Integrated Microwave Photonics

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THE BANDWIDTH BOTTLENECK

Researchers are scrambling to repair and expand data pipes worldwide — and to keep the information revolution from grinding to a halt.

BY JEFF HECHT

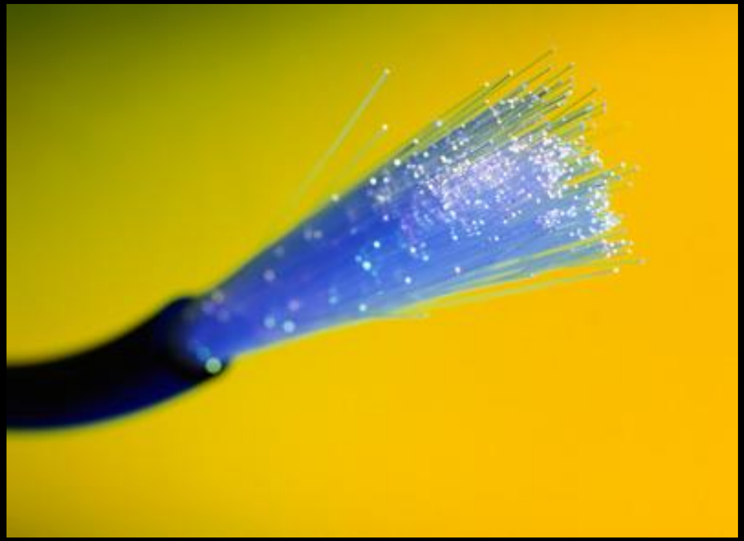
J. Hecht, Nature **536**, 2016

Microwave photonics

Microwave photonics (MWP): manipulation of RF signals using photonic techniques/components

Capmany and Novak, Nat. Photon **1** (2007)
Seeds and Williams, J. Lightwave Technol.**24** (2006)
Yao, J. Lightwave Technol. **27** (2009)
Marpaung et al., Laser Photon. Rev. **7** (2013)

vs.



- Heavy (copper, 567 kg/km)
- High loss(190 dB/km @ 6 GHz)
- Rigid and large cross section

- Lightweight
- Low loss(0.25 dB/km)
- Very flexible

Microwave photonics

MWP applied in the generation, distribution, processing, measurement of RF signals

Next generation wireless

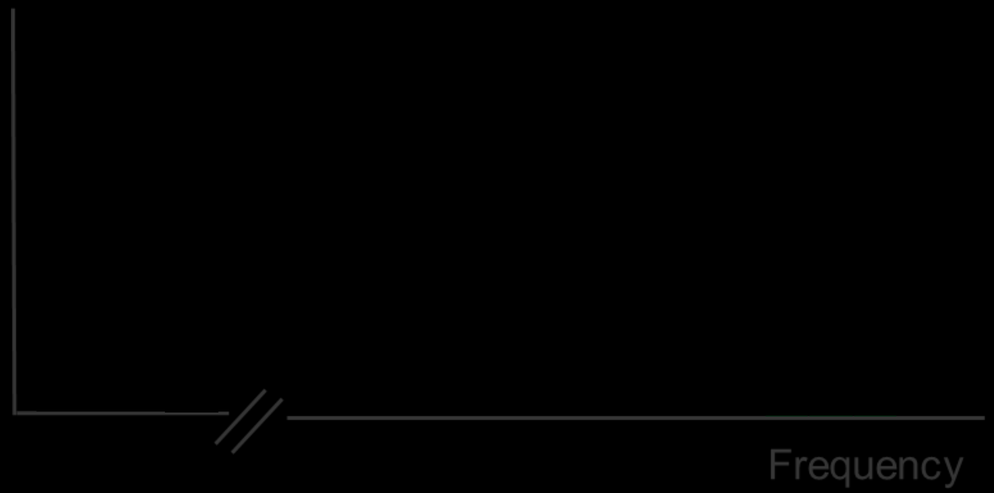
Radio astronomy

Satellite communication

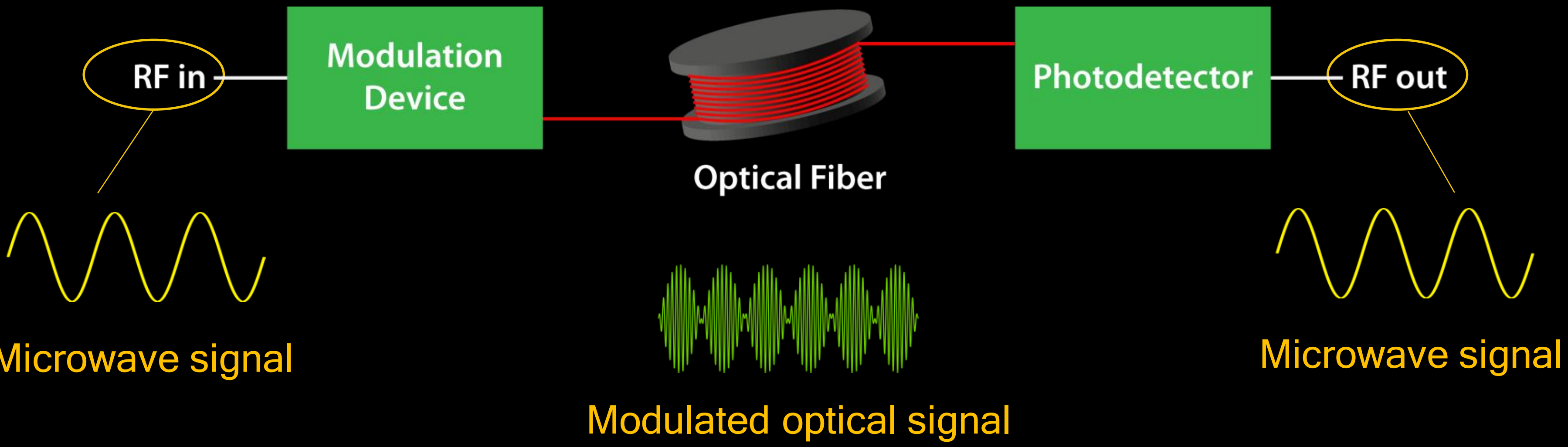
Defense

Microwave photonics

Key concepts: Optical modulation and detection

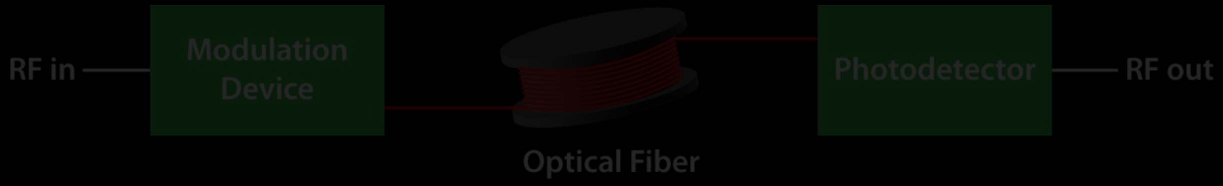


Microwave photonic link

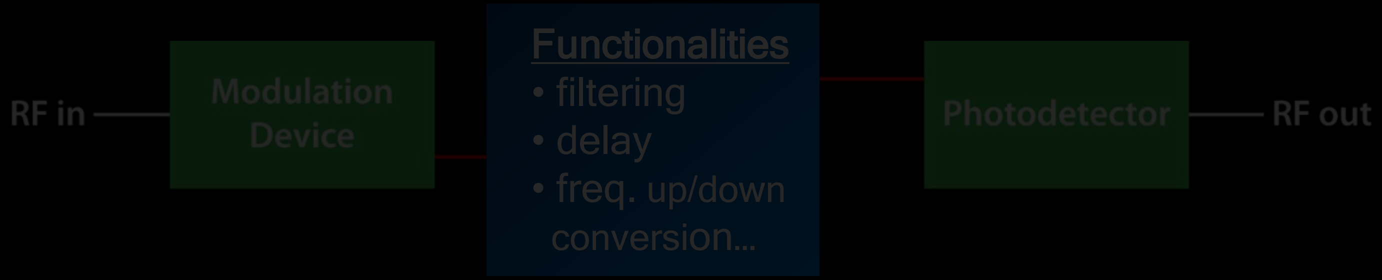


Integrated microwave photonics

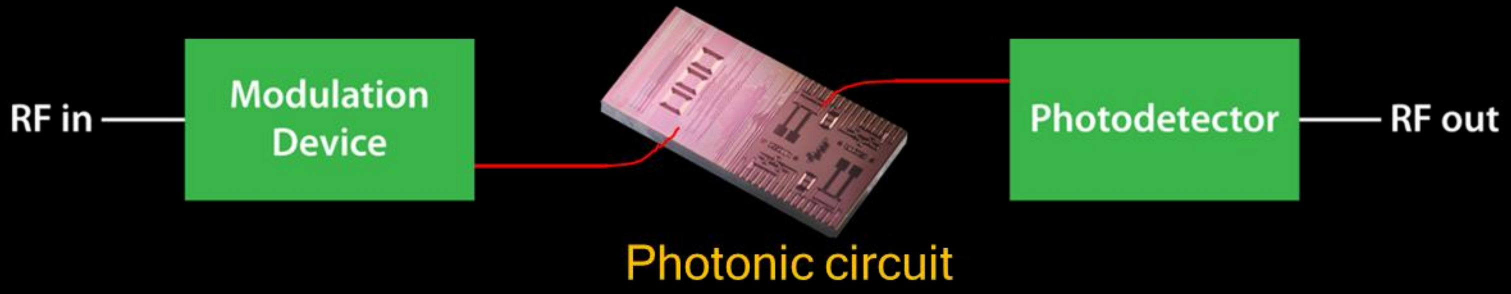
MWP link: low loss signal transport/distribution



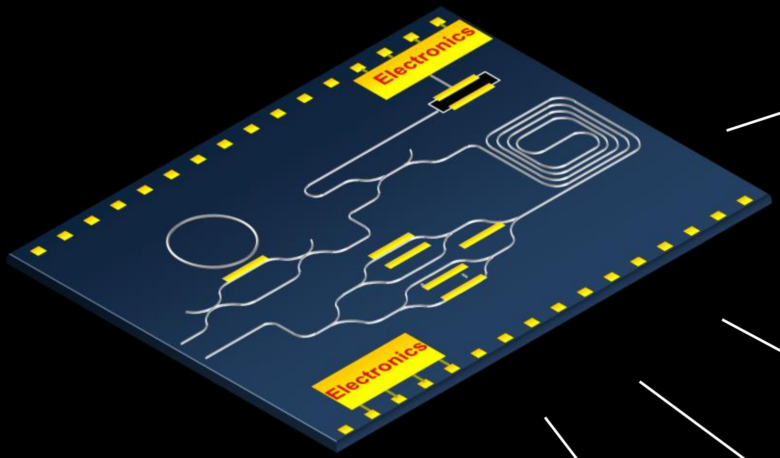
MWP system: wideband, reconfigurable RF signal processing



Integrated MWP: PICs for advantage in size, weight and power

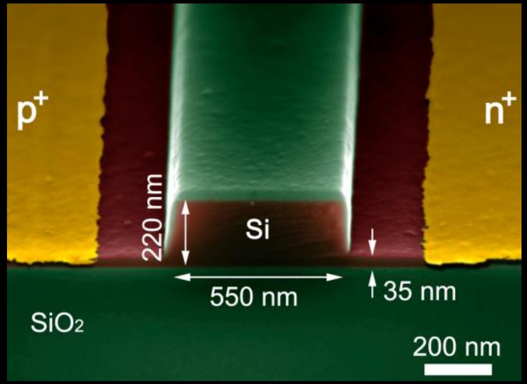


Material platforms



- Low loss ✗
- High power handling ✗
- Compact ✓
- Lasers ✗
- Linear modulation & detection ✗
- Optical nonlinearities ✓
- CMOS compatible ✓

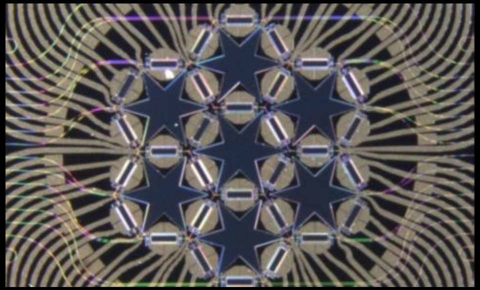
Standard silicon



- Loss ~ 1-3 dB/cm
- Tens of micron bend radius
- Carrier depletion modulator
- Nonlinear loss for high intensity (TPA and FCA)

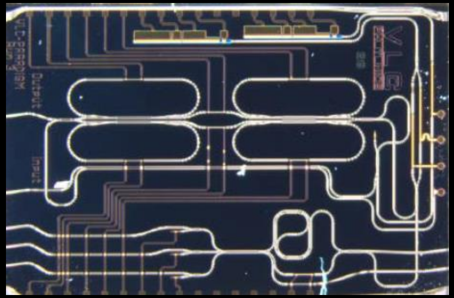
Material platforms

Silicon



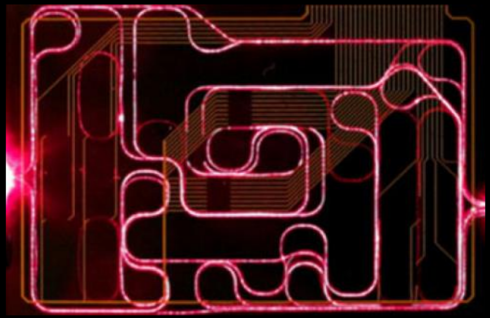
Universal signal processor
(UPV, Nat. Comm. 2017)

Indium phosphide



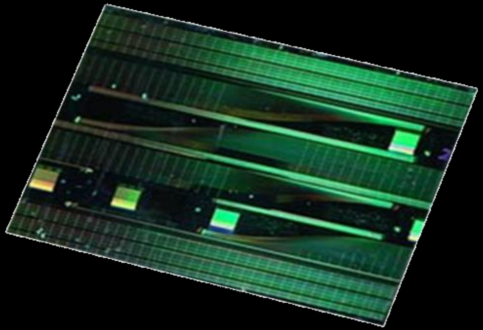
All integrated filter
(UPV, Nat. Photon. 2017)

Silicon nitride



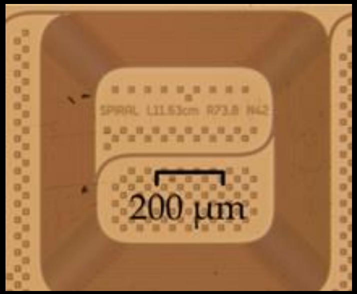
Channelizer, processor
(LioniX, JSTQE 2018)

Chalcogenide



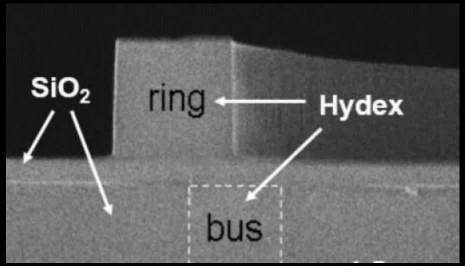
SBS tunable filter
(Sydney, Optica 2015)

Thick SOI



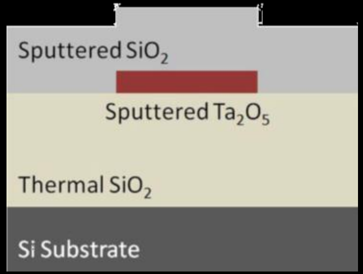
Instantaneous frequency
measurement
(Sydney, Optica 2016)

Hydex

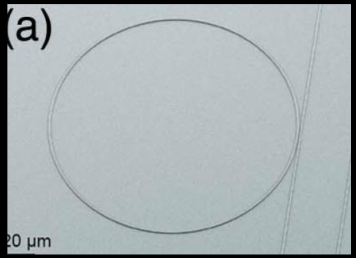


Comb-based RF photonics
(Swinburne, JSTQE 2018)

Emerging materials

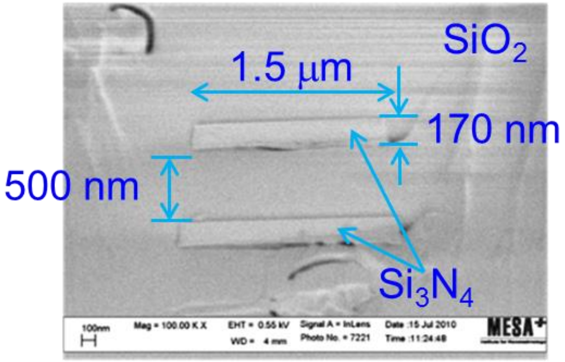


Ta_2O_5 (UCSB, Optica 2017)



LNOI (Harvard, Optica 2017)

Silicon nitride

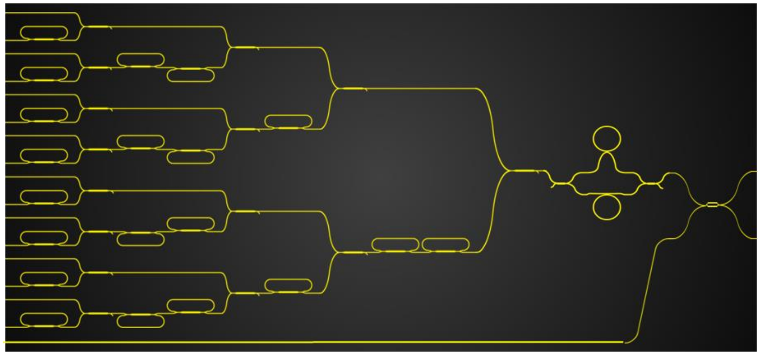


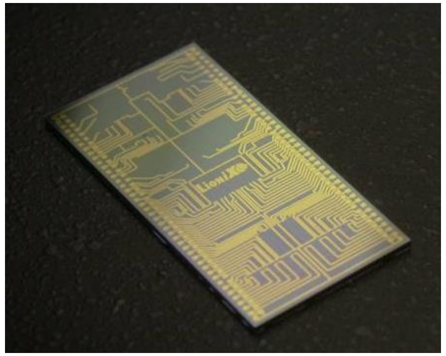
- Cross section: ~ 1 μm x 1.5 μm
- Propagation loss: < 0.2 dB/cm
- Bend radius ~ 100 μm
- Coupling loss ~ 1 dB/facet
- Moderate nonlinearity (~ 10 x n_2 of silica)
- TPA and FCA free

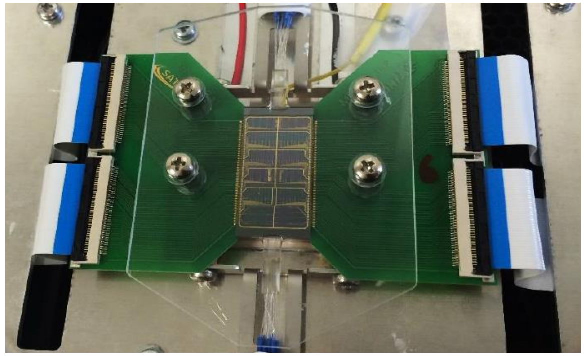
Silicon nitride microwave photonic circuits

Chris G. H. Roeloffzen,[1, 2,*] Leimeng Zhuang,[1] Caterina Taddei,[1] Arne Leinse,[3] René G. Heideman,[3] Paulus W. L. van Dijk,[2] Ruud M. Oldenbeuving,[2] David A. I. Marpaung,[4] Maurizio Burla,[5] and Klaus -J. Boller[6]

Beamformer, filters, frequency discriminator, modulation transformer. UWB pulse shaper, frequency measurement, ...





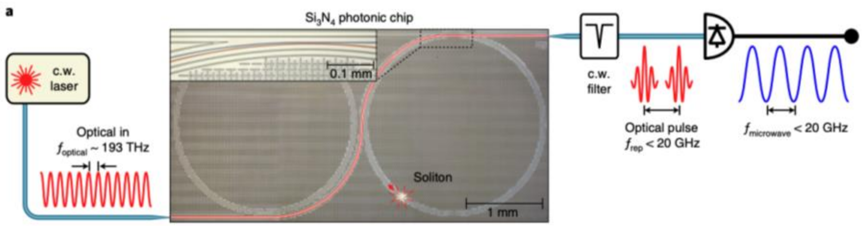


Roeloffzen et al. Opt. Express 21(19), 2013.

Microwave Photonic functions

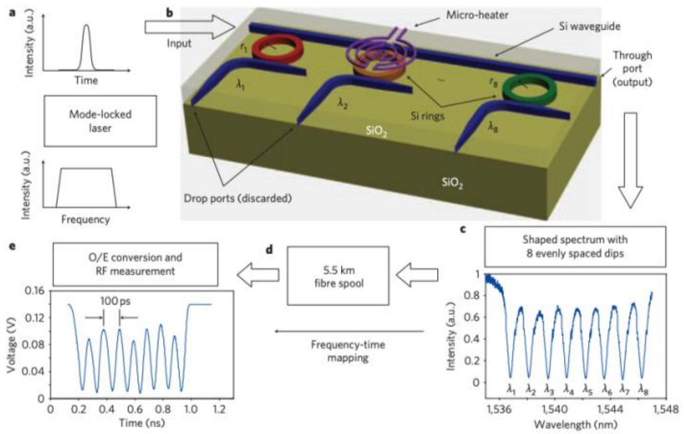
Signal Generation

Microwave tone



J. Liu et al., *Nat. Photon., 2020*

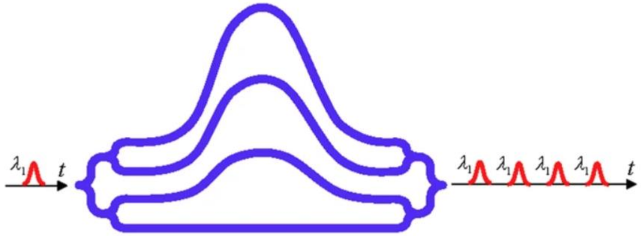
RF waveform



M. Khan et al., *Nat. Photon., 2010*

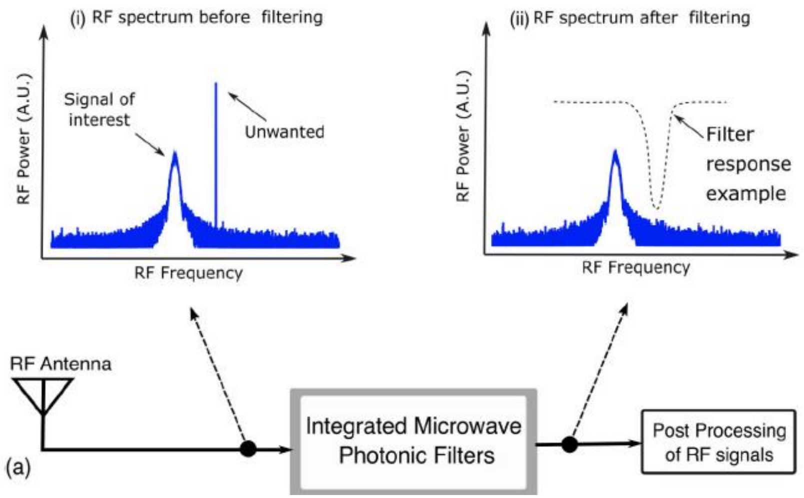
Signal processing

Tunable delay line



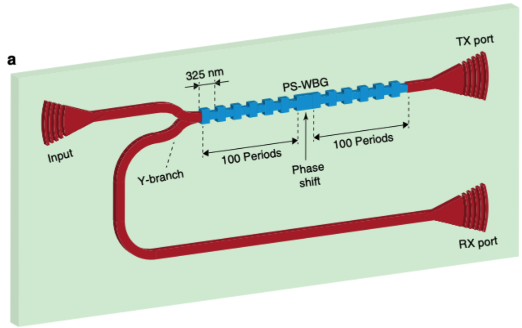
J. Wang et al., *Sci. Rep., 2016*

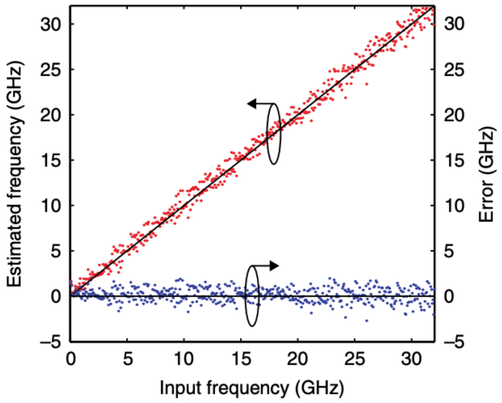
Filtering



Y. Liu et al., *Adv. Opt. Photon., 2020*

Signal measurement



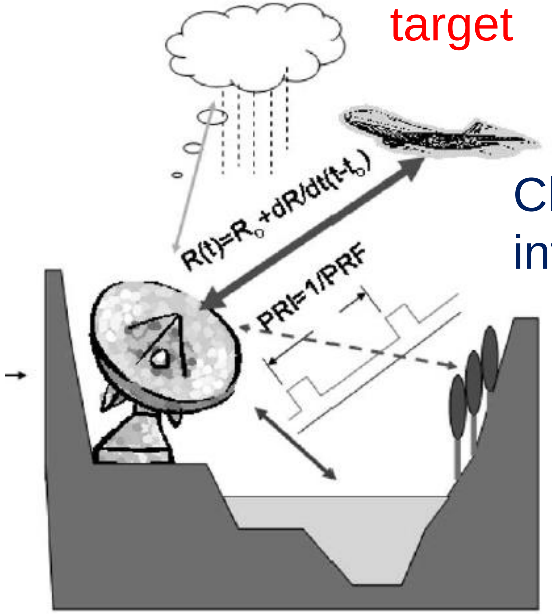


M. Burla et al., *Nat. Comm., 2016*

Why MWP filter?

Radar

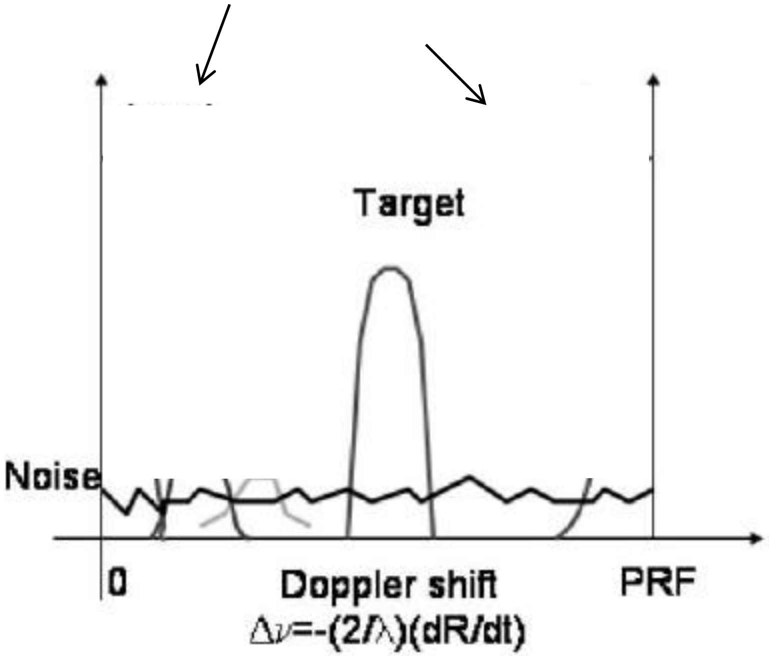
target



Clutter/
interferer

J. Capmany et al, JLT, 24, 201, 2006

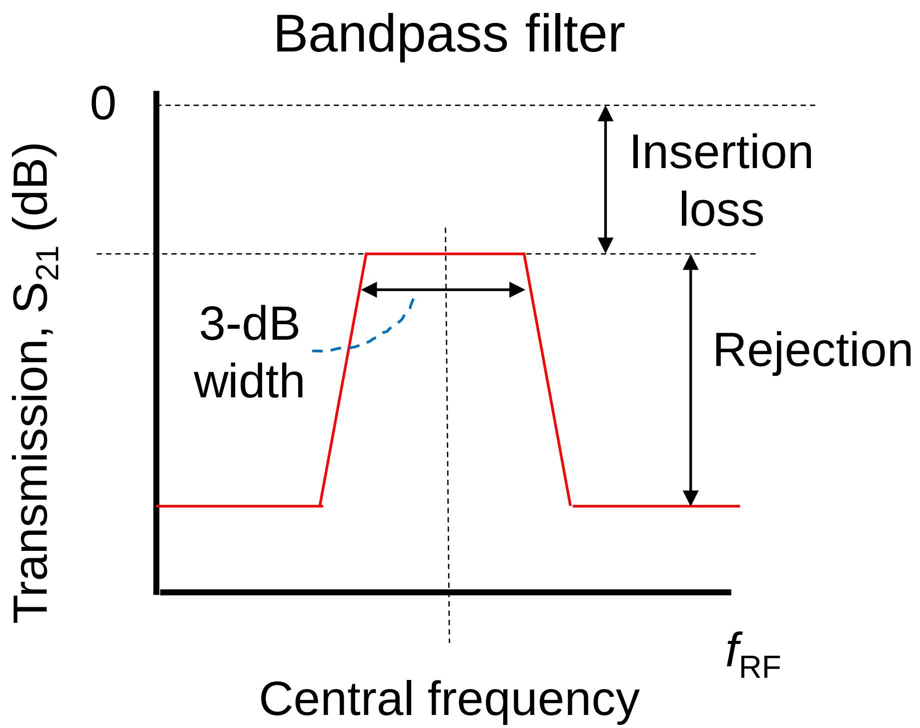
Strong interferers saturate receiver
(should be removed)

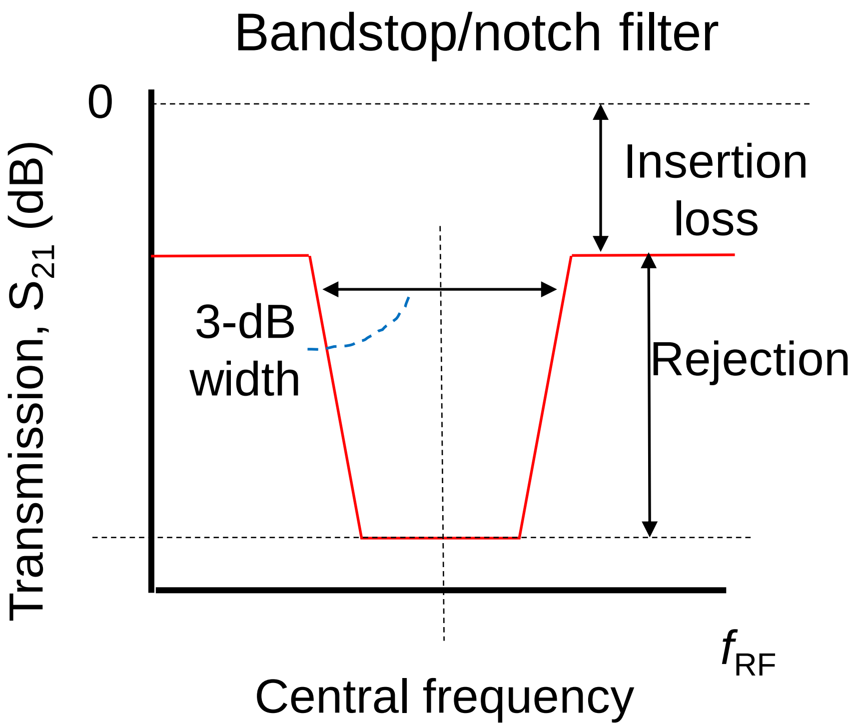


Requires: RF filters with high selectivity, widely tunable frequency, dynamically reconfigurable

Microwave photonics filter!

Filter performance





Desired:

- Low insertion loss
- Large rejection
- Narrow/wide/tunable bandwdith
- Tunable central frequency
- Low (near 1) shape factor → (30-dB BW)/(3-dB BW)

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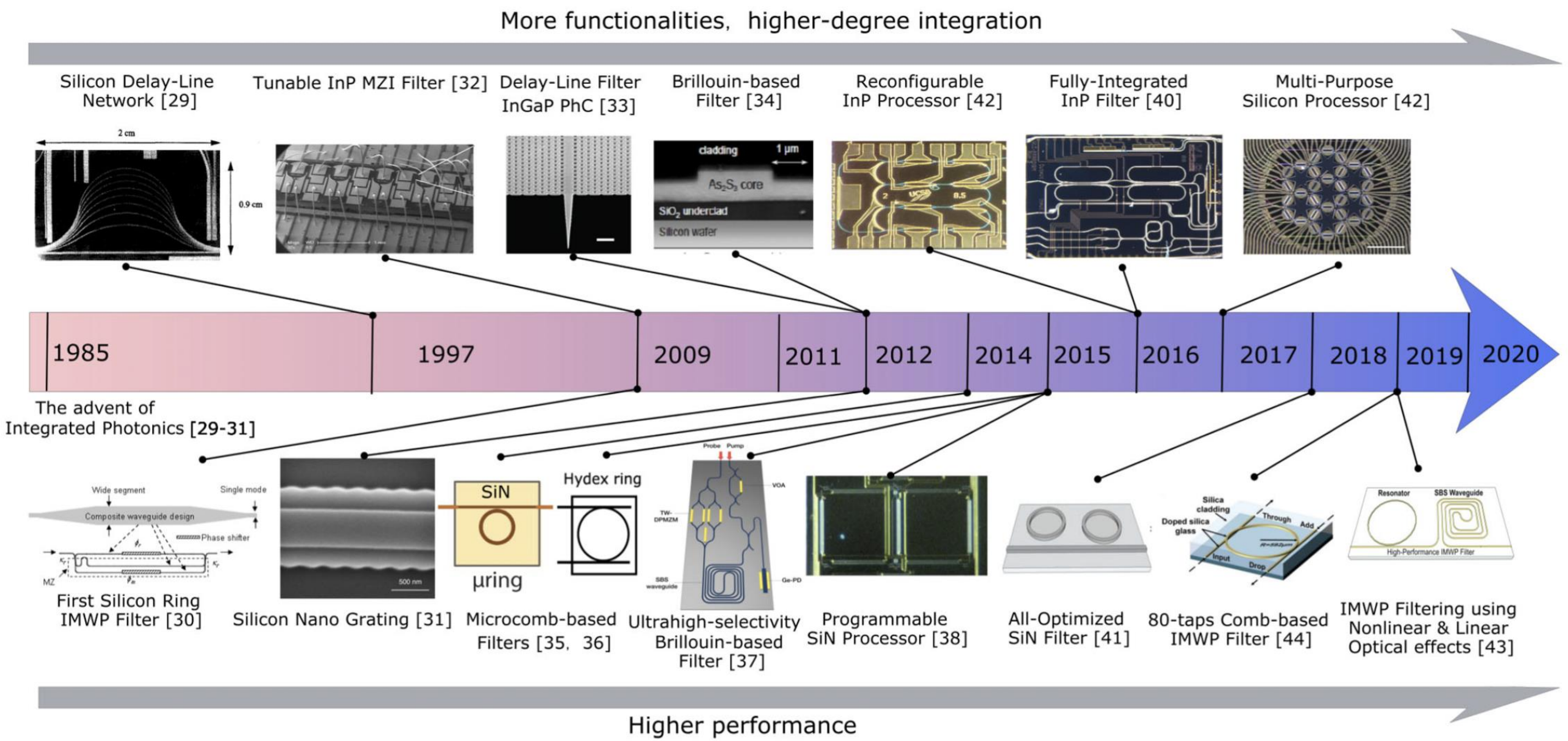
Advances in Optics and Photonics

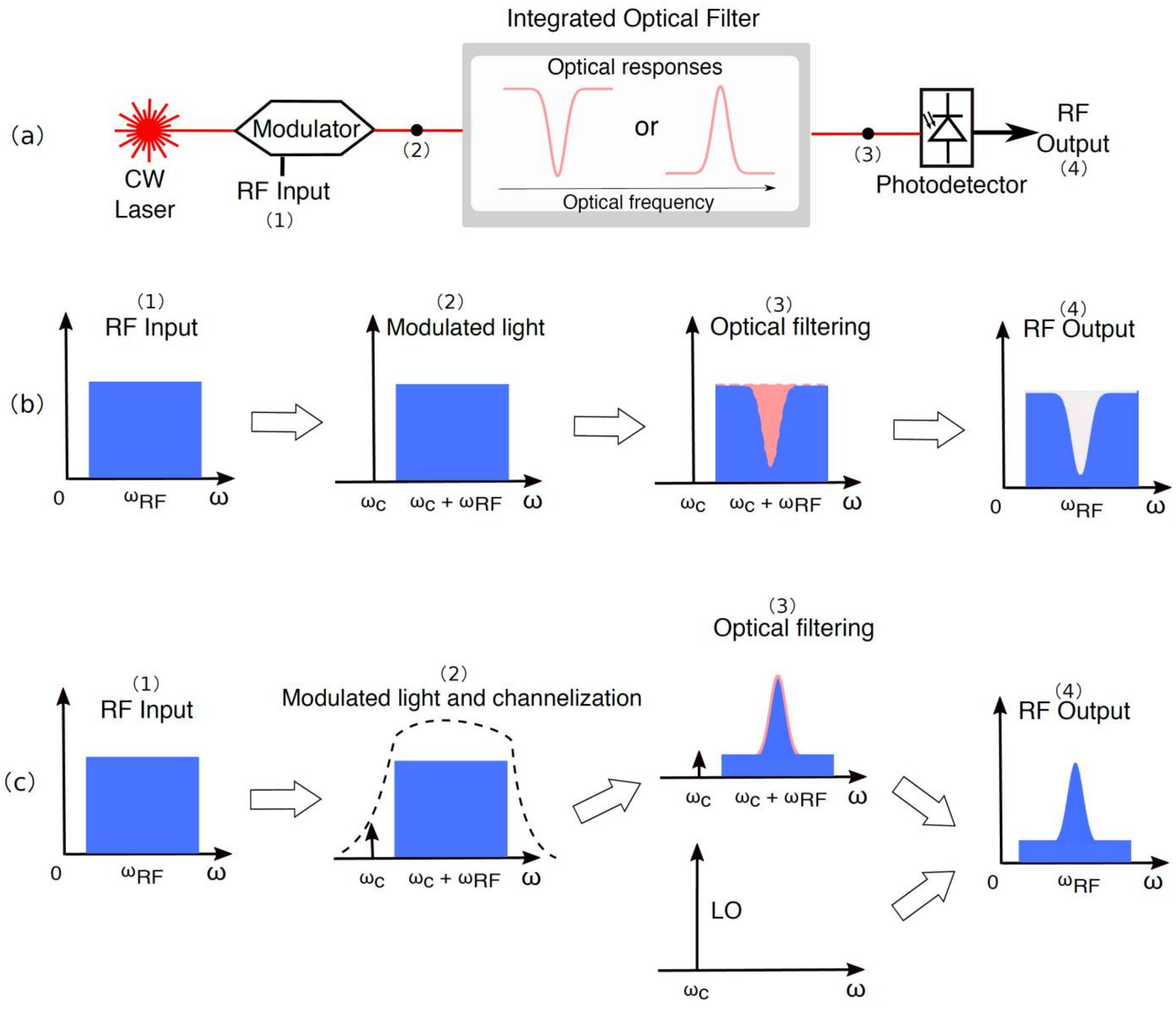
Integrated microwave photonic filters

Yang Liu,[1,2,5] Amol Choudhary,[3] David Marpaung,[4] and Benjamin J. Eggleton[1,2,6]

Figure 2



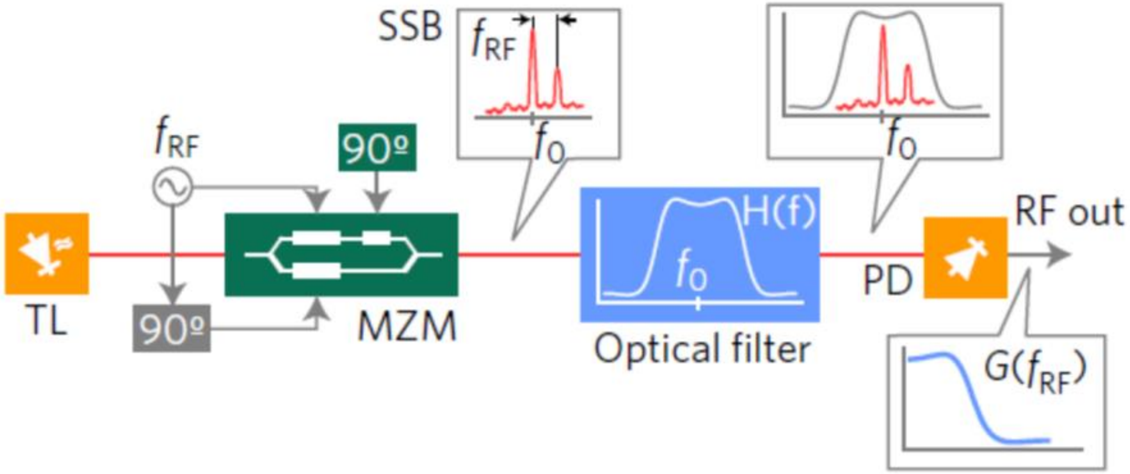
Optical filter-based MWP filter

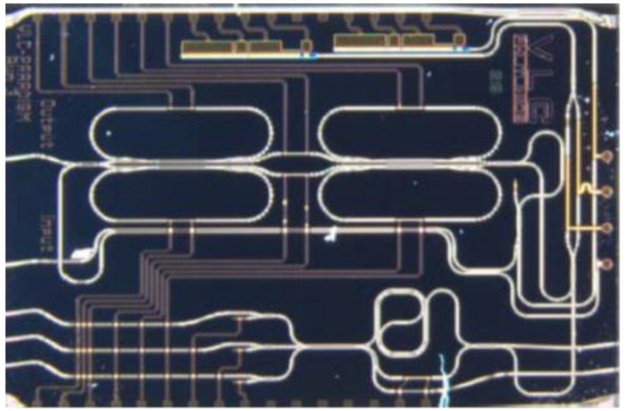


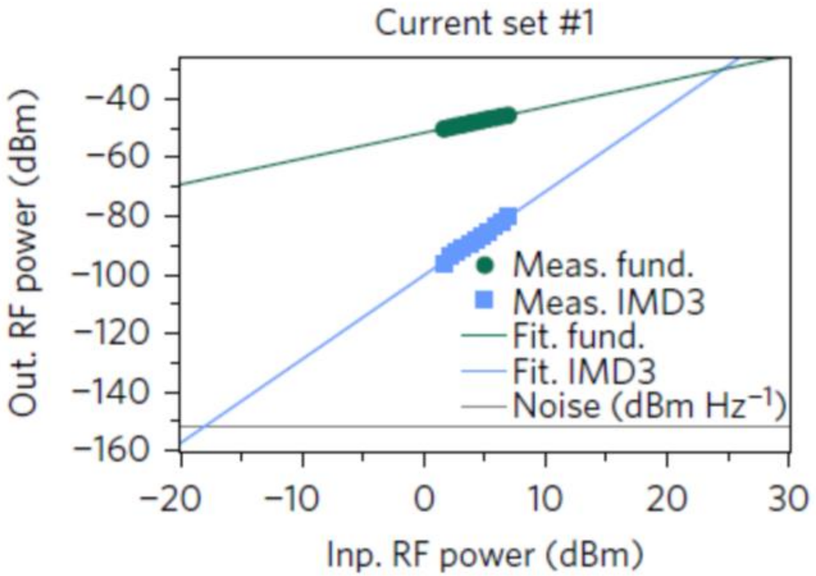
ARTICLES
PUBLISHED ONLINE: 5 DECEMBER 2016 | DOI: 10.1038/NPHOTON.2016.233
nature photonics

A monolithic integrated photonic microwave filter

Javier S. Fandiño[1], Pascual Muñoz[1,2], David Doménech[2] and José Capmany[1]*

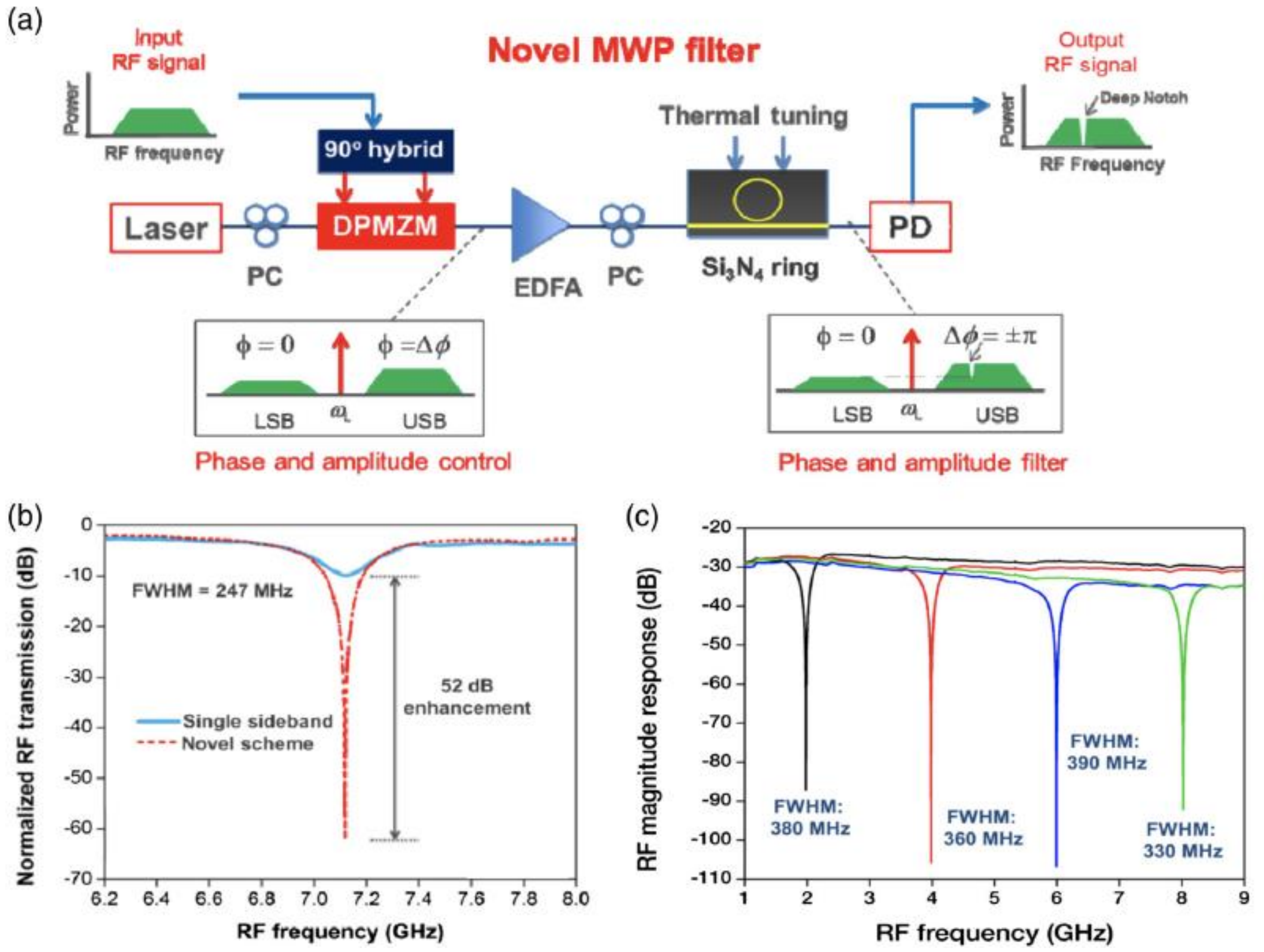






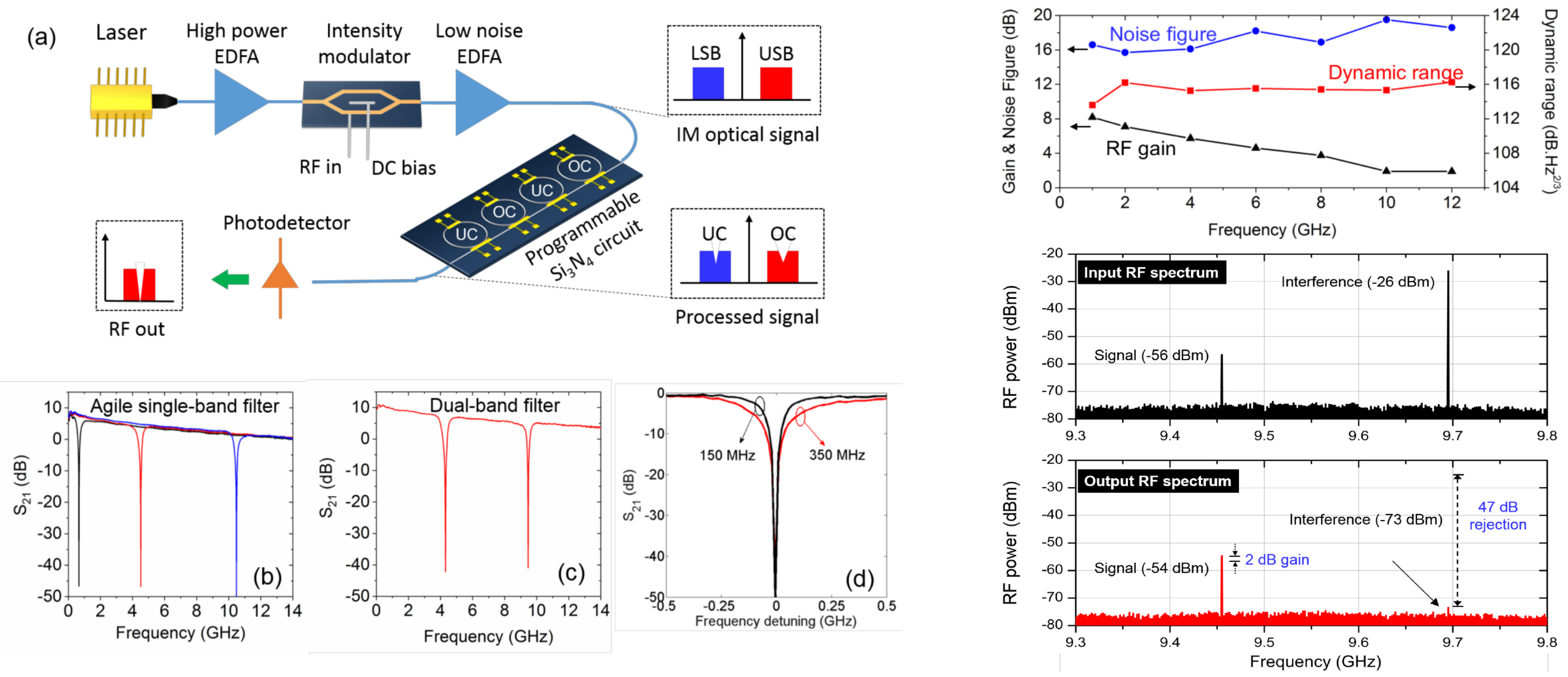
- Platform: indium phosphide
- 100% integration (laser, modulator, rings, PD)
- But relatively low performance

Implementation: ring resonator



D. Marpaung et al.,Optics Express, *2013*

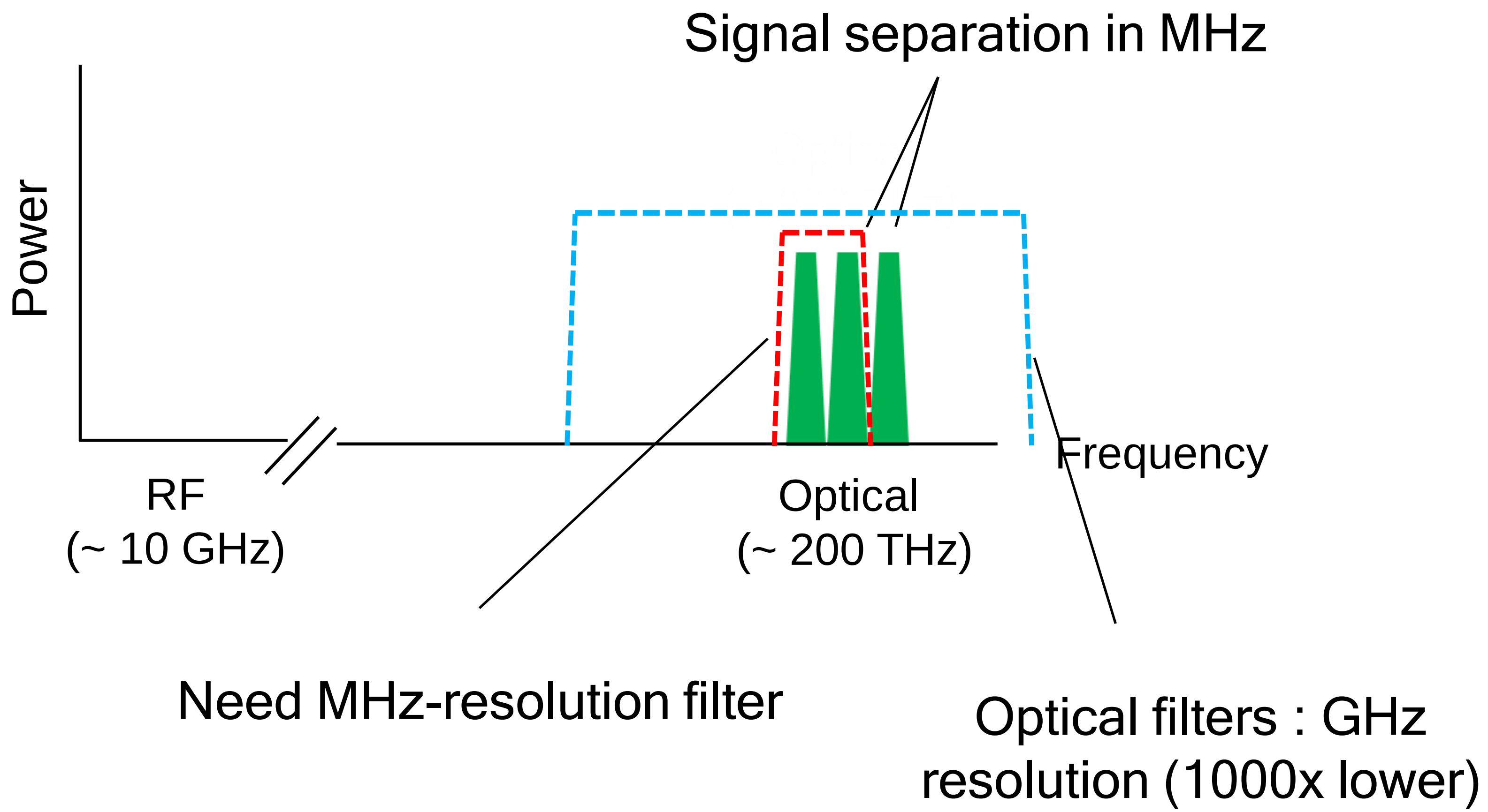
High performance notch filter



Y.Liu et al.,Optics Letters, *2017*

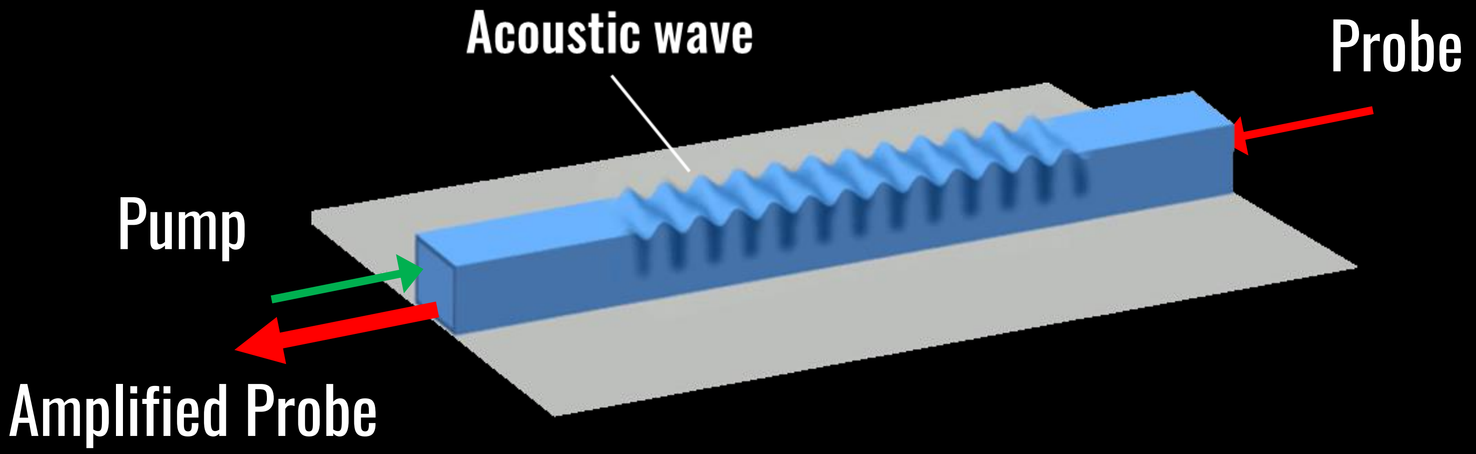
The need for higher spectral resolution

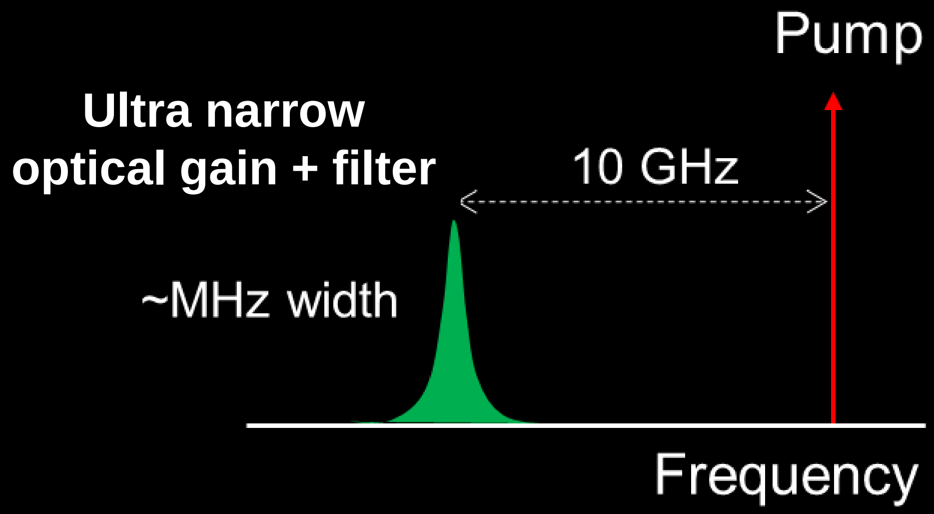
Limitation: optical filters have low resolution (GHz)



Coherent light-sound interactions

Stimulated Brillouin scattering (SBS)

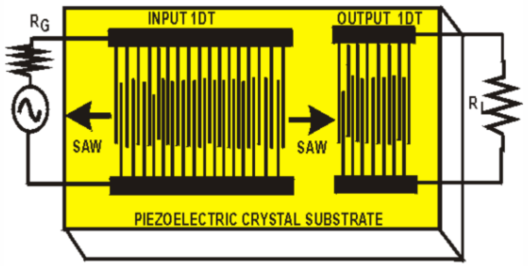




- Highest resolution optical filter
- 1000x higher resolution than silicon rings
- Application: RF processing and low noise laser

Application: information processing

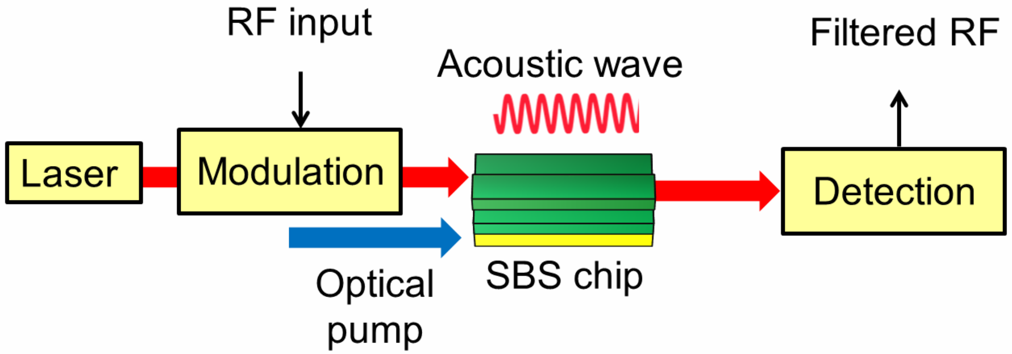
SAW filters



RF → acoustic waves
via transducer (IDT)

✓ Compact
✓ High resolution
× Low frequency (1-2 GHz)
× Not tunable

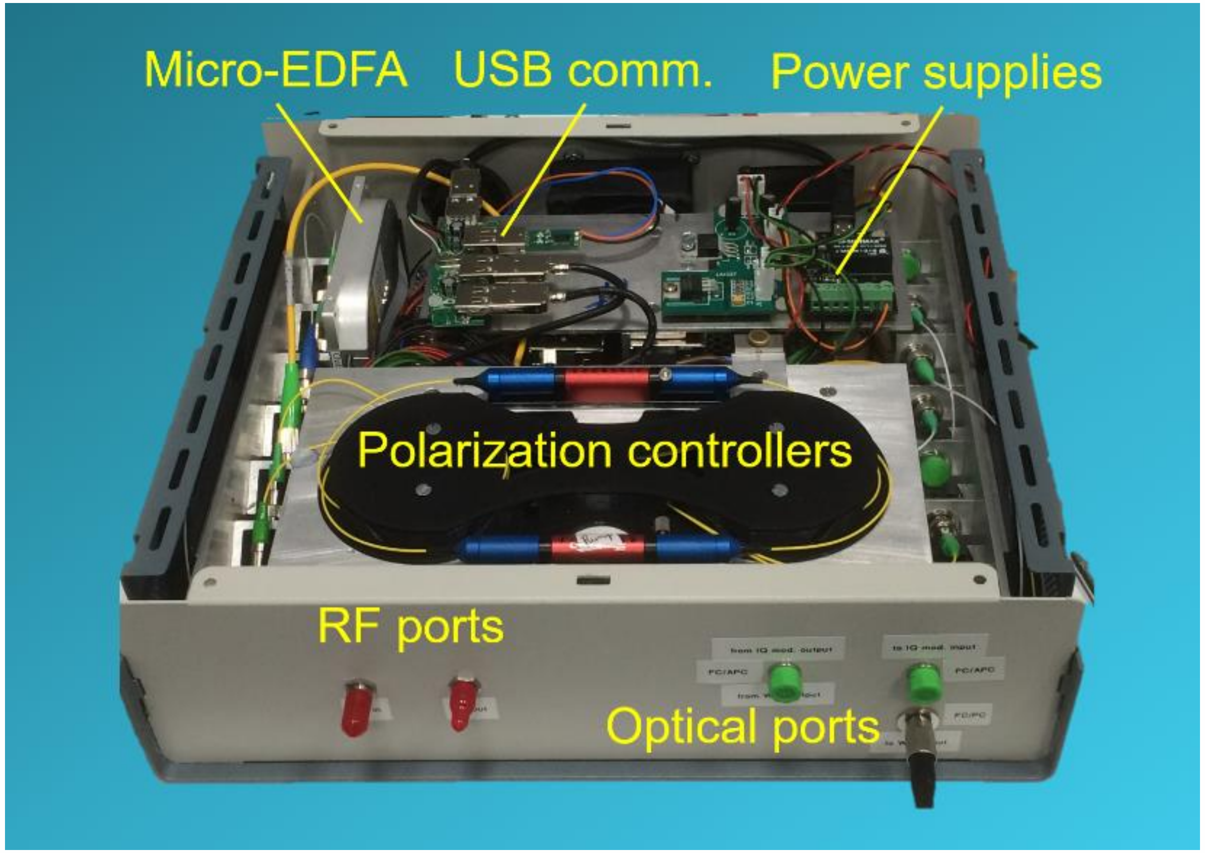
SBS RF photonic



- Optics → wide bandwidth
- Acoustic → high resolution

✓ High resolution (MHz)
✓ High extinction (60 dB)
✓ Tunable (~100 GHz)
✓ Integrated on chip
✓ Programmable device

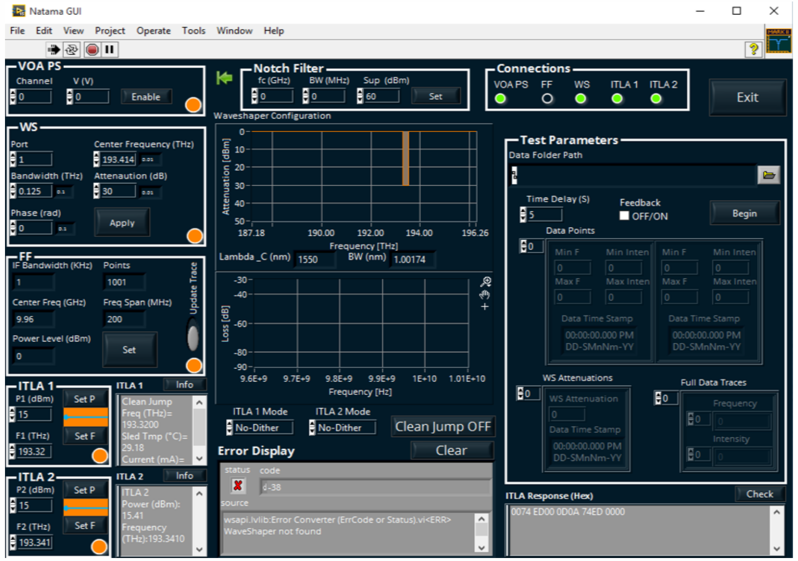
Filter prototype



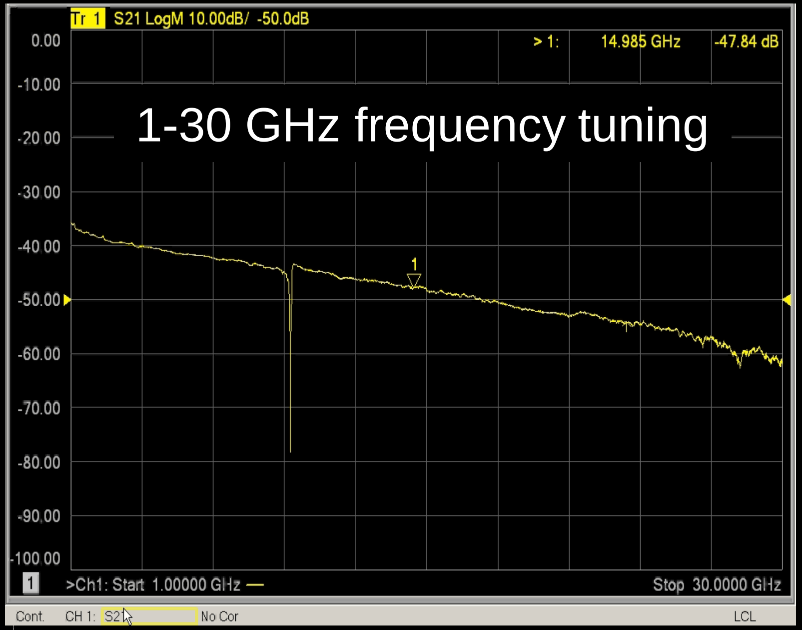
Dimension of 28cm x 30cm x 10cm.

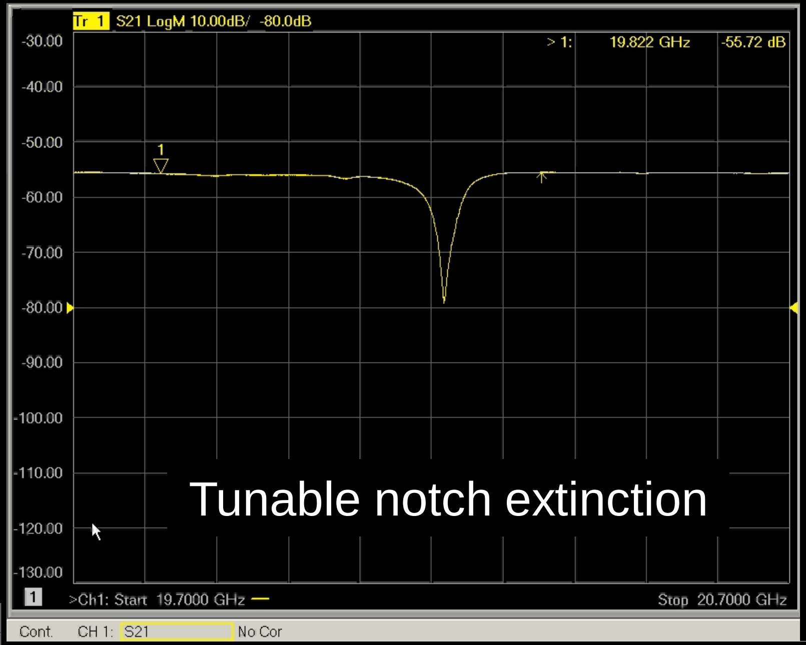
US Air Force Lab
US Army Lab
AOARD

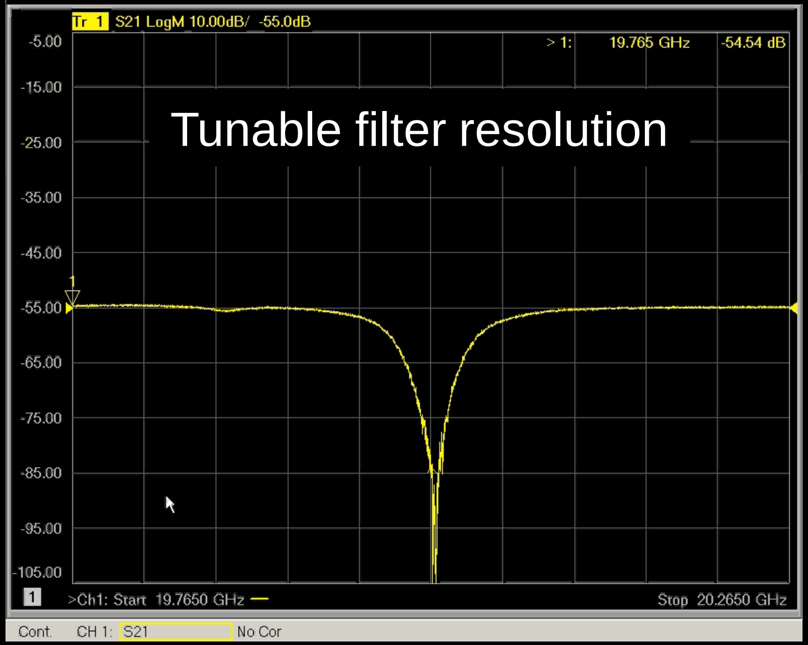
Software user interface

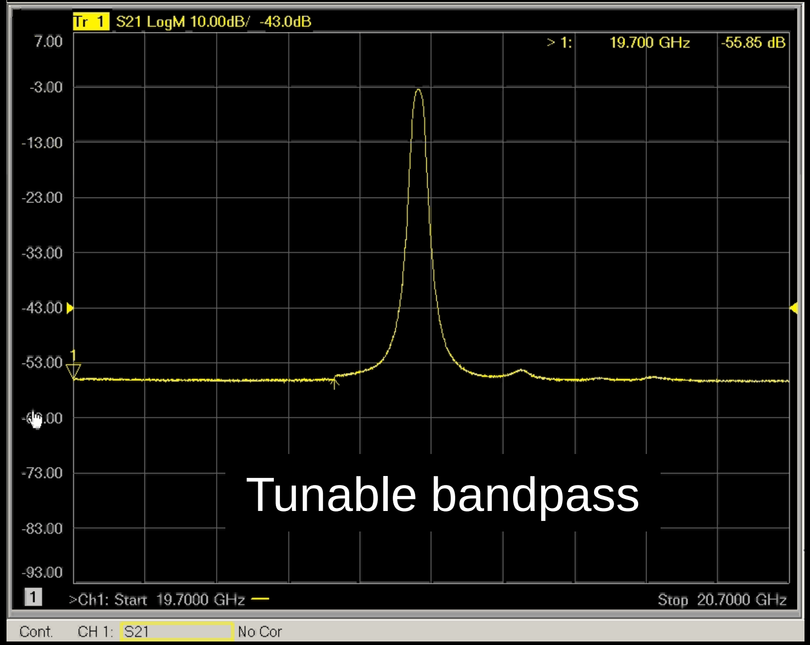


Prototype capabilities

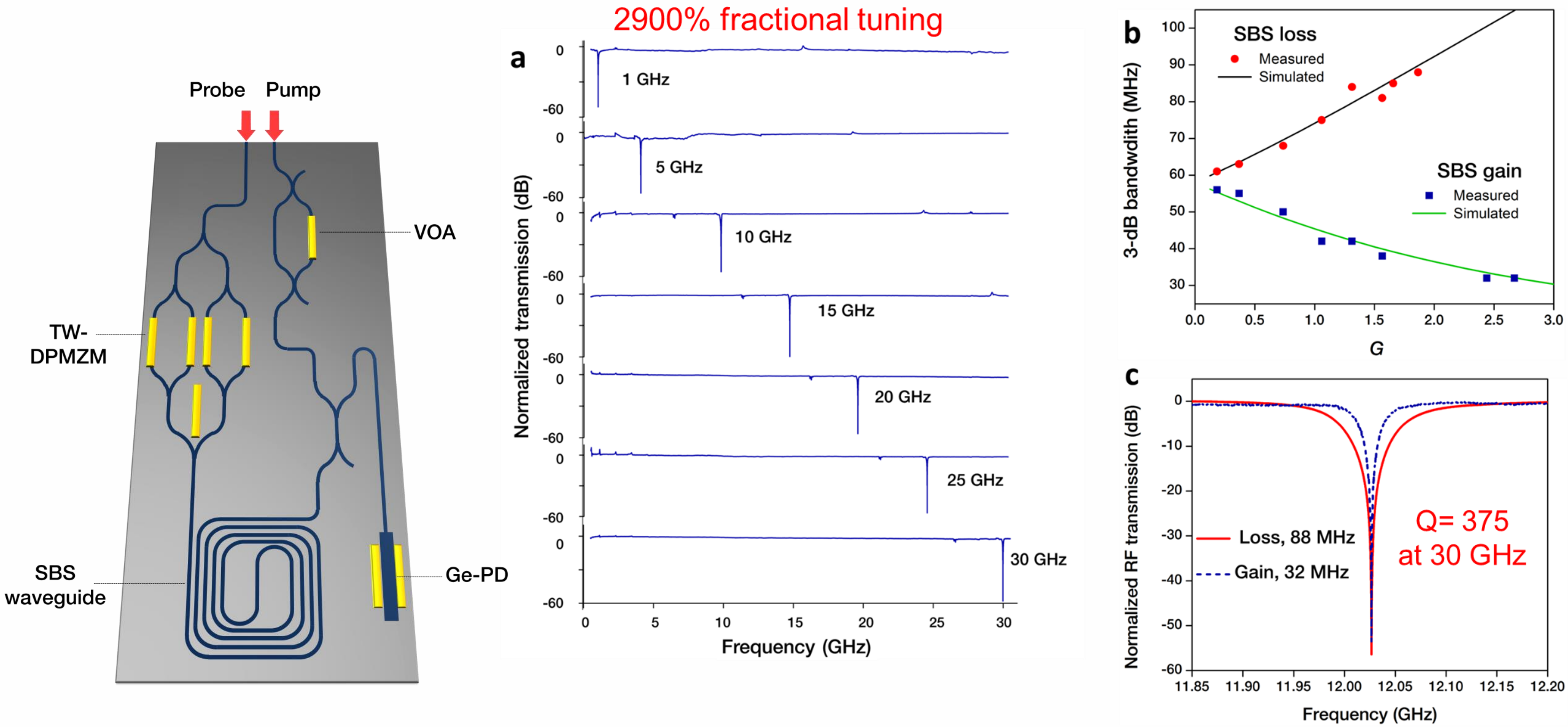








Chip-scale SBS filter



D. Marpaung et al., *Optica*, **2**, 76-83 (2015)

Summary

- Integrated MWP filter is a promising technology
- Brillouin scattering for high(est) resolution signal processing
- Next step in integrated MWP: on-chip functionalities + RF performance

Nonlinear Nanophotonics group

- Established in 2018
- Now: 1 senior researcher, 1 postdoc, 5 PhD students, 8 MSc and BSc students