Integrating new materials into Silicon Photonics

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Head of Nanophotonics
AMO GmbH

Company Profile: Overview

Gesellschaft für Angewandte Mikro- und Optoelektronik mbH

Managing Directors:
- Prof. Max Lemme
- Dr. Michael Hornung

- **High-Tech SME (non-profit)**
- **Research Foundry**
- Close ties to RWTH Aachen University
- operating since 1997

- ~75 staff members

- **Applications**
  - Nanoelectronics
  - Nanophotonics
  - Integrated Sensors
  - Quantum photonics
- **Key technologies**
  - Nanofabrication (Stepper, E-Beam, IL, NIL)
  - Silicon technology base
  - 400 m^2 “extended CMOS” clean room

Why non-CMOS materials at a CMOS workshop?

- There are great things you **can do** with CMOS compatible photonics
- BUT there are also great things you **can‘t do** with CMOS compatible photonics

AMO history

- CMOS heritage: High-k/metal gate transistors mid ‘90s to early 2000‘s
- Starting strictly with CMOS compatible photonics: SOI waveguides in 2004
- Most complex: depletion type pn-modulators, >14 GHz (2015)
- Established LPCVD Si_3N_4 waveguides in 2011
- **New material integration**
    - Graphene integration: first 50 GHz graphene photodetector (2014)

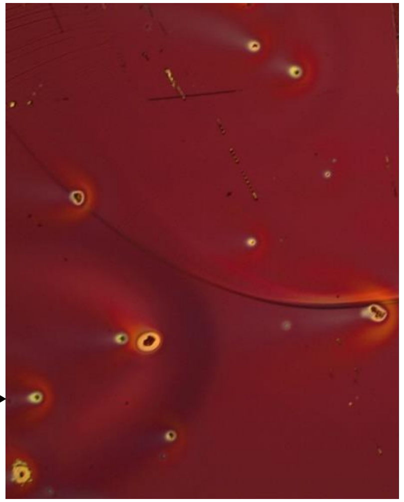
    → Cedric Huyghebaert, Black Semiconductor
    - Perovskite integration: first wafer scale perovskite lasers (2017)
    - $PtSe_2$ integration: 2D material selectively grown on waveguides (2021)

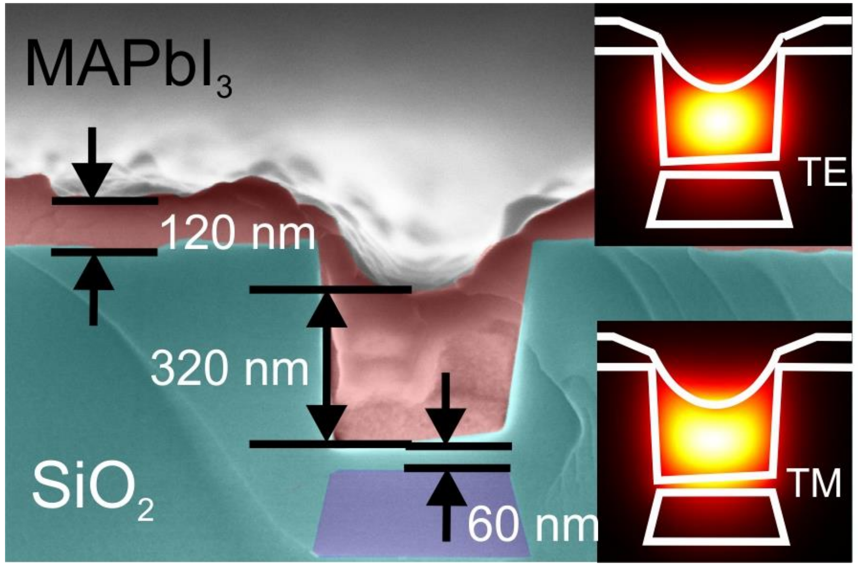
Perovskite lasers: indirect patterning

Relevant perovskite properties
- Direct bandgap semiconductors
- Solar cell (with $MAPbI_3$) rival Si cells
- Deposition via spin coating possible → simple integration?
- Solved by polar solvents → no standard lithography!

Indirect patterning
- Etch trench into cladding
- Spin coat $MAPbI_3$ onto samples
- Requires tight etch depth control
- Rough $MAPbI_3$ layer → scattering
- Leaves residual layer everywhere
- **Works**

$MAPbI_3$ partially immersed in standard developer →



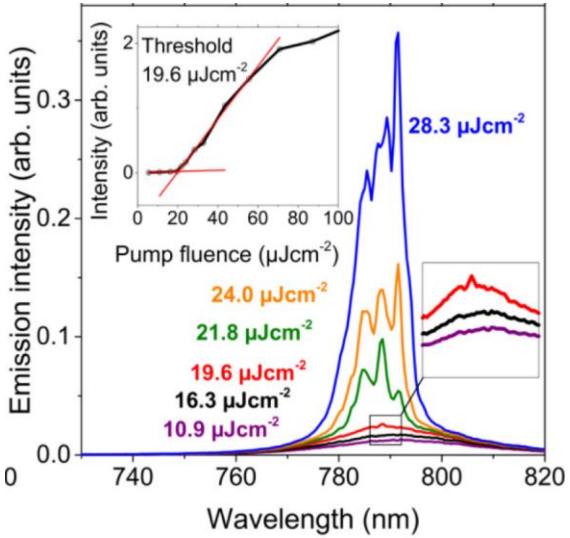


Perovskite deposited at IIT in Milan, Annamaria Petrozza

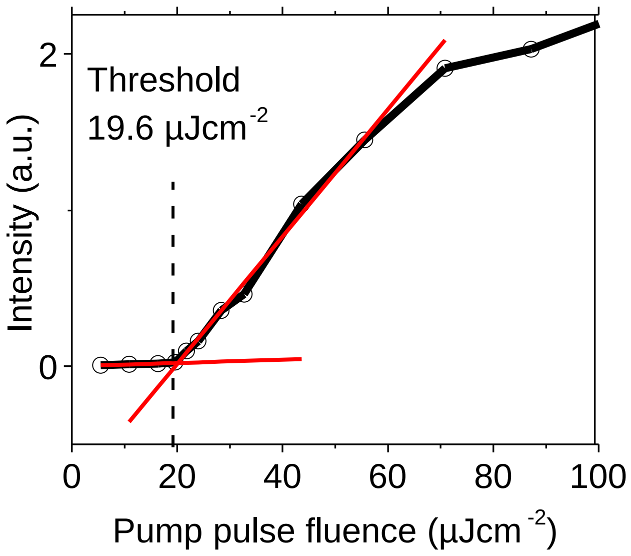
P. J. Cegielski, …, A.L. Giesecke, Opt. Express **25**, 13199-13206 (2017)

Perovskite lasers: indirect patterning

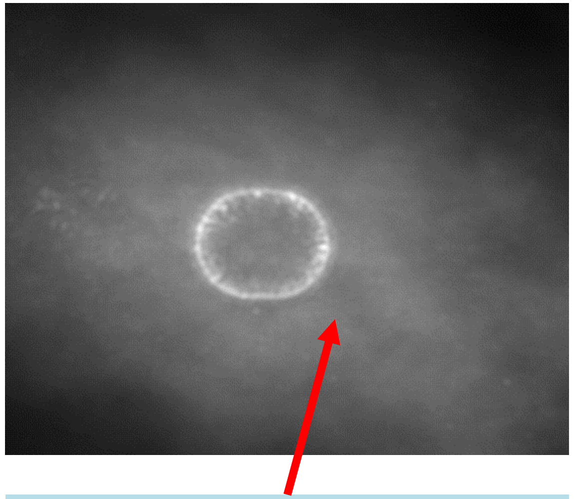
Ring below and above lasing threshold



Lasing threshold plot



Camera image from top



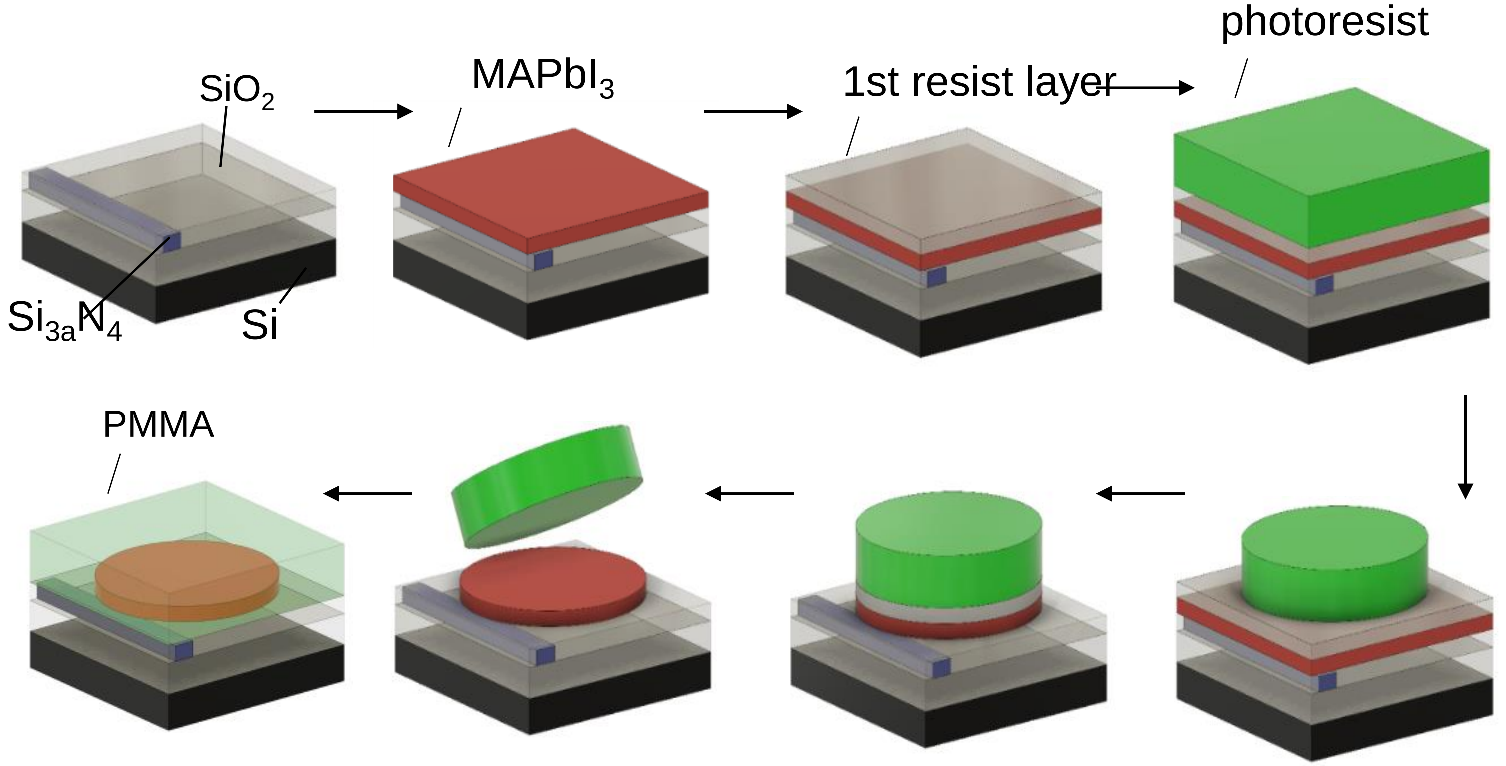
Strong scattering due to structure of the pervoskite

- Clear threshold for optically pumped lasing
- Strong scattering (material-limited and patterning method limited)
- 2017: First (optically pumped) perovskite laser integrated on SiN waveguides
- Using standard wafer scale i-line stepper lithography
- **Generalize indirect patterning of last layer to other CMOS incompatible materials and other substrates**

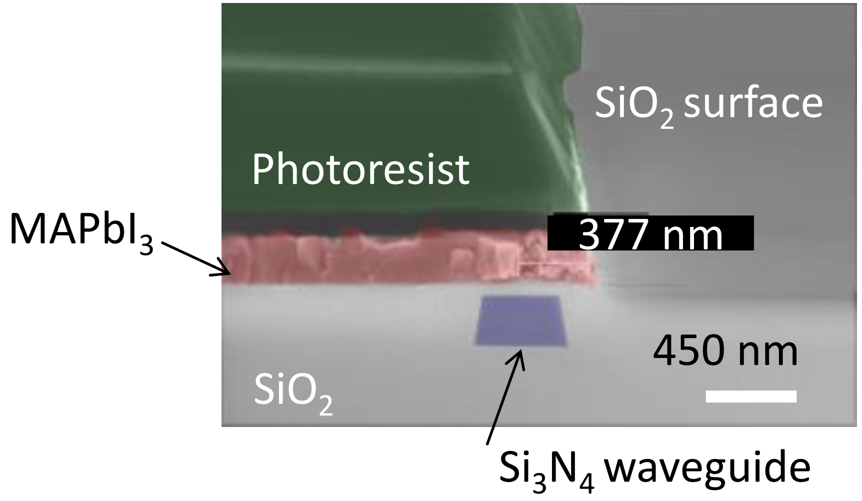
P. J. Cegielski, …, A.L. Giesecke, Opt. Express **25**, 13199-13206 (2017)

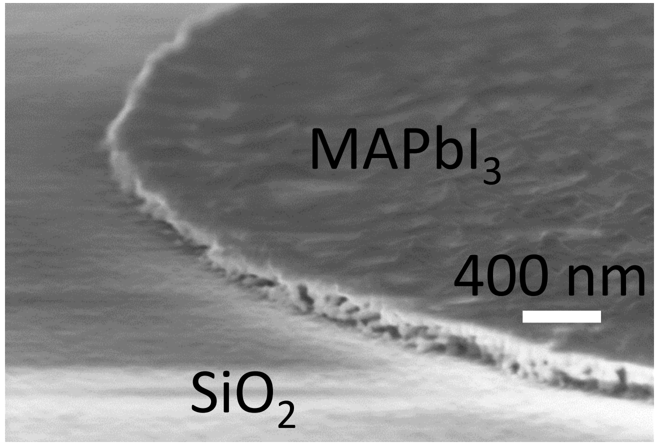
Perovskite lasers: direct patterning by RIE

Process



Results





- Special lithography process developed
- Reactive Ion Etching (RIE) process developed
- **Top-down patterning of perovskite on Si_3N_4 waveguide**

Perovskite deposited at IIT in Milan, Annamaria Petrozza

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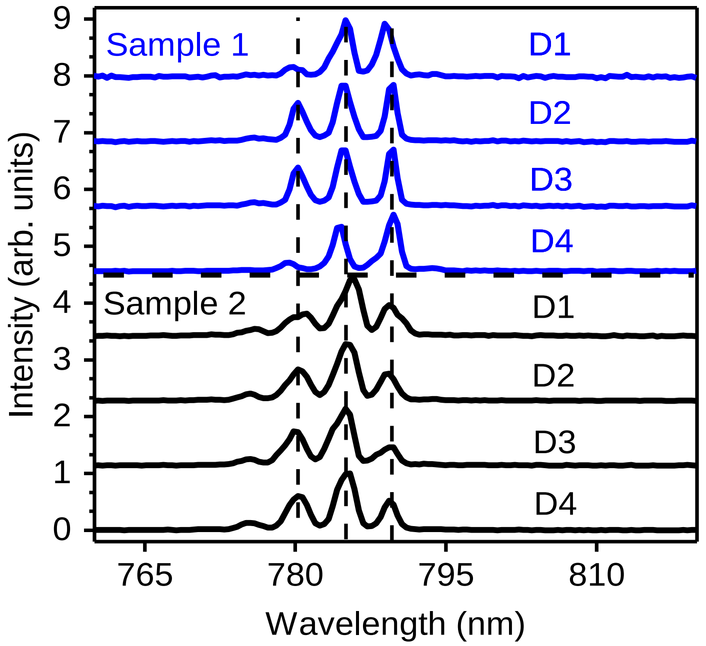
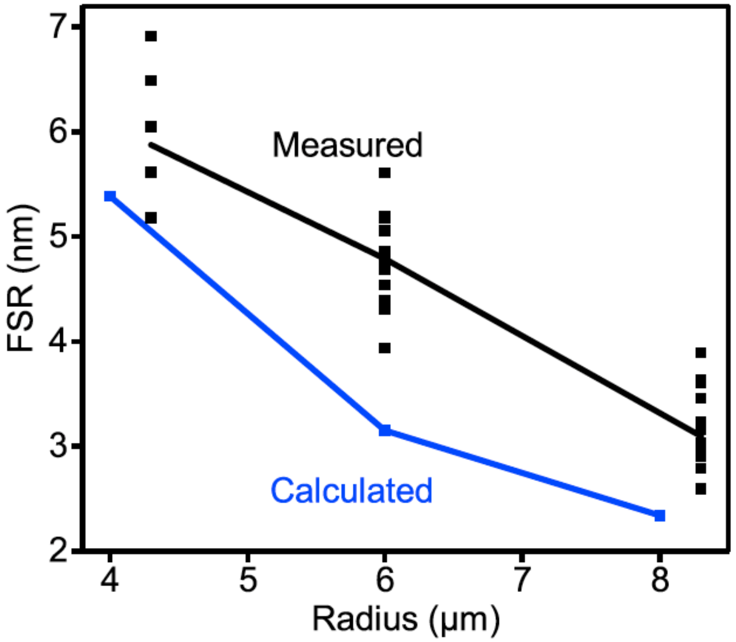
P. J. Cegielski et al., DOI: 10.1021/acs.nanolett.8b02811

RIE patterned Perovskite disks lasers: results

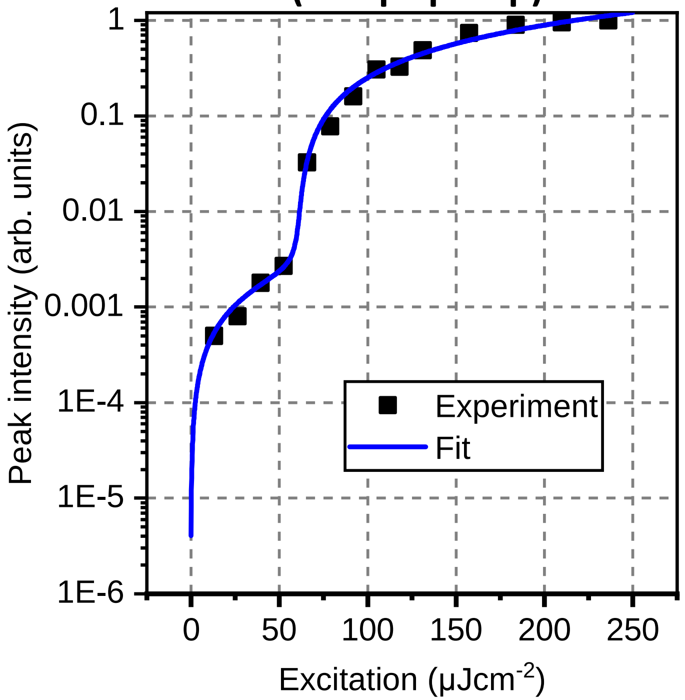
4 Disc lasers with 6 µm radius on 2 different samples



Free spectral range (FSR) vs. disc radius



Peak intensity vs. pump fluence (700 ps pump)



- Reproducible patterning
- Uniformity of perovskite films challenging

- FSR vs. disc radius: whispering gallery modes confirmed

- Clear lasing threshold

- **Record low lasing threshold of 4.7 µJcm^{-2} (2018)**
- Conditions: room temperature, 120 fs pump, monolithically integrated, CMOS & BEOL compatible

suckow@amo.de
P. J. Cegielski et al., DOI: 10.1021/acs.nanolett.8b02811

$PtSe_2$ photodetectors: templated growth

Perovskite intregration: (not so) „easy win“

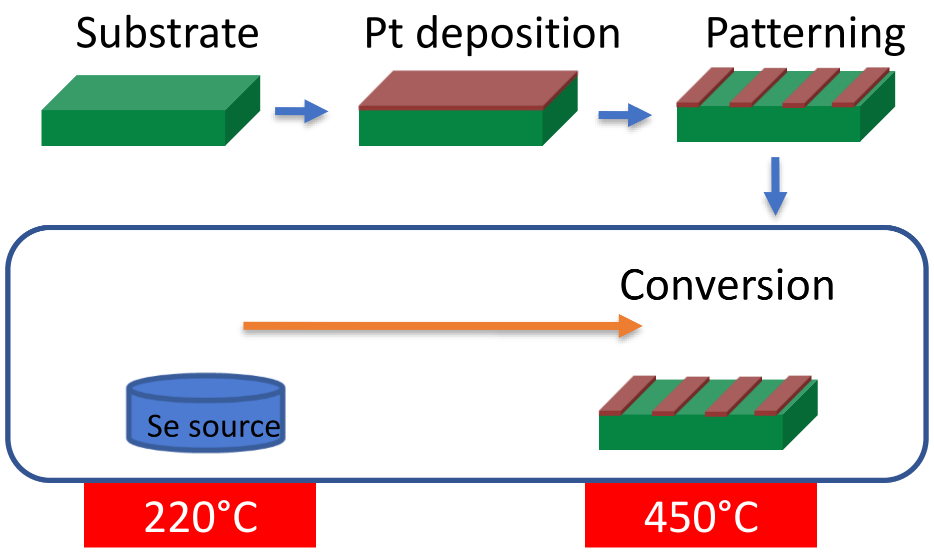
- Trump card „nasty stuff last“ – only once per chip
- What about something more sturdy, like $PtSe_2$?

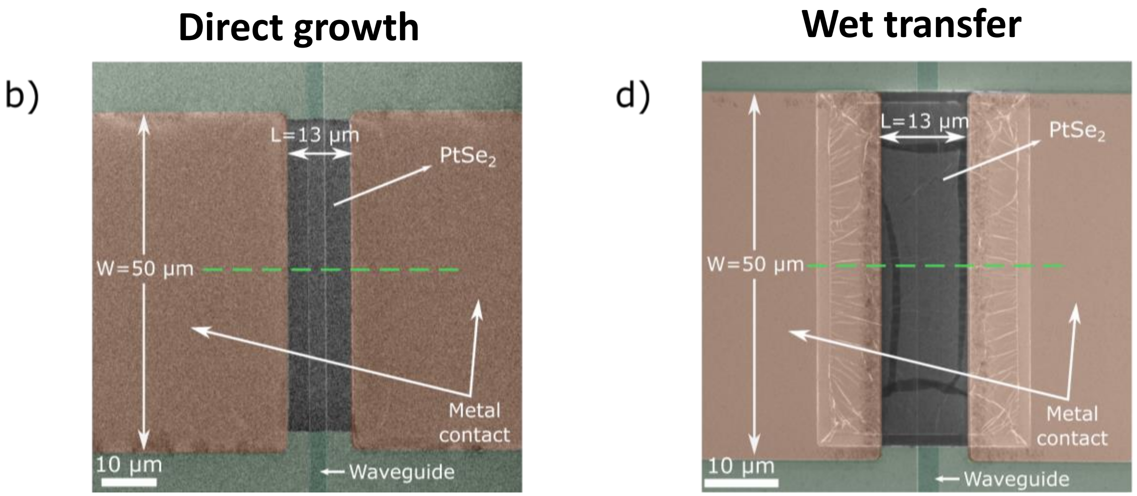
$PtSe_2$ properties

- 2D family of Transition Metal Dichalcogenide
- Monolyer: semiconductor (1.2 eV), Multi-layer: semi-metal
- **Stable** in ambient condition
- Broadband absorption → **photodetector**

$PtSe_2$ fabrication

- Thermally assisted conversion (TAC)
- Multilayer films
- **Direct growth at BEOL compatible temperature**
- Wet transfer also works





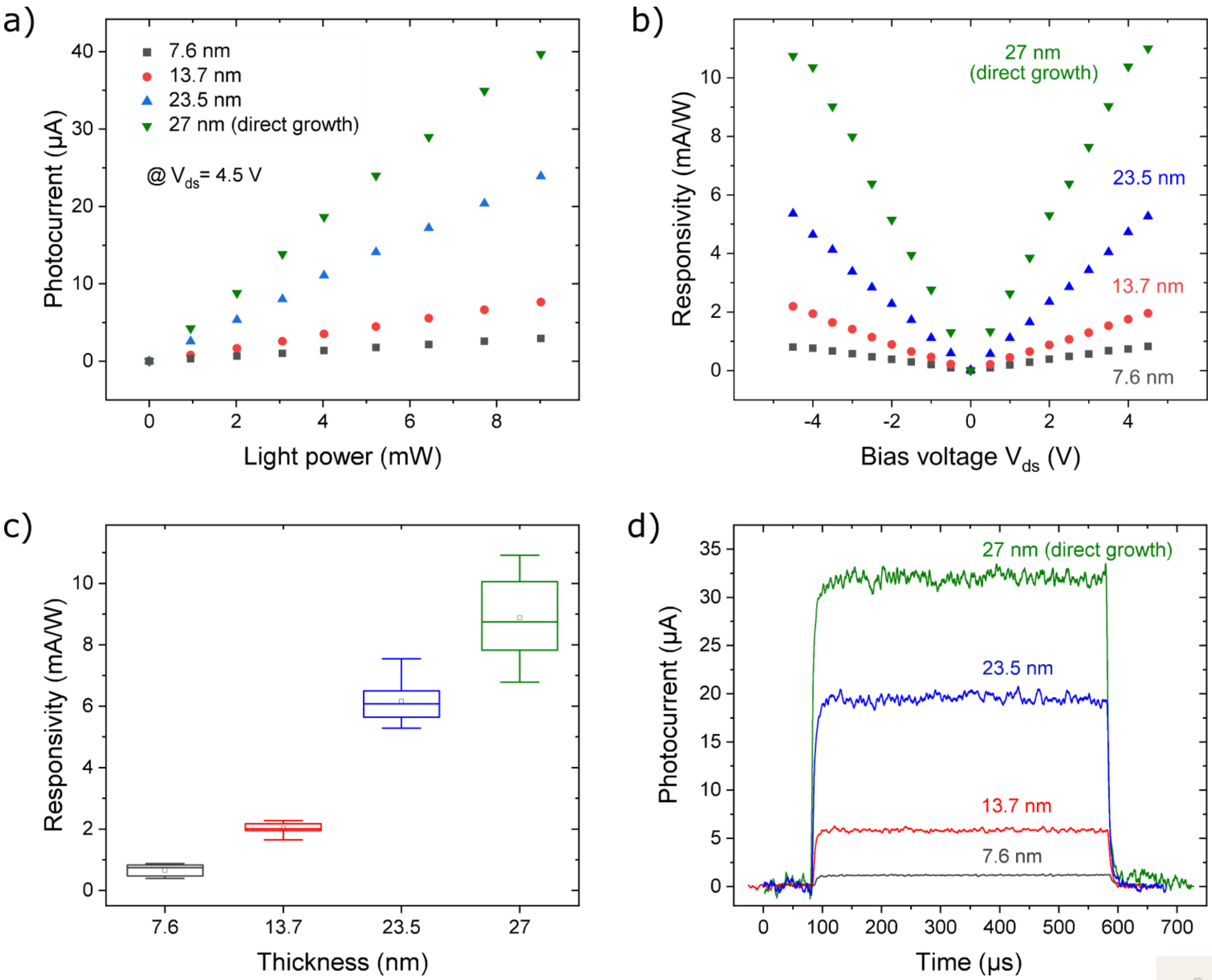
Prechtl, Maximilian, et al. *Advanced Functional Materials* 31.46 (2021) 2103936

Parhizkar, Shayan, et al. ACS photonics 9.3 (2022): 859-867

$PtSe_2$ photodetectors: results

Result summary

- Linear I-V (semi-metal)
- Linear dependence on light power
- Linear dependence on bias
- Resistance and absorption scale with layer thickness
- Response time of ~9 µs likely setup-limited
- Detectivity ~10^8 Jones competitive with graphene and Mid-IR photodiodes (10^8 – 10^{10} Jones typically)
- **Can process "normally" on this**
- (maybe not in the CMOS fab)



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Commercial foundry services at AMO

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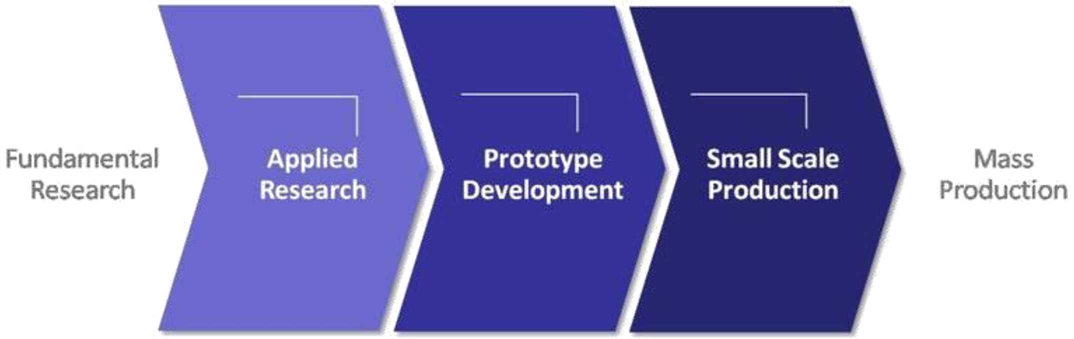

Our strengths

- Individual service
- Customer-specific prototyping
- From small scale to volume production
- Flexible process flow
- Short turnaround
- IP protection

Acknowledgements

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