# Photonic Smart Sensing

**Stephan Suckow**

**Group Leader Nanophotonics**

**AMO GmbH**

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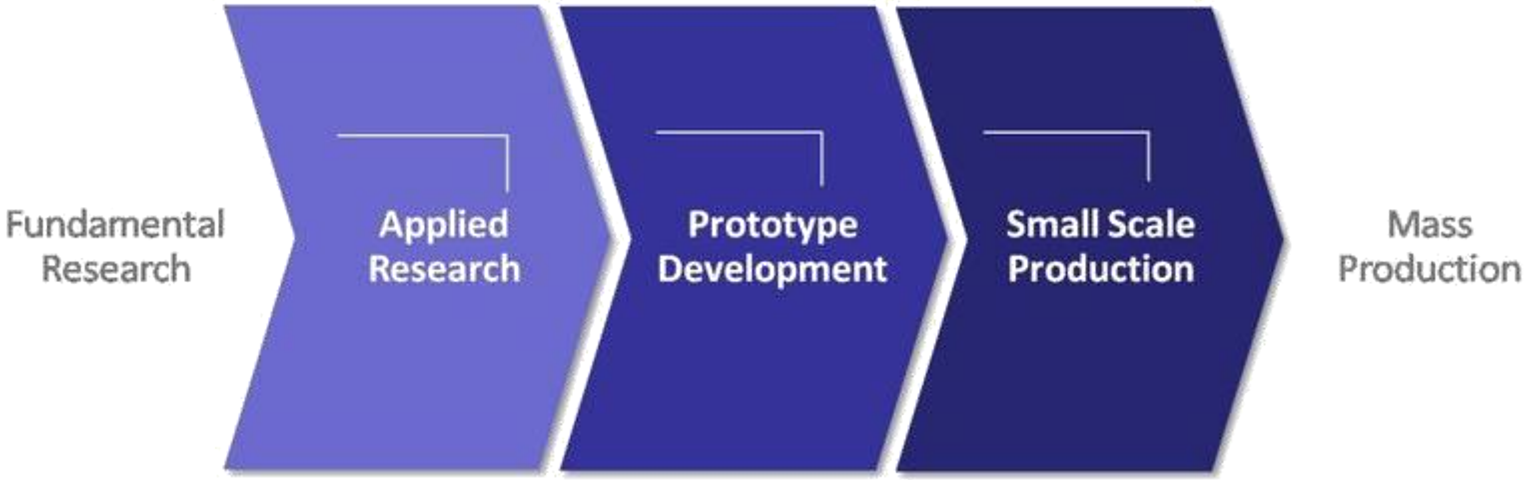
# AMO GmbH Overview

**Gesellschaft für Angewandte**
**Mikro- und Optoelektronik mbH**
Managing Director: Prof. Max C. Lemme
~85 staff members

- **High-Tech SME (non-profit)**
- **Research Foundry**
- Close ties to RWTH Aachen University
- operating since 1997
- **Departments**
  - Nanostructuring
  - Nanoelectronics
  - **Nanophotonics**
  - Sensors
  - Perovskites
- **Key technologies:**
  - Silicon technology base
  - 400 $m^2$ “extended CMOS” clean room
  - Integration of new materials

# Commercial foundry services at AMO




- R&D is our "product"
  - Publicly funded research projects
  - Contract research
  - Customer services

# Photonic Smart Sensing

- Electrons are dumb and photons are smart?

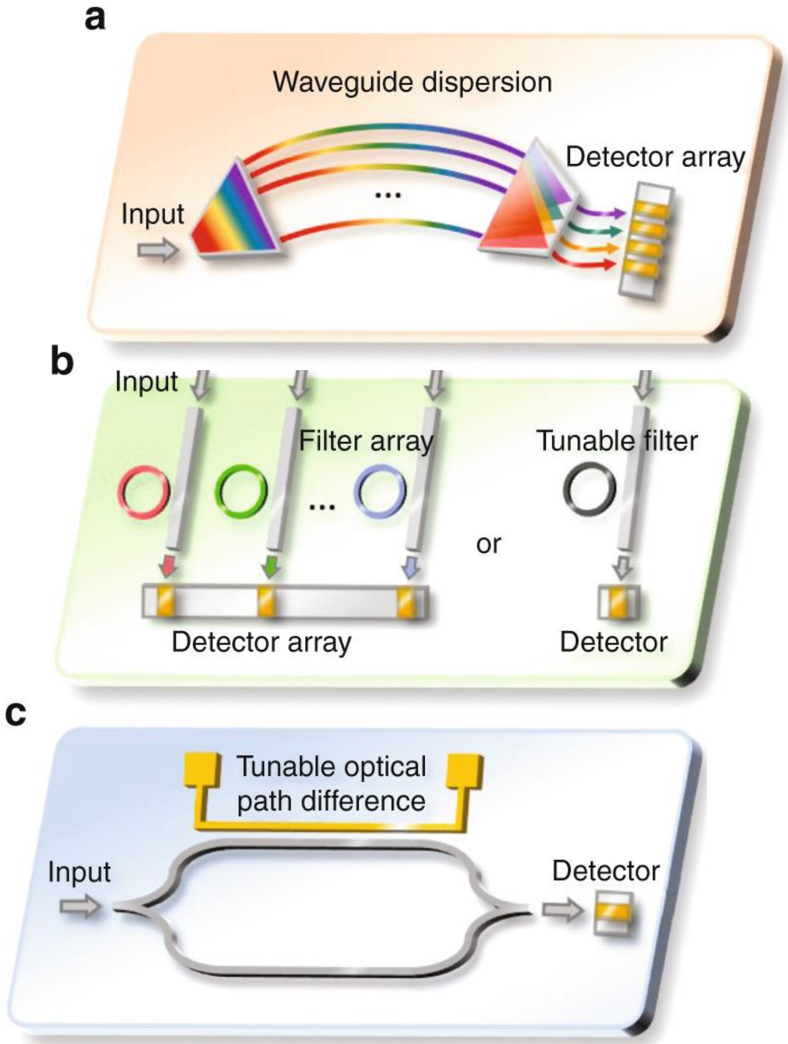
| Electrons | Photons |
|---|---|
| Current & voltage | Intensity |
| Wavelength | Wavelength |
| Modulation frequency | Modulation frequency |
| Electrical nonlinearity | Optical nonlinearity |
| Temperature-dependent resistance | Thermo-optic effect |
| Spin | Polarization |
| | Chirality |

# Electrons vs. Photons

- Electrons: Coulomb Interaction
  - Easy to manipulate
  - States very short-lived
- Photons: Bosons
  - Incredibly stable
  - Hard to manipulate
  - Can be very useful to **sense specifically** and over **longer distances**

# “Classic” Photonic Sensing

- Wavelength-specific detection
  - Spectrometers
  - Absorption / Reflection spectroscopy
  - FTIR (Fourier Transform Infrared Spectroscopy)
  - Raman spectroscopy / microscopy
- Well suited for on-chip integration
  - Less than 1 $mm^2$ die space
  - Simple process
  - Negligible cost

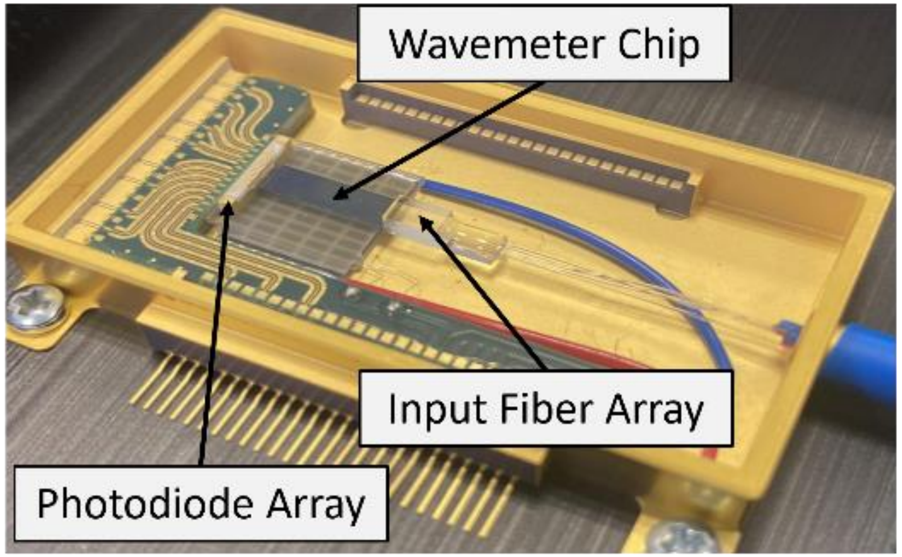


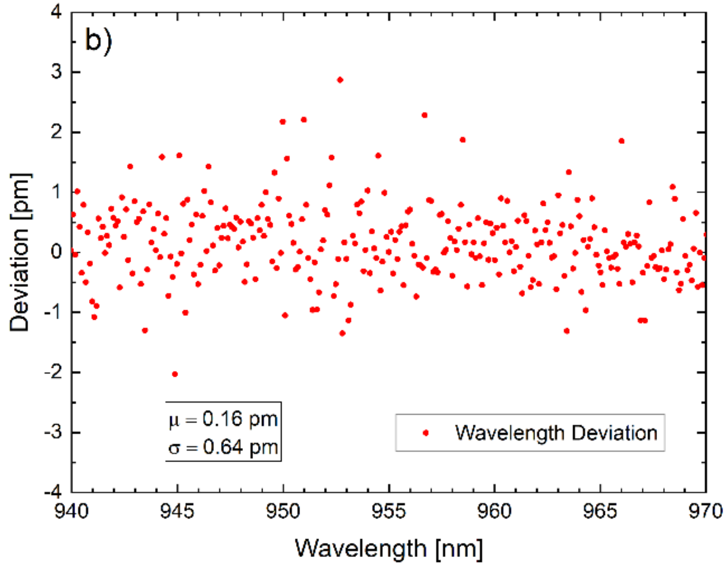

A. Li et al., “**Advances in cost-effective integrated spectrometers**“, *Light Sci Appl* **11**, 174 (2022)

# Example: Integrated Wavemeter

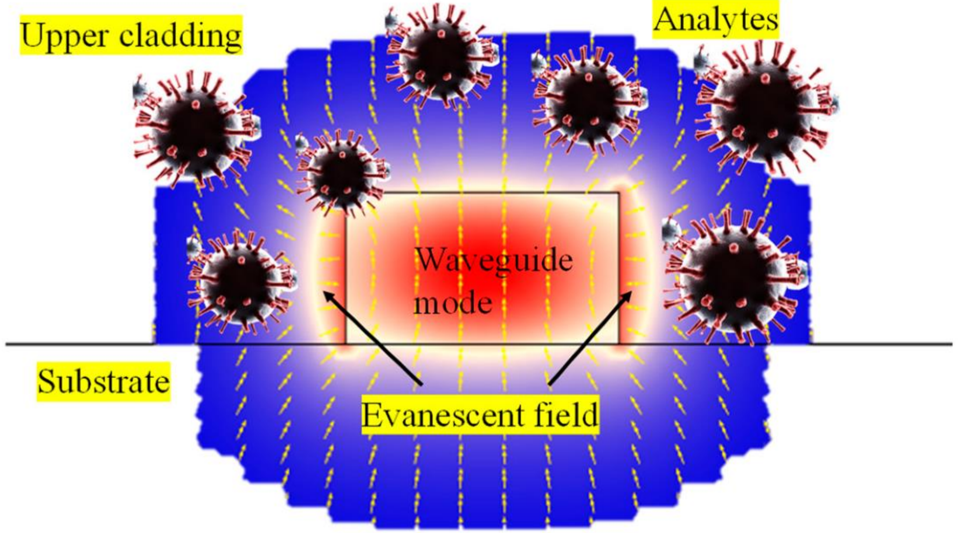
- Device to precisely measure monochromatic wavelength
- Bristol Instruments 872 Series: typ. 20 – 40k USD

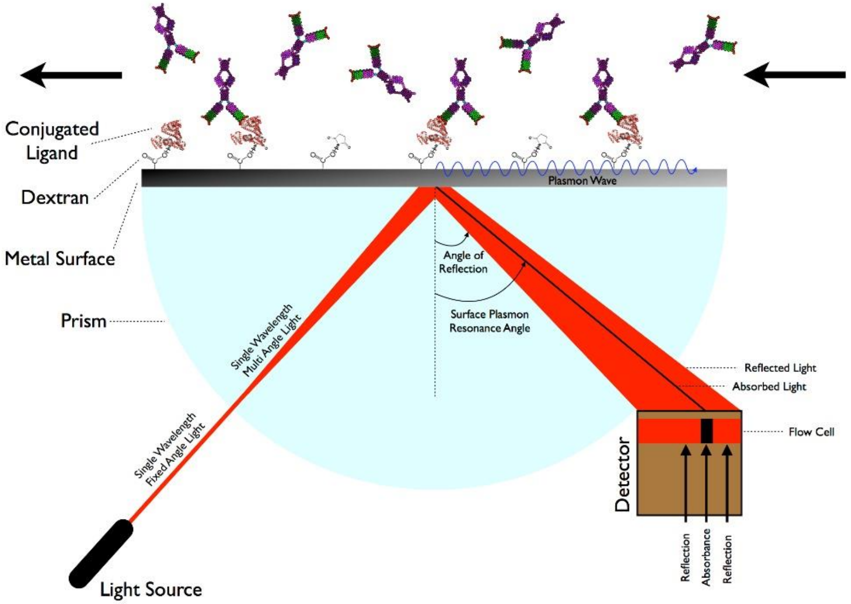

- AMO device: accuracy comparable in best case (0.2 pm vs. 0.16 pm)
- Performance limit: **temperature stabilization of package**



# Combine Photonics & Plasmonics?



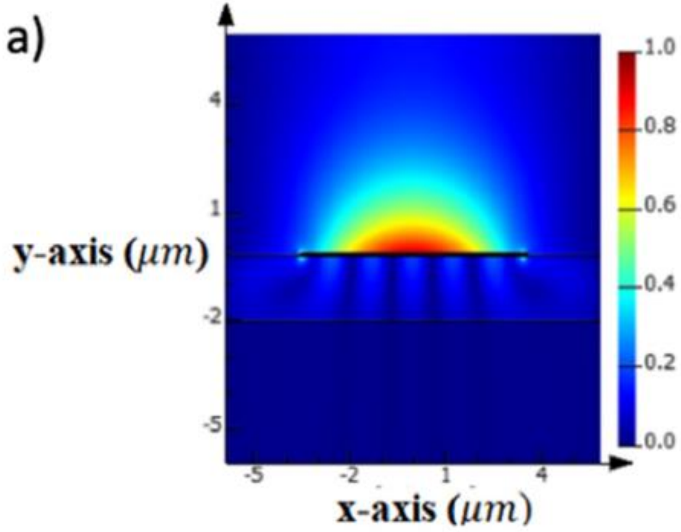

- Photonic evanescent field sensing
- More interaction needed: Slot waveguide, Photonic crystal…

- Surface Plasmon Resonance: SPR
- Good interaction, high field strength, limited to surface

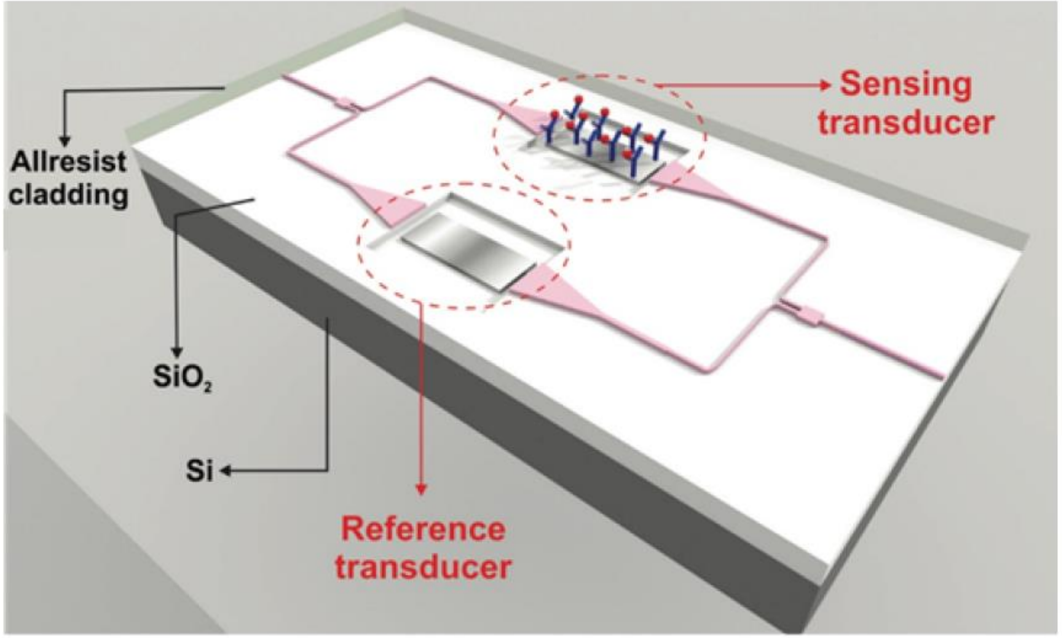
M. Butt, "Dielectric Waveguide-Based Sensors with Enhanced Evanescent Field: Unveiling the Dynamic Interaction with the Ambient Medium for Biosensing and Gas-Sensing Applications—A Review", *Photonics* **2024**, *11*(3), 198

S. Sabban, "Development of an in vitro model system for studying the interaction of Equus caballus IgE with its high- affinity FcεRI receptor" (PhD thesis 2011), The University of Sheffield, CC BY-SA 3.0

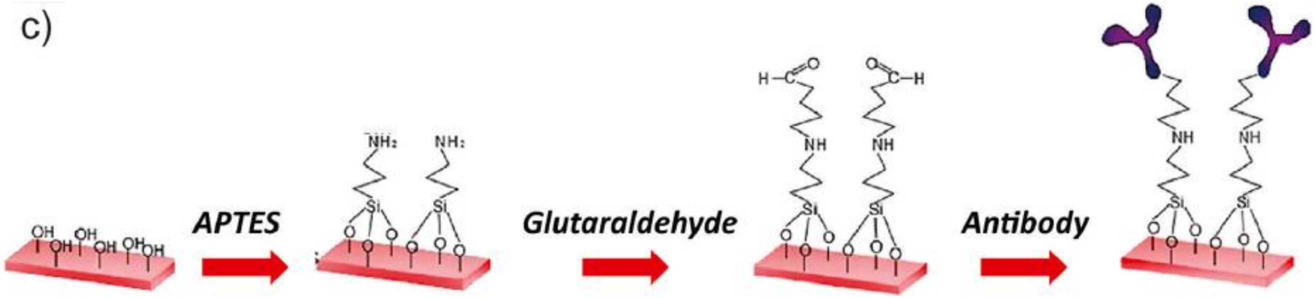
# Surface Plasmon Polaritons (SPPs)



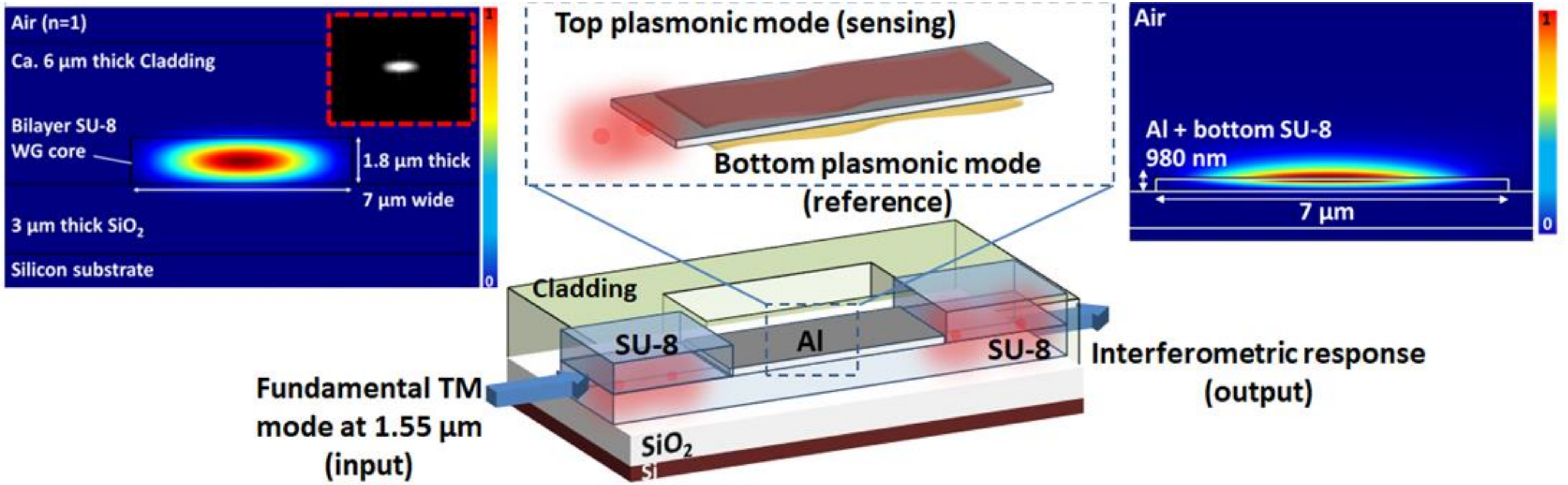

A. Manolis et al., "Ultra-fast detection of pathogens and protein biomarkers using a low-cost silicon plasmonic biosensing platform", Sensors and Actuators Reports 8 (2024) 100221.
M. Elrabiaay et al., "Balanced plasmonic-augmented silicon photonic interferometric sensor for biosensing applications", Opt. Expr. 33(**11**), 23110 (2025).




- Strong interaction
- SPPs reach ~1 µm into analyte
- Versatile functionalization
- **Best of Photonics & Plasmonics**



# Miniaturized hybrid SPP sensor




O. Bhalerao, “High-sensitivity polymer-based bimodal plasmonic refractive index sensors with polymer cladding”, Opt. Expr. 33(**5**), 9813 (2025)

- Bimodal, “single arm” interferometer
- **Best of Photonics & Plasmonics**
- Active area 75 x 7 µm ⟶ extremely high sensor density

# Refractive Index Sensor Comparison

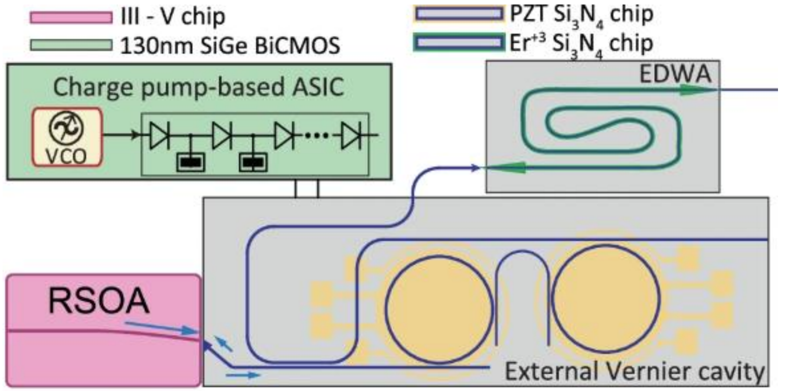
| Sensor | Sensitivity in nm/RIU | Penetration depth | Footprint |
|---|---|---|---|
| Photonic | 100 – 1,000 | 100's of nm | Single digit $mm^2$ |
| SPR | ~60,000 | 10's of nm | Small spot, large chips |
| SPP MZI | 2,000 – 4,500 | ~1 µm | 100's of $\mu m^2$ |
| SPP bimodal | 6,000 – 13,000 (+) | ~1 µm | 10's of $\mu m^2$ |

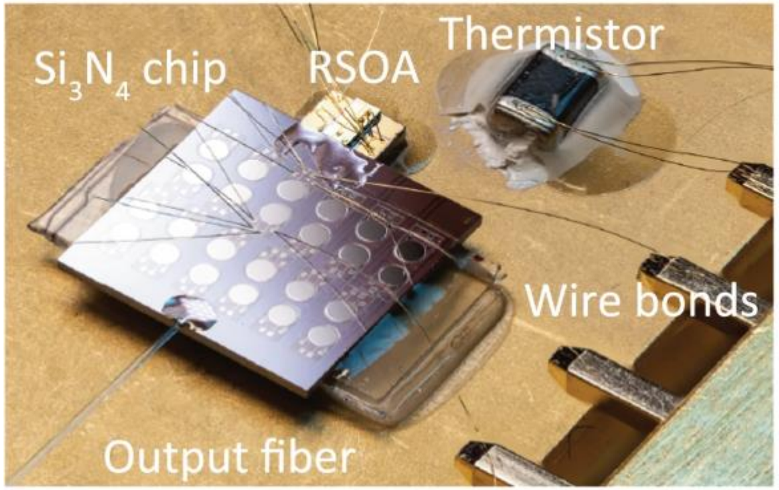
- Sensitivity: spectral shift (nm) per refractive index unit change (RIU)
- **Sensors push performance so far, that functionalization and the system around them limit performance**
  **→ spectrometer, detector & read-out integration?**

# Let's not forget about the electrons!

A. Lukashchuk et al., "Photonic-electronic integrated circuit-based coherent LiDAR engine", Nat. Comm. 15, 3134 (2024)

- spectrometer, detector & read-out integration
  - Lower cost
  - Less electronic noise
  - Higher data rate
  - Neuromorphic computing in hardware
- Options
  - Package level integration
  - Zero-Change CMOS Photonics
  - Back-end-of-line (BEOL) photonic integration



# BEOL integration: the holy grail

- Idea
  - Few additional processes hardly increase cost
  - Have metal & dielectrics in BEOL $\longrightarrow$ passive photonics
  - Adjust processes for lower temperature budget
  - Add material for active functionality
  - Graphene and other transferred 2D materials are a prime candidate
- Prospects
  - AMO spun-off **Black Semiconductor** to develop exactly that
  - They secured ~250 M€ funding and are building "Fab 1" in Aachen

# THANK YOU

ICOS
International Cooperation On Semiconductors

European Commission

INFRACHIP
European Research Infrastructure on Semiconductor Chips

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