Empa
Materials Science and Technology

Towards a digital Lippmann camera: integration challenges

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ETH-Domain

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Matthias J. Grotevent, Sergii Yakunin, Dominik Bachmann, Carolina Romero, Javier R. Vázquez de Aldana, Matteo Madi, Michel Calame, Maksym V. Kovalenko, and Ivan Shorubalko
Integrated photodetectors for compact Fourier-transform waveguide spectrometers
Nature Photonics 17, pages 59–64 (2023); https://doi.org/10.1038/s41566-022-01088-7

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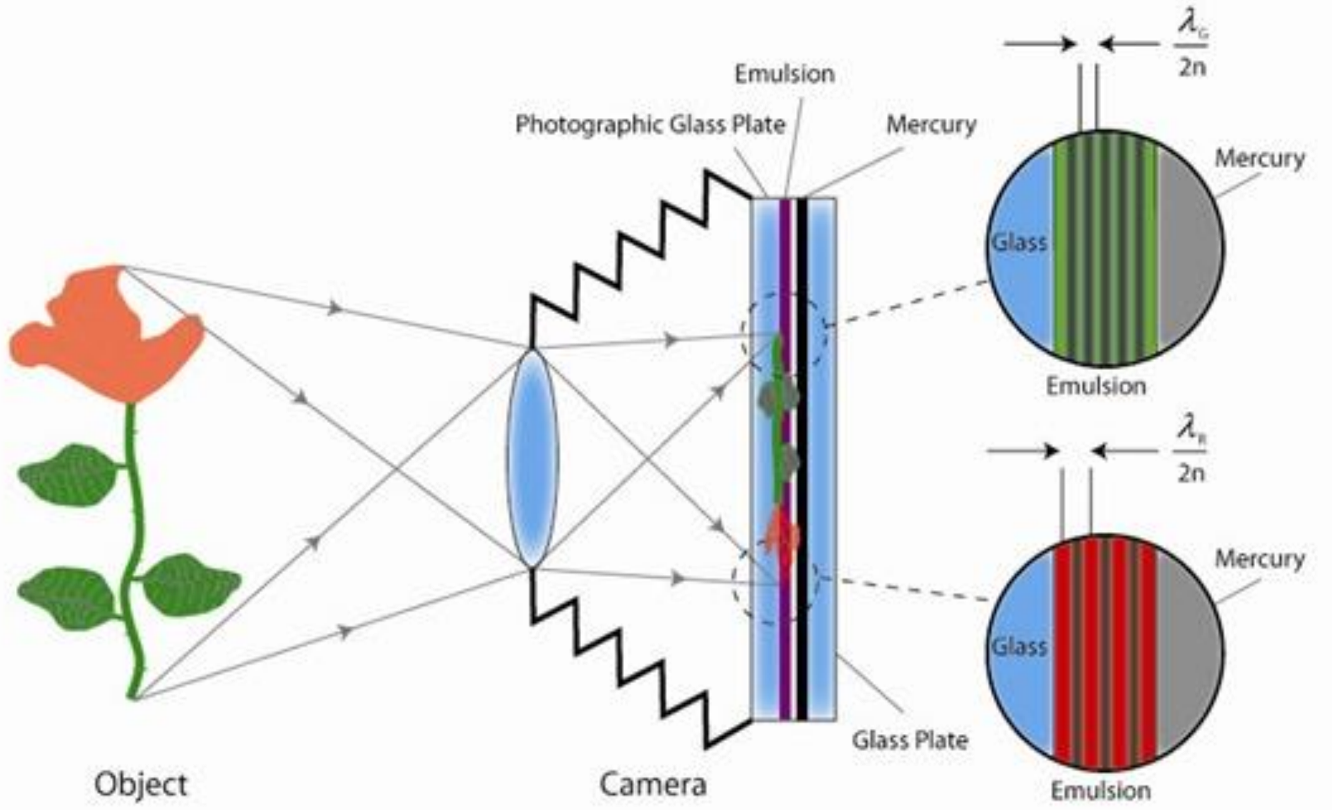
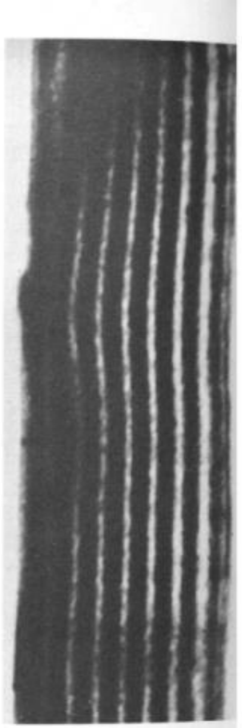
Gabriel Lippmann

The Nobel Prize in Physics 1908





Prize motivation:
"for his method of reproducing colours photographically based on the phenomenon of interference"

A **Lippmann plate** is a clear glass plate coated with an almost transparent (very low silver halide content) emulsion of extremely fine **grains**, **10 to 40 nm** in diameter

Sources: www.nobel.se

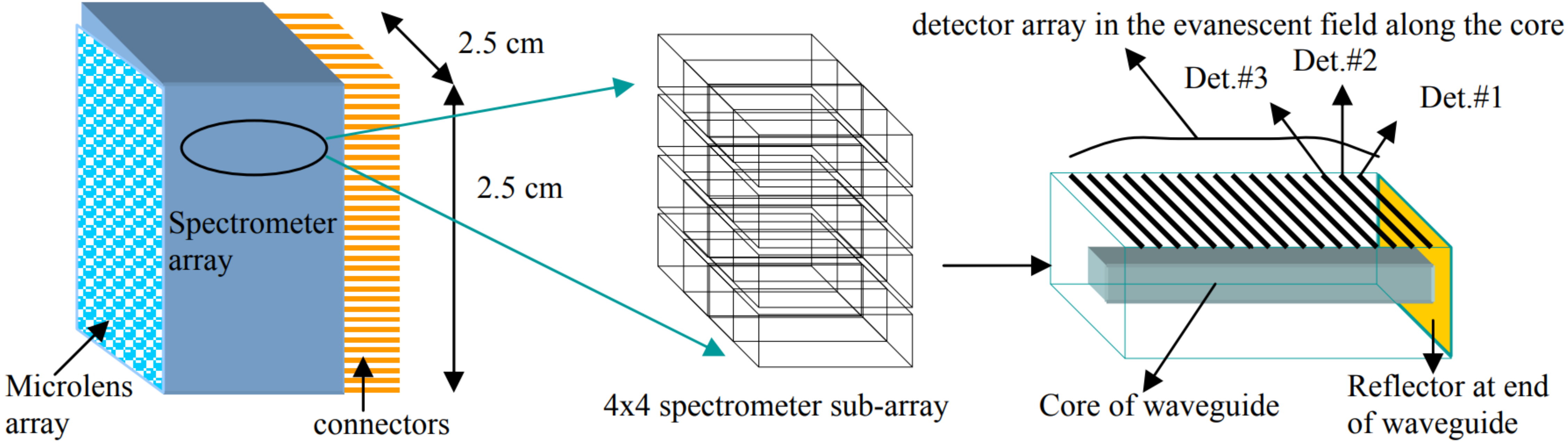
The Nobel Prize in Physics 1908. NobelPrize.org. Nobel Prize Outreach AB
https://www.nobelprize.org/prizes/physics/1908/summary/

https://elysee.ch/en/exhibitions/gabriel-lippmann/

https://en.wikipedia.org/wiki/Gabriel_Lippmann

Focal **P**lane **A**rray **S**pectrometer: Miniaturization effort for space optical instruments

The main idea introduced by Benedikt Guldimann and Stefan Kraft from European Space Research and Technology Ctr. (Netherlands)
Proc. of SPIE Vol. 7930 79300O-1 (2011), **https://doi.org/10.1117/12.882501**



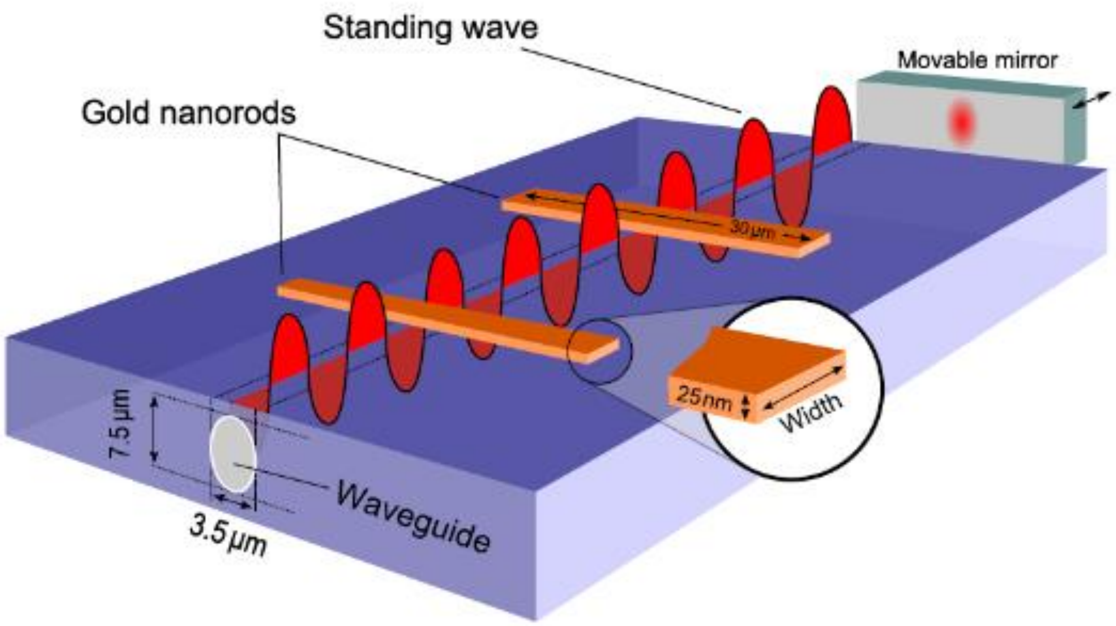
Technological development is highly desirable for FPAS realization
Materials and geometries choice is crucial
A real integration challenge

- Very compact
- No intrinsic limit on spectral resolution

Introduction: digital Lippmann photography – one pixel concept

Stationary-**w**ave **i**ntegrated **F**ourier-**t**ransform (SWIFT) spectrometry
Introduced by **Etienne le Coarer, *et al*** in Nature Photonics **1**, 473 (2007)

https://doi.org/10.1038/nphoton.2007.138



doi:10.1088/2040-8978/17/2/025801

Main figures of merit

- High spectral resolution

$$\Delta\lambda = \lambda^2/OPD = \lambda^2/2Ln_{eff}$$

Examples

1) λ = 850 nm, L =1 mm, n_{SiO_2} = 1.5 -> $\Delta\lambda$ = 0.24 nm

2) λ = 2000 nm, L =5 mm, n_{Si} = 3.5 -> $\Delta\lambda$ = 0.11 nm

- Bandwidth (Nyquist criterion)

Sampling -> $\lambda/4n_{eff}$, *d* – distance between samplers

$$\delta\lambda = \lambda^2/d4n_{eff}$$

Examples

1) λ = 850 nm, d =10 μm, n_{SiO_2} = 1.5 -> $\delta\lambda$ = 12 nm

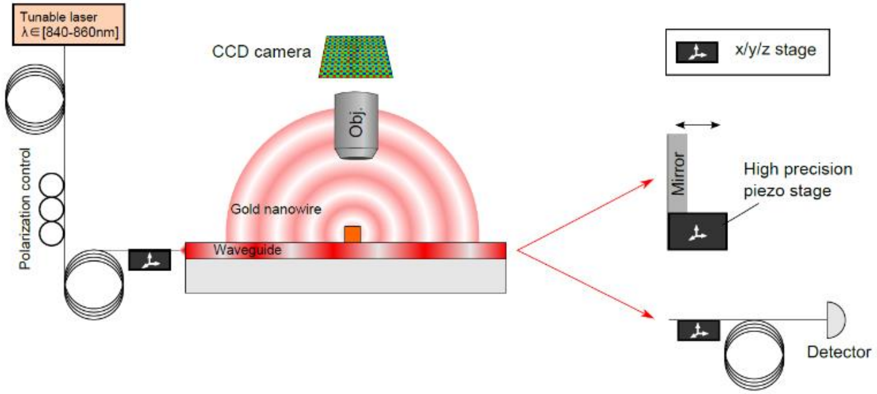
2) λ = 2000 nm, d =3 μm, n_{Si} = 3.5 -> $\delta\lambda$ = 95 nm

3) moving mirror by steps of $d = \lambda/4n_{eff}$ -> $\delta\lambda = \lambda$
no undersampling -> bandwidth limited by other physics

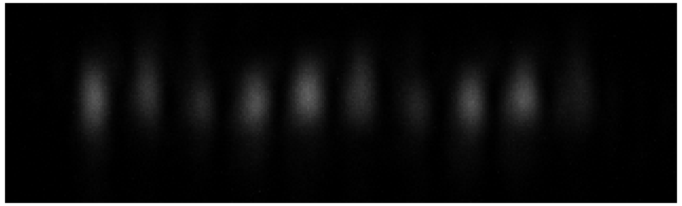
- Efficiency

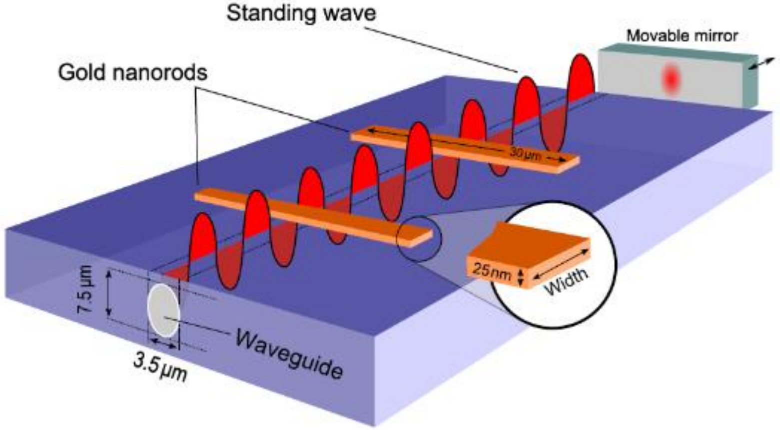
Optimized when every sampler extracts 1/N of the local power
74% of the input power contributes to detectors

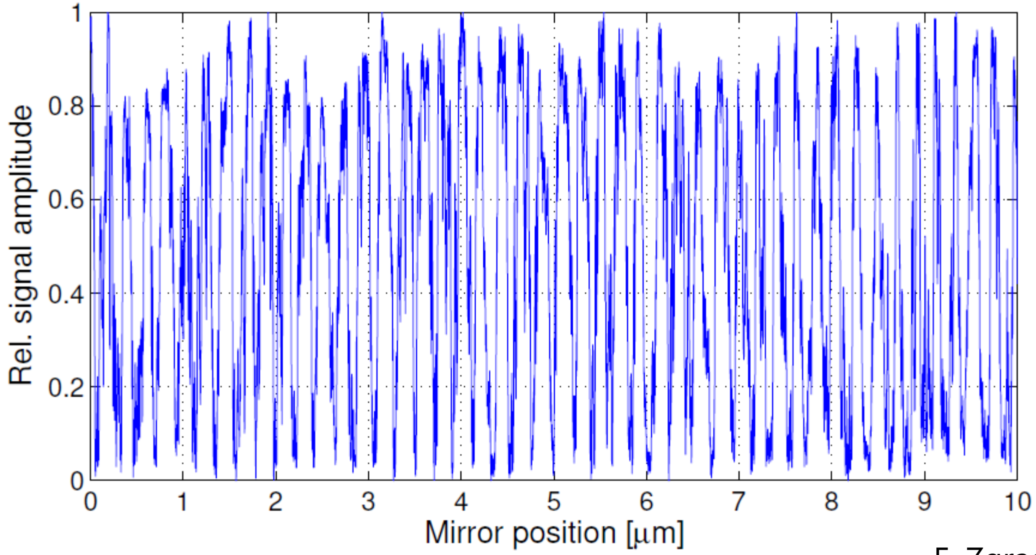
Realization of one pixel with scanning mirror



Scan mirror – record out-scattered intensity



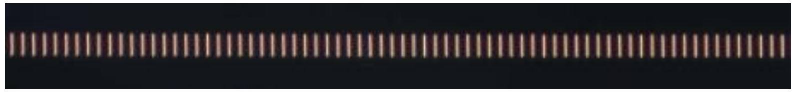




Out-scattered light intensity by one nanowire for 10µm mirror scan

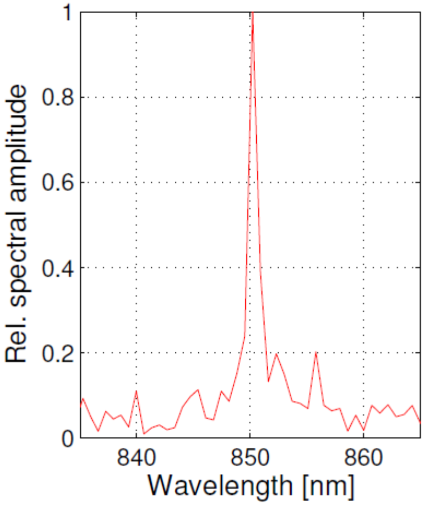
X 150

nanowires 10µm spaced



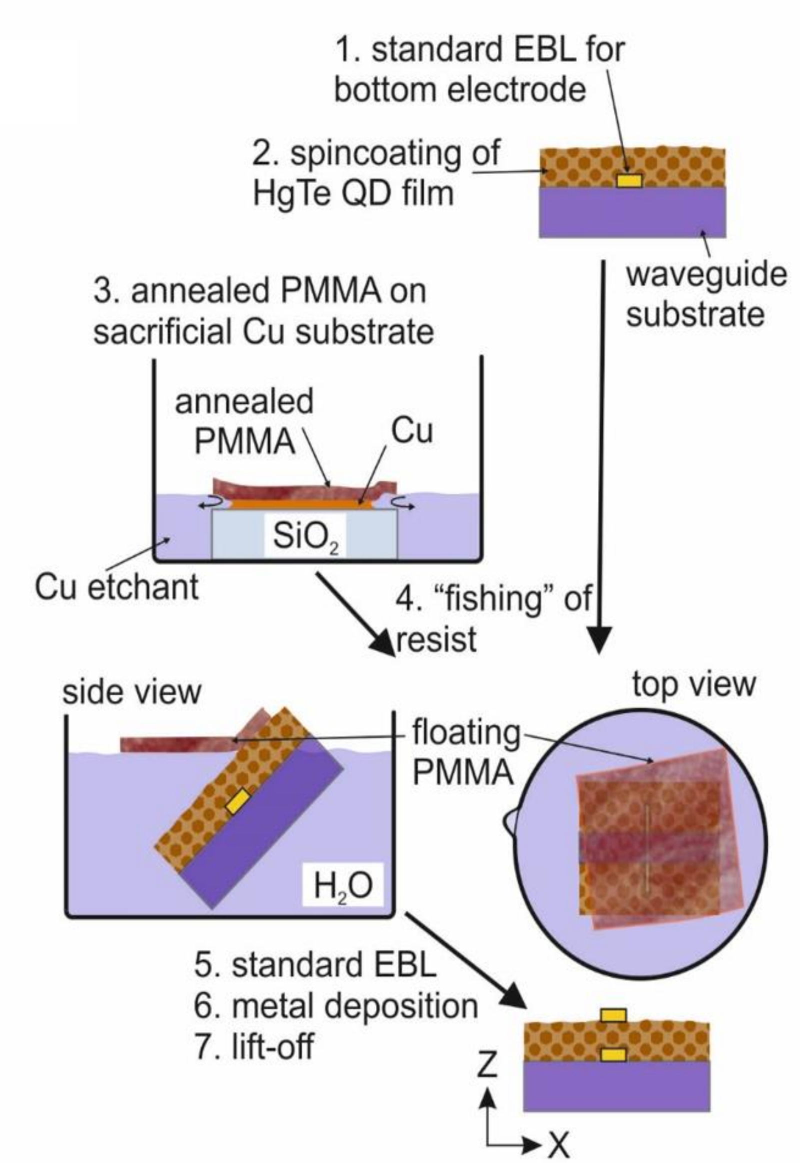
Full (no undersampling)

E. Zgraggen, O. Scholder, G-L. Bona, F. Fontana, E. Alberti, A. Crespi, R. Osellame, T. Scharf and I. Shorubalko
J. Opt. 17 (**2015**) 025801,
doi:10.1088/2040-8978/17/2/025801



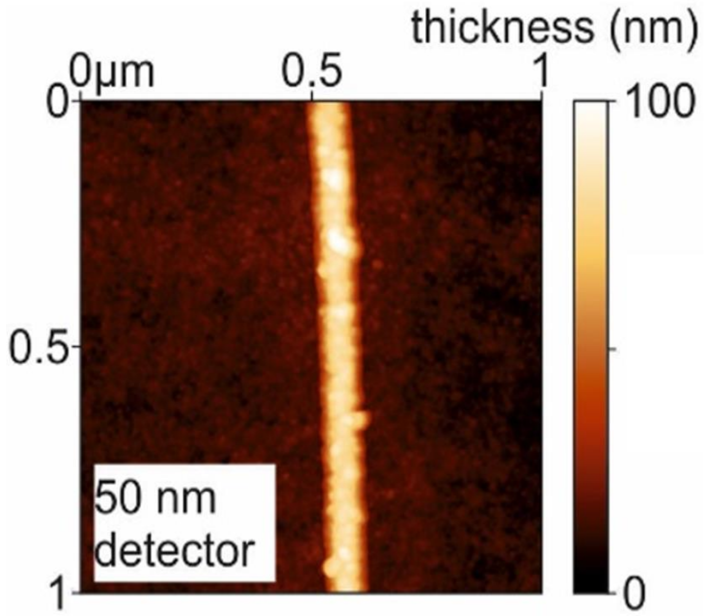
Fourier-Transform

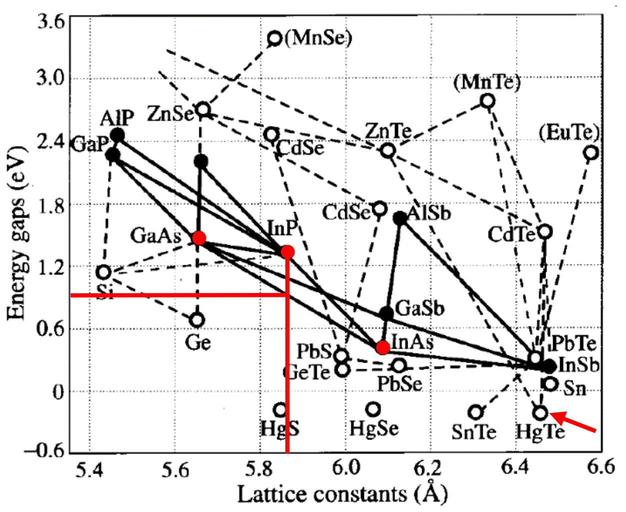
Fabrication



Surface optical waveguides are written into $LiNbO_3$ by fs-laser at sub-ablation threshold power.

IR-absorber,
HgTe QDs were fabricated using the $HgCl_2$ precursor followed by ligand exchange with 1,2-ethanedithiol





Nature Photonics 17, pages 59–64 (2023);
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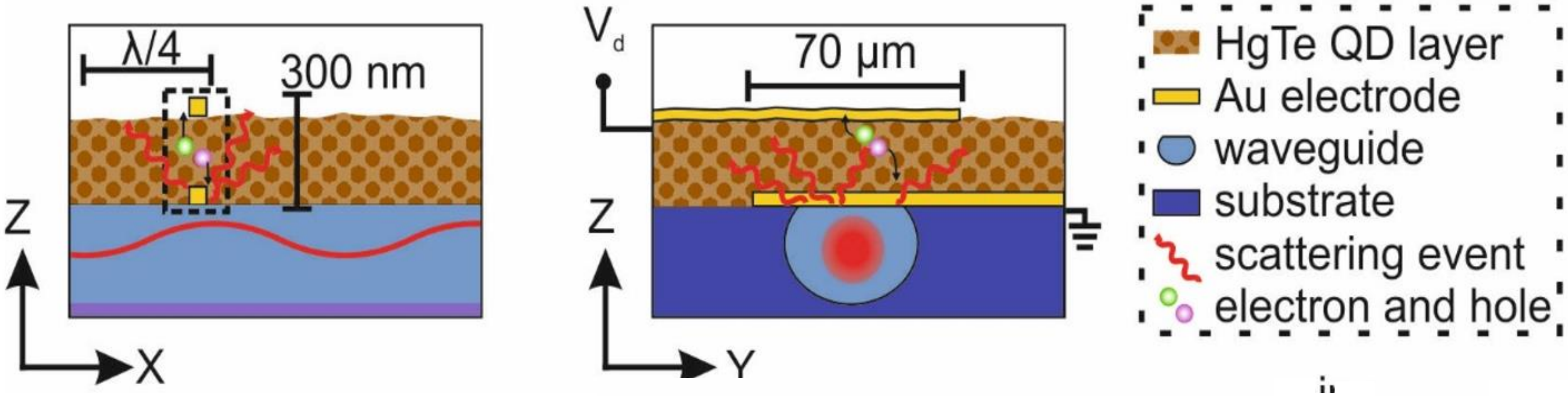
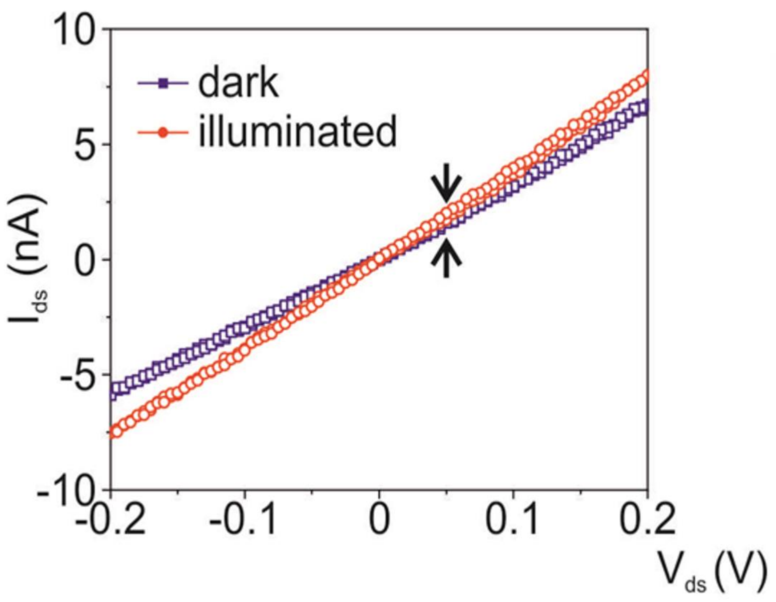
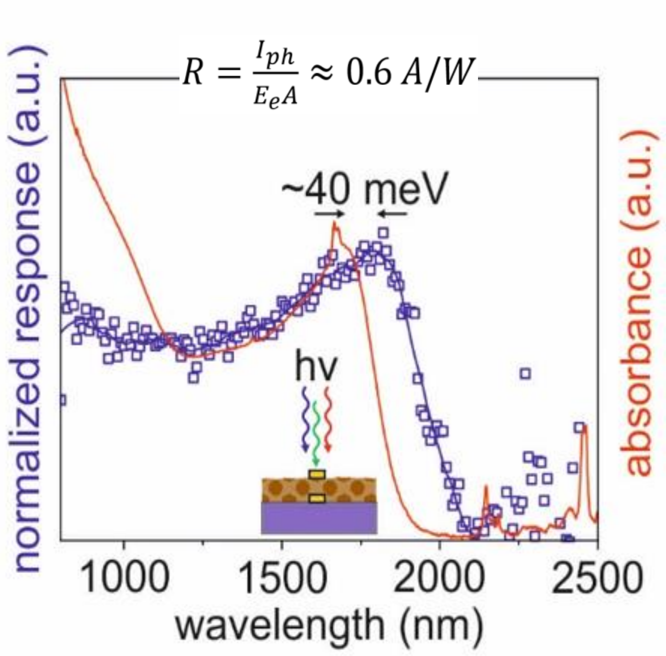
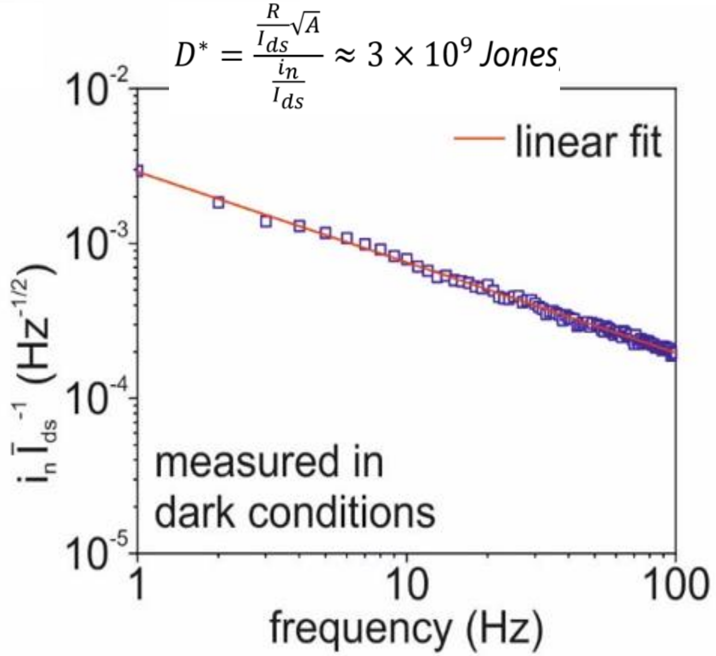
Integrated Colloidal Quantum Dots Photodetectors









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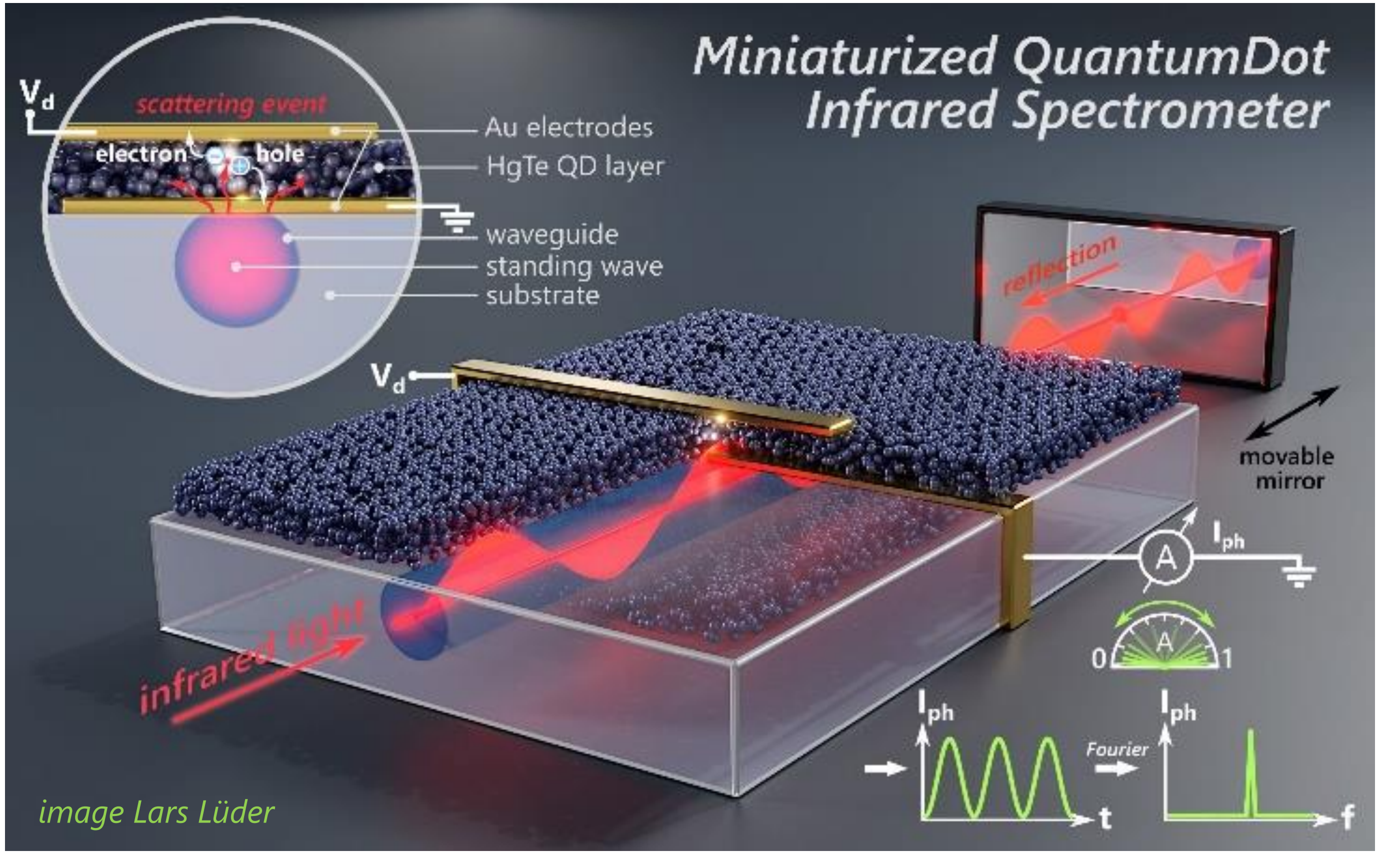
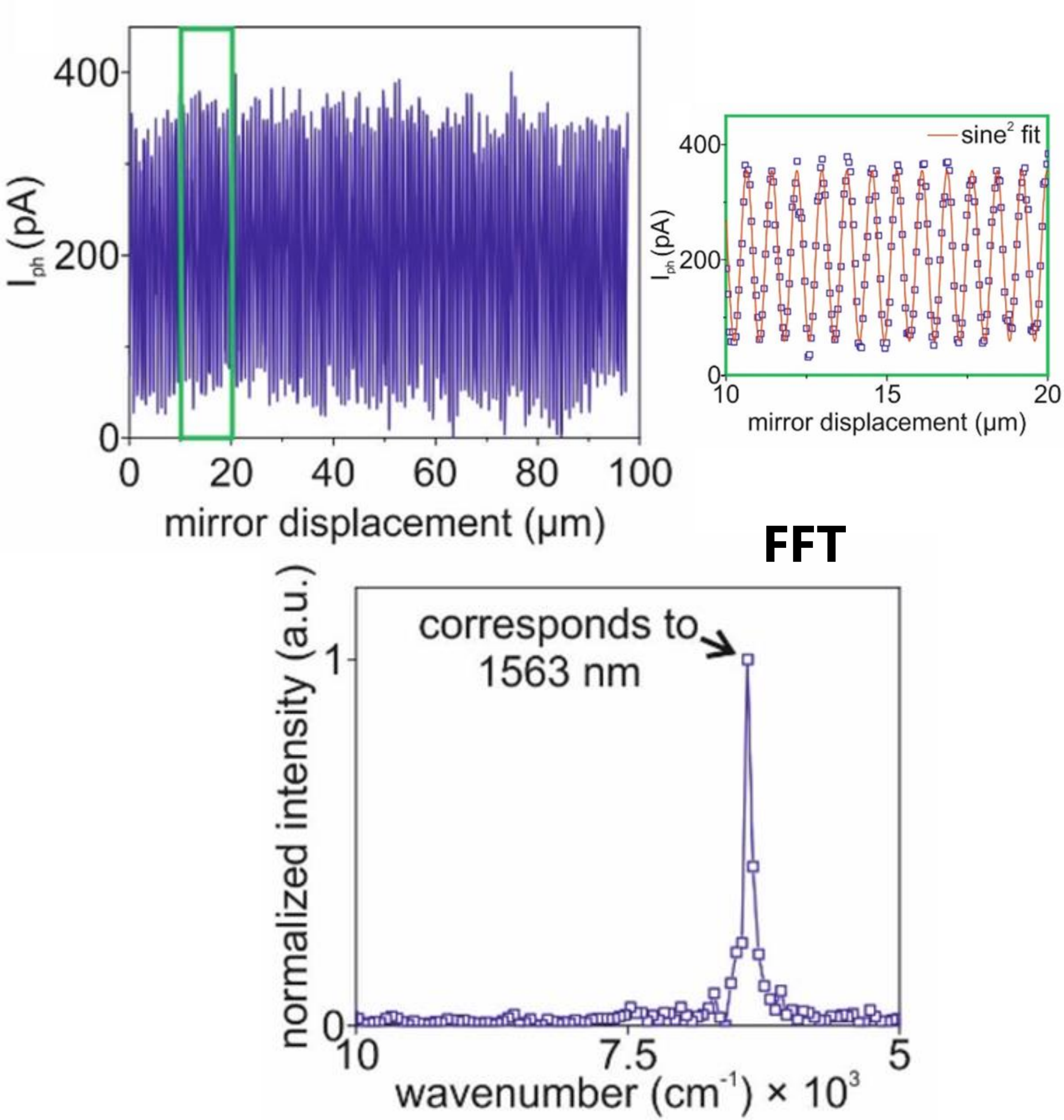
Spectrometer functionality





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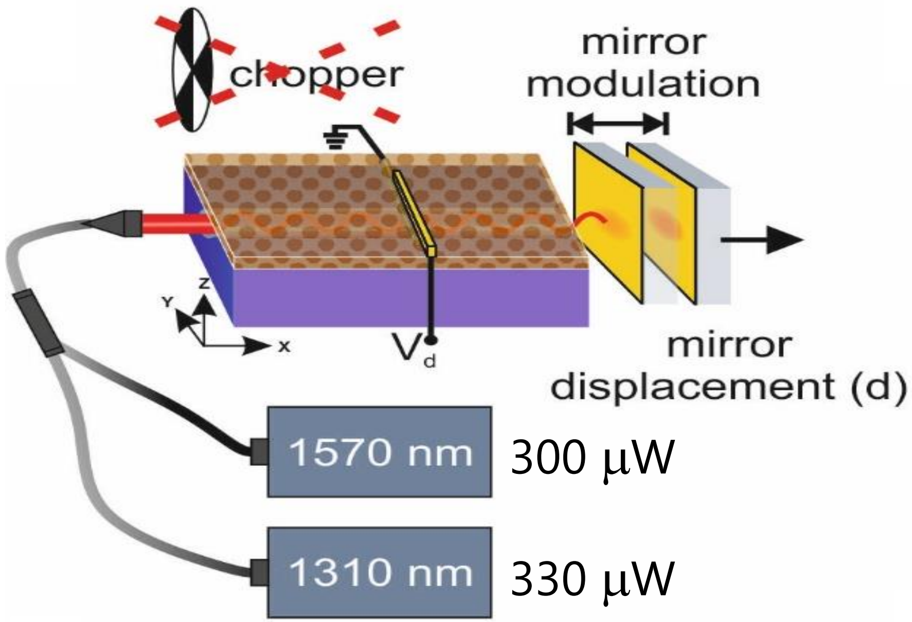

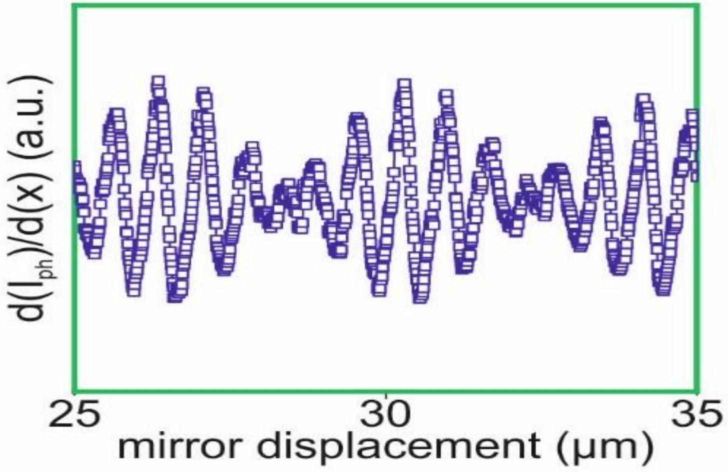

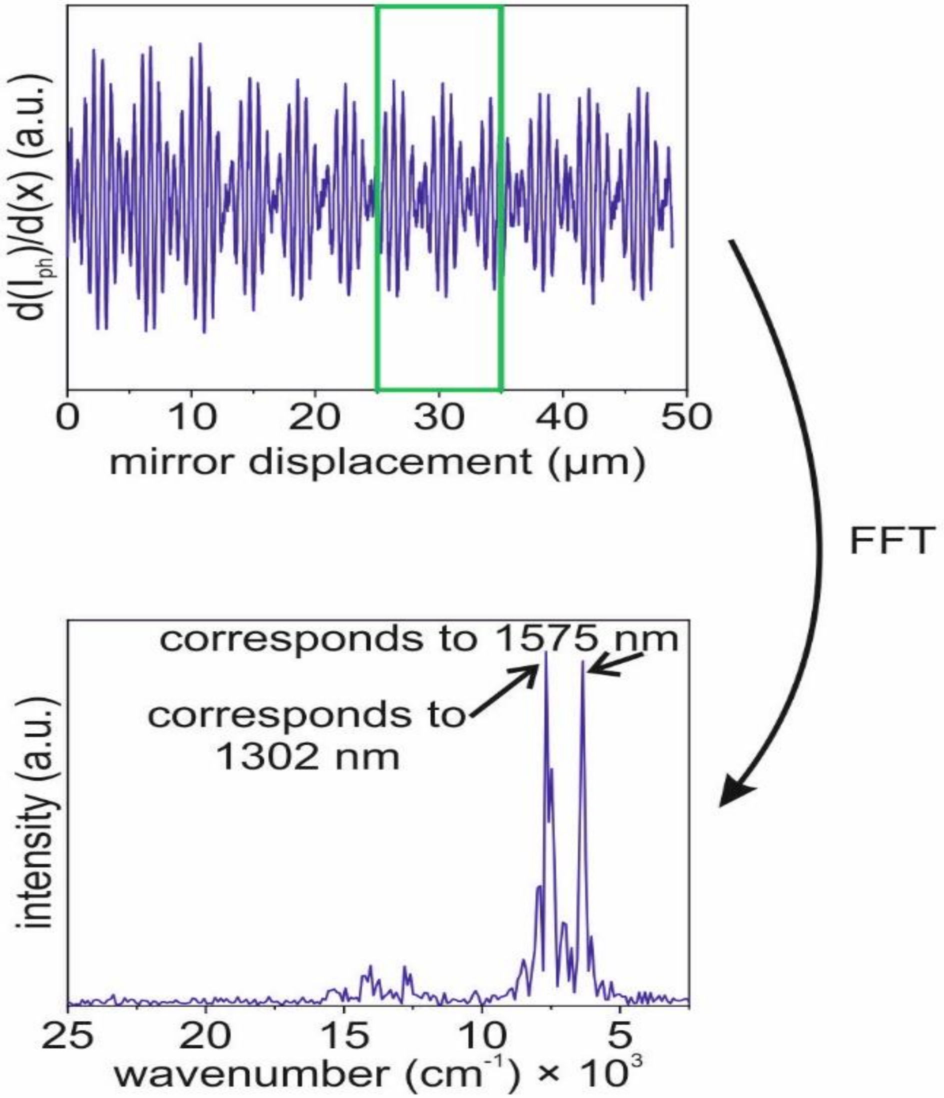

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Summary, prospective and applications

- Demonstrated small (<$\lambda/4$ in 2 dimensions) QDs-based IR photodetector sensitive up to λ = 2 μm
- Integration of the nano-sized photodetector with an optical waveguide
- Demonstrated standing wave sensing for spectroscopy application
- The technology is compatible with 2D/3D integration idea for FPASs
- A step forward towards a digital Lippmann camera
- Applications in remote sensing

Thank you !