# Two-dimensional Materials in Semiconductor Pilot Lines


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**AMO GmbH, Aachen, Germany**


AMO

RWTH AACHEN UNIVERSITY

# RWTH Aachen University & AMO GmbH

**RWTH Aachen University**

- Large European Technical Univ.
- Public University
- 45.000 students
- Chair of Electronic Devices

**AMO GmbH**

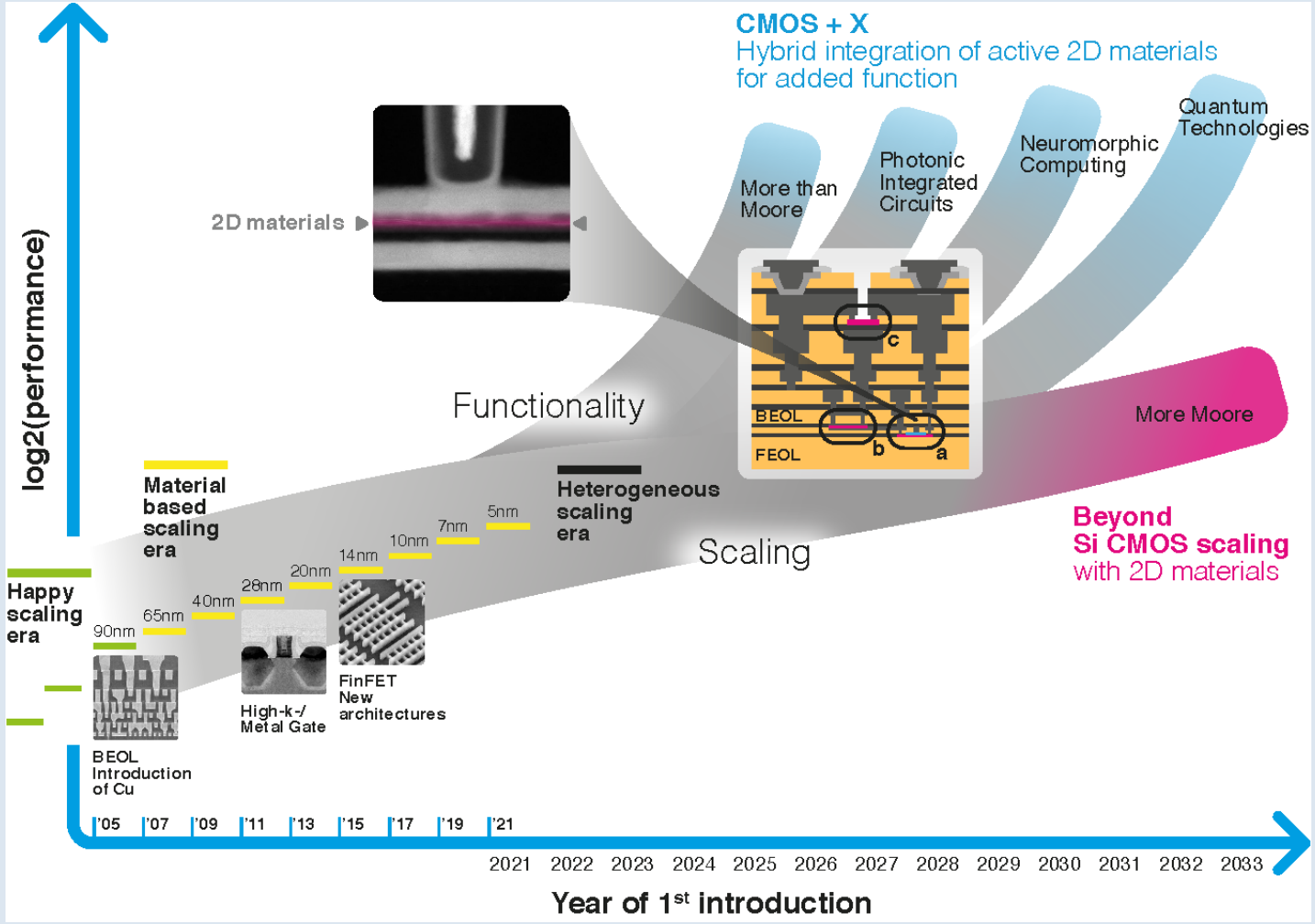
High-Tech SME / Institute (non-profit) / Research Foundry

- 400 $m^2$ clean room
- Ca. 80 staff members in 40 funded R&D projects
- Key technologies
  - Silicon technology
  - Nanofabrication & new materials integration
- Demonstrate applications
  - Nanoelectronics, Flexible Electronics
  - Nanophotonics
  - Integrated Sensors
  - Quantum Technologies
  - Neuromorphic Computing
  - Environmental Nanotechnology
- Mission: Technology Transfer
  - Project partners
  - Start Ups (Black Semiconductor, Protemics, AMOtronics)

Funded by the European Union

# 2D Materials in Semiconductor Pilot Lines

## Why 2D Materials?




Lemme *et al.*, arxiv, 2021

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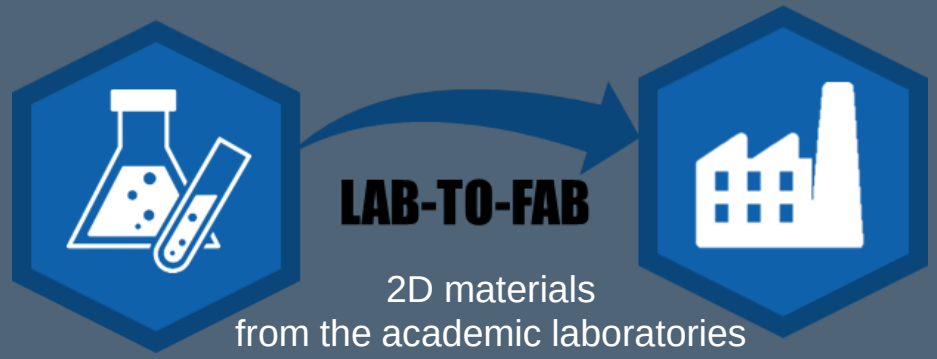
# 2D Materials in Semiconductor Pilot Lines

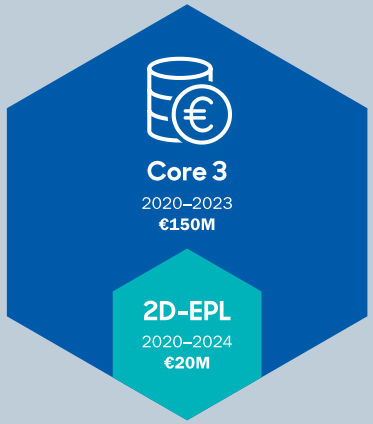
## 2D Experimental Pilot Line – From Lab to Fab




2D materials
from the academic laboratories
to the semiconductor production lines

- ❑ Establish a **European ecosystem for 2D material** integration
- ❑ Make **2D Materials compatible** with the **standards in the industry**
- ❑ **Develop** the critical tools, chemistry and materials
- ❑ **Foundry-service** with transparent access for developing new industries
- ❑ Technology transfer to commercial foundries

**ULTIMATE GOAL:** build demonstrators and achieve low volume production of innovative 2D technologies integrated with traditional semiconductors




- **One project of the Graphene Flagship**
- **Started Oct 2020**
- **4 years duration,**
- **20 M€ funding**

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the European Union

# 2D Materials in Semiconductor Pilot Lines

## Approach of the 2D EPL

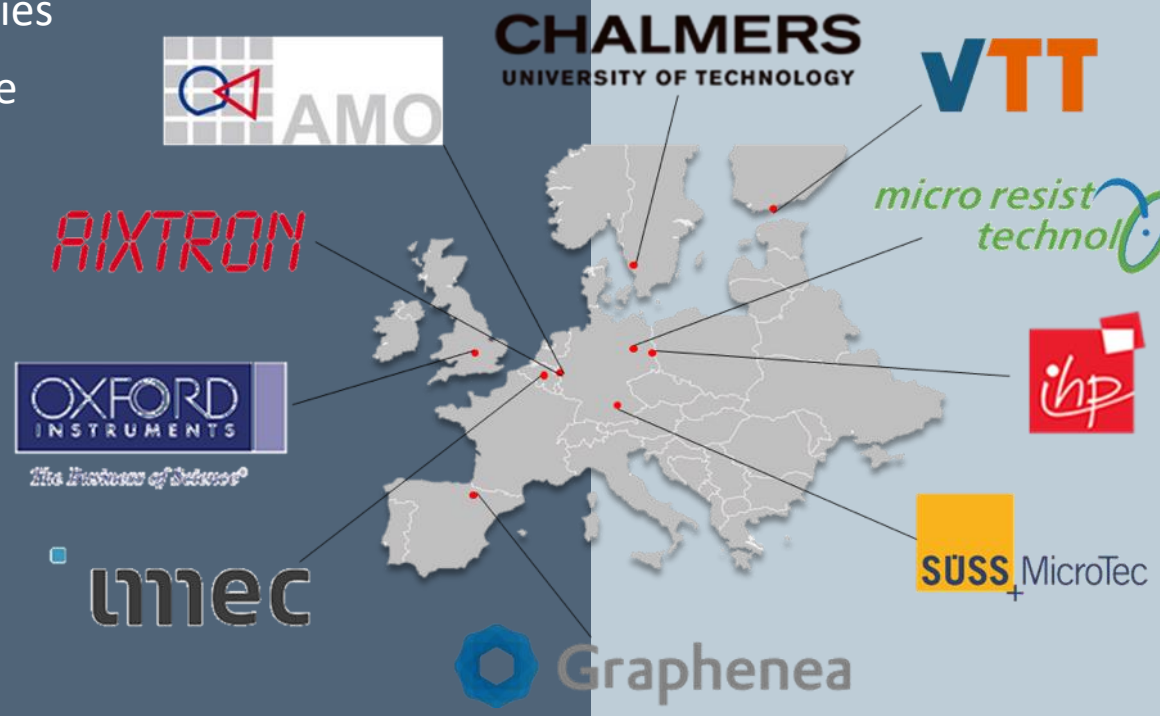
**11 partners all around Europe**

### Pillar I – Prototyping from day one

- ❑ Provide processing services based on existing technologies
- ❑ Improve device performance and yield on polycrystalline CVD graphene at 200 mm platform

### Pillar II – Towards generic integration platform

- ❑ Single crystalline growth of 2D materials
- ❑ Automated transfer tools for up to 300 mm
- ❑ Planarization based generic platform
- ❑ Photonics, electronics and sensor modules

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# 2D Materials in Semiconductor Pilot Lines

## Develop the critical tools, chemistry and materials

1. **Development of tools & materials**

SÜSS MicroTec · AIXTRON · micro resist technology · OXFORD INSTRUMENTS · Graphenea

2. **Development of module & platform**

VTT · imec · AMO · ihp

3. **Multi-purpose wafer runs** *(open access for testing novel ideas)*

VTT · imec · AMO

**WP1 – Wafer Scale Growth**
**WP2 – Wafer Scale Transfer**

**WP3 – Wafer Scale Integration**
**WP4 – Modules for Industry**

**WP5 – Multi Project Wafer**

**Coordinator** CHALMERS UNIVERSITY OF TECHNOLOGY

2D PILOT LINE

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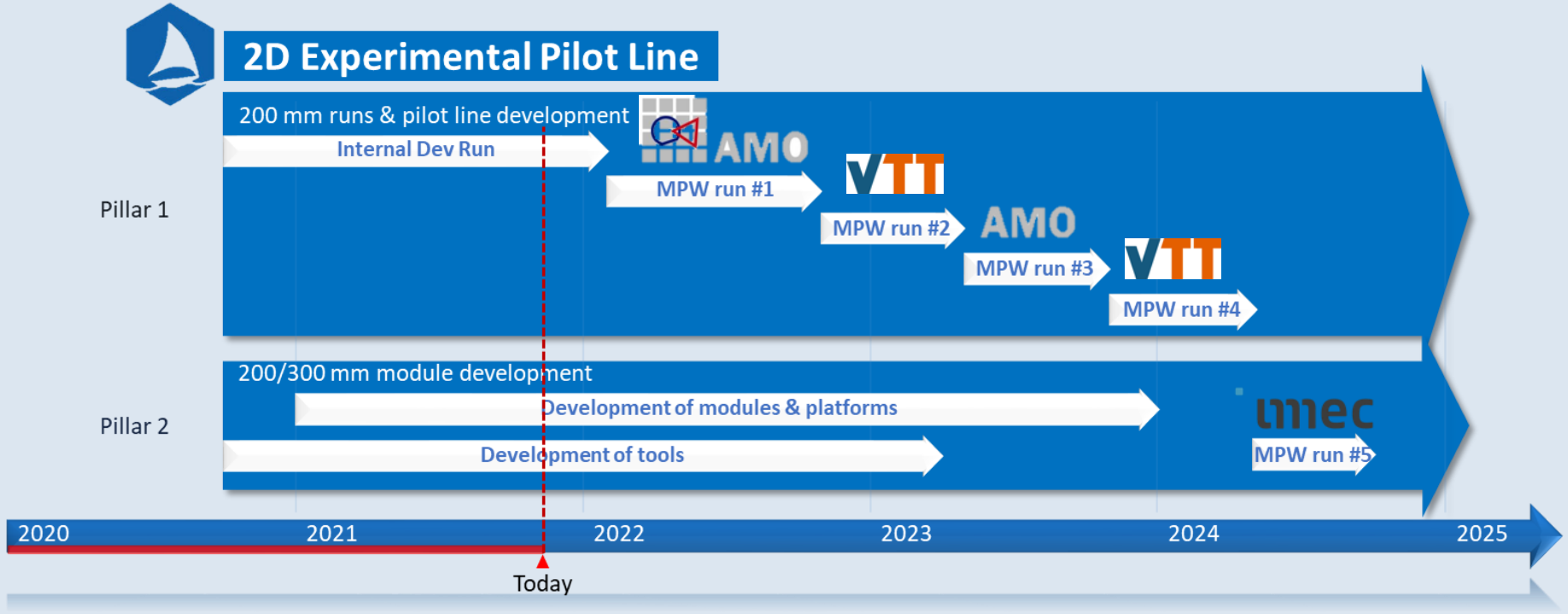
# 2D Materials in Semiconductor Pilot Lines

## Foundry-service with transparent access for developing new industries




- Start of the project with the two pillars in parallel
- Pillar 1 just about to start the MPW run phase in parallel to the development of tools, modules and platforms
- AMO offers the first MPW run in Oct. 2022

**Graphene Sensors** — Run 1
- Bio/Gas/Chemical sensors, Hall Sensors, Photodetectors

**Graphene Sensors** — Run 2

**Electronic Devices incl. Graphene Sensors** — Run 3

**Graphene Sensors devices on CMOS wafers** — Run 4

**TMDC based transistors** — Run 5

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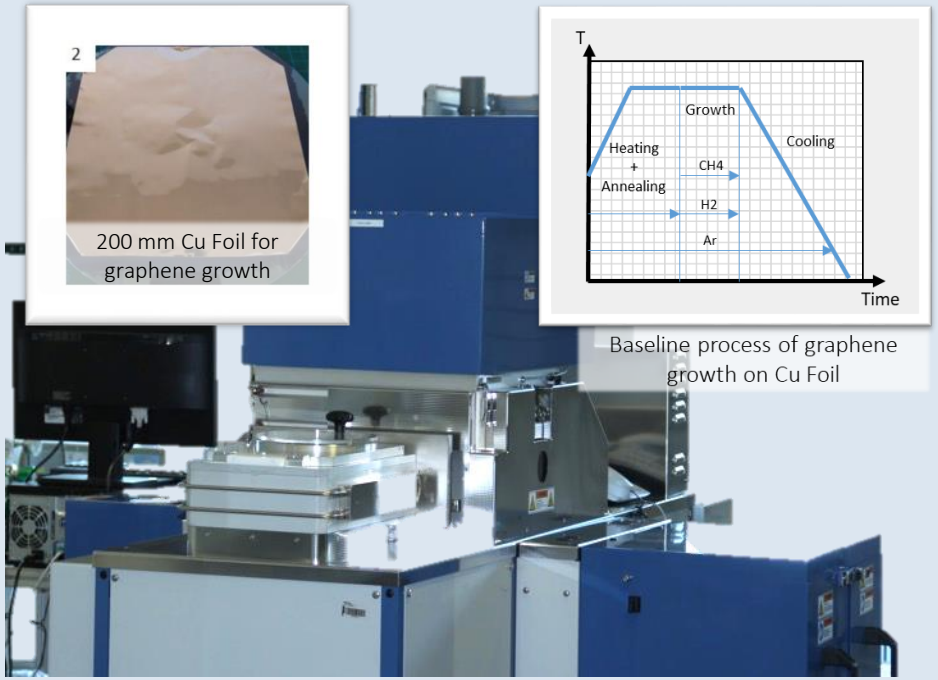
# 2D Materials in Semiconductor Pilot Lines

## The 2D Experimental Pilot Line at AMO

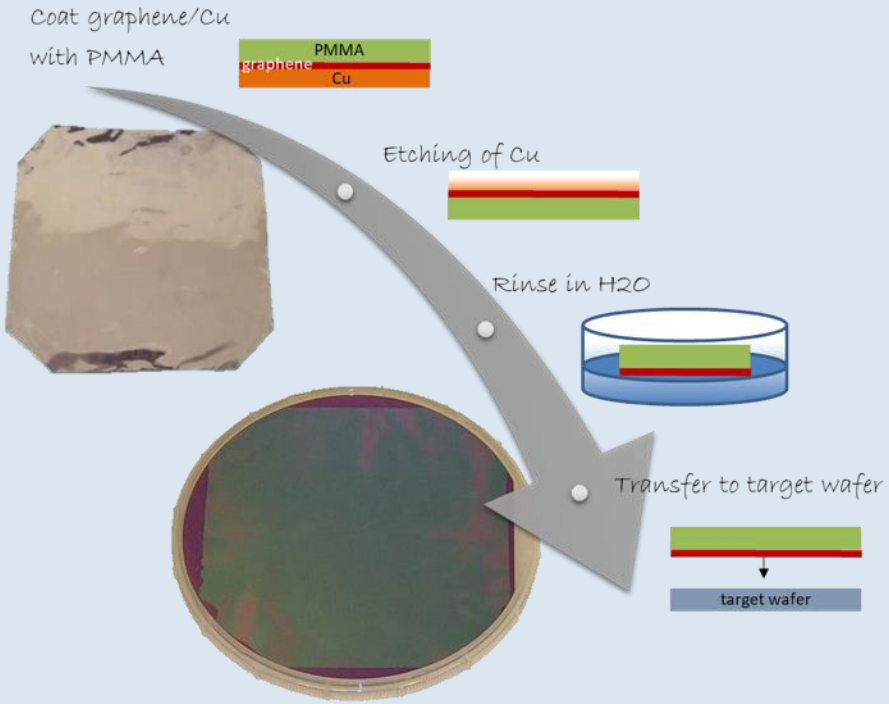
### 1. Wafer Scale Growth




- Oxford NANOFAB
- 8” compatible
- Temperature: 1200 deg.C
- Max. pressure: 4 Torr

**CVD Tool used for graphene growth on 200 mm substrate size**

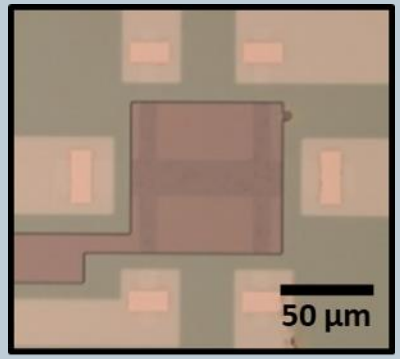
### 2. Wafer Scale Transfer

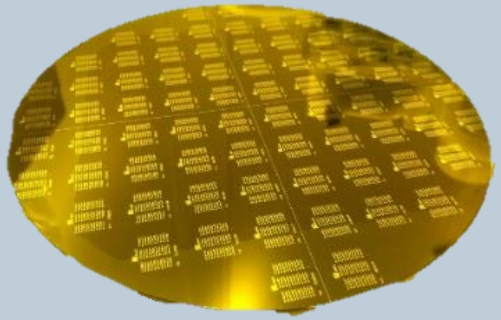



*Nano Lett.* 2009, 9, 12, 4359−4363

**Current wet transfer process at AMO at wafer scale for 6” and 8“ wafers**

### 3. Wafer Scale Integration



**Wafer scale device fabrication with developed tools and methods**

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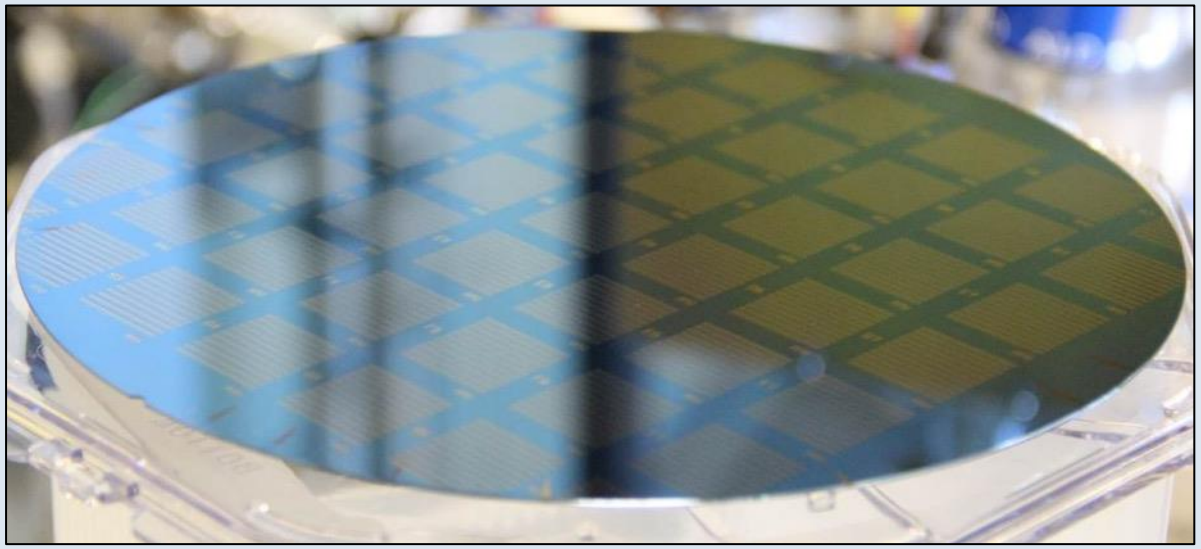
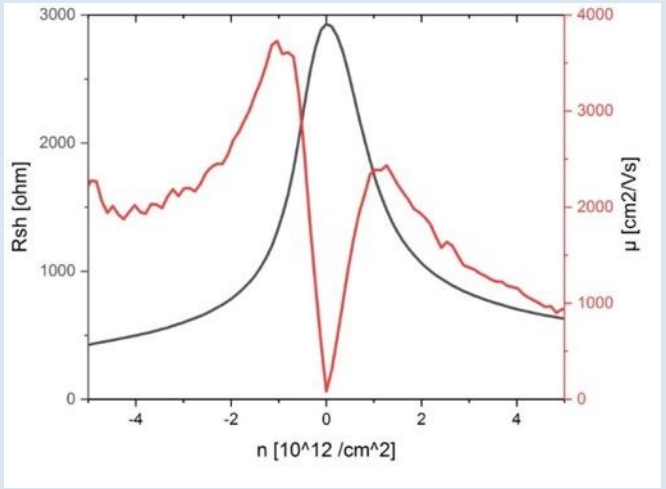
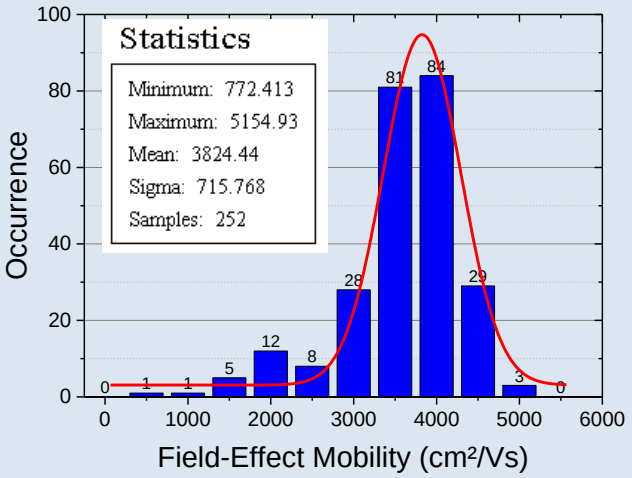
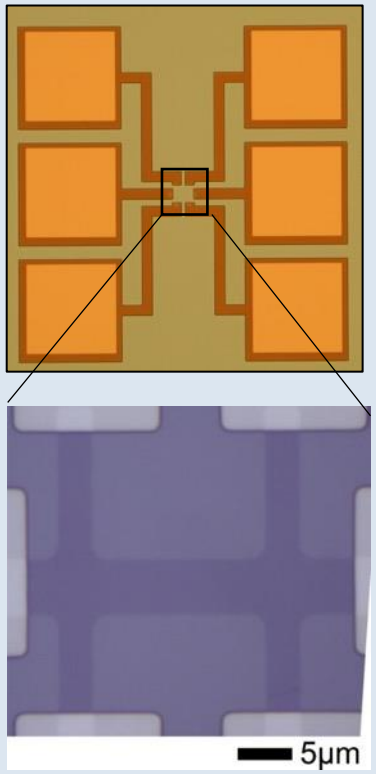
# 2D Materials in Semiconductor Pilot Lines

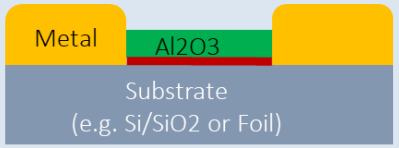
## Example: Encapsulated GFETs with Global BG






Encapsulated GFETs with global BG

- Example of a processed 6” wafer with GFET
- 252 devices analyzed
- avg. Mobility μ ~3800 cm²/Vs
- Target 2D-EPL:
  μ > 5000 Vs/cm2 on 200 mm wafers with > 80% uniformity over wafer

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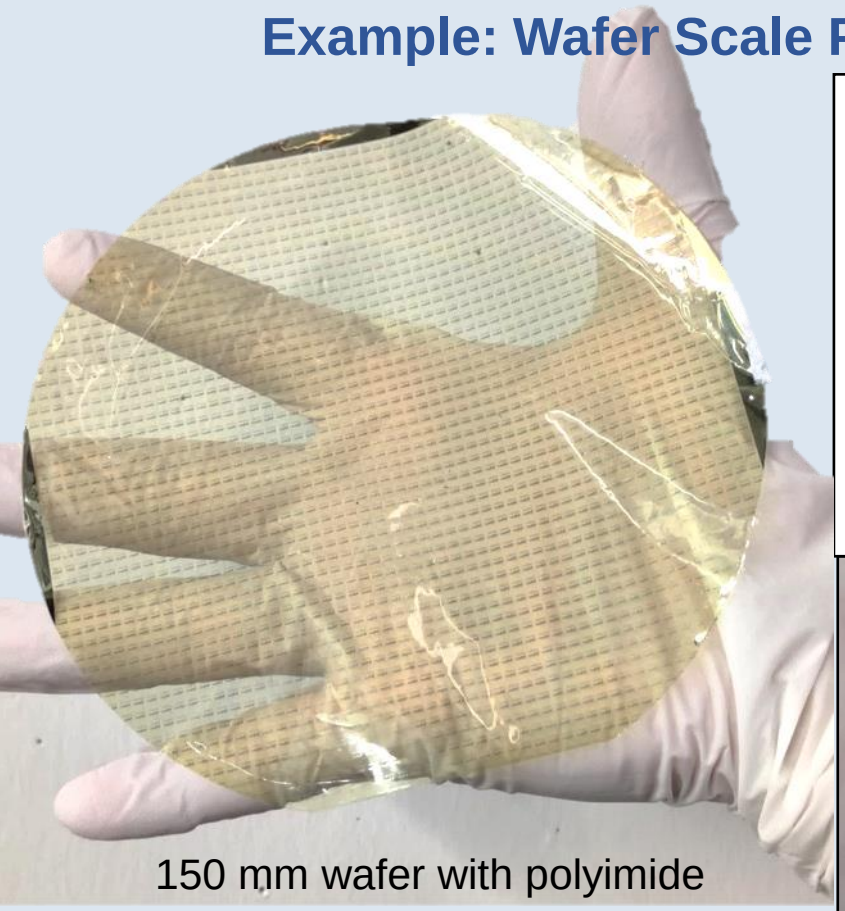
# 2D Materials in Semiconductor Pilot Lines

## Example: Wafer Scale Process on Flexible Substrate

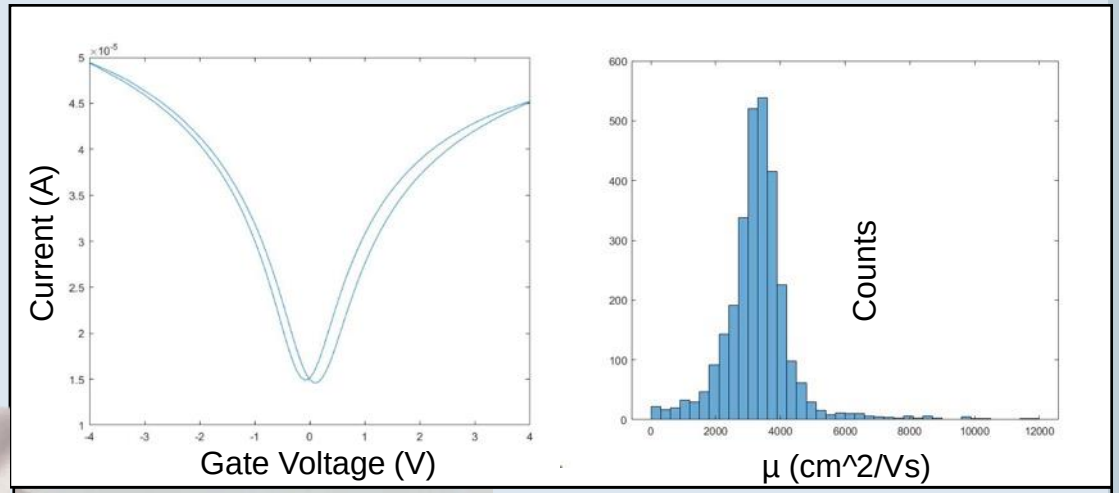


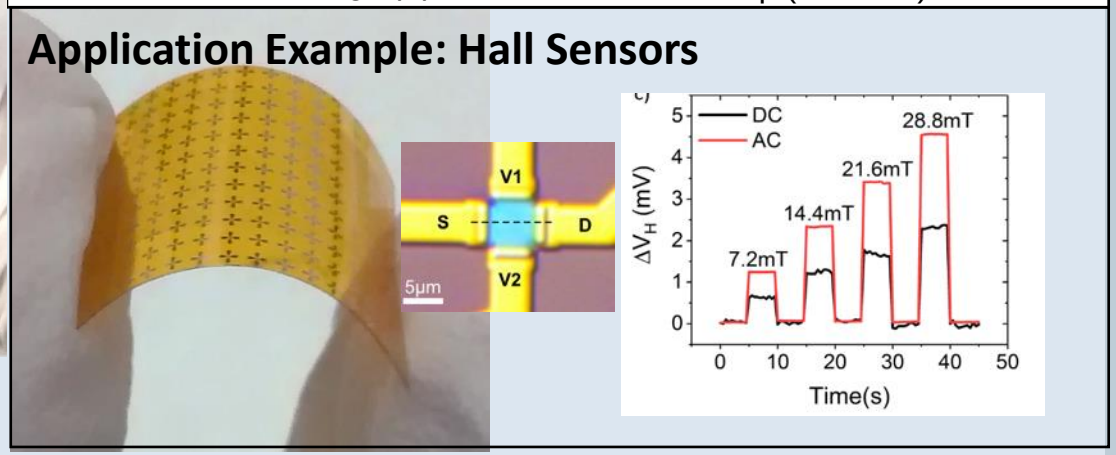
150 mm wafer with polyimide

Top gate FETs as test devices

4 point van der pauw measurement

Average mobility: 3230 cm²/Vs

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# 2D Materials in Semiconductor Pilot Lines

## 2D EPL - MPW Run #1 @ AMO

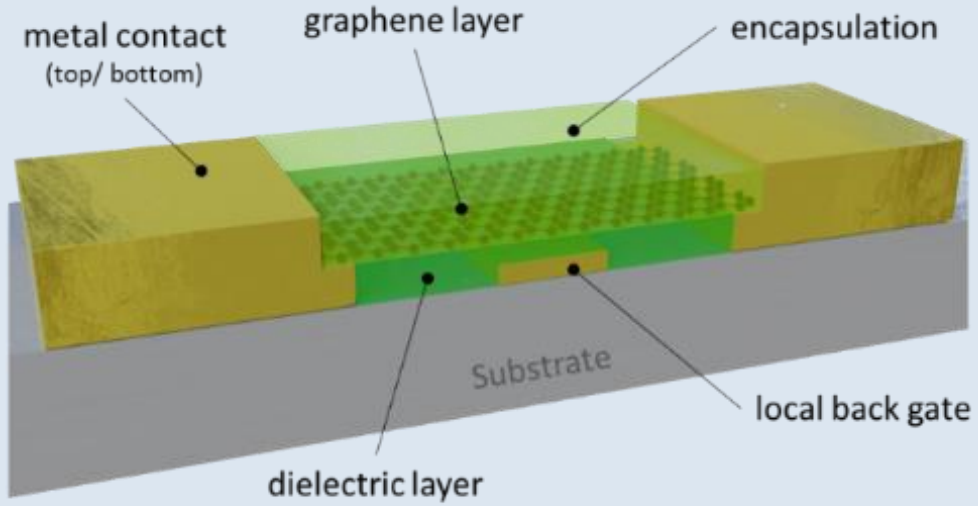
**Application**
- Bio/Gas/Chemical sensors, Hall Sensors, Photodetectors

**Substrate**
- Material: Silicon
- Basic die size: 1 x 1 cm² (a different size can be consulted upon individual request)

**Resolution**
- General design rule: 5µm for in-layer critical dimension and over-layer alignment

**Characterization**
- Raman characterization
- Basic electrical device measurements

**Baseline Process:**
- Top/Bottom metal contact
- Wafer scale graphene transfer
- ***Optional:*** *metal local or global back gate*
- ***Optional:*** *encapsulation, and via opening on top of metal pads*
- ***Optional:*** *graphene sensing area opening*
- Device Library provided in PDK: Hall cross, TLM devices, 4-point measurement bar




**Important Dates**
**1 February 2022:**
Call opens

**30 June 2022:**
Call closes, design freeze

**2022:**
MPW run

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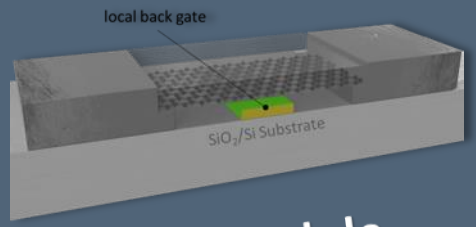
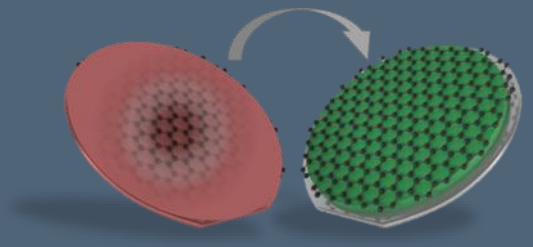
# 2D Materials in Semiconductor Pilot Lines

## MPW Run #1 Modules




### Gate Module

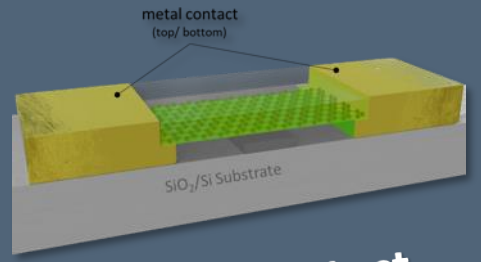
- **global back gate** is realised through **p-doped $SiO_2$/Si** substrate
- **local back gate** by 5/40 nm Ti/Pd
- **gate dielectric** by $Al_2O_3$ with a thickness of 75 nm grown by ALD



### Graphene Module

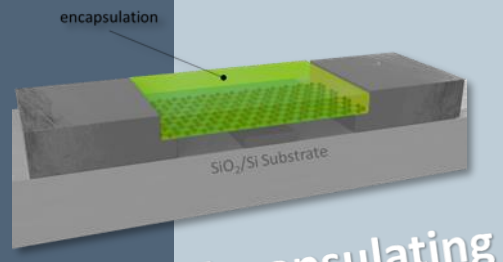
- **CVD Graphene** on 200 mm x 200 mm Cu foils
- **Graphene wafer scale transfer** by semidry method or wet transfer
- **graphene patterning** by photo-lithography and reactive ion etching

*Mobility: 1000 – 2500 cm²/Vs*




### Graphene Contact

- **Sandwich contact** by of bottom and top Pd metal layers
- Pd layer thickness in the range of **30-50 nm**




### Graphene Encapsulating

- Encapsulation by ALD deposition **of 30-80 nm $Al_2O_3$** and via etching
- Encapsulation **by SU-8 coating** (>7µm) and patterning

ongoing development

- *Local top gate*
- *mobility improvement => 5000 cm²/Vs*
- *lower contact resistance*

2D PILOT LINE

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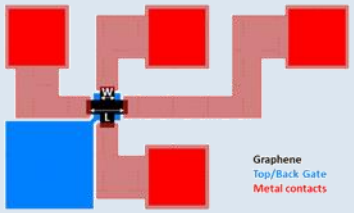
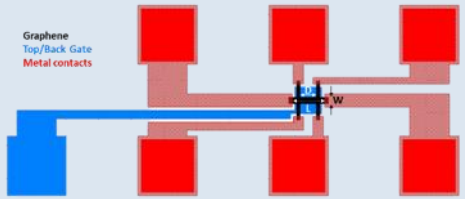
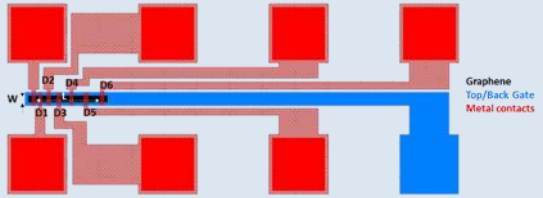
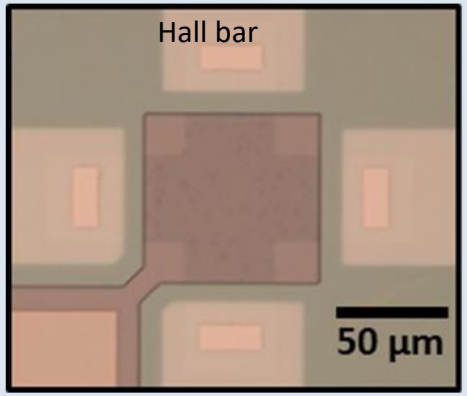
# 2D Materials in Semiconductor Pilot Lines

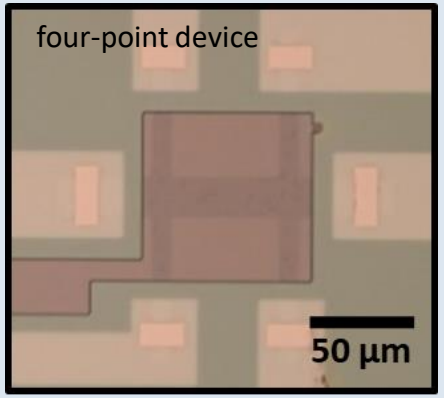
## Device library and die design

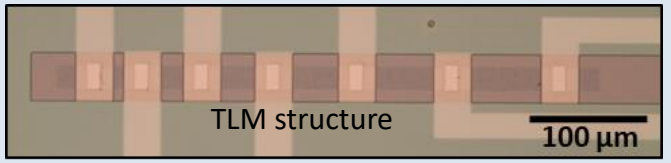


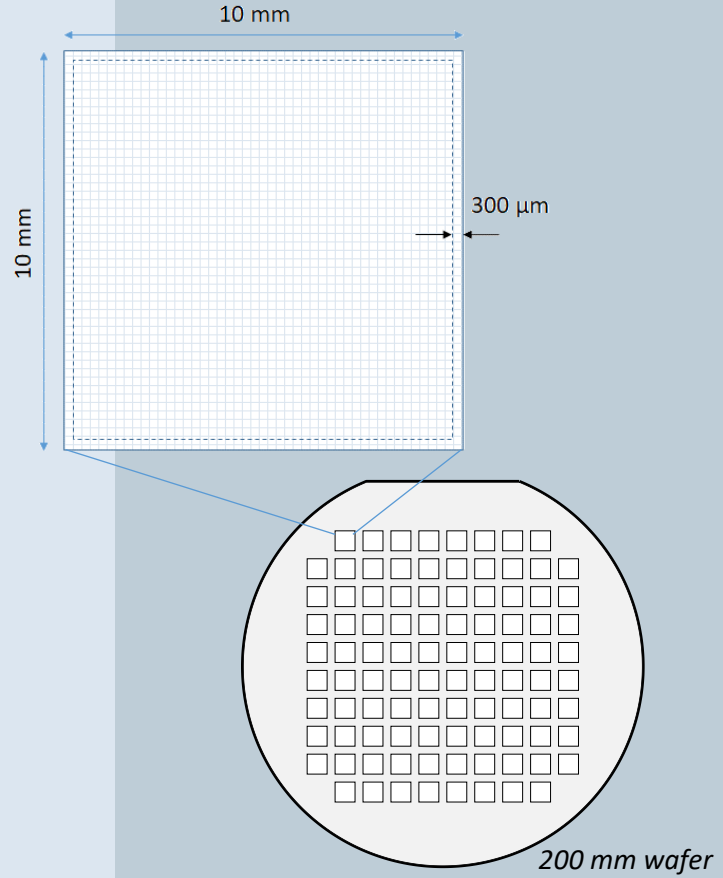




- Full custom design inside 10 mm x 10 mm die size within the design rules
- Device Library available for standard reference devices available:
  - hall bar, four-point, TLM

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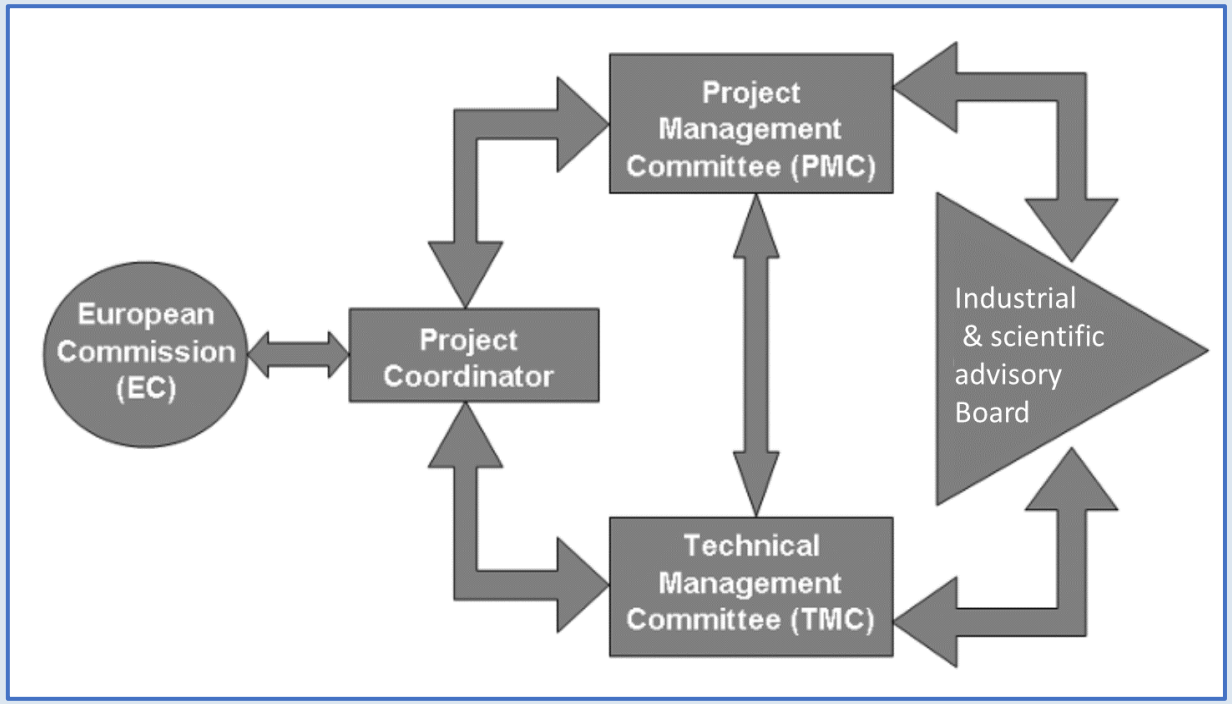
# 2D Materials in Semiconductor Pilot Lines

## Technology transfer to commercial foundries

Chalmers, imec, AMO,
VTT, Graphenea




| Industrial Advisory Board |
| --- |
| X-FAB |
| AMS |
| NXP |
| Infineon |
| STMicroelectronics |
| Emberion |
| Nokia |
| ELMOS |
| Representative Flagship 1 |
| Representative Flagship 2 |

→ Semiconductor industry as Advisory Board

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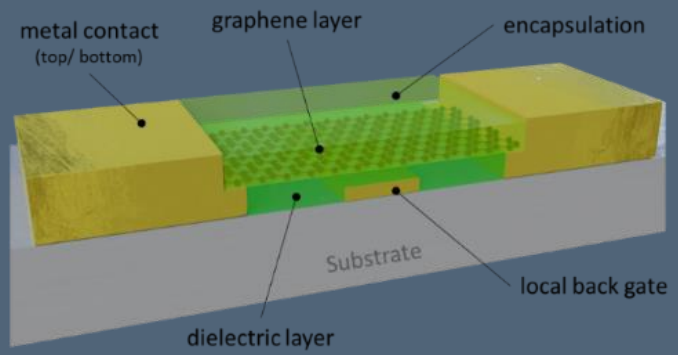
# 2D Materials in Semiconductor Pilot Lines

## Summary - Establish a European ecosystem for 2D material integration

- 2D EPL Project wants to bridge the gap from lab to fab
  - ⇒ developing tools, materials, modules
  - ⇒ Providing access to the current technology for 2D Material processing
- AMO is one of the pilot line locations beside VTT and IMEC
- AMO will provide first MPW run in Oct. 2022
  - Back gated Graphene FET for applications as Bio/Gas/Chemical sensors, Hall Sensors, Photodetectors

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More Information available on:
https://graphene-flagship.eu/innovation/pilot-line/

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