Neuromorphic Computing - At the intersection between Electronics and Photonics

Stephan Suckow

Group Leader Nanophotonics

AMO GmbH

AMO Company Profile

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

- 80 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 neuromorphic?

- If you have a hammer as good as AI, everything looks like a nail [1]
  - ChatGPT: training GPT-3 consumed 1,287 MWh = 552 t of CO_2 [2]
    - Efficient car: driving 5.5 million km = 137 times around the globe
    - Average yearly CO_2 emissions of 50 Danes [3]
  - Using ChatGPT (BLOOM): 3.6 Wh = 1.5 g CO_2 per request [4]
- Brain: massively parallel neuro-computer at 20 W

[1] https://en.wikipedia.org/wiki/Law_of_the_instrument
[2] https://arxiv.org/ftp/arxiv/papers/2204/2204.05149.pdf
[3] https://kefm.dk/aktuelt/nyheder/2021/apr/foerste-officielle-vurdering-af-danmarks-globale-klimaaftryk
[4] https://arxiv.org/pdf/2211.02001.pdf

NeuroSys Cluster

« Who has the better AI chip has the product »

Projektpartner

Wissenschaft

- Forschungszentrum Jülich
- RWTH Aachen University
- AMO

Wirtschaft

- AIXTRON
- aixscale photonics
- Gremse-IT
- elmos
- Black Semiconductor
- STAR Healthcare Management GmbH
- aixACCT
- AppTek
- Clinomic

Gesellschaft

- Industrie- und Handelskammer Aachen – IHK
- Innovation | RWTH Aachen University

Beirat

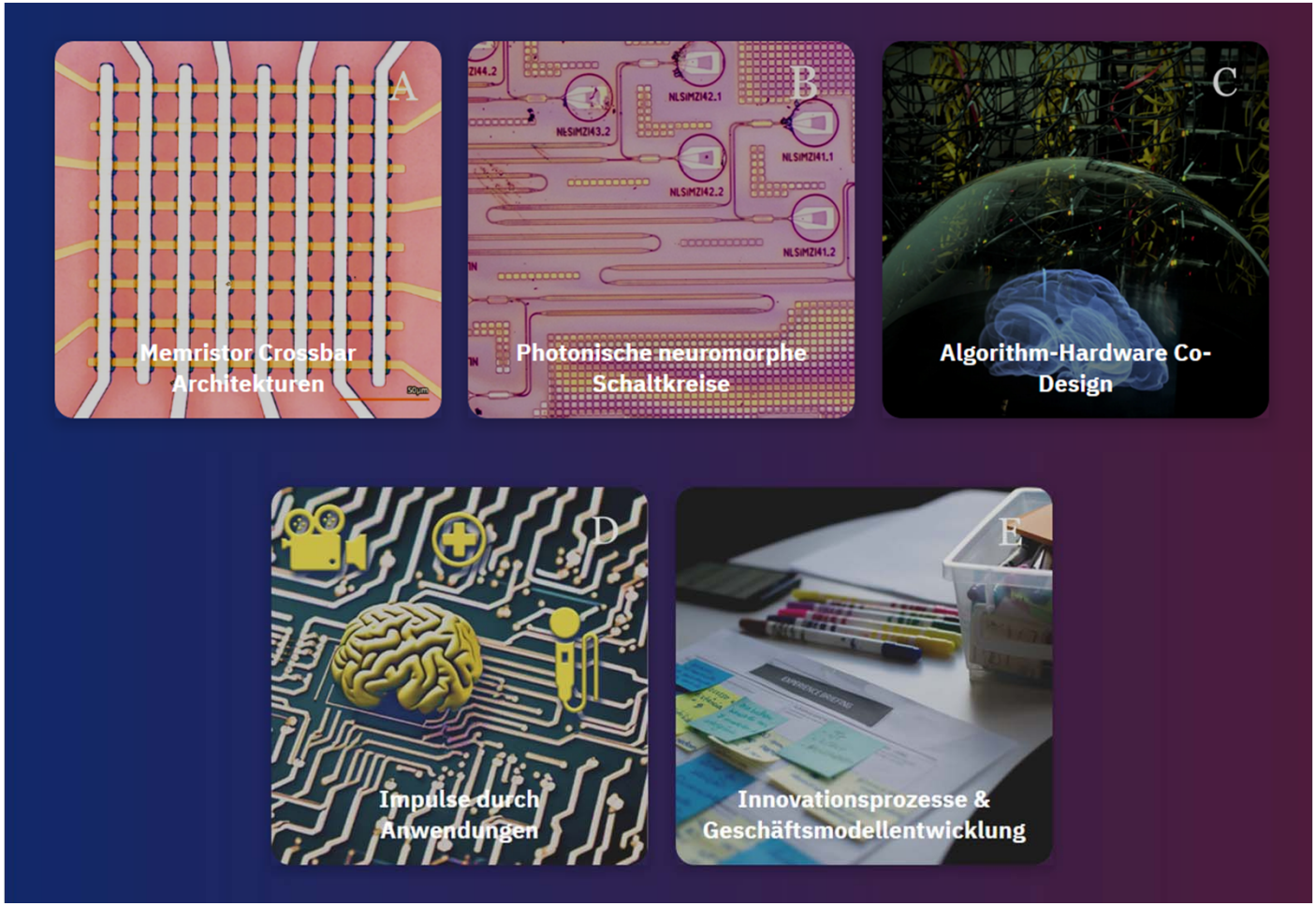
- Technische Universität München
- namlab
- Eberhard Karls Universität Tübingen
- Technische Universität Dresden

Prof. Klaus Mainzer
Prof. Thomas Mikolajick

- BOSCH
- SIEMENS
- BMW
- infineon
- Ford
- HEAD acoustics
- elmos
- SIPEARL
- utimaco
- umlaut

- Industrie- und Handelskammer Aachen – IHK
- Zukunftsagentur Rheinisches Revier
- KiNRW
- Fraunhofer
- StädteRegion Aachen

NeuroSys Cluster

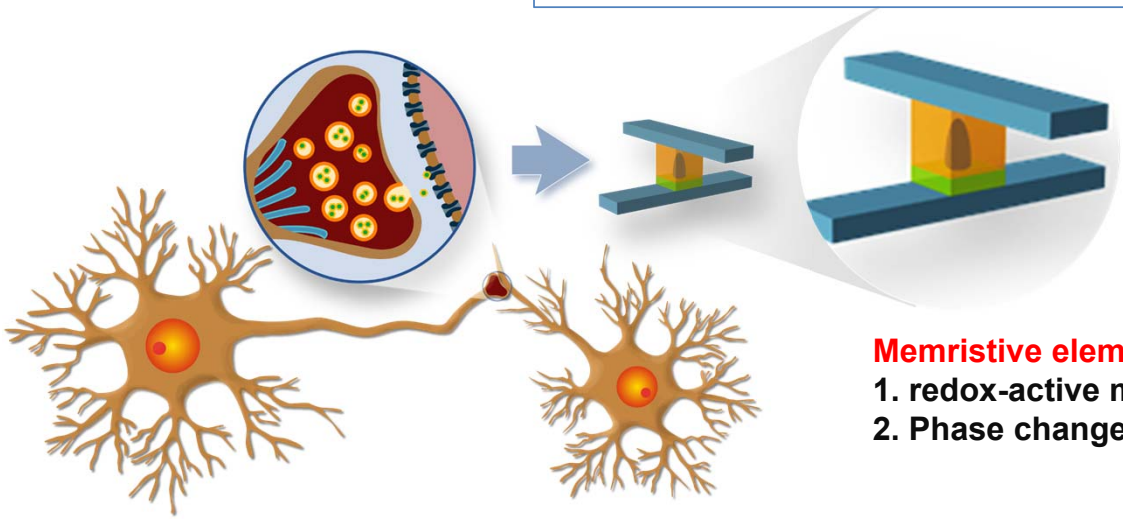


Neuromorphic hardware

Von Neumann — **Power efficiency** — **Neuromorphic**

CPU GPU ASIC memristors brain

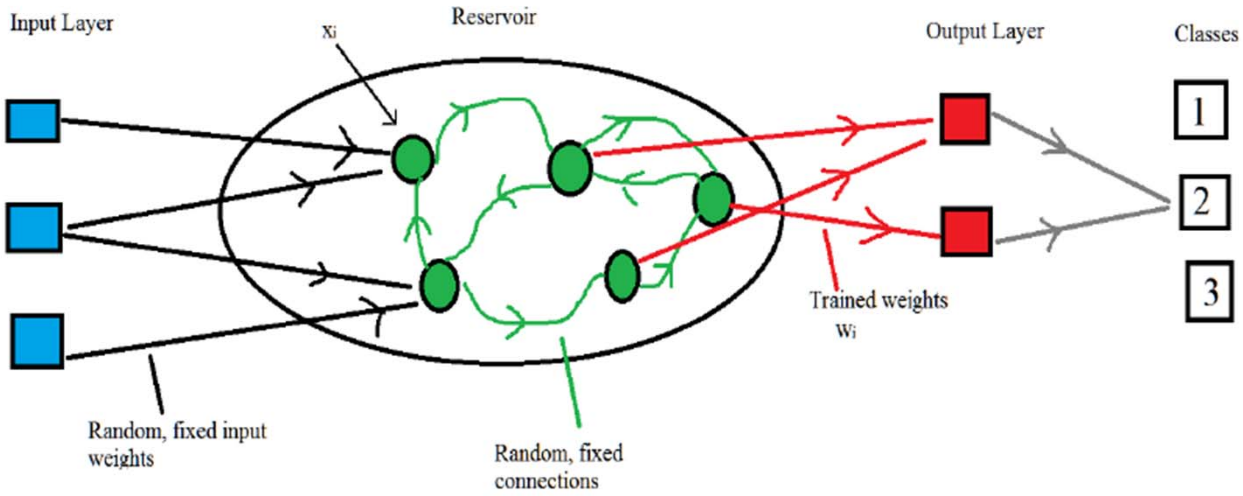
Photonic calculations | Photonic networks



Memristive elements
1. redox-active materials
2. Phase change materials

Photonic Reservoir Computing

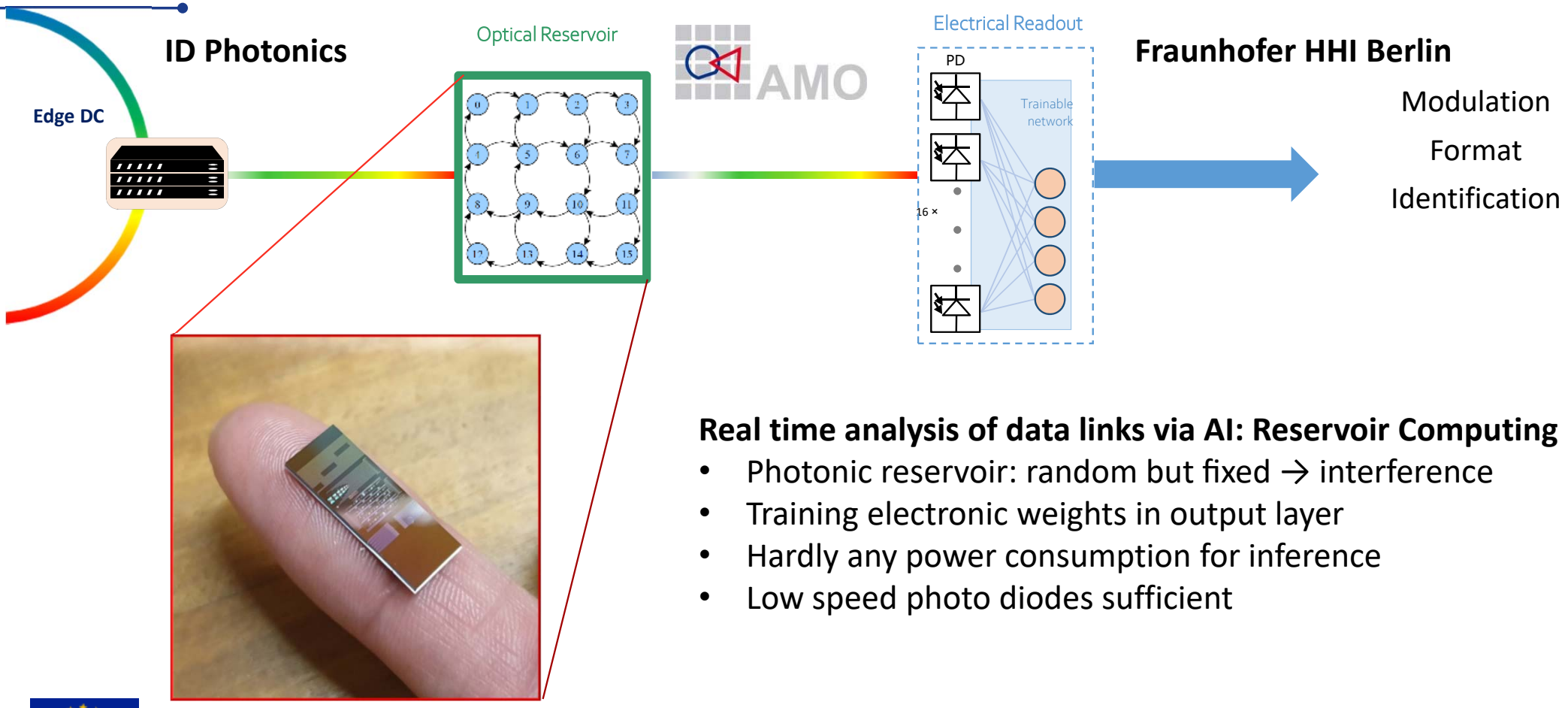
Reservoir sketch [1]



- Form of recurrent neural networks
- « fixed but random » passive reservoir with nonlinearities
- Training only output layer

[1] https://golden.com/wiki/Reservoir_computing-3AMPNA

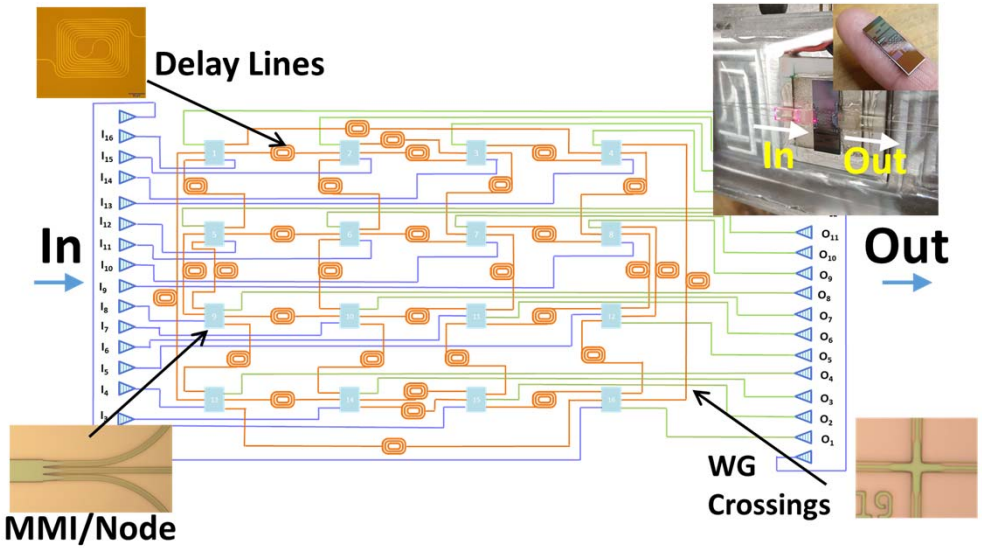
Overview project AI-NET-PROTECT

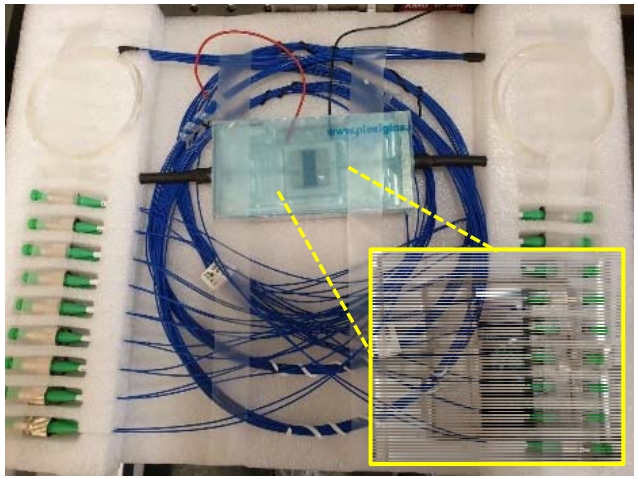


Real time analysis of data links via AI: Reservoir Computing

- Photonic reservoir: random but fixed → interference
- Training electronic weights in output layer
- Hardly any power consumption for inference
- Low speed photo diodes sufficient

The AI-NET-PROTECT Chip



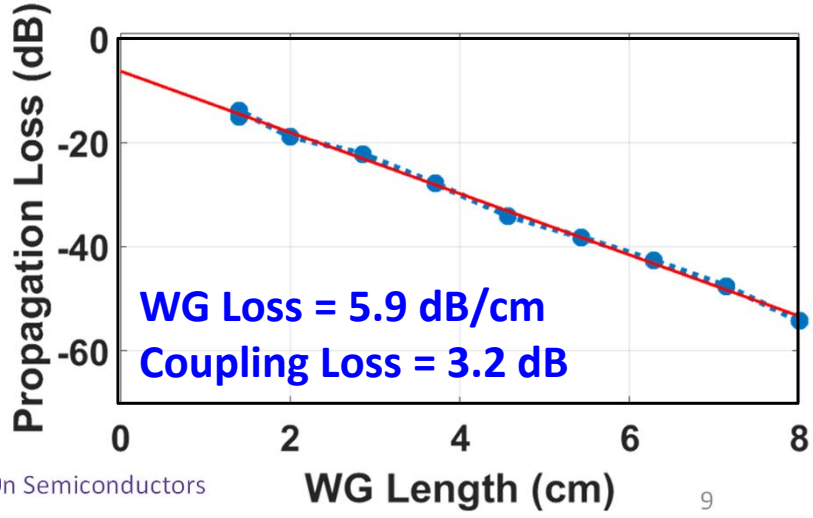


Packaged NeuroPIC

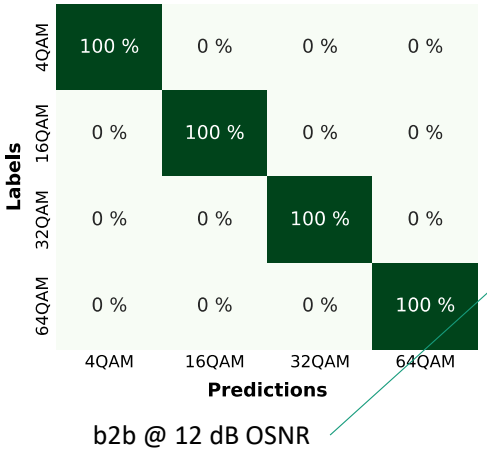
Fig1: Cutback Plot

NeuroPIC overview

- 4x4 nodes in “4-Port” architecture
- Fiber array I/O at each node → 2x16 fiber array
- Passive Silicon-on-Insulator Chip
- Readout layer can be moved on-chip
  - Massively simplified setup
  - Application specific: Loosing generality
- Waveguide (WG) loss can be 1 – 1.5 dB/cm

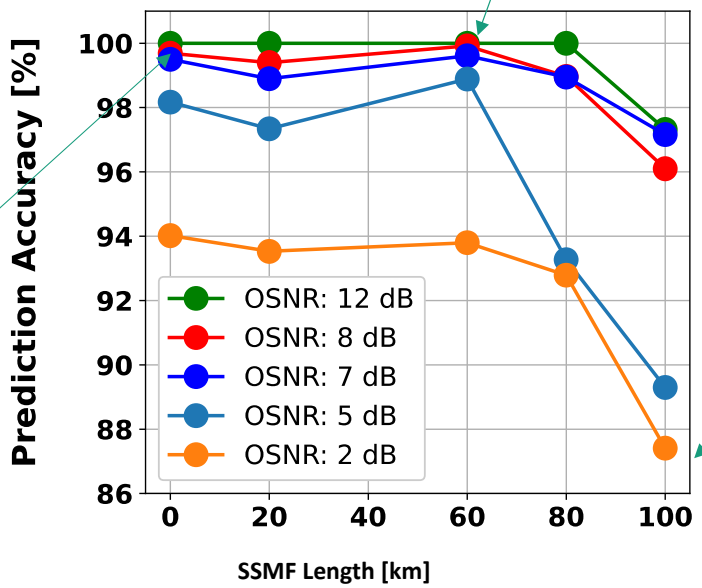


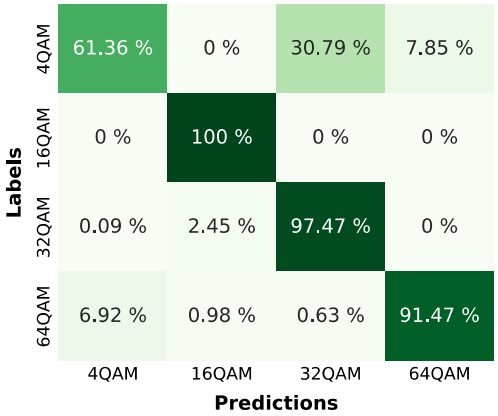
NeuroPIC results and perspective



b2b @ 12 dB OSNR

Some levels of dispersion and optical noise can improve accuracy



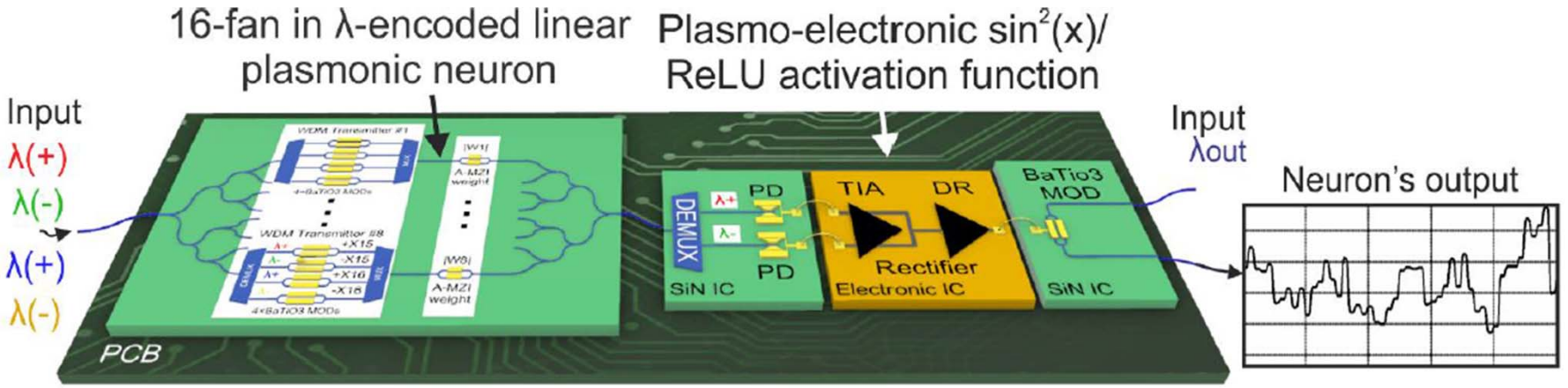


100 km SSMF @ 2 dB OSNR

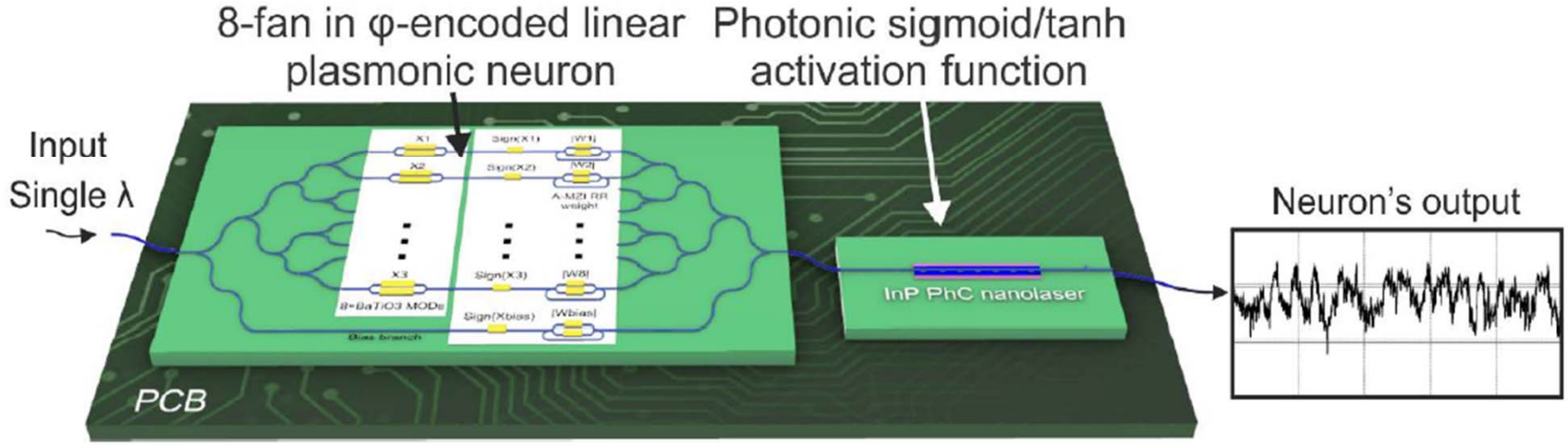
- Very high classification accuracy achieved → fault tolerant “fixed but random” network
- Output layer can be moved on-chip → merging photonics and electronics
- Method suitable for other tasks with high speed dynamics → **looking for follow-up activity**

PlasmoniAC approach

Neuron Type 1:



Neuron Type 2:



PlasmoniAC overview

- High risk
  - Combining photonics and plasmonics
  - Hetero-integration on common silicon nitride platform (Southampton)
    - SiOxNy thermo-optic phase shifters (CNRS)
    - InP laser (III-V Labs)
    - BTO phase shifters & 100 GHz modulators (Lumiphase)
    - 100 GHz Graphene photodetectors (AMO, AUTH - Uni Thessaloniki)
    - Memristors (IBM)
    - 100 GHz electronics: TIA & modulator driver (IMEC, Mellanox)
- High gain: artificial plasmonic neurons with **1 to 6 orders of magnitude** better energy and footprint efficiencies

Outlook

- Integration complexity extremely challenging
  - « One technology to rule them all » to simplify?
  - « best of all worlds » for best performance?
- Co-integration with electronics, 100+ GHz
  - Photonics & plasmonics in CMOS BEOL
- AMO recent Spin-Off Black Semiconductor:
  - Targetting just that with graphene

Acknowledgements

This work has received funding from the German Ministry of Education and Research (BMBF) under grant agreements 16KIS1291 (**AI-NET-PROTECT**) and the **PlasmoniAC** project is an initiative of the Photonics Public Private Partnership and has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 871391.

This project has received funding from the European Union's Horizon Europe research and innovation programme under GA N° 101092562