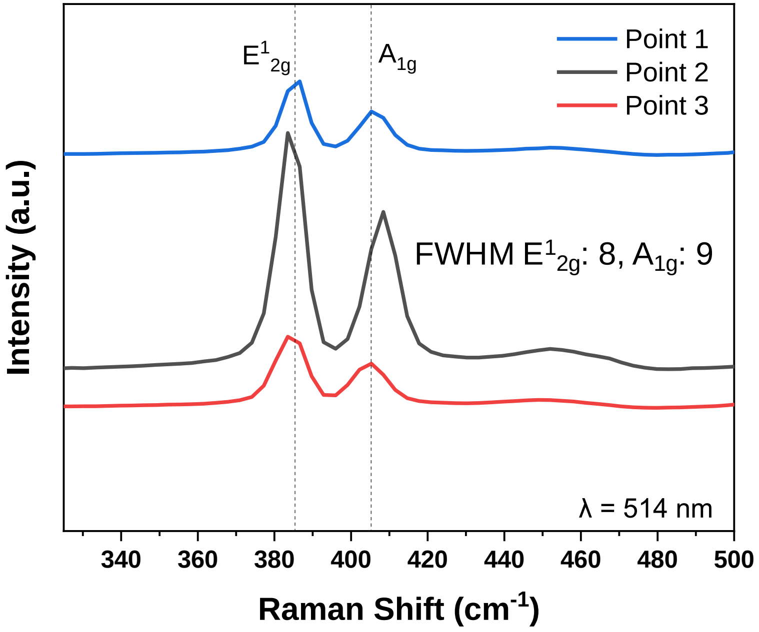


- Location-specific polycrystalline (PC) and single-crystalline (SC) flakes can be obtained by adjusting the CVD synthesis parameters.
- The electrical properties of monolayer MoS_2 were measured, demonstrating competitive performance compared to published results, though the recipe for equilateral triangle monolayers requires further refinement.
- In contrast, the recipe for circular dots is well-optimized and promising for further investigation.

Material characterization - Raman spectroscopy



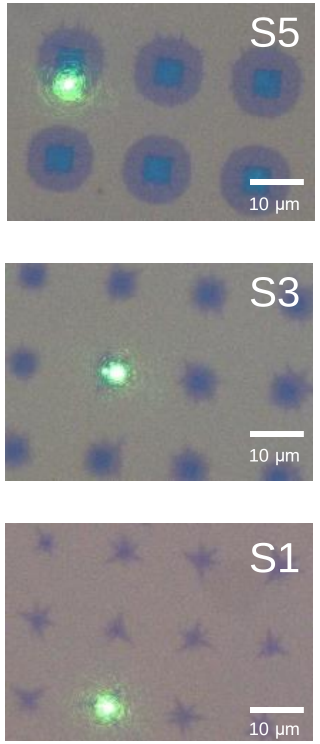


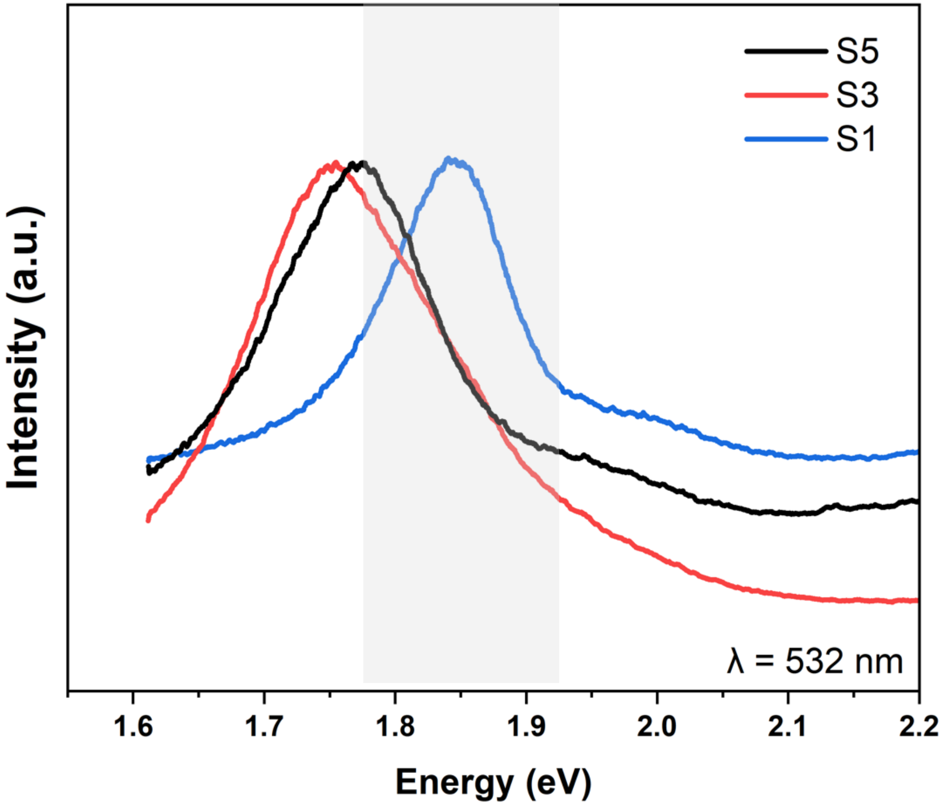


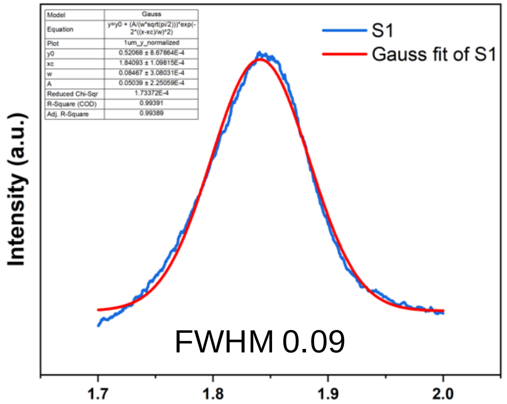
Point	E^1_{2g} (cm^{-1})	A_{1g} (cm^{-1})	Frequency difference (Δ)	Layers
1	386.5	405.3	20.8	2
2	383.5	408.4	24.9	> 3
3	383.5	405.3	21.9	3

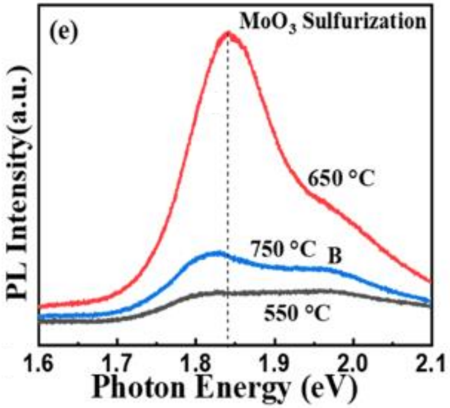
The Raman analysis verifies that the flakes consist of MoS_2, as indicated by the presence of characteristic peaks at 387cm^{-1} for E^1_{2g} and 407cm^{-1} for A_{1g}.

Material characterization - Photoluminescence spectroscopy





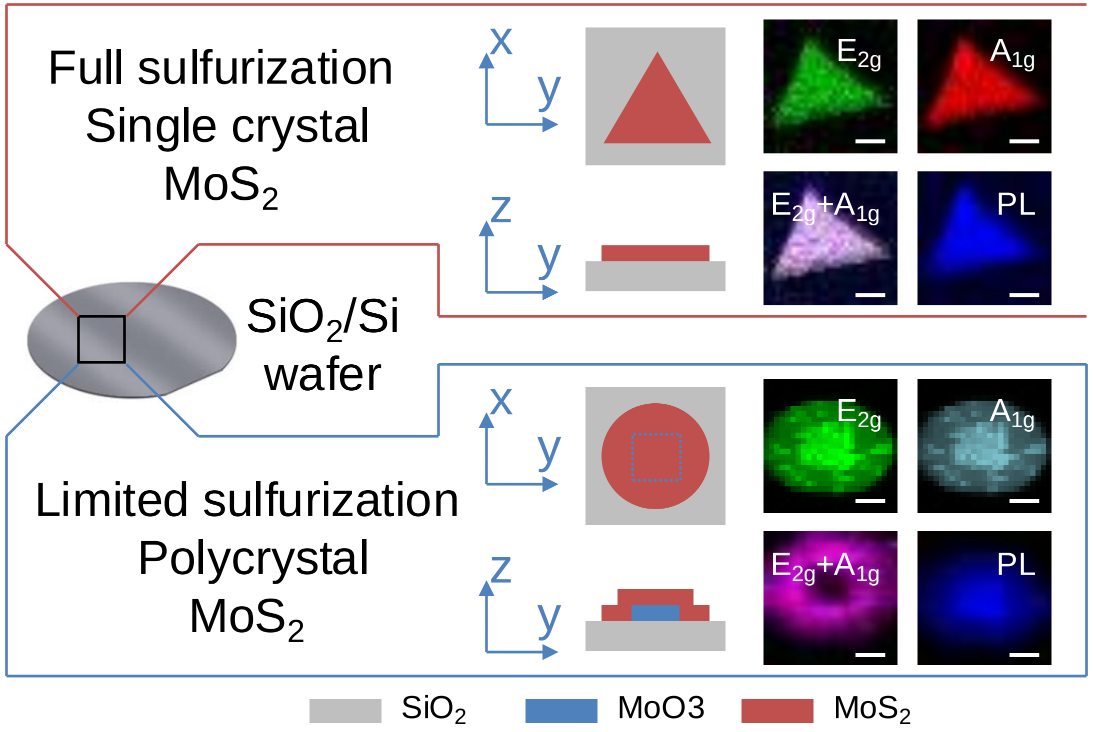


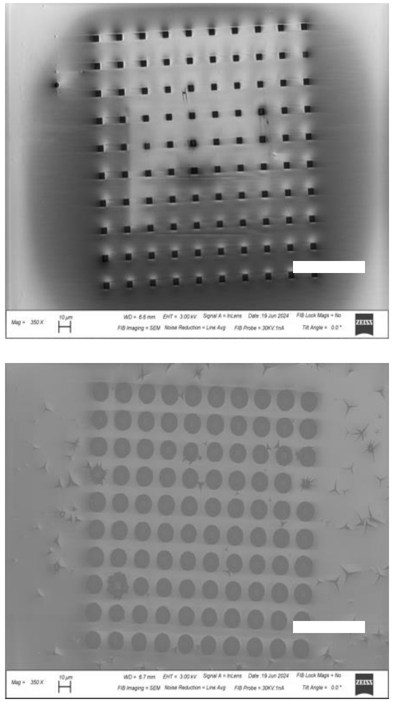


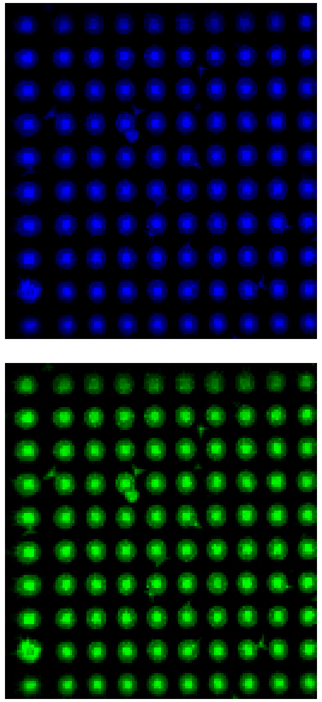
The photoluminescence (PL) spectrum of monolayer molybdenum disulfide (MoS_2) exhibits peaks in the range of approximately 1.85 eV to 2.00 eV. The S1 region displayed monolayer/bilayer (ML/BL) flakes, while the S3 and S5 regions showed multilayer flakes.

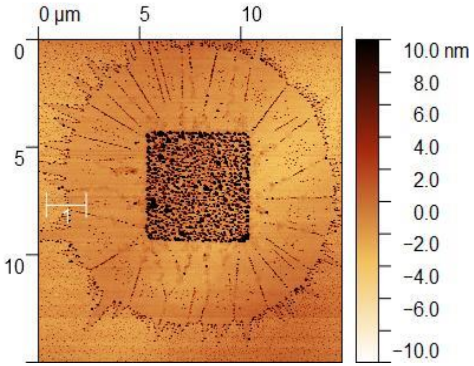
1. ACS Appl. Mater. Interfaces 2023, 15, 16308−16316

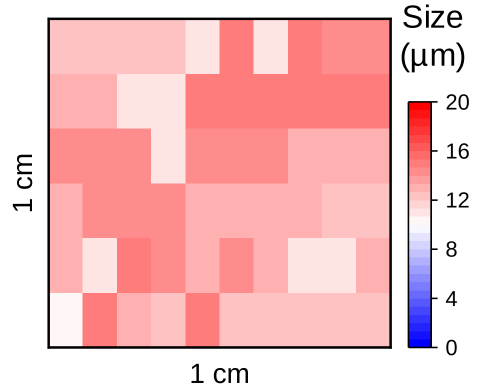
Material characterization - Array scale mapping





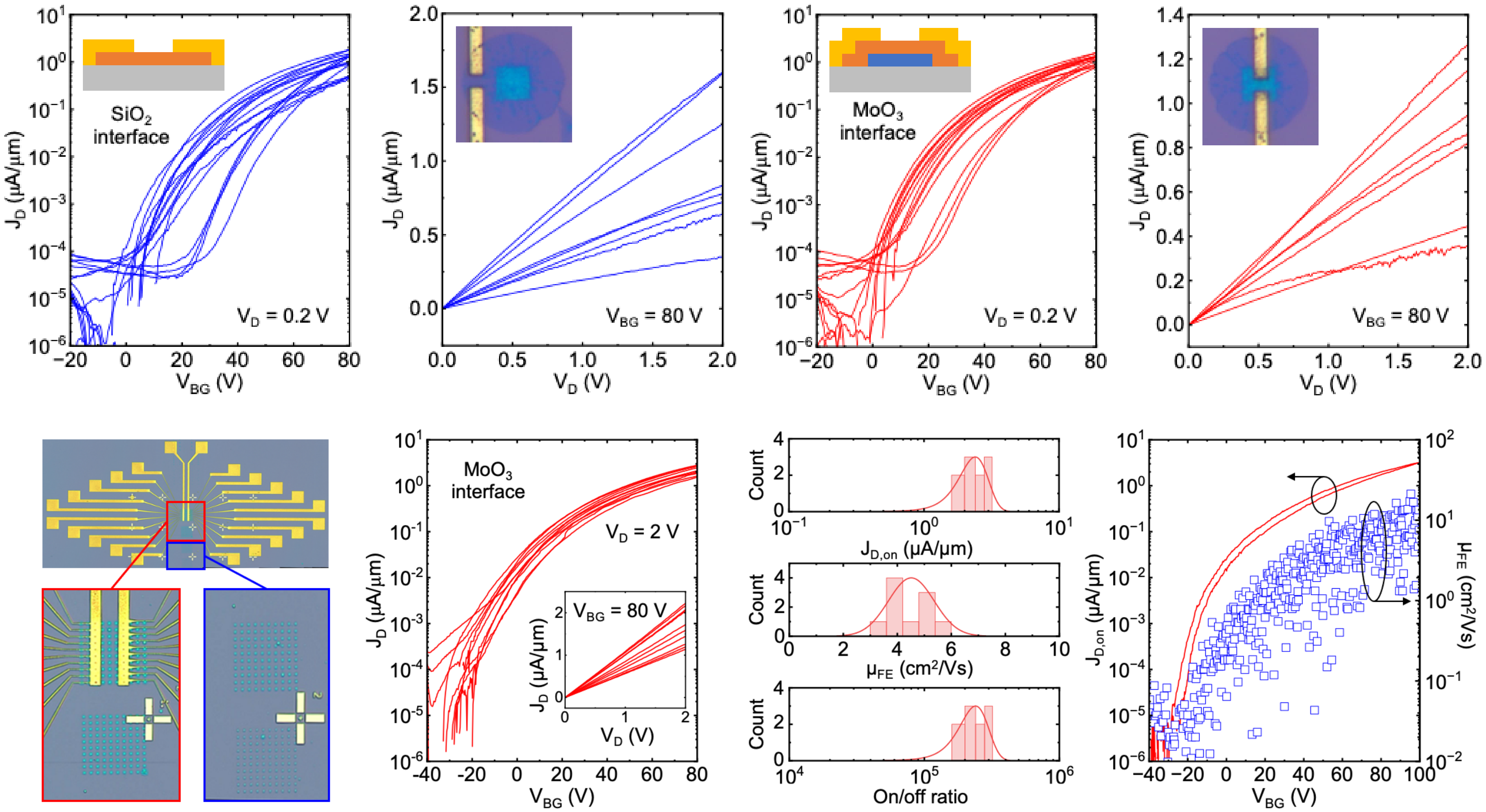






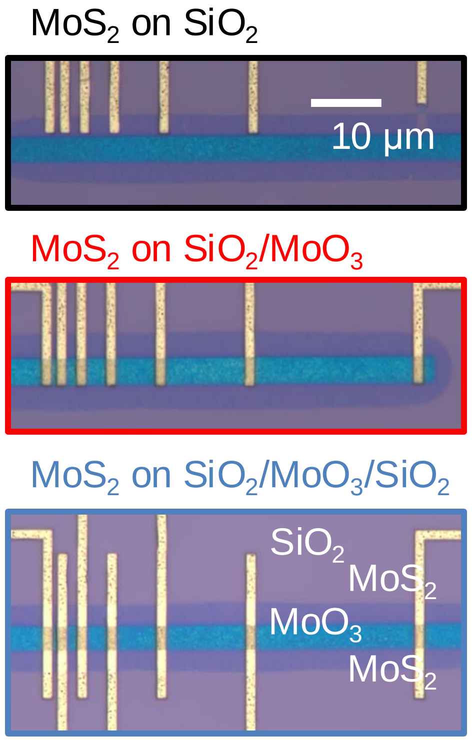
- The uniformity of the flakes can be assessed using 10 x 10 arrays through various characterization techniques such as SEM, AFM, Raman, and PL mapping.

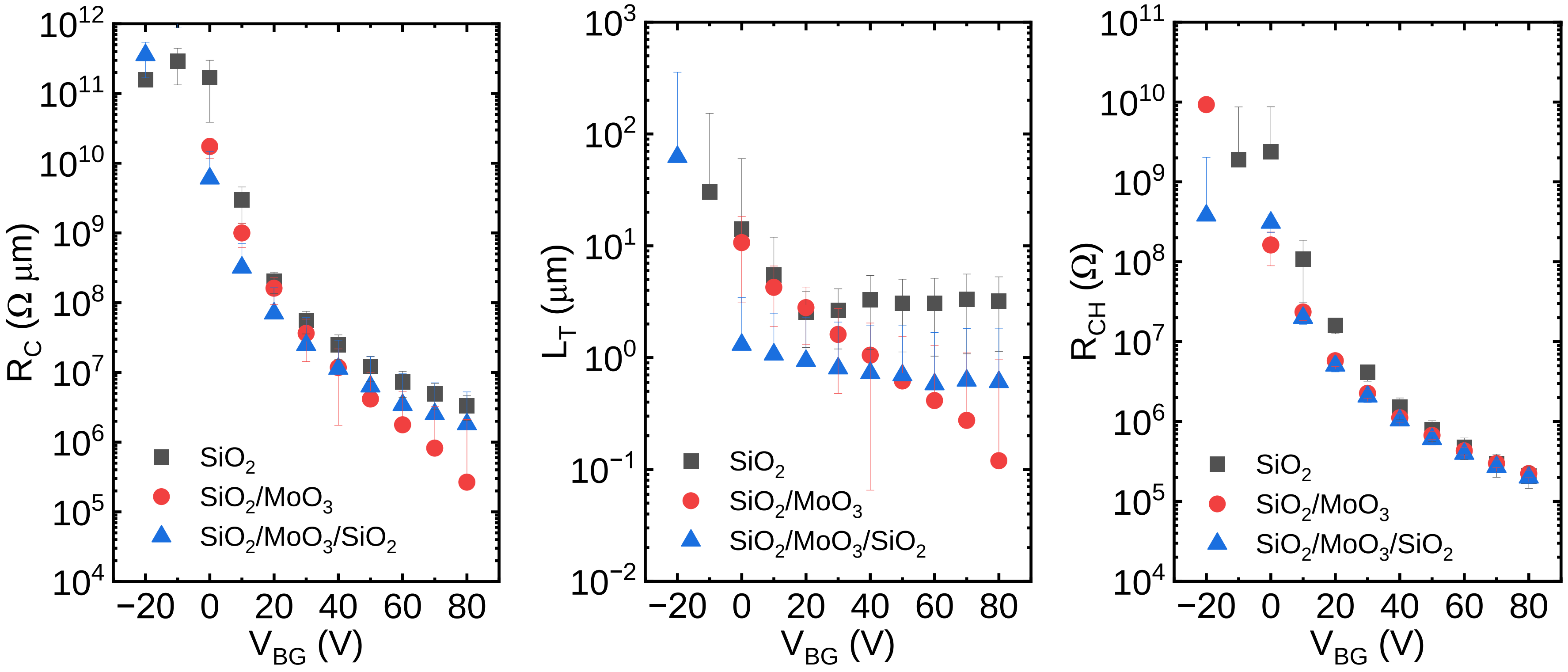
Material characterization - Carrier transport measurement



- A comparative investigation of MoS_2 FETs with MoO_3 and SiO_2 dielectric interfaces is performed, focusing on output and transfer characteristics (J_D-V_D and J_D-V_{BG}).
- Both FET types show linear J_D-V_D characteristics, indicating Ohmic contact.
- Optimized MoS_2 FET achieves $J_{D,on}$ of 3 μA/μm, μ_{FE} of 20 cm²/Vs, and on/off ratio up to 10^6.

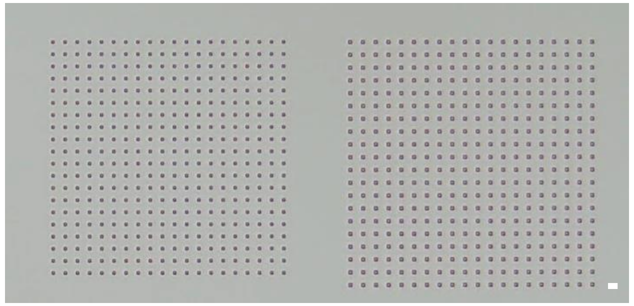
Material characterization - Transmission line measurement



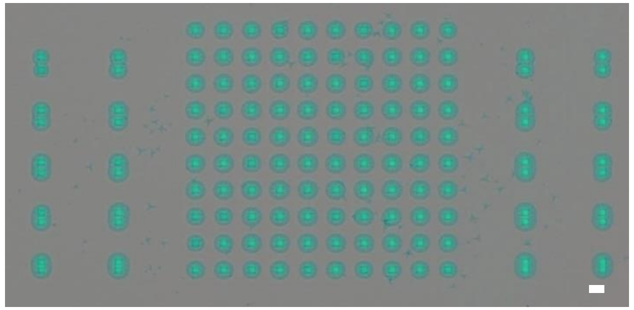


- Well-controlled growth enables defining the geometry of as-grown MoS_2 in arbitrary shapes. No need for lithography or etching processes.
- Created a long MoO_3 ribbon (5 μm × 200 μm) for Transmission Line Measurement (TLM).
- Greater involvement of the MoO_3 interface (compared to SiO_2) improves metal contact conditions. Lower contact resistance (R_c) and transfer length (T_L). Maintains the MoS_2 channel resistance (R_{CH}).

❑ Location-selective growth of MoS_2 on SiO_2 (scale bar: 10 μm)

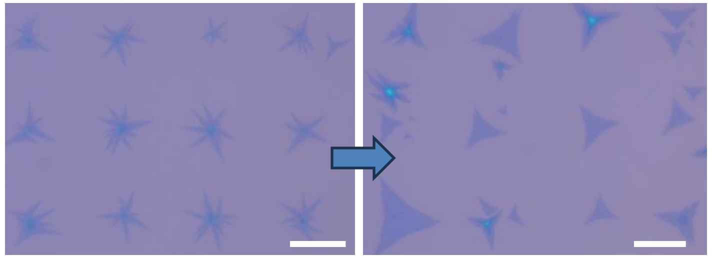


Patterned Mo precursor

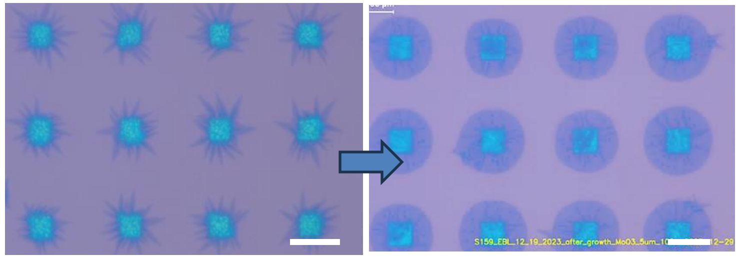


CVD grown MoS_2 on SiO_2

❑ Controlled MoS_2 morphology evolution (scale bar: 10 μm)

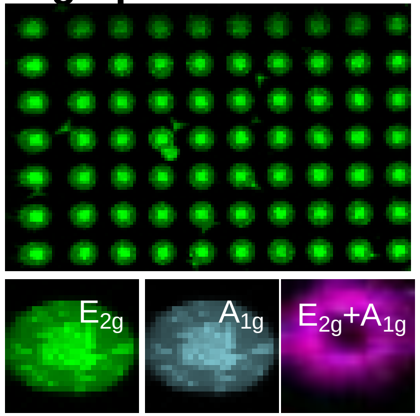


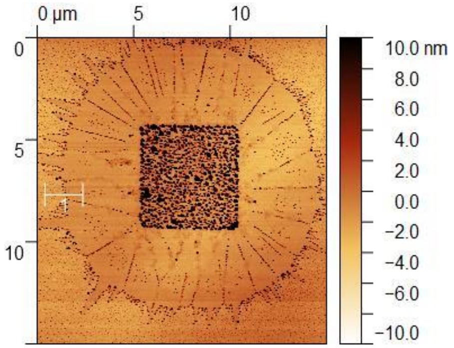
Dendrite → Concaved triangle

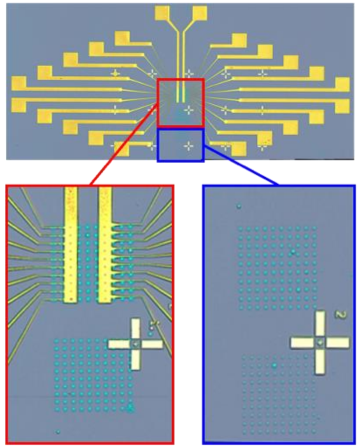


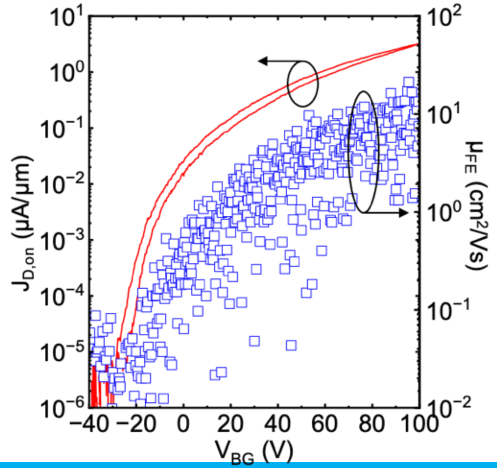
Dendritic dot → Circular dot

❑ High performance MoS_2 transistors







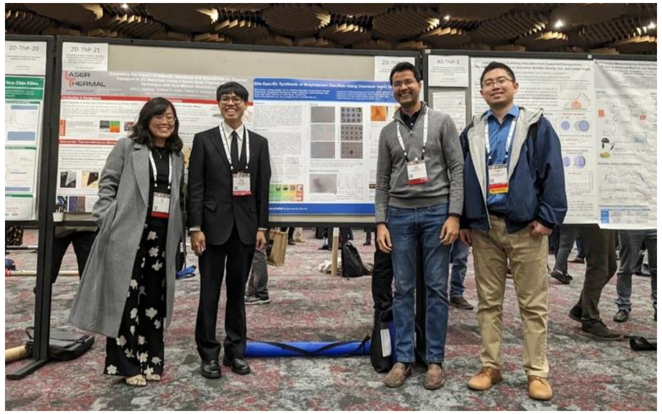


Successfully demonstrate the selective CVD growth of 2D MoS_2 arrays directly on SiO_2 substrates with controlled morphologies and excellent electronic quality (~20 cm^2/Vs electron mobility).

Acknowledgement

Team members

- Nano Energy Technology Laboratory
- Emerging Nanoelectronics Research Group



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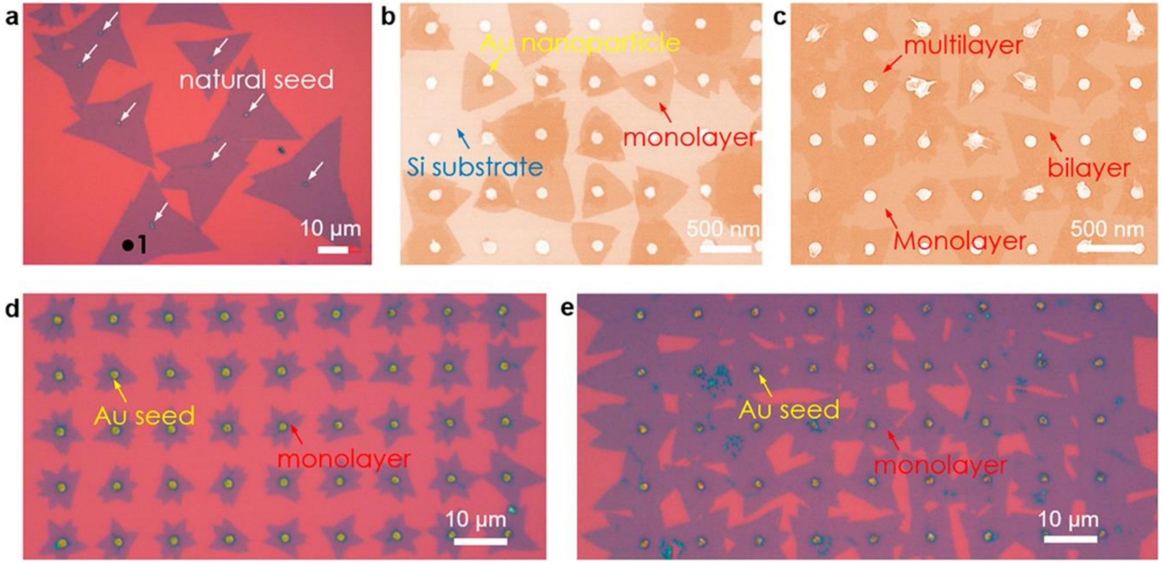
SUPPORTING INFORMATION

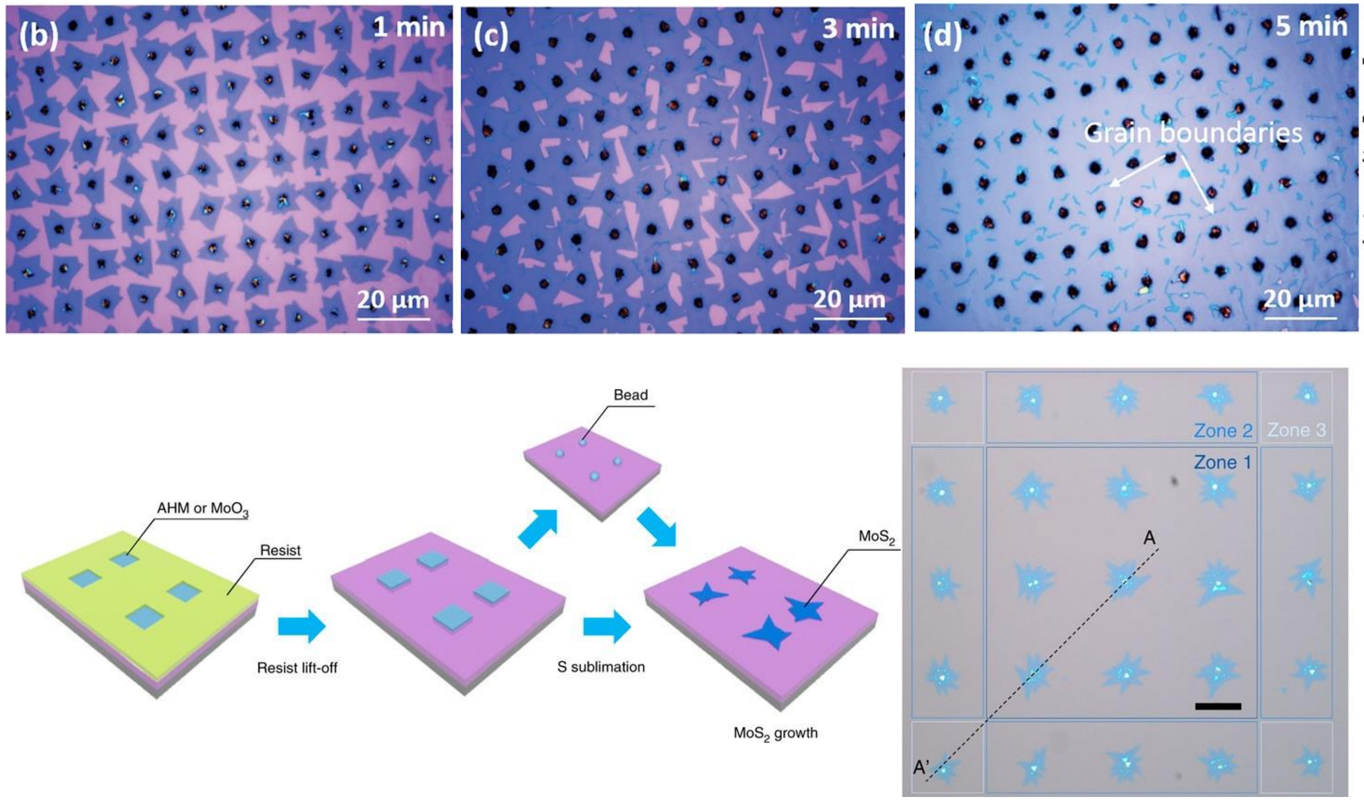
State of the art: site-specific synthesis



- Metal (e.g., Au) nanoparticles to seed the growth of MoS_2 monolayers and thereby provide a means to achieve controllable synthesis.

Issues

- Conventional photolithography crafts relatively large seed area → polycrystalline
- The metal seeds residuals will need extra steps to be removed during the fabrication

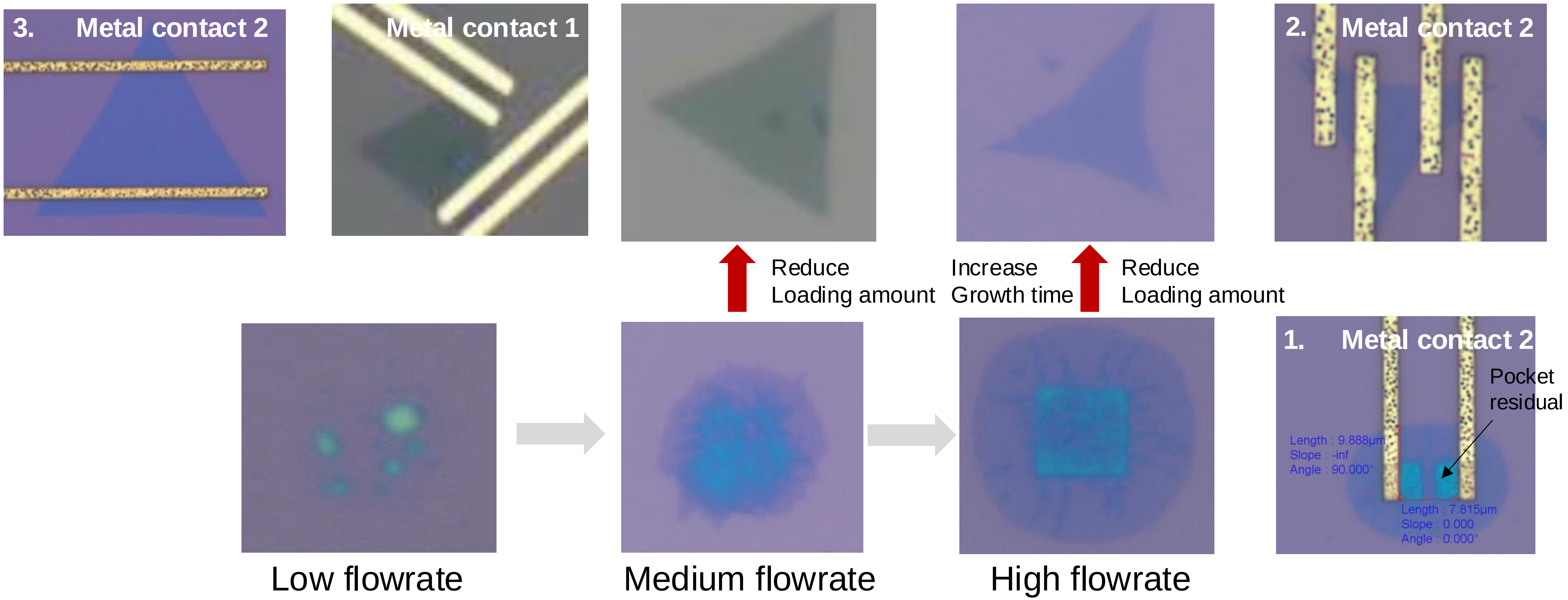


Our approaches

- Exploit Electron beam lithographic patterning of the Mo precursors to enable micrometer scale MoS_2 nucleation at predefined locations on SiO_2 substrates

1. ACS Nano 2018, 12, 9, 8970–8976
2. Adv. Mater. Interfaces 2020, 7, 2001549.
3. Nature Communications volume 6, Article number: 6128 (2015)

Process-Morphology-Carrier Transport Diagram



Contact	1. Circular	2. Concaved	3. Triangle
Metal contact 1	1	-	< 1
Metal contact 2	20	1 ~ 10	1 ~ 10