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Latest results about the development of amorphous-silicon-based microchannel plates

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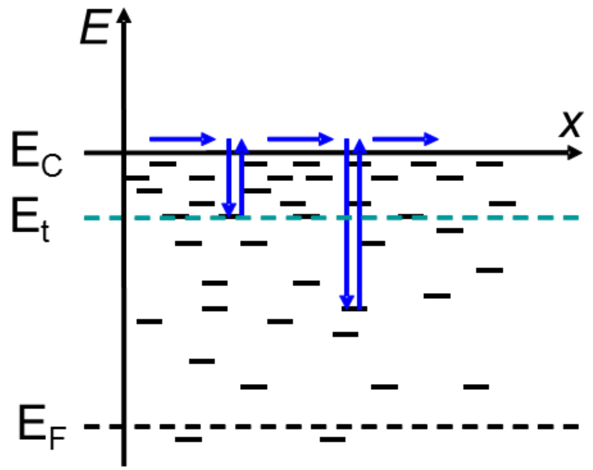
Outline

- Hydrogenated amorphous silicon
- Fabrication of amorphous-silicon-based microchannel plates (AMCPs)
- AMCPs results of electron multiplication
- Conclusions and outlook

Hydrogenated amorphous silicon (a-Si:H)

- Si–Si bonds in tetrahedral coordination but ordered structure lost at long range
- 5–20% of atomic hydrogen, for dangling bonds passivation
- Bandgap of 1.8 eV
- Thermally-activated electrical conductivity: $\sigma = \sigma_0 \exp\left(-\frac{E_a}{kT}\right)$

	a-Si:H resistivity (Ω cm)	E_a (eV)
intrinsic	10^{10}–10^{12} (10^4 for c-Si)	0.7–0.8
n-doped	10^2–10^5 (10^{-1}–10^{-3} for c-Si)	0.1–0.4
p-doped	10^4–10^6 (1–10^{-2} for c-Si)	0.3–0.6



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Amorphous-silicon-based microchannel plates (AMCPs)

Novel fabrication process: **a-Si:H as MCP bulk material**

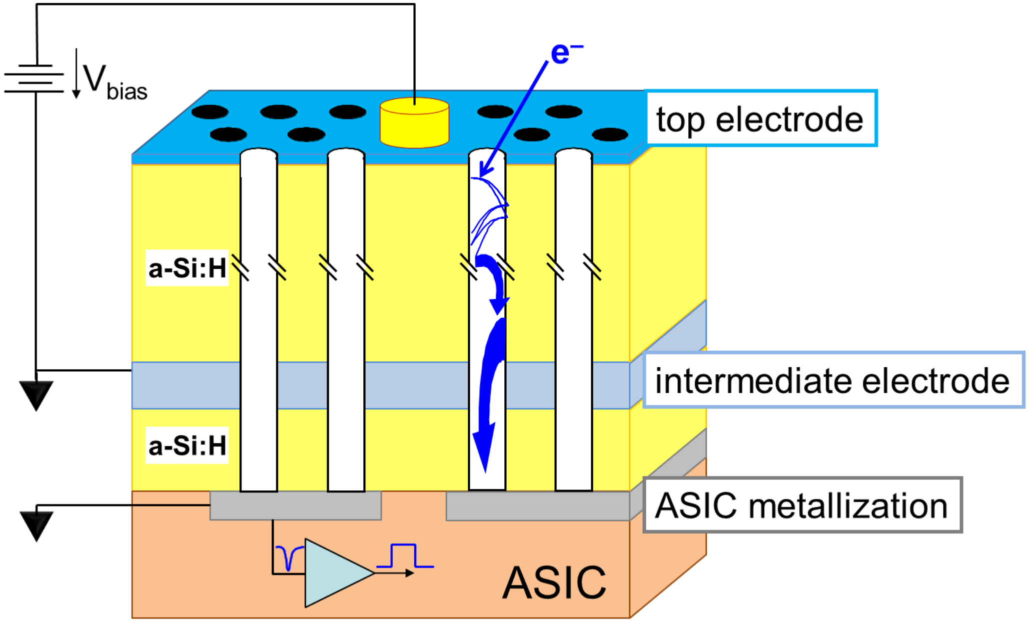
- a-Si:H with $\rho \approx 10^{11}\ \Omega$ cm
- a-Si:H PE-CVD
- a-Si:H similar to c-Si

→

AMCP withstands large bias voltages and provides charge replenishment

vertically integrated AMCP on readout electronics

channels micromachined with techniques of microelectronics industry, such as deep reactive ion etching (DRIE)



AMCP fabrication

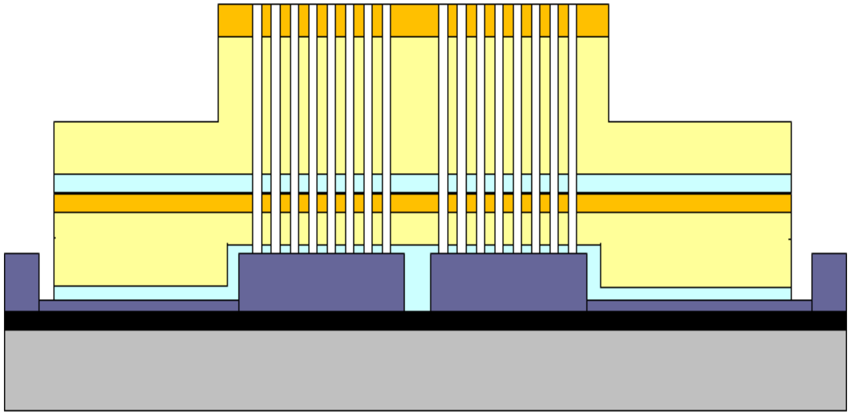
DRIE of channels

Mesa patterning of layer stack

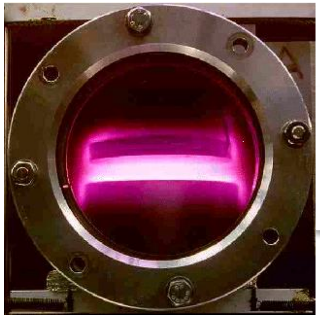
PE-CVD of layer stack

100 nm chromium and patterning

1.5 μm of SiO_2 on 4'' c-Si wafer



PE-CVD reactor for a-Si:H

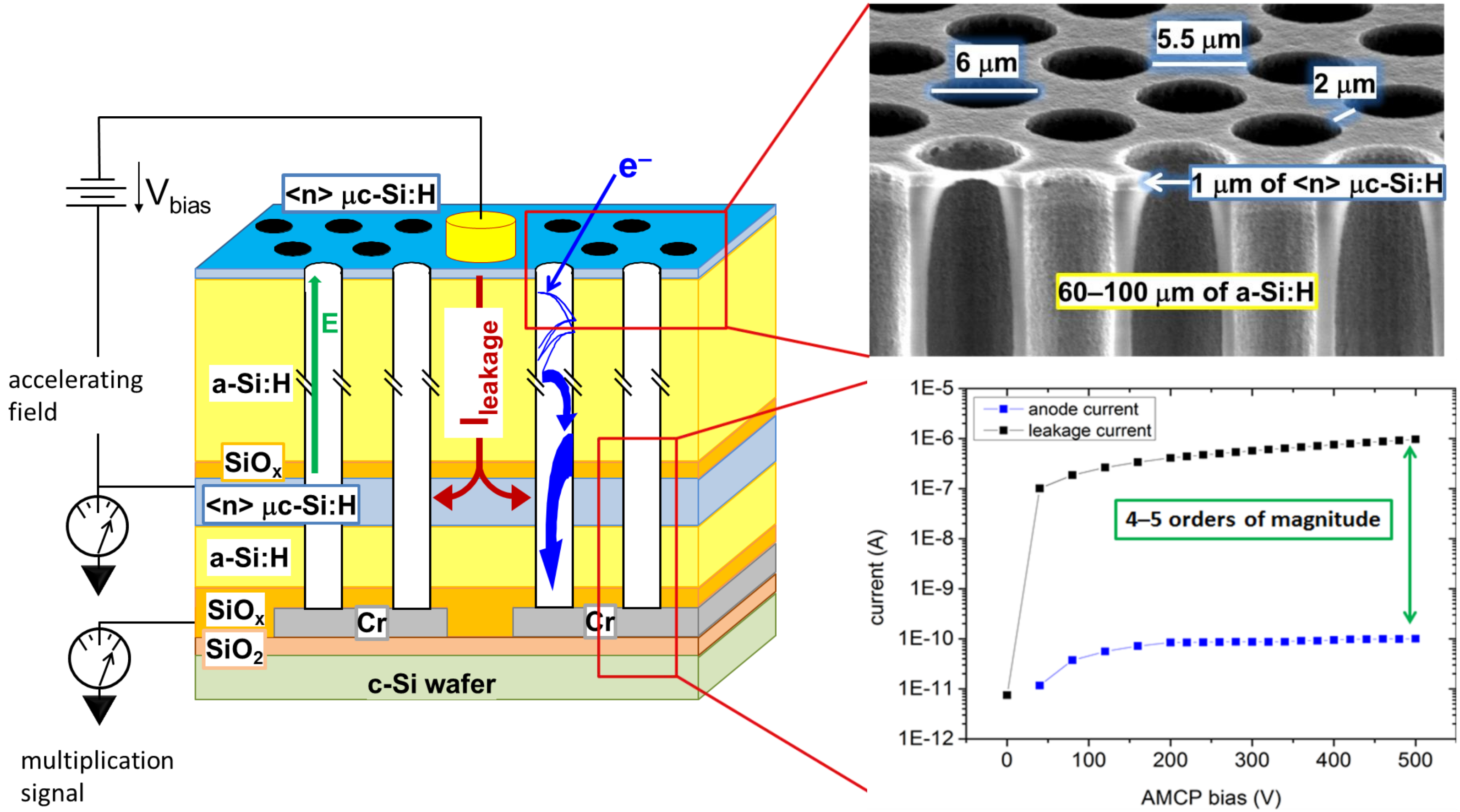


20 Å/s deposition rate
120 μm of total a-Si:H

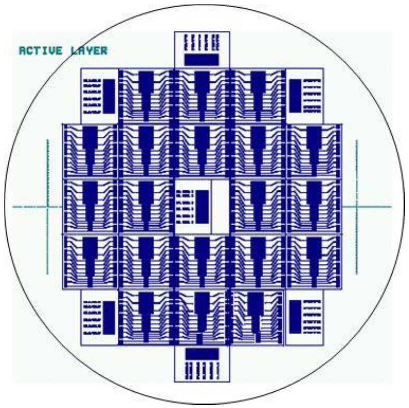
AMCP architecture with three electrodes

Three independent electrodes:

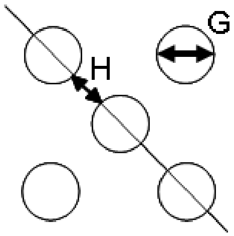
- <n> μc-Si:H top electrode is biased up to -700 V (~10^5 V/cm)
- <n> μc-Si:H intermediate electrode evacuates the leakage current
- Cr anode collects the multiplied electrons



AMCP test structures

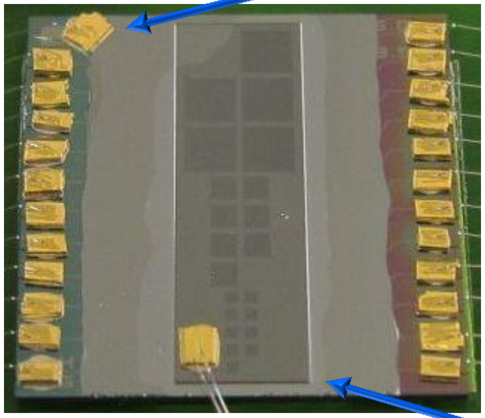


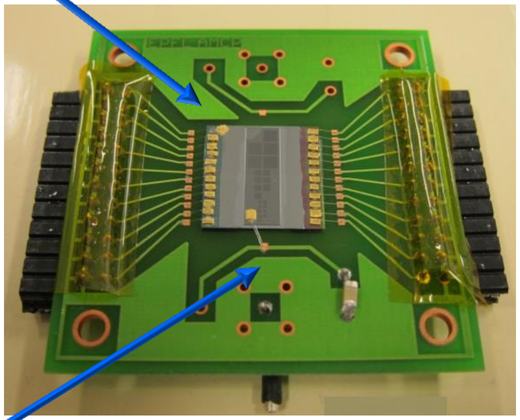
- 20 AMCP test structures on 4” wafer
- AMCP surface of 0.25, 1 and 4 mm^2
- G: 5–9 μm
- H: 2–7 μm
- Channel length 60–100 μm
- **Aspect ratio (AR) 6:1–12.5:1**



Evacuation of leakage currents

Independent chromium anodes





AMCP bias up to -500 V

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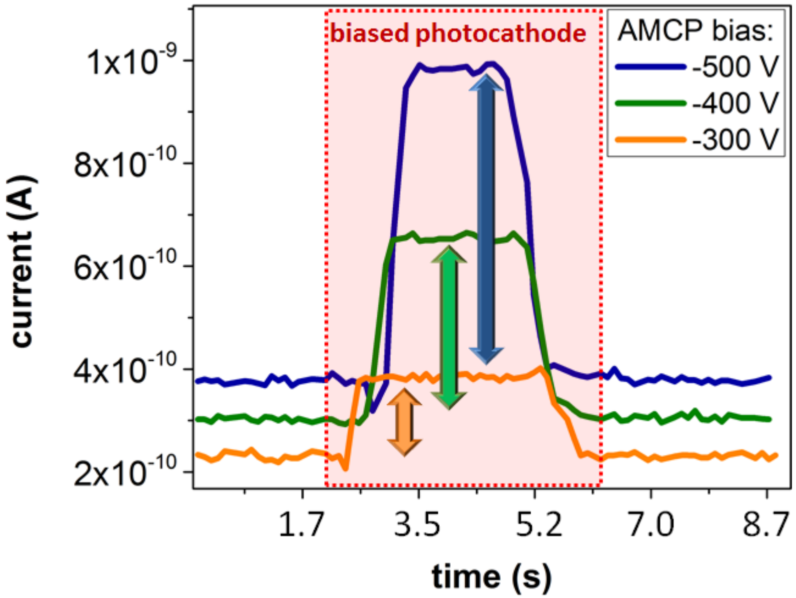
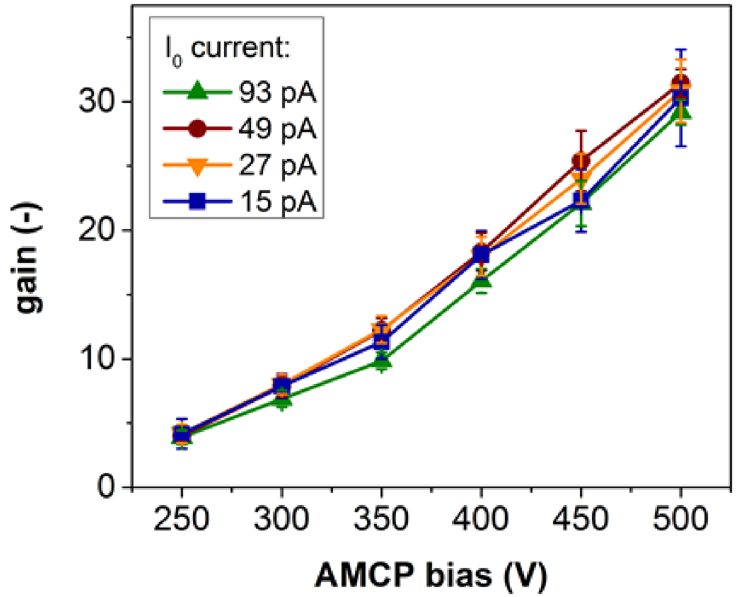
Gain in continuous illumination regime

Full-field illumination at 254 nm with 16 nm of gold as photocathode

- Electron multiplication increases up to tested voltage of 500 V (7×10^4 V/cm)
- Gain > 30 at -500 V, aspect ratio of 12.5:1
- Gain independent on input current → enough charge replenishment

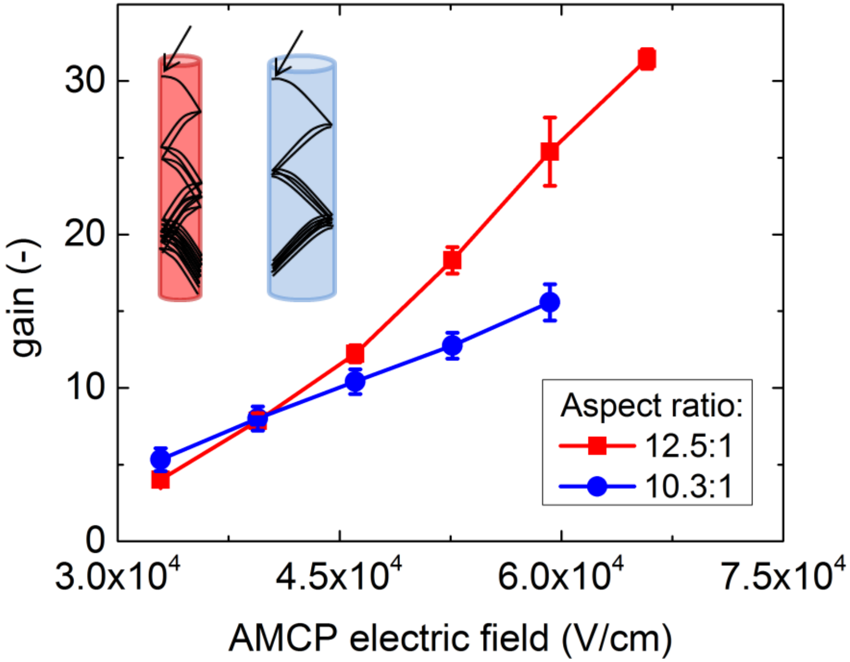


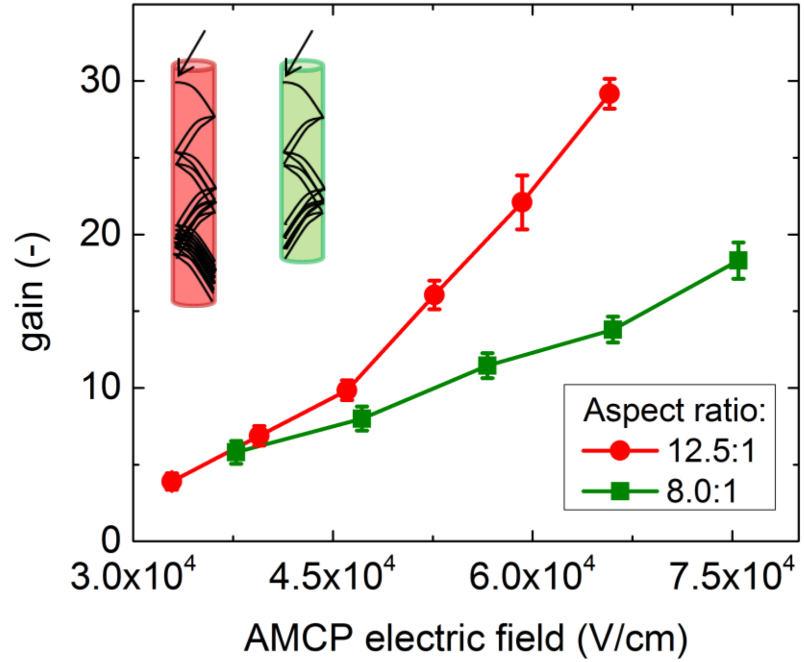


Franco et al., Scientific Reports **4**, 4597, 2014

Gain versus aspect ratio

Gain increases as a function of aspect ratio → AMCP proof of concept



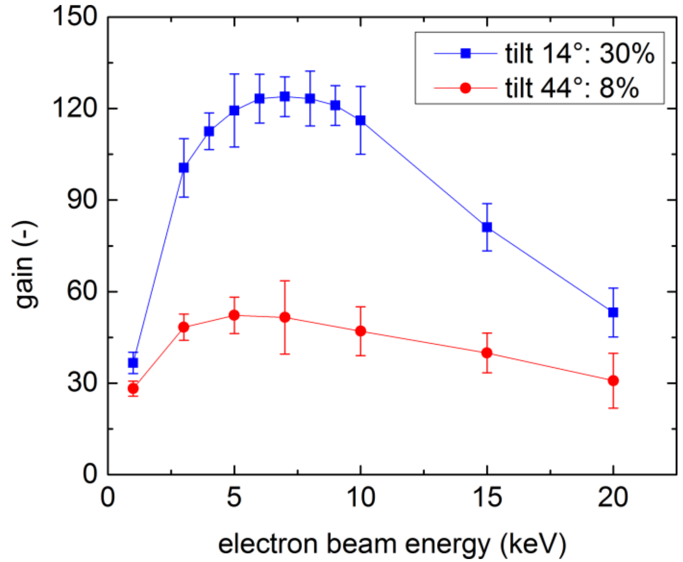


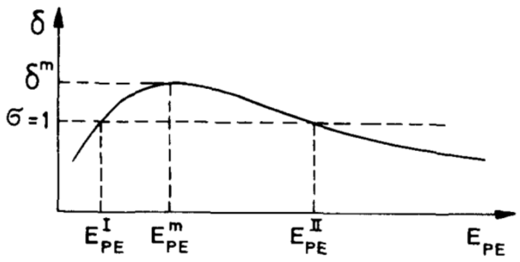
Franco et al., Scientific Reports **4**, 4597, 2014

Gain dependency on electron energy

Gain depends on the primary electron energy, according to the number of secondary electrons emitted at the first collision.

- gain increases by a factor 4 with AMCP tilt of 14°
- gain increases by a factor 2 with AMCP tilt of 44°

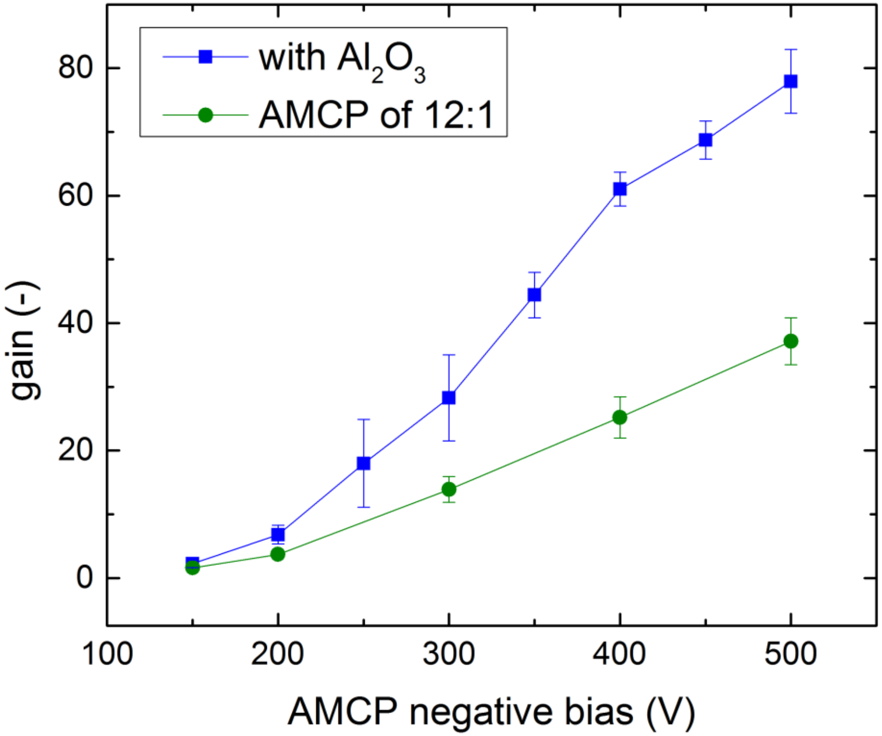




Seiler, JAP **54**, R1-R18, 1983

Atomic layer deposition for gain enhancement

First ALD of 5 nm of Al_2O_3 on AMCP doubled the gain.



Conclusions

- Improved AMCP architecture.
  Enhanced sensitivity to electron multiplication.
- AMCPs vertically integrated on metallic anodes.
  Proven feasibility for AMCP integration on ASIC.
- AMCP proof of concept.
  Gain increases with the channel aspect ratio.
- Enhanced gain with high-emissive SE layer.

Outlook

- To improve the aspect ratio, 20:1 within immediate reach.
- To engineer a funnel structure at the channel entrance.
- Vertical integration on ASIC (e.g. Medipix2, Timepix)
  - Compact and rugged detector
  - High spatial resolution (vertical integration)
  - High temporal resolution (D_{ch} < 10 μm, conductive bulk)
  - AMCP insensitivity to magnetic fields up to a few teslas

  - Applications: fast fluorescence imaging, simultaneous PET/MRI, space missions, neutron detection, …

Acknowledgements

PV-Lab: Sylvain Dunand for helping with the PE-CVD depositions

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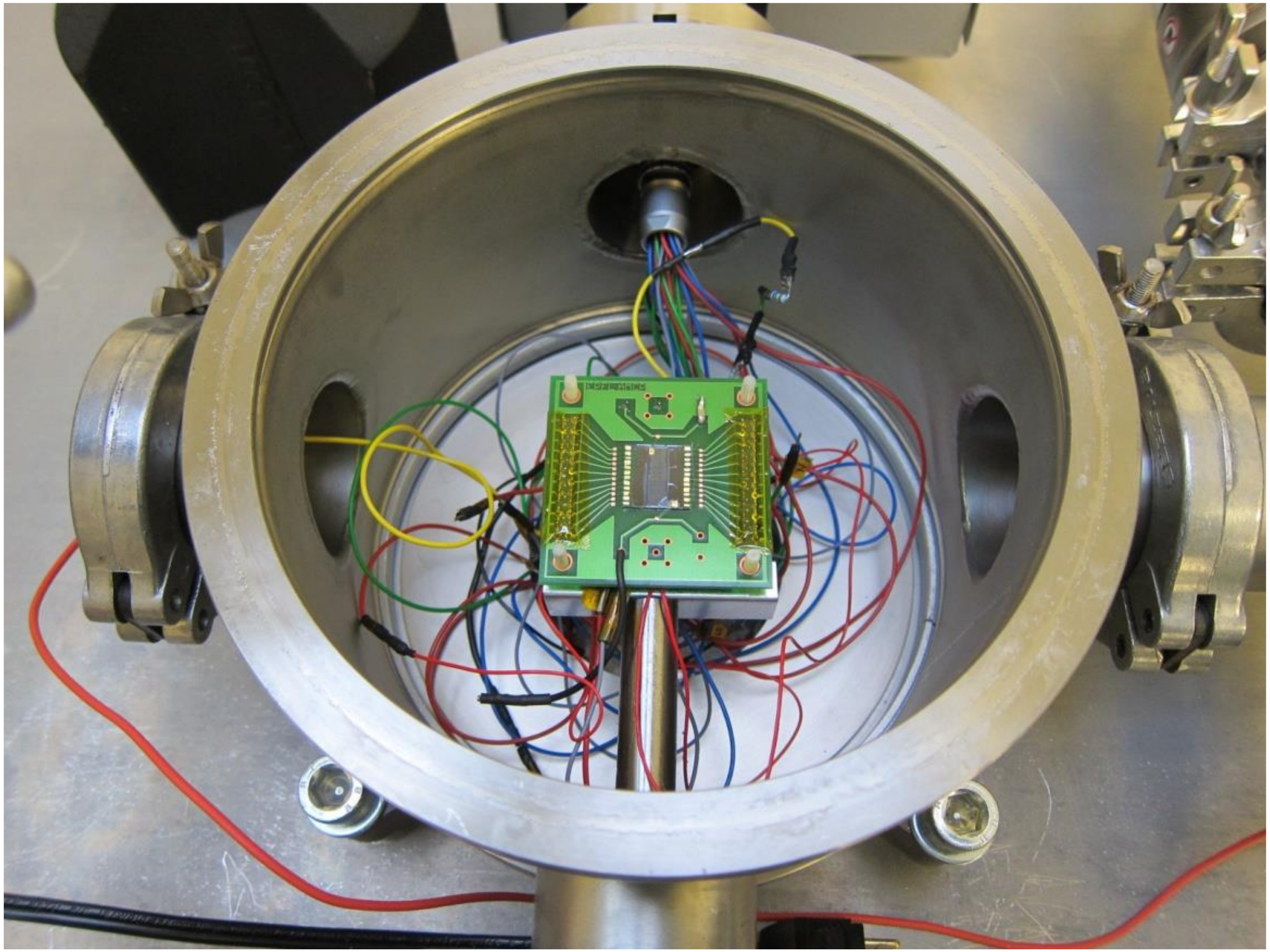
Thank you for your attention

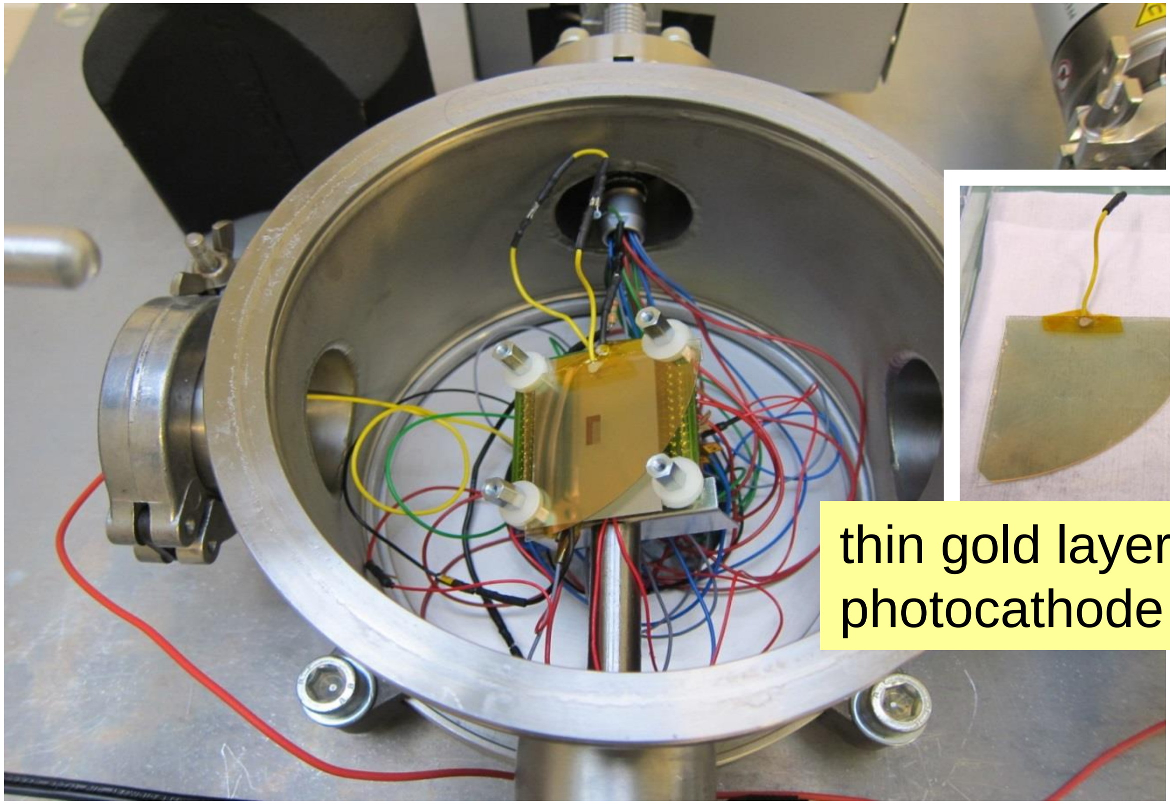
Questions?

Back-up slides

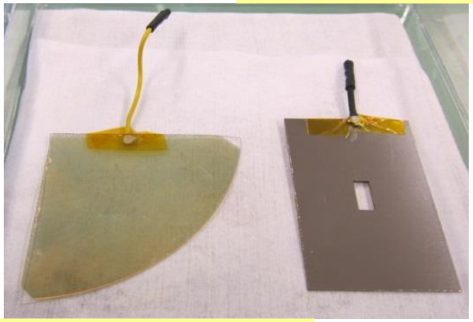
AMCP characterization set-up



AMCP characterization set-up -2

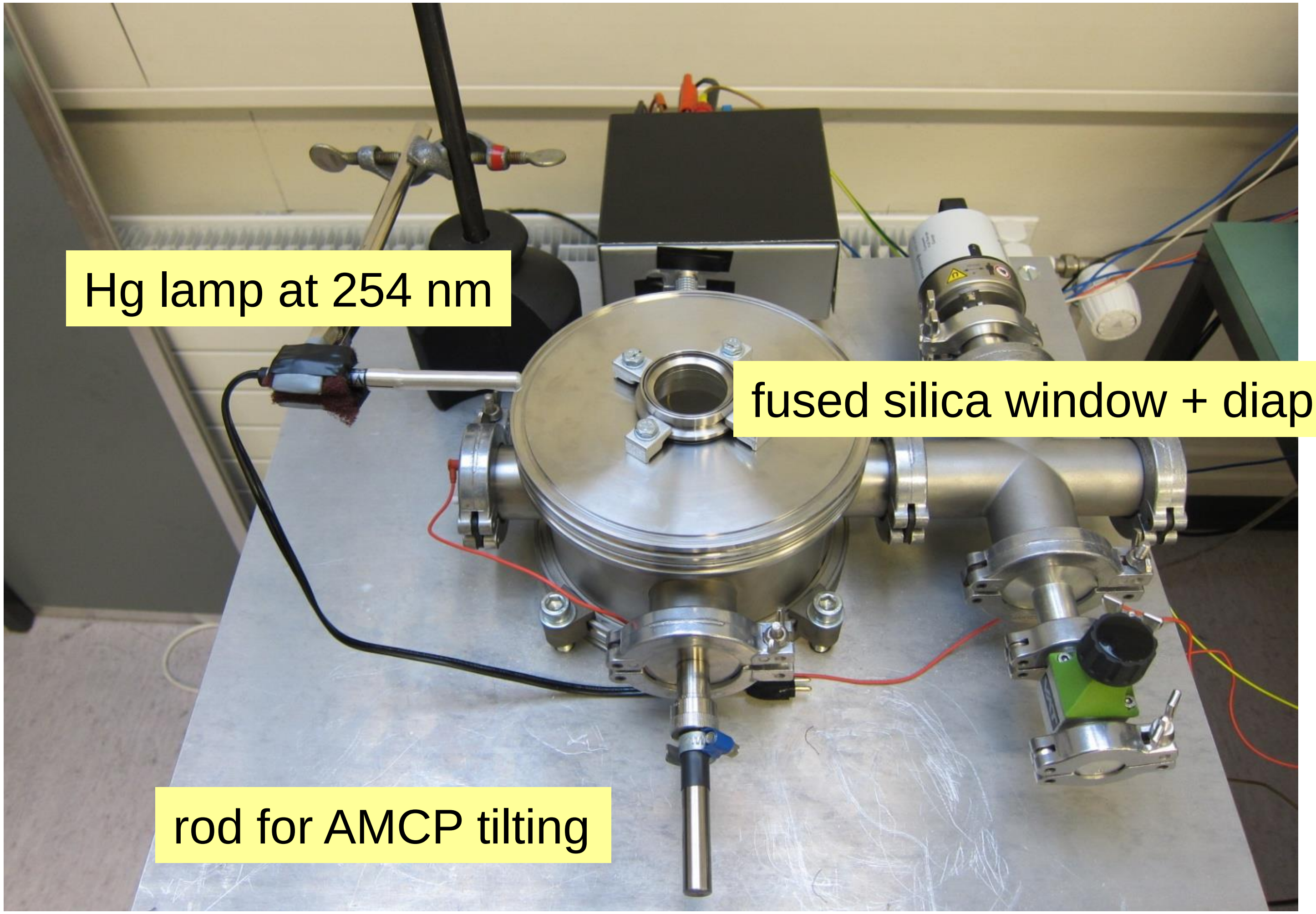


photolectron screen

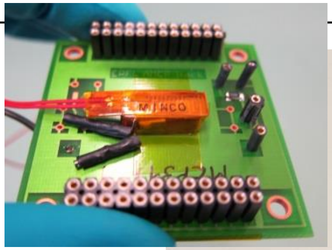


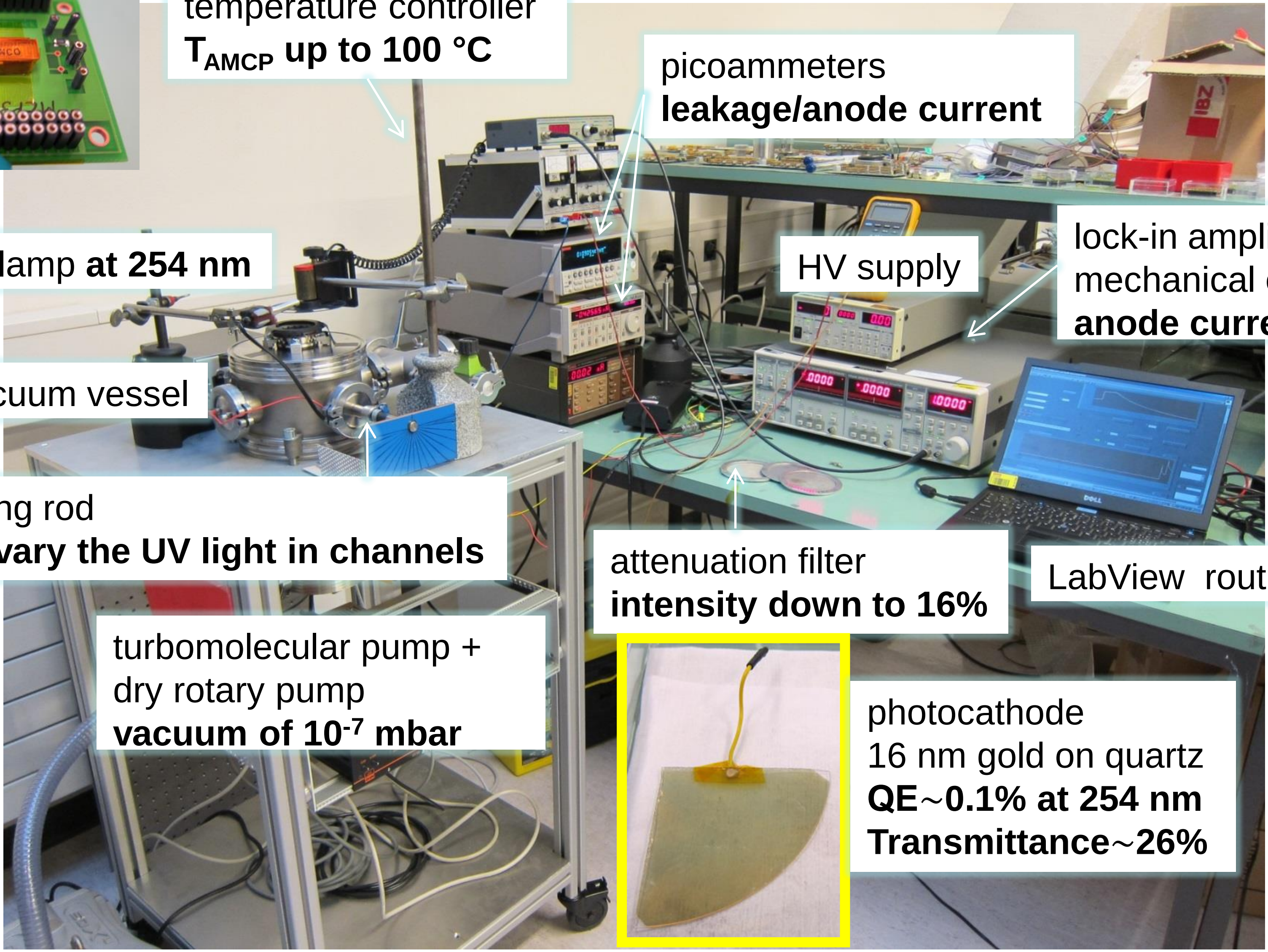
thin gold layer as photocathode

AMCP characterization set-up -3

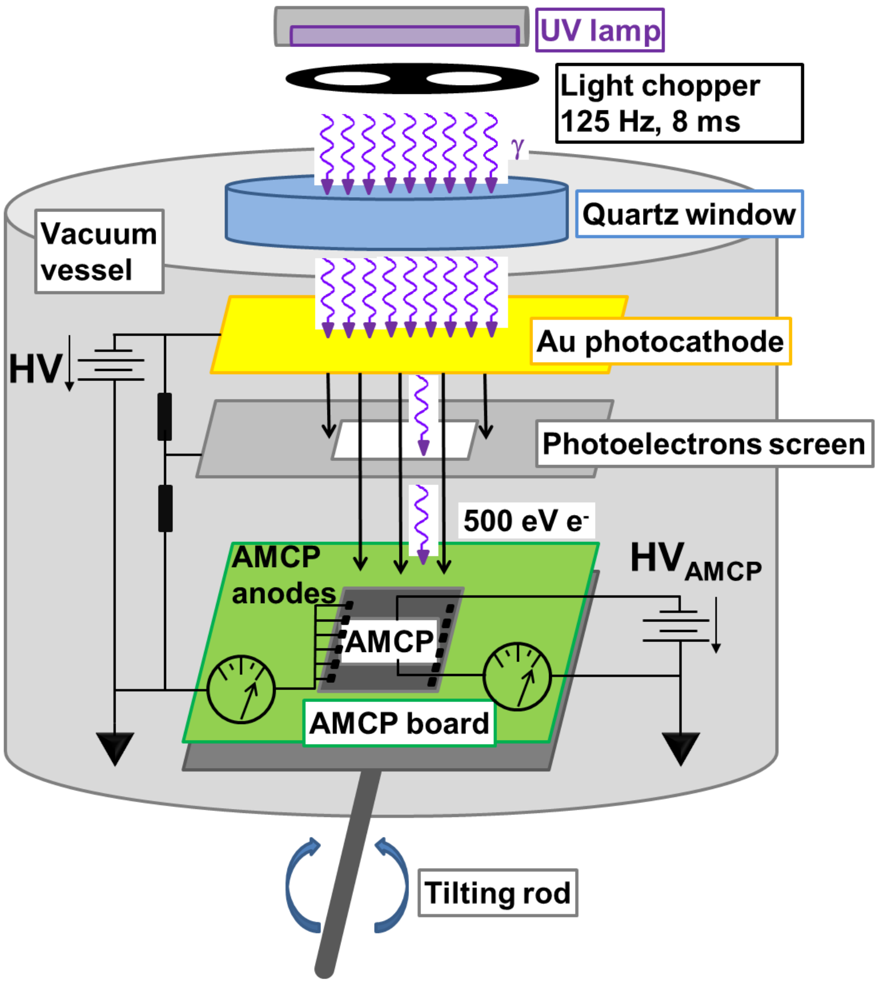


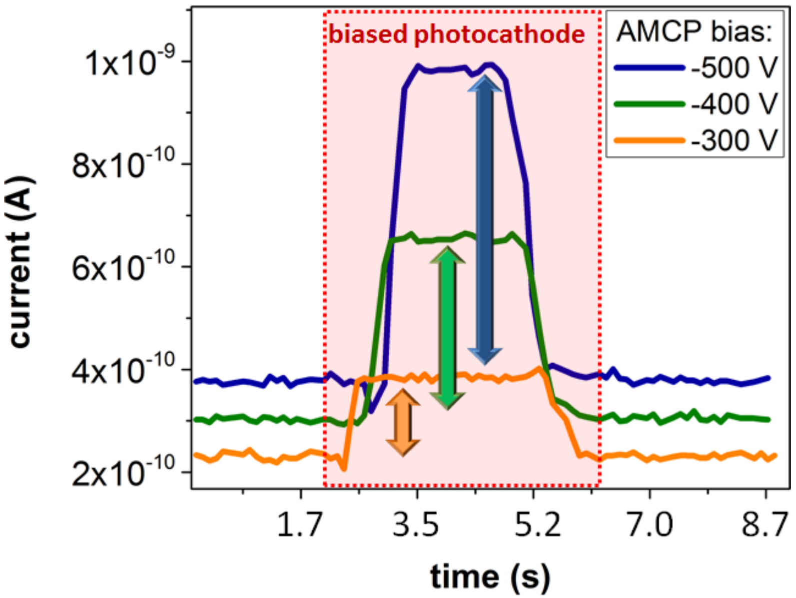
AMCP characterization set-up -4





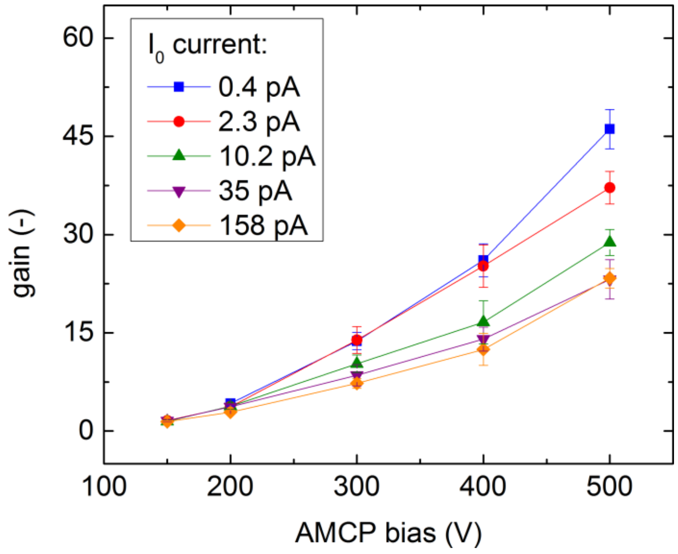
Gain measurements with UV setup

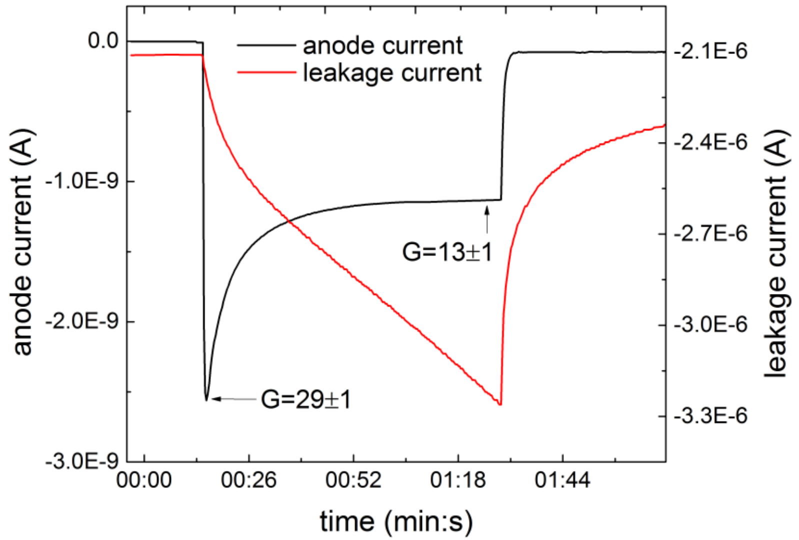




Gain with the SEM beam

Each channel exposed for < 10 μs, exposure rate of 10 Hz





Gain **drops** after having reached a maximum

- charge replenishment ok (I_{leak} >> I_{out})
- charging of the decoupling layer surface