

# Bragg-Reflection Waveguides

## Towards an all On-chip Photon Pair Source

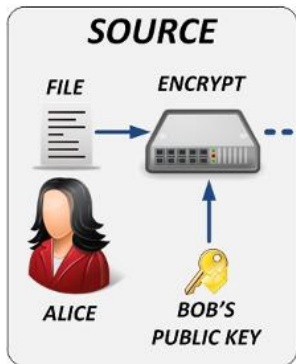


Alexander Schlager

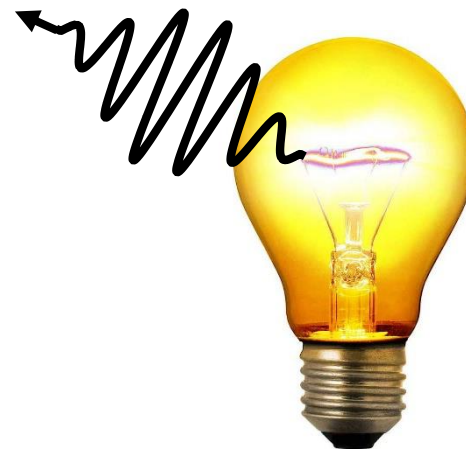
Photonics Group, Department of Experimental Physics

Supervisors: Gregor Weihs, Gerhard Kirchmair

# Secure Communication



Can never be 100% secure



Use photons as qubits

Qubits (states) cannot be copied  
Measurements destroy qubits (states)

# Parametric Down-Conversion (PDC)

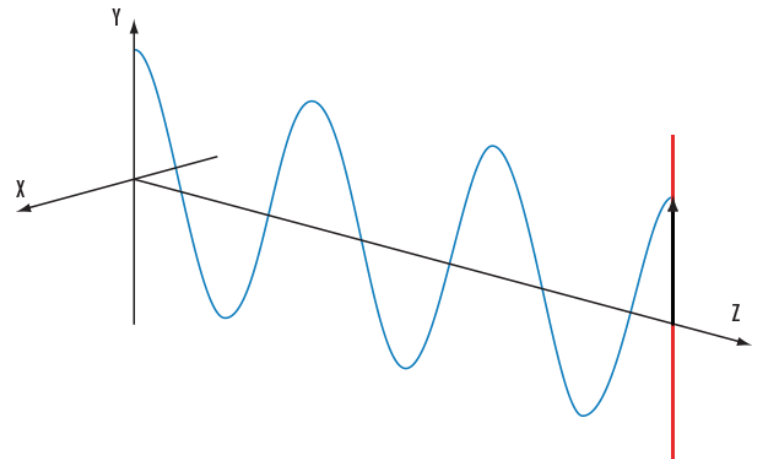


Polarization:

Type 0:  $V \rightarrow V + V$

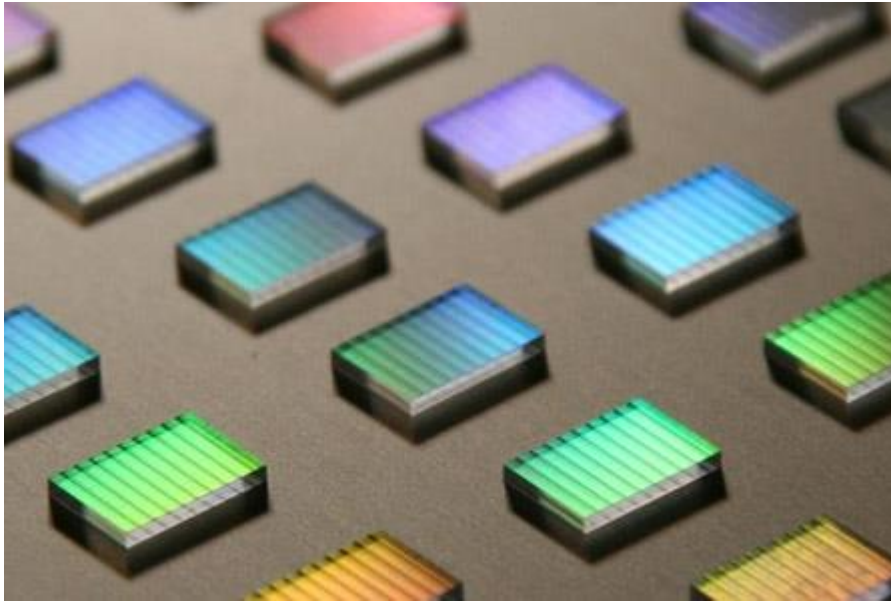
Type 1:  $V \rightarrow H + H$

Type 2:  $H \rightarrow H + V$



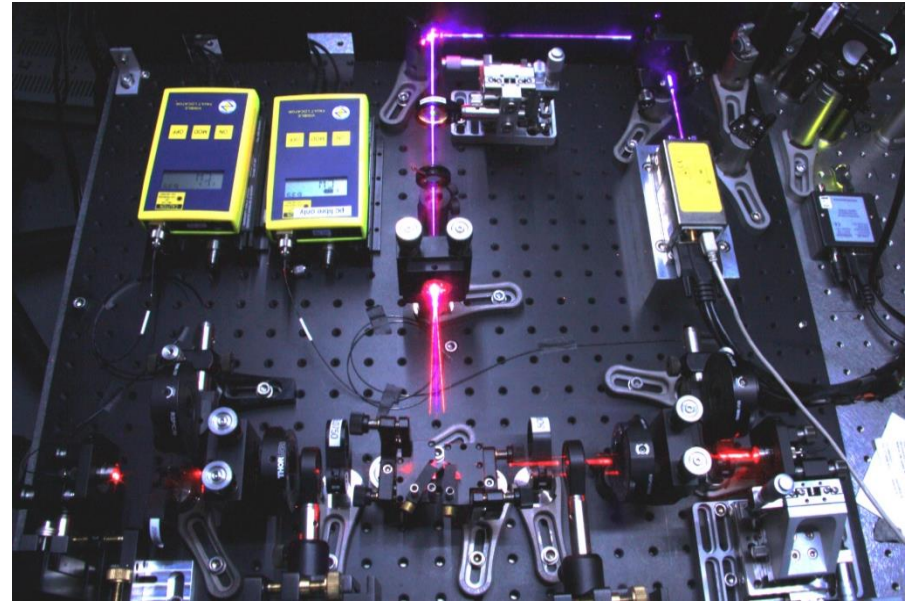
# Single Photon Source

Nonlinear Crystals



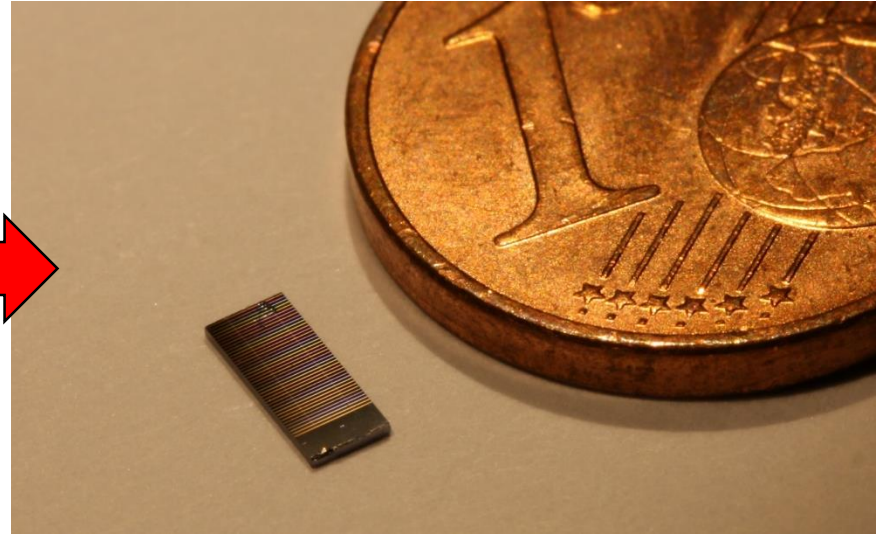
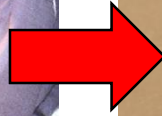
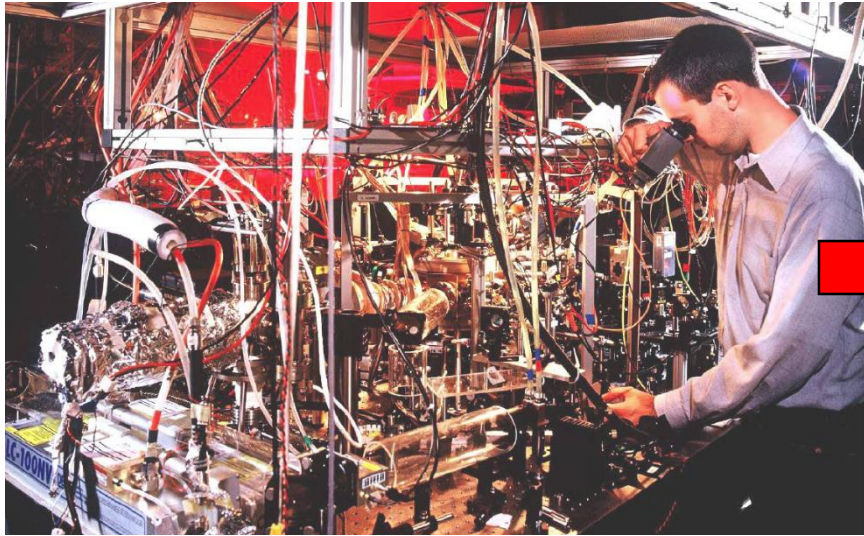
covesion.com

Lab course for students

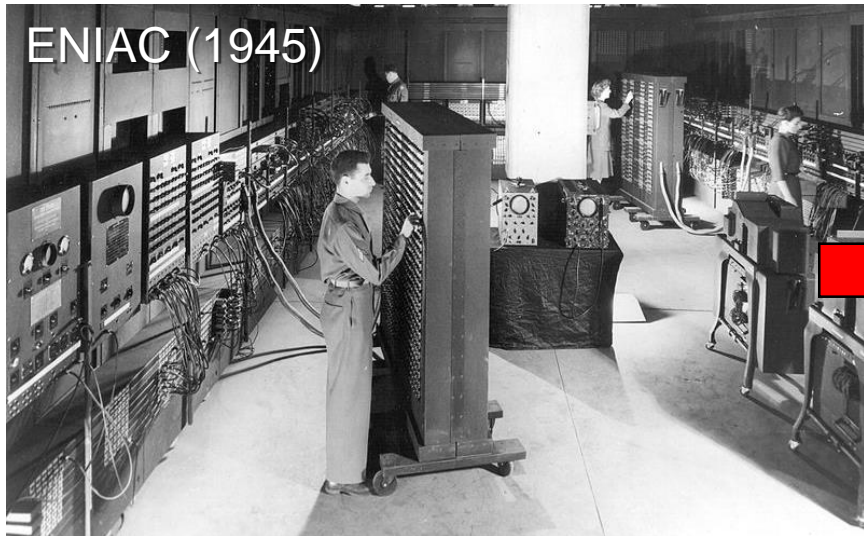




# Towards On-chip Quantum Labs



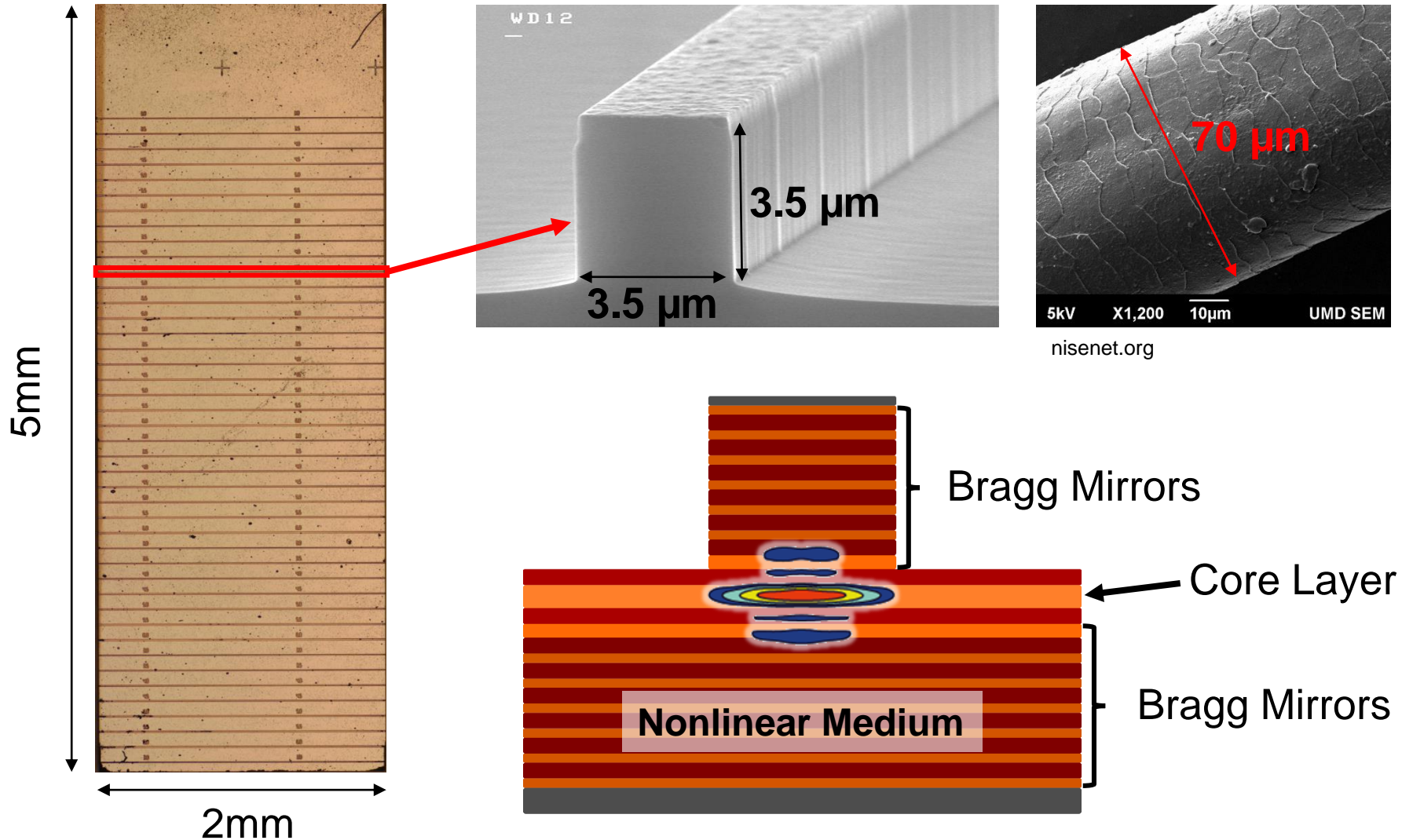
H.-C. Nägerl & C. Roos, Cooling & Trapping lecture notes



ENIAC (1945)

Michigan Micro Mote (2018)

# Bragg-Reflection Waveguides<sup>1,2</sup>

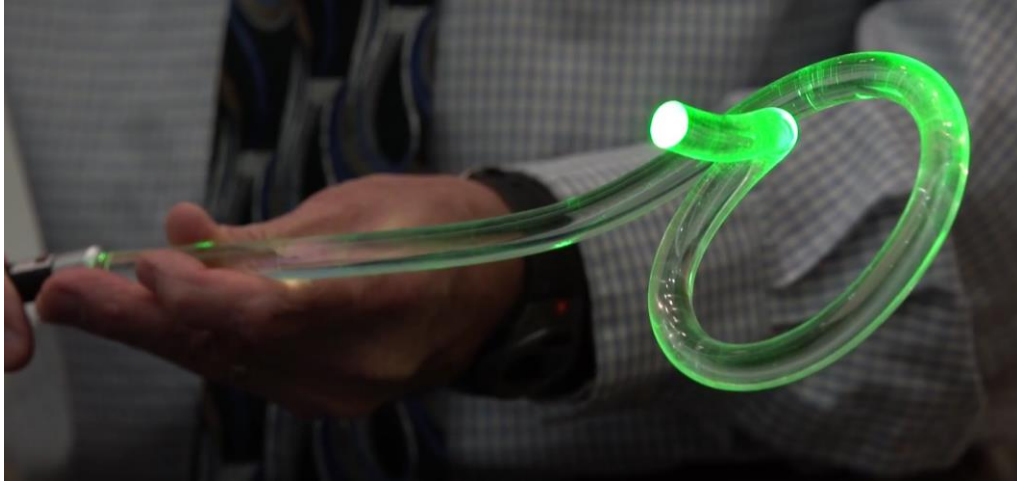


<sup>1</sup>B. Pressl, K. Laiho, H. Chen, T. Günthner, A. Schlager et al., *Quantum Sci. Technol.* **3** (2018)

<sup>2</sup>H. Chen, K. Laiho, B. Pressl, A. Schlager et al., *J. Opt.* **21** (2019)

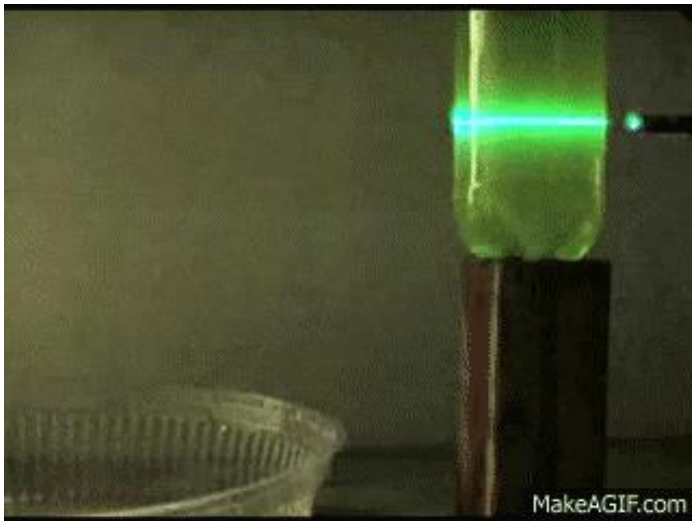
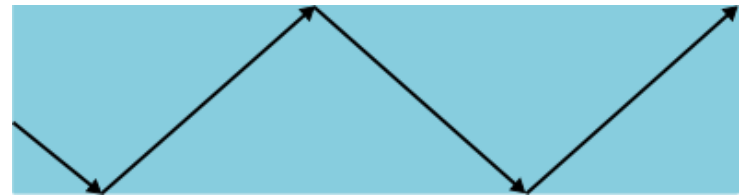


# What is a Waveguide?

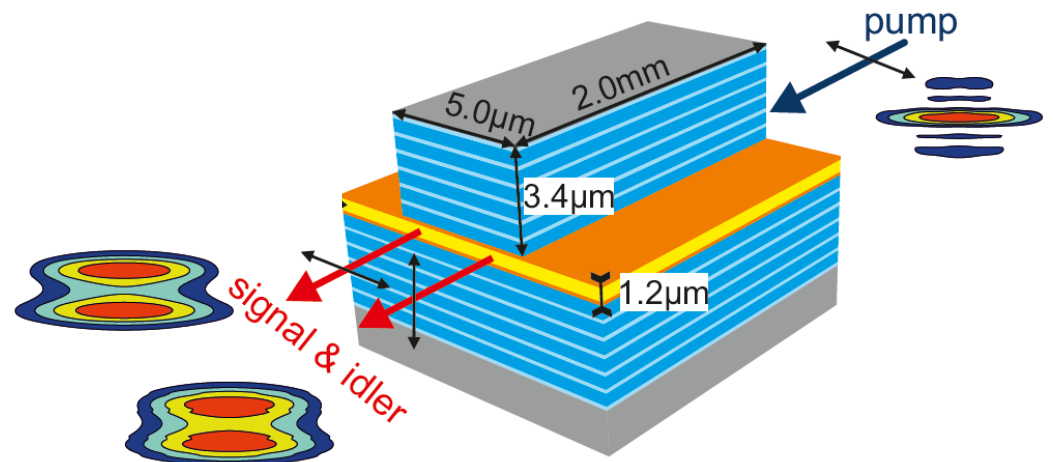


youtube.com, Physics Demos

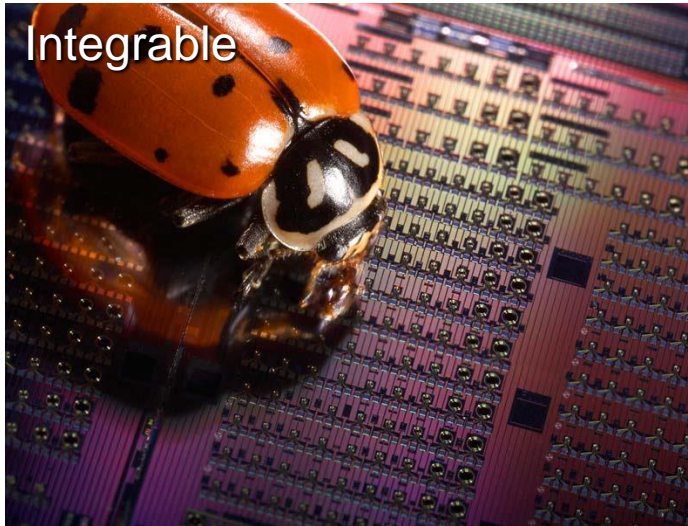
Light is guided by reflection



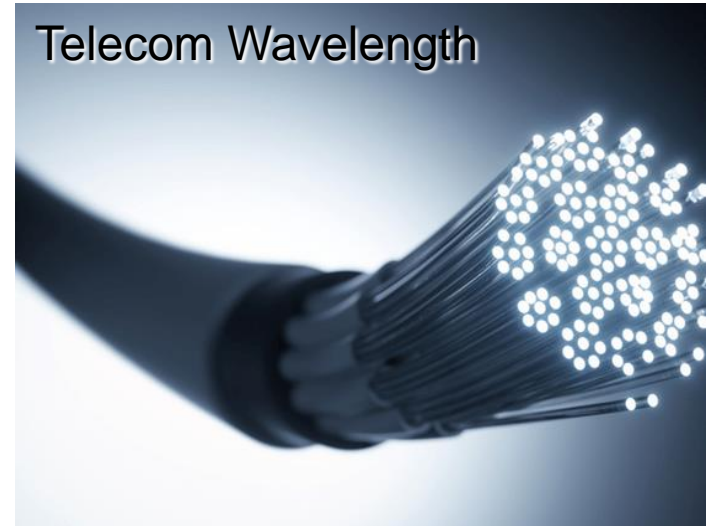
youtube.com,  
Dept of Physics & Astronomy at the University of Utah



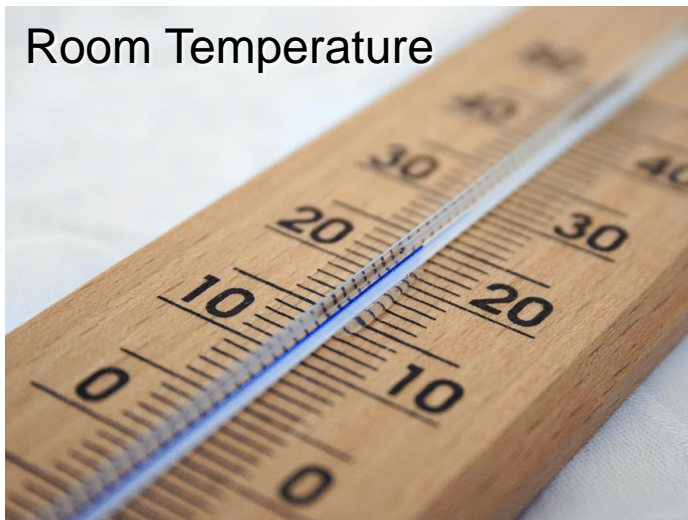
# Properties of the Device



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startech-cc.de



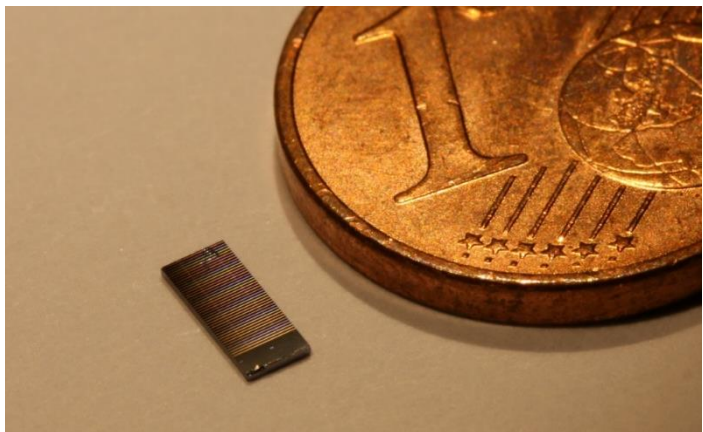
bauredakteur.de



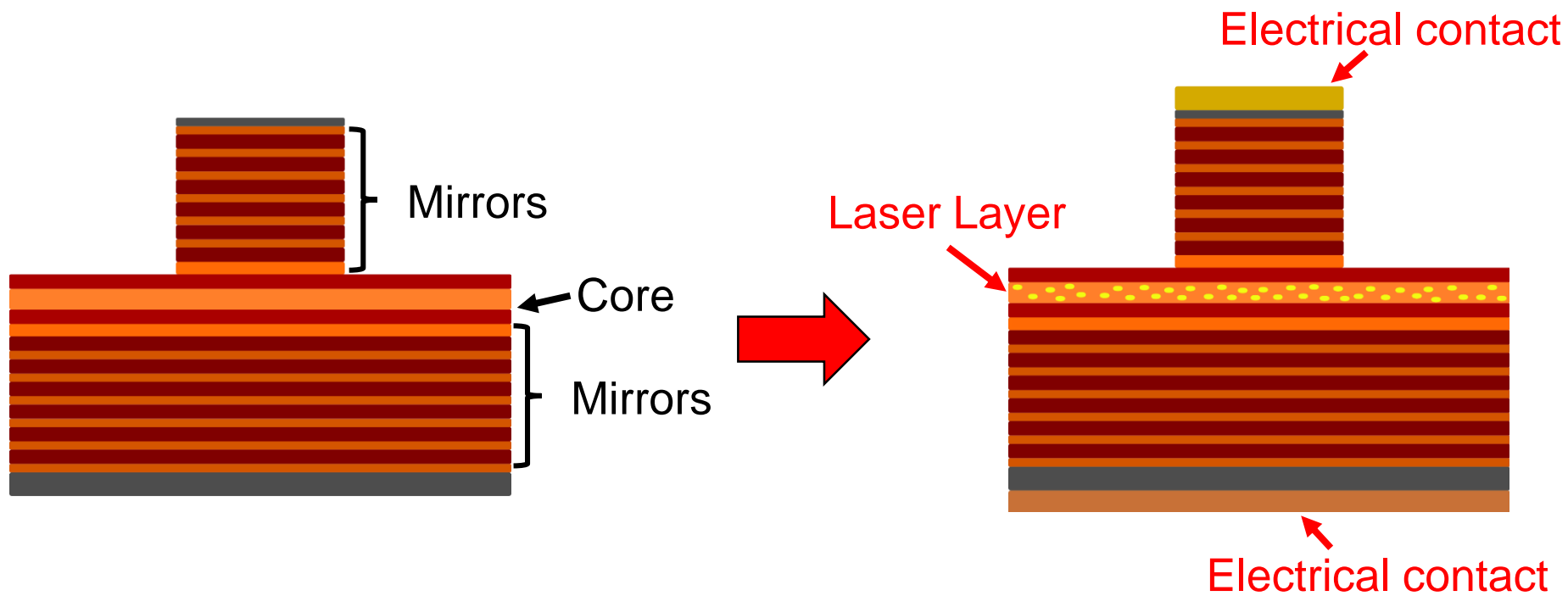
adafruit.com



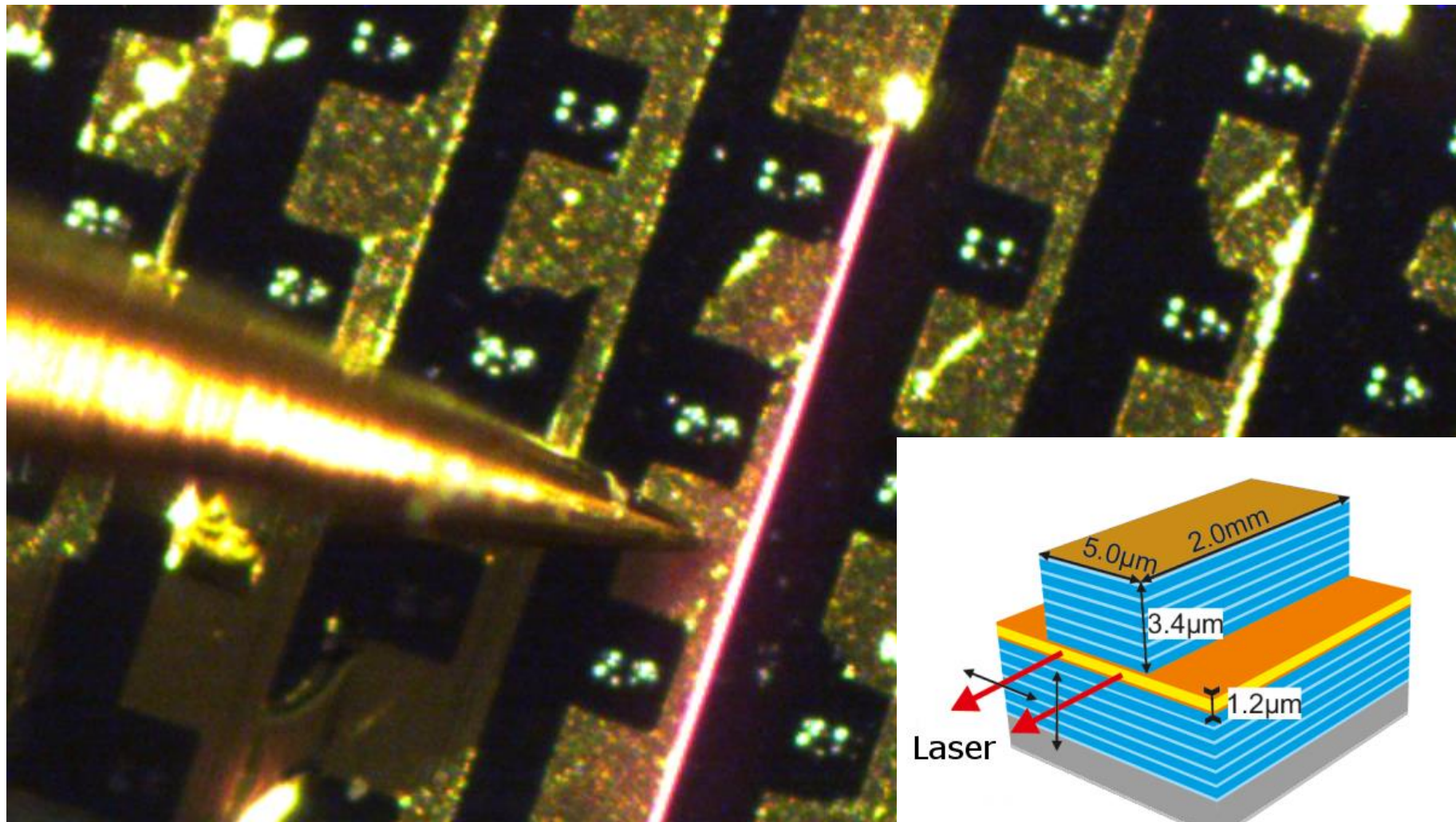
# Integration of a Laser



laserfest.org



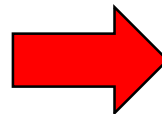
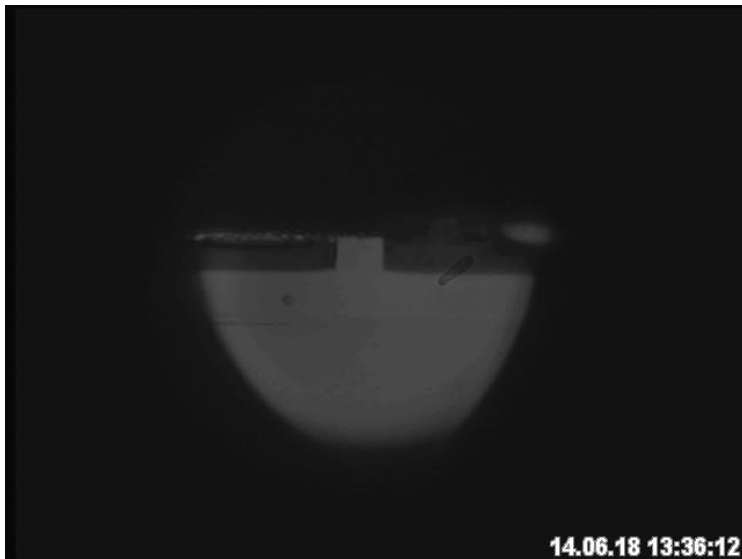
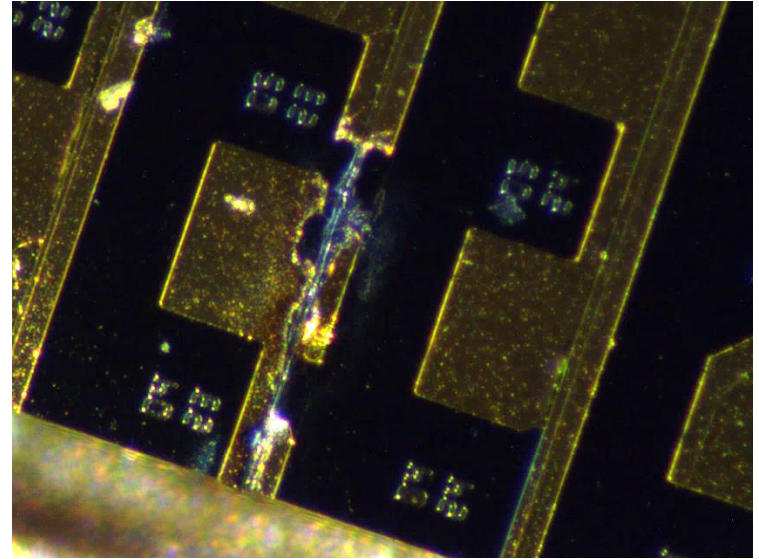
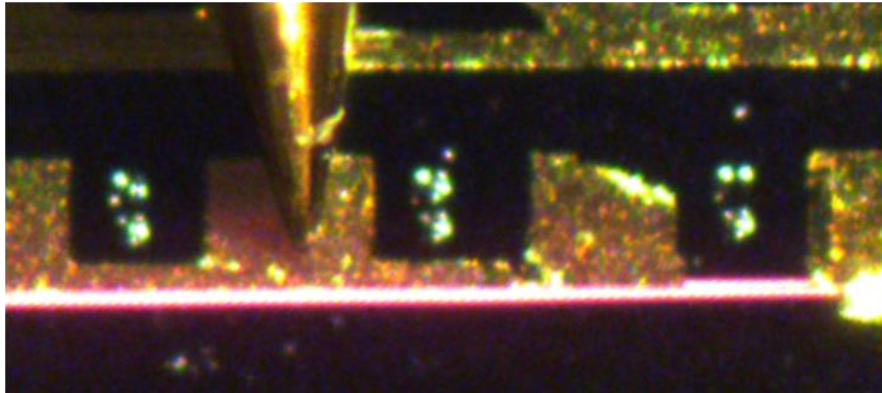
# Does the Laser work?



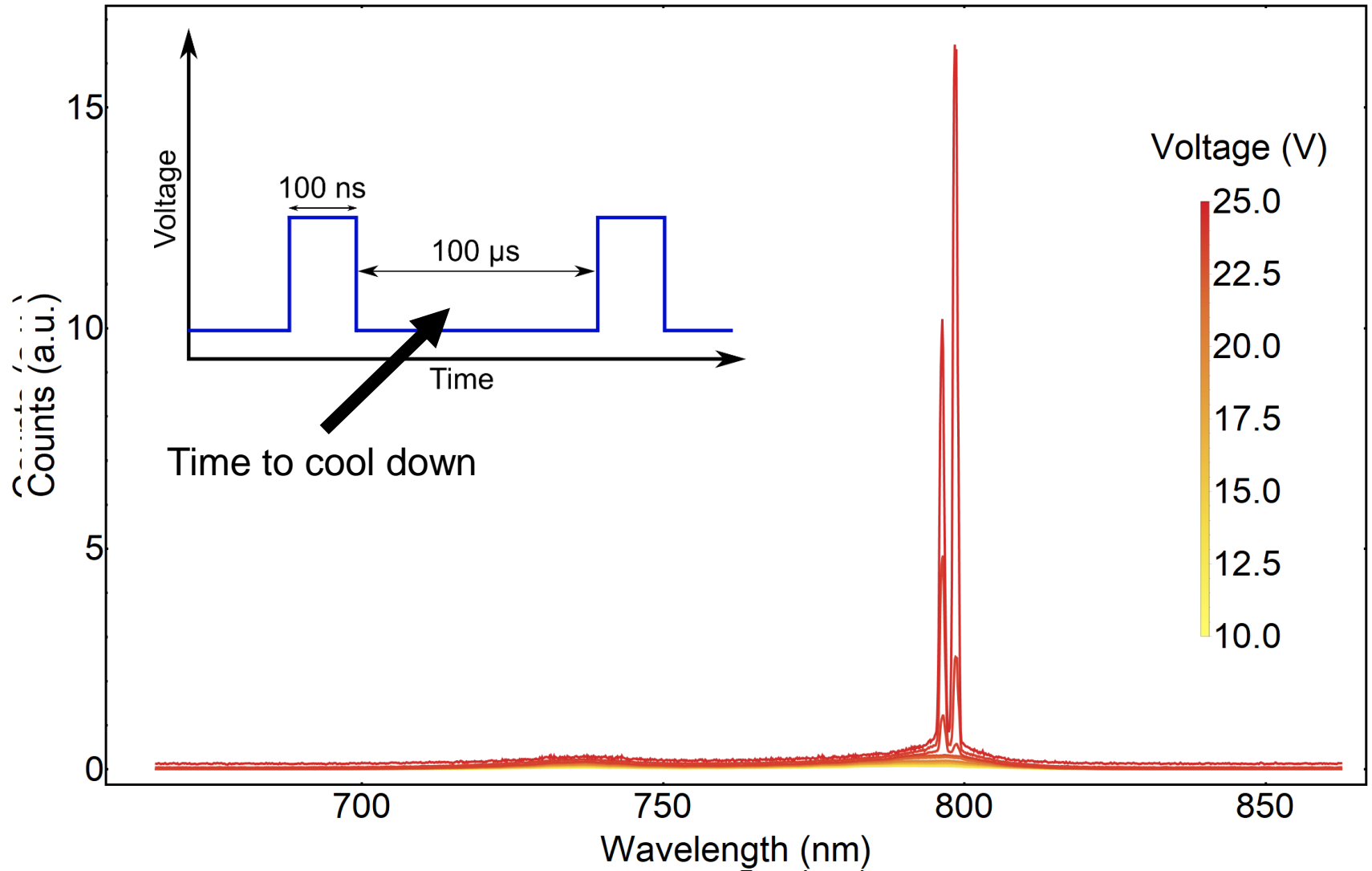




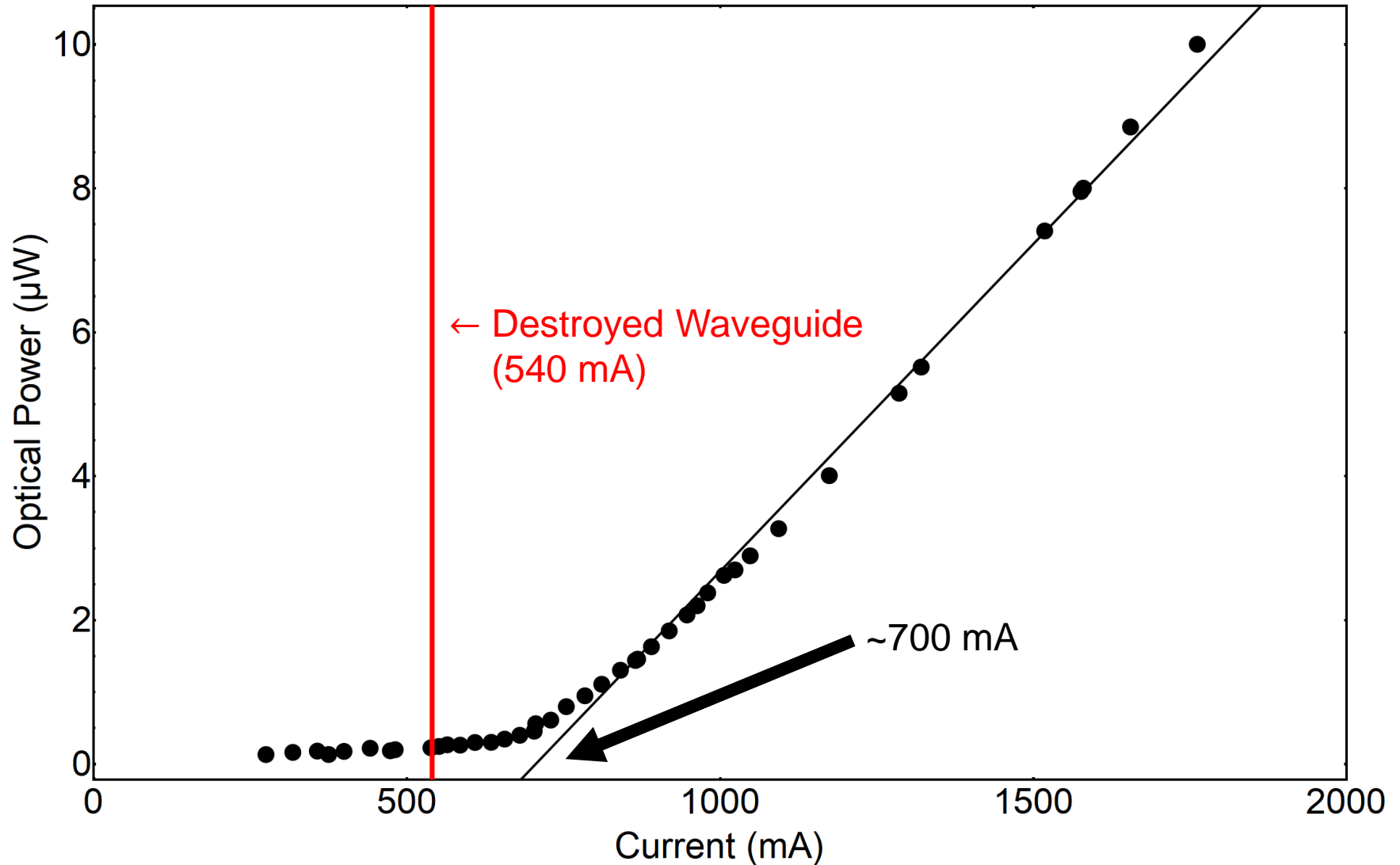
# At about 1.8 Watt of Electrical Power



# Using Electrical Pulses

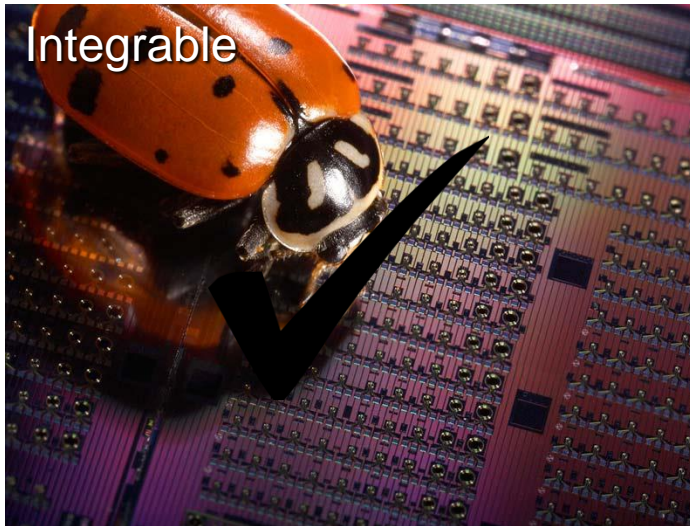


# Using Electrical Pulses

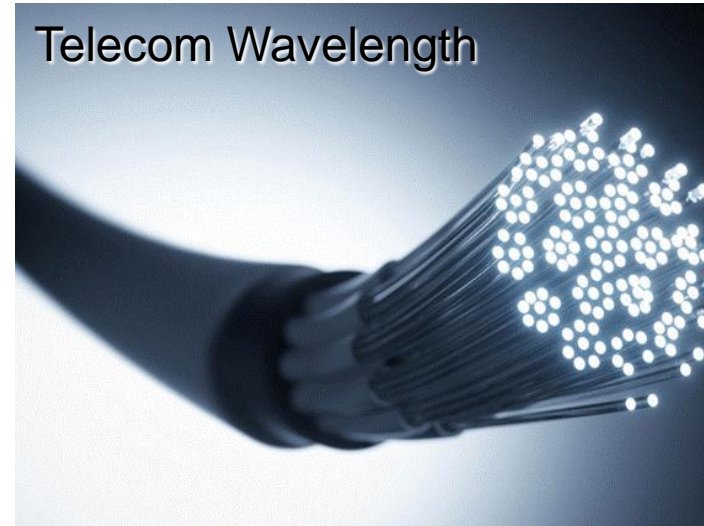




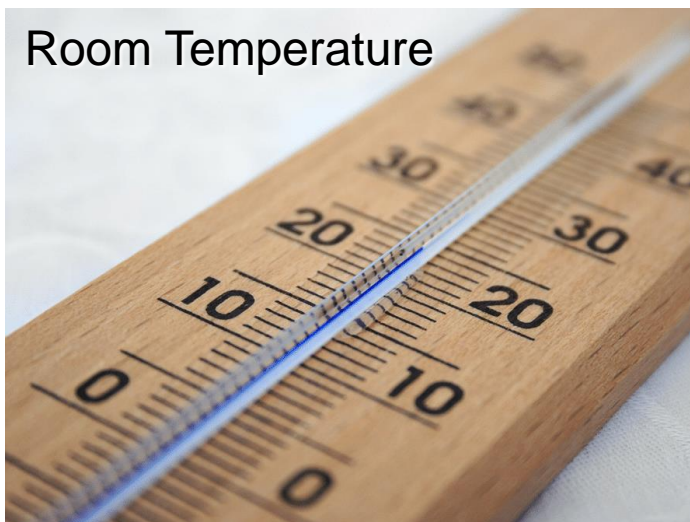
# Properties of the Device



[thefutureofthings.com](http://thefutureofthings.com)



[startech-cc.de](http://startech-cc.de)



[bauredakteur.de](http://bauredakteur.de)



[adafruit.com](http://adafruit.com)

# Parametric Down-Conversion (PDC)



Polarization:

Type 0:  $V \rightarrow V + V$

Type 1:  $V \rightarrow H + H$

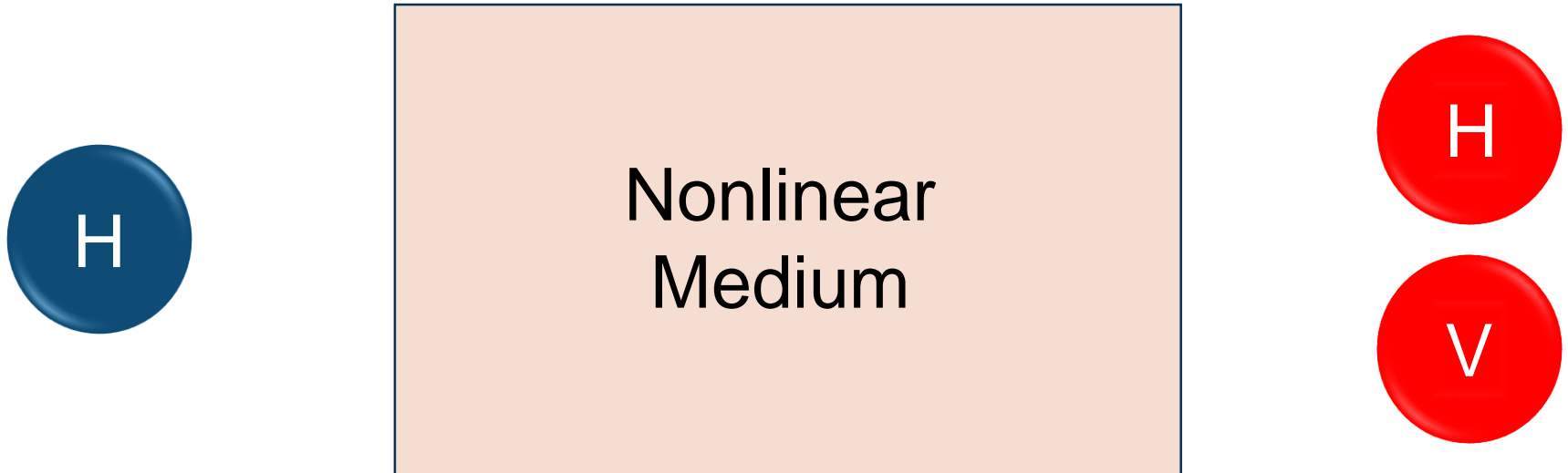
Type 2:  $H \rightarrow H + V$

Wavelengths:

$$2 \lambda_p = \lambda_{1,2}$$

Pump wavelength?

# Second Harmonic Generation (SHG)



Polarization:

Type 0:  $V + V \rightarrow V$

Type 1:  $H + H \rightarrow V$

Type 2:  $H + V \rightarrow H$

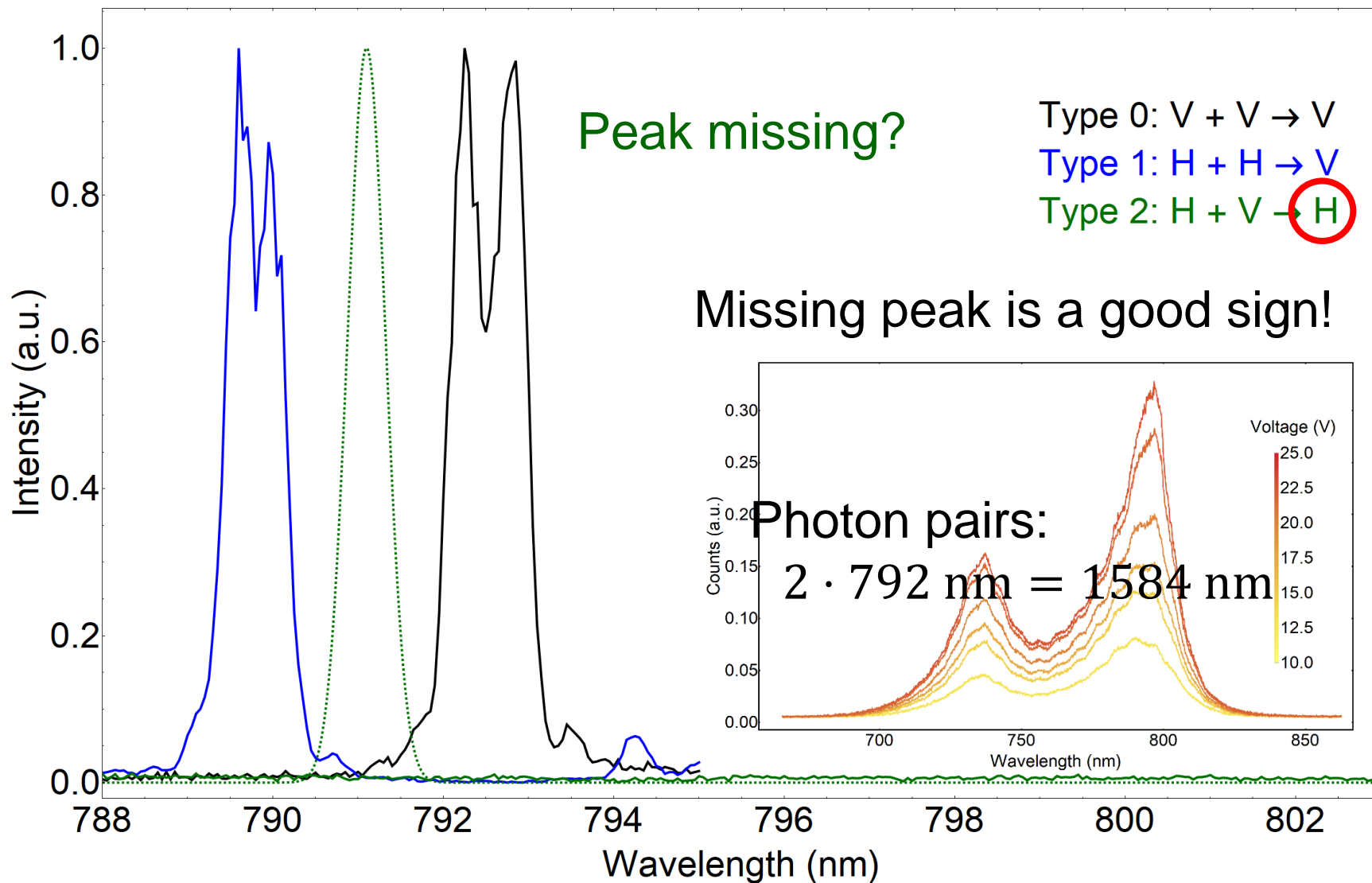
Wavelengths:

$$2 \lambda_p = \lambda_{1,2}$$

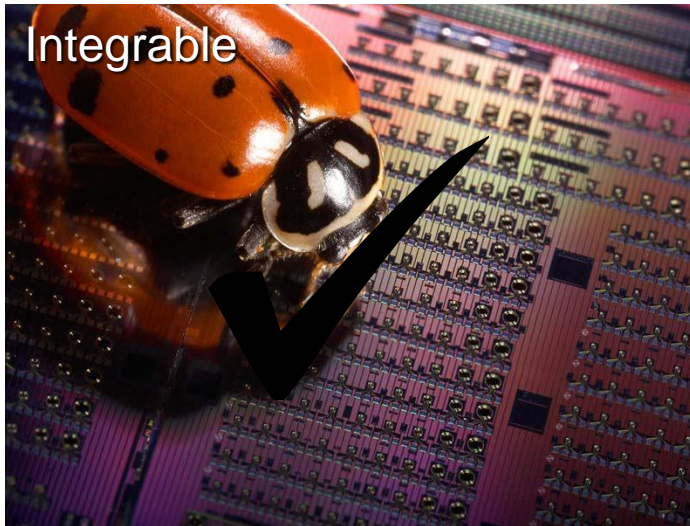
Pump wavelength?



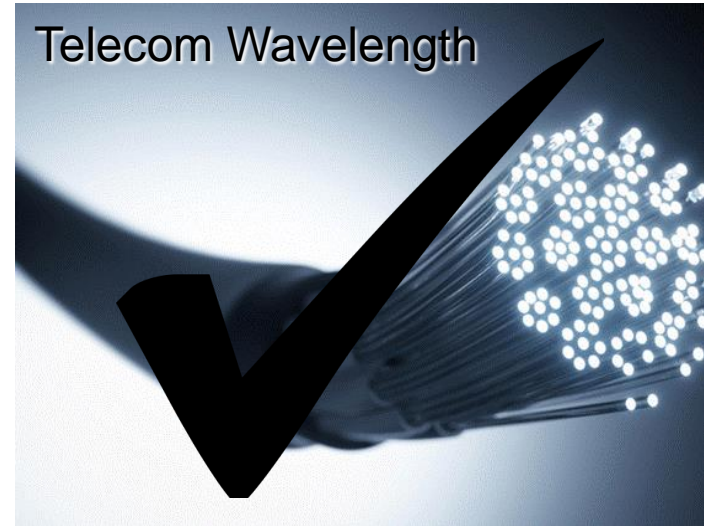
# Second Harmonic Generation (SHG)



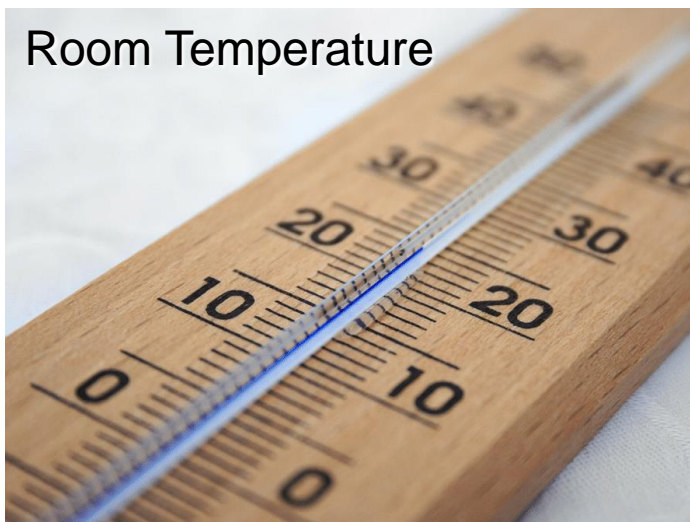
# Properties of the Device



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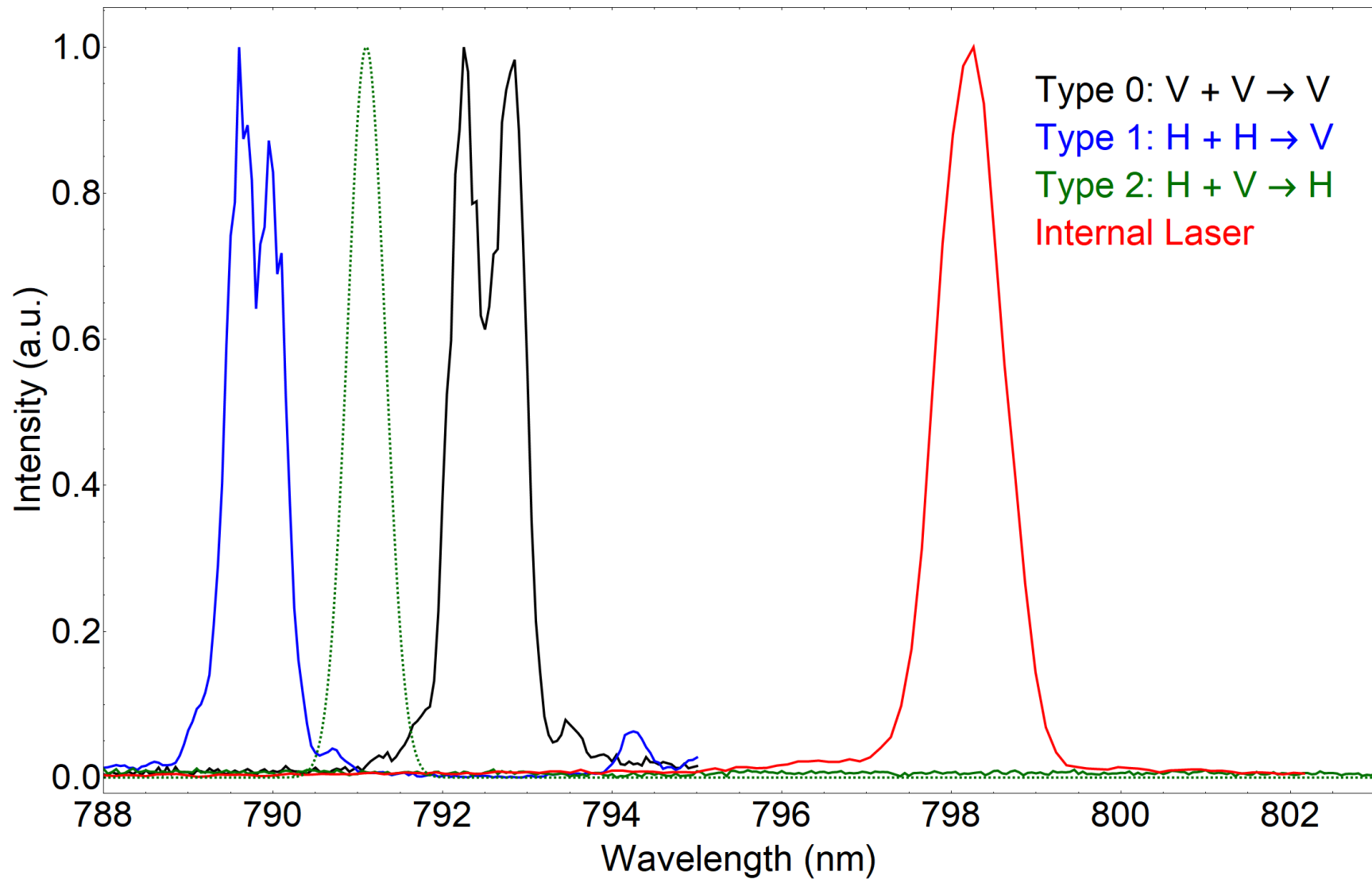


bauredakteur.de



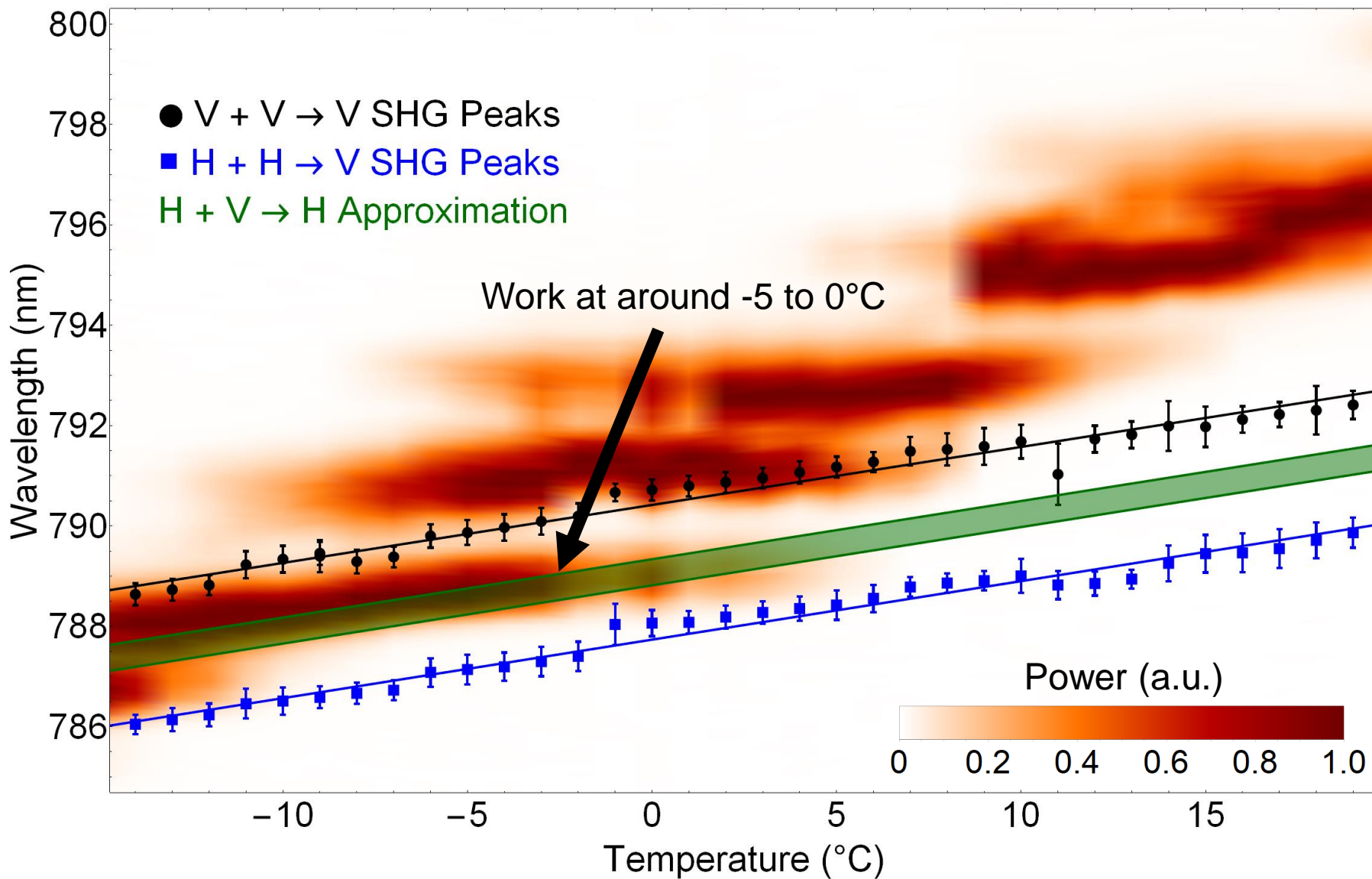
adafruit.com

# Spectra at 20°C





# Temperature Tuning

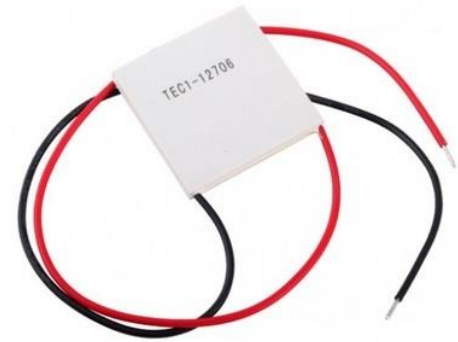


# Is that Room Temperature?



booking.com

## Peltier Element

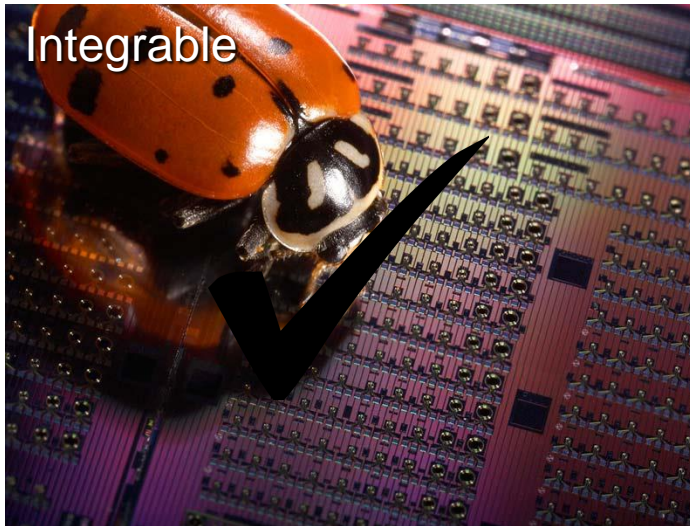


imimg.com

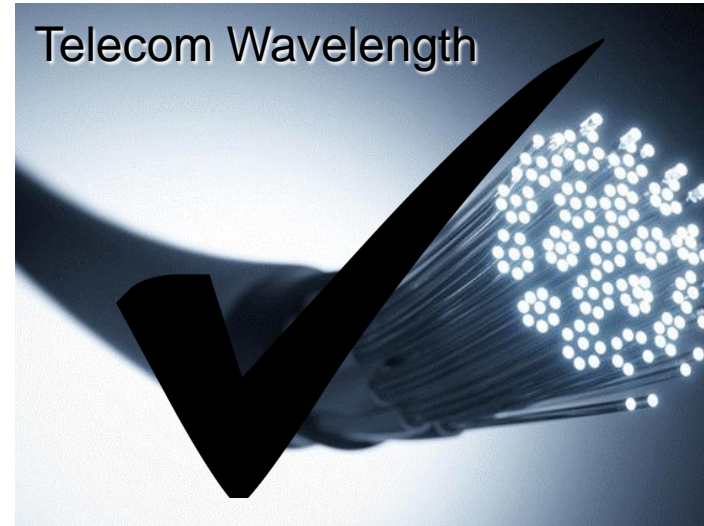


alternate.co.uk

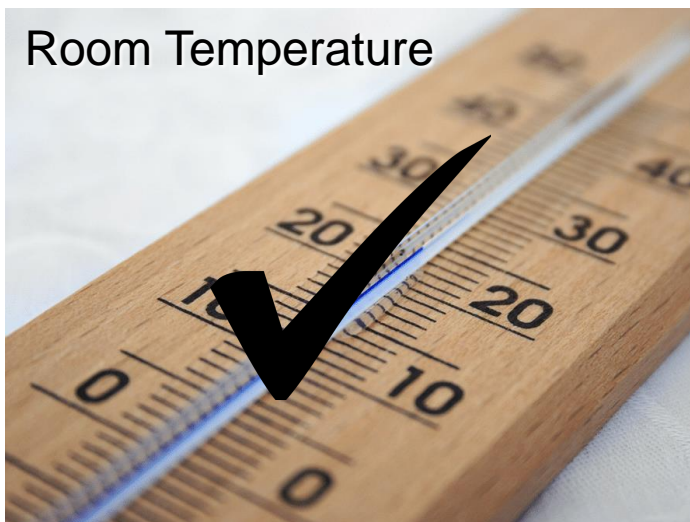
# Properties of the Device



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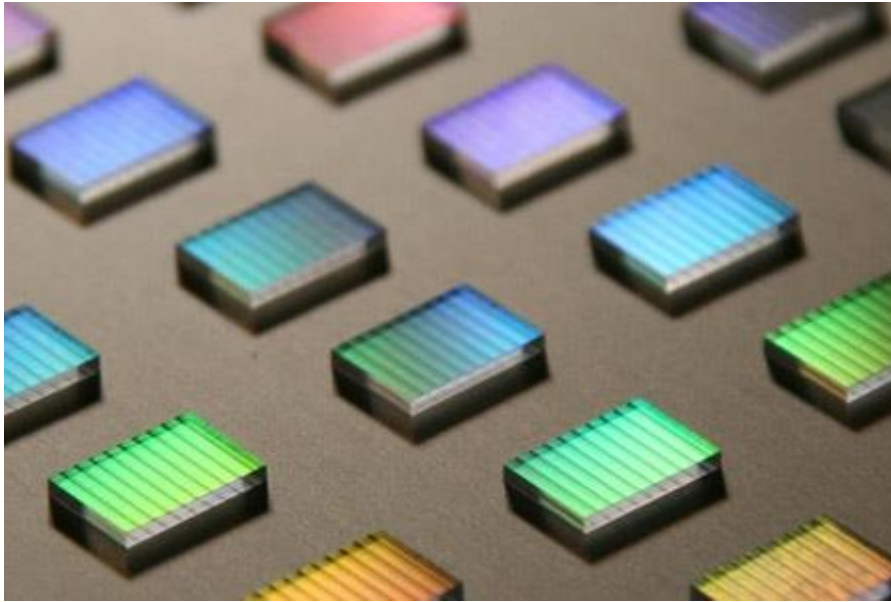


adafruit.com



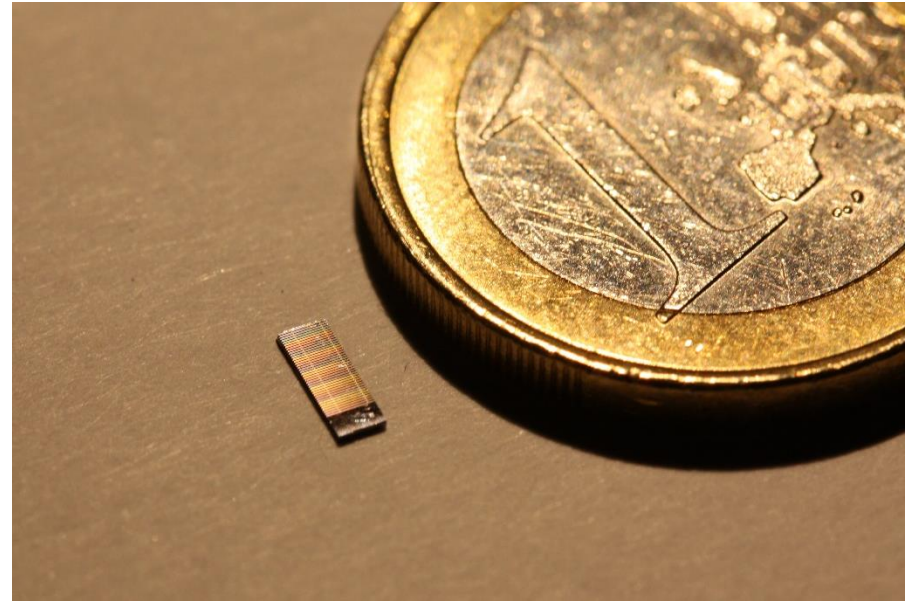
# Comparison to Crystal

Nonlinear Coefficient for Telecom Wavelengths<sup>1</sup>:



covesion.com

ppLN:  $\sim 30$  pm/V

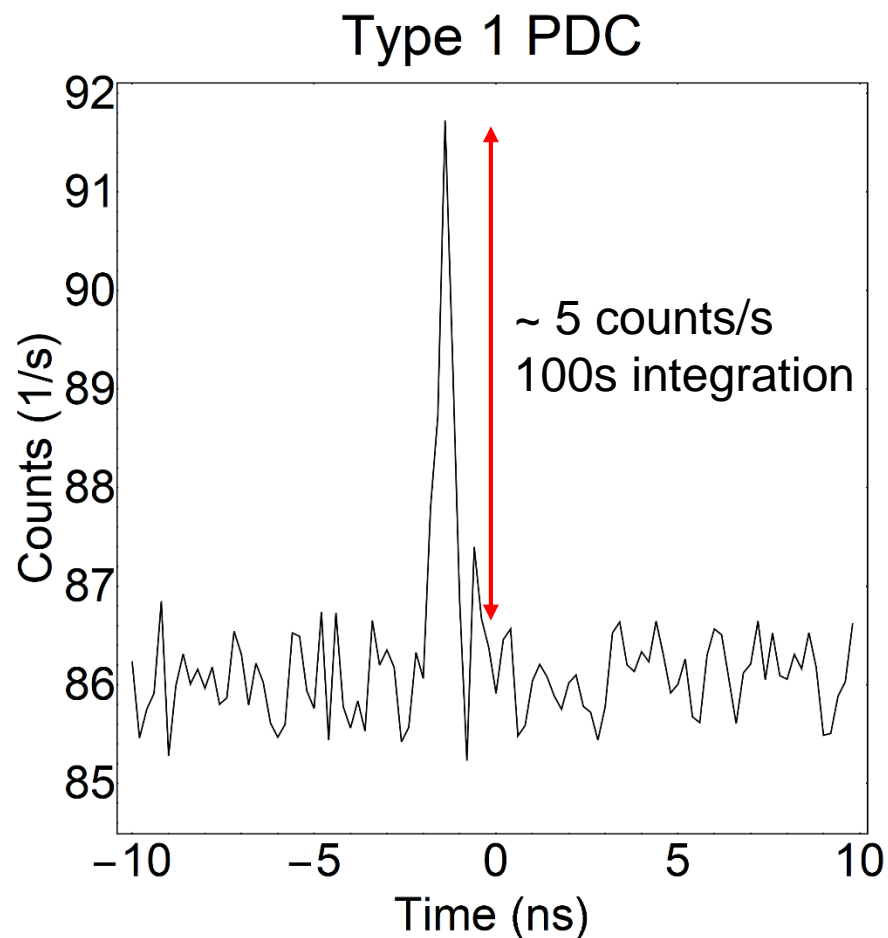
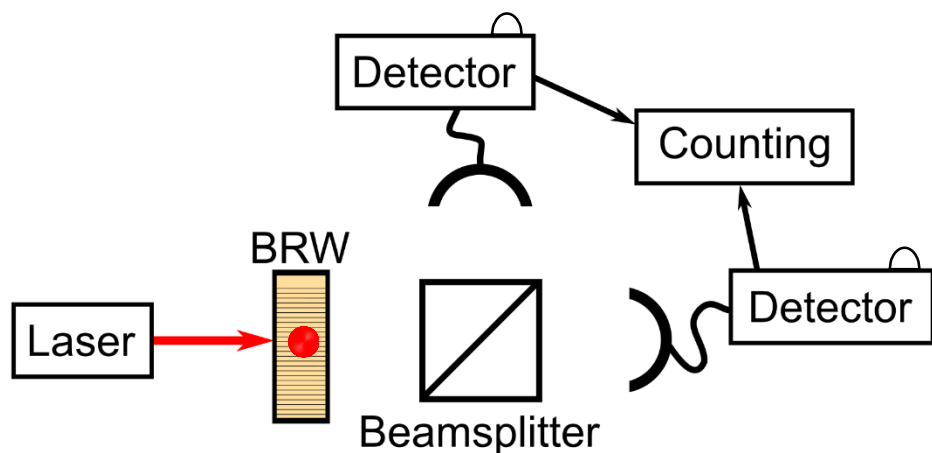


BRW:  $\sim 50$  pm/V

<sup>1</sup>T. Günthner., PhD Thesis, University of Innsbruck (2018)



# Optically pumped PDC



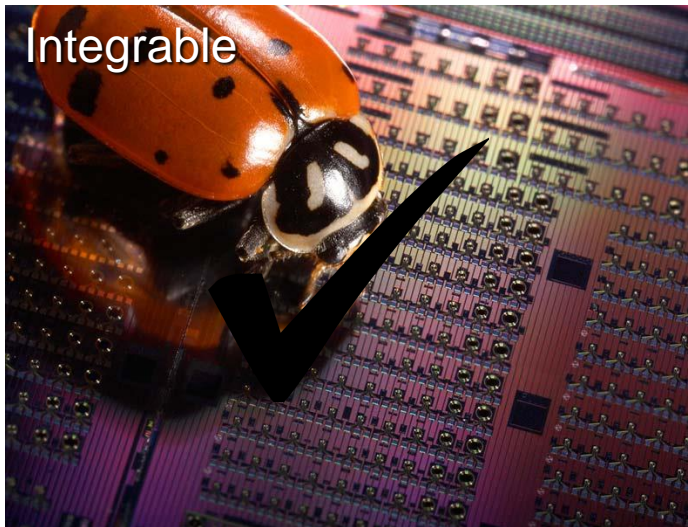
Old samples without integrated laser<sup>1-3</sup> >3000 counts/s

<sup>1</sup>K. Laiho, B. Pressl, A. Schlager et al., *Nanotechnology* **27** (2016)

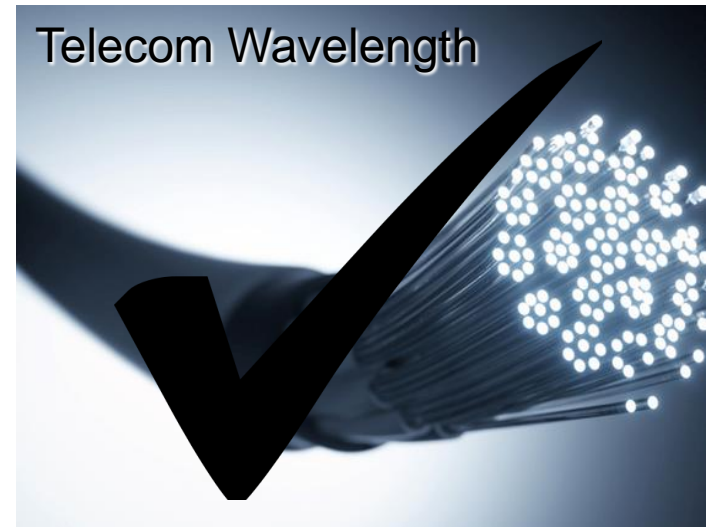
<sup>2</sup>A. Schlager, B. Pressl, K. Laiho et al., *Optics Letters* **42.11** (2017)

<sup>3</sup>H. Chen, K. Laiho, B. Pressl, A. Schlager et al., *APL Photonics* **3** (2018)

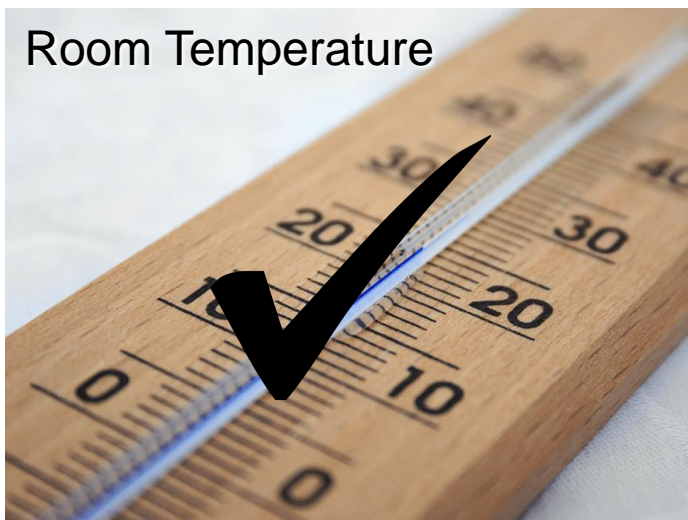
# Properties of the Device



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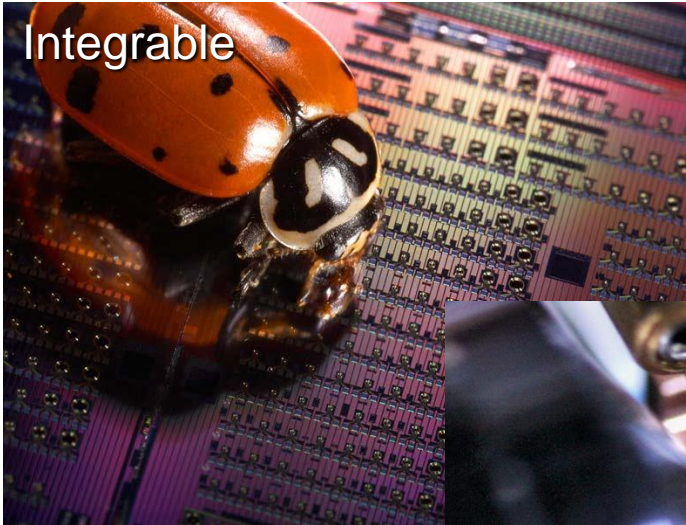
bauredakteur.de



adafruit.com

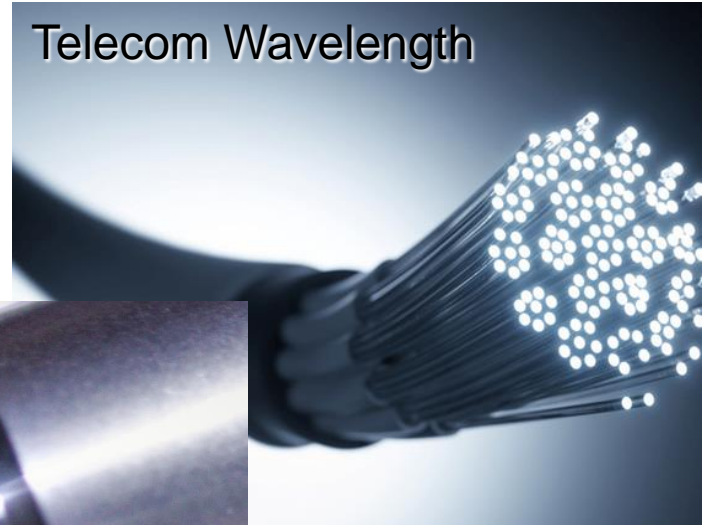
# Properties of the Device

Integrable

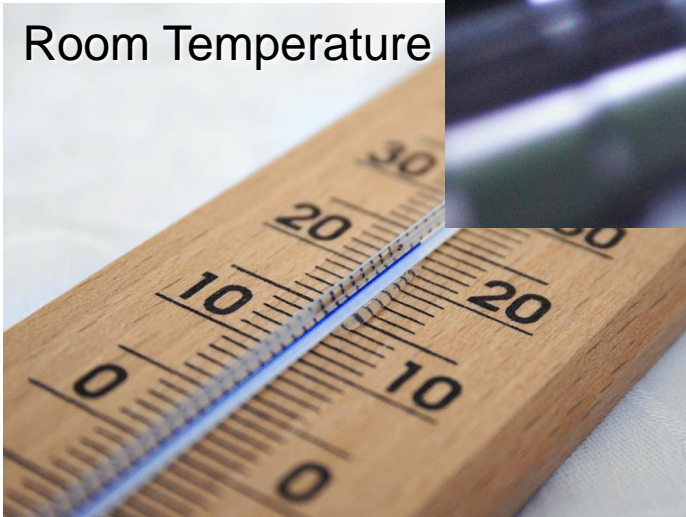


[thefutureofthings.com](http://thefutureofthings.com)

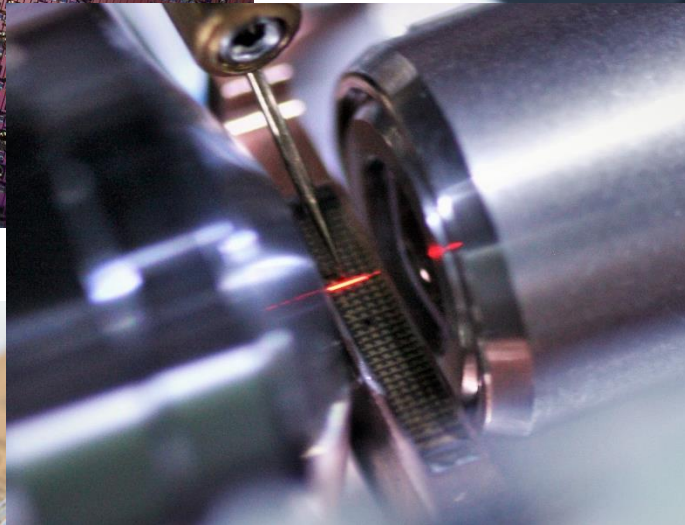
Telecom Wavelength



Room Temperature



[bauredakteur.de](http://bauredakteur.de)



[adafruit.com](http://adafruit.com)

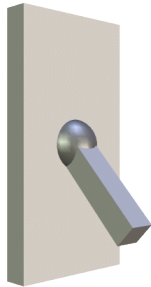
# Appendix



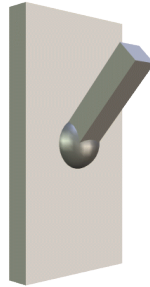
# From Bits to Qubits

Classical Bit

0

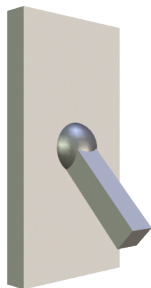


1

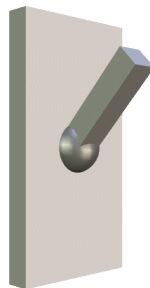


Qubit

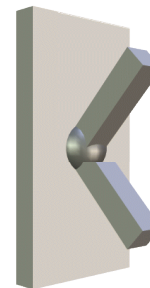
$|0\rangle$



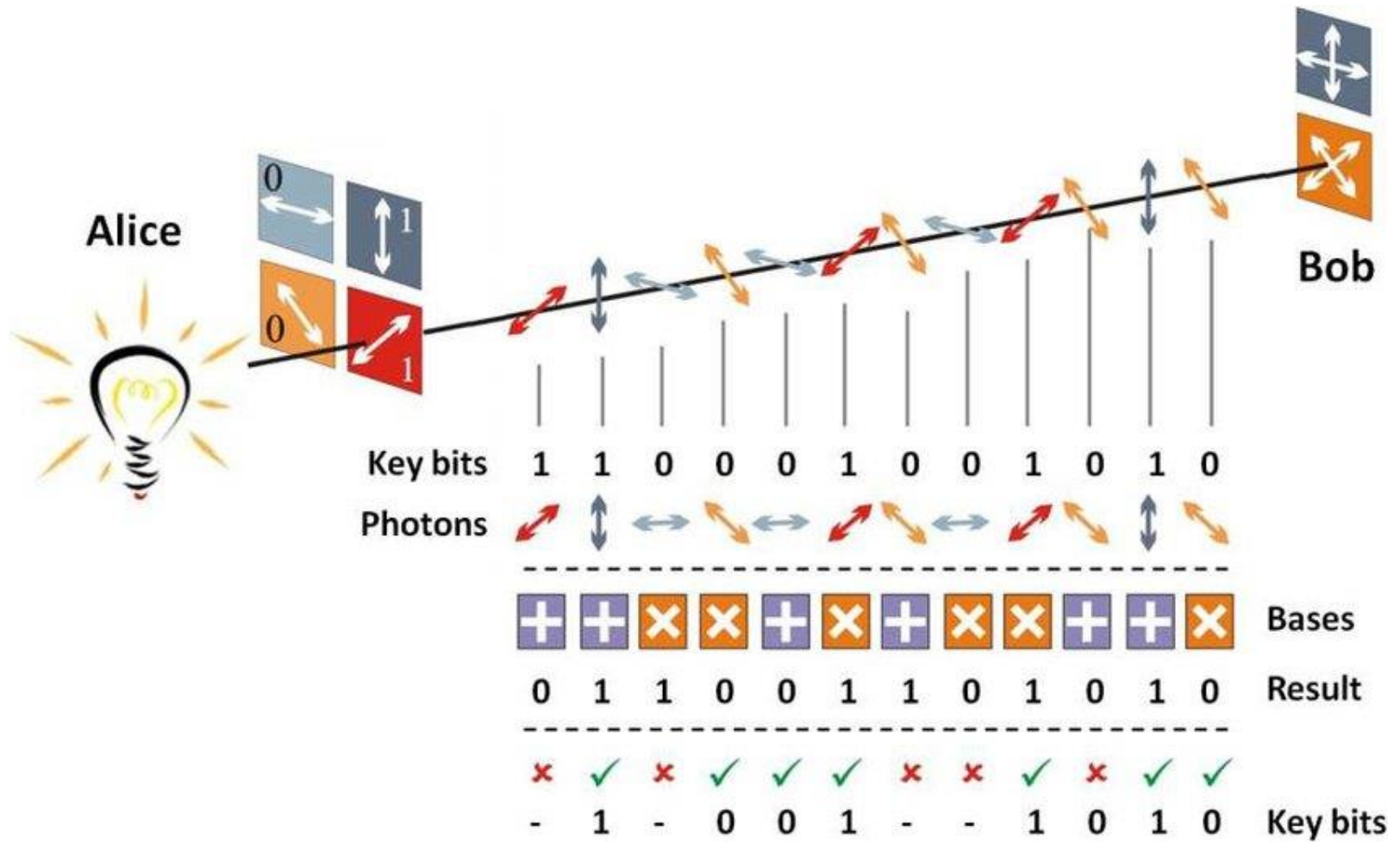
$|1\rangle$



$|0\rangle + |1\rangle$

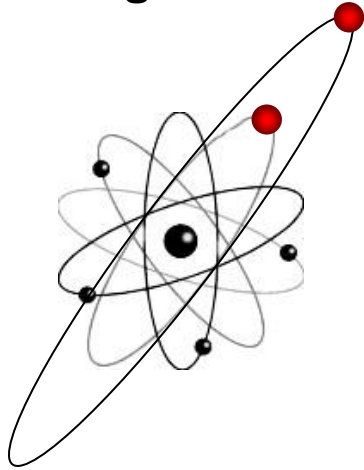


# BB84



# What are photons?

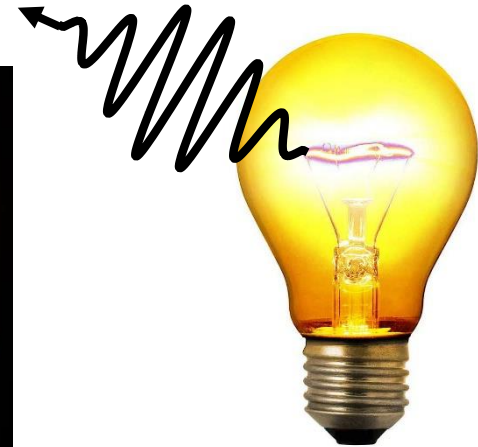
discrete energies:



electron state

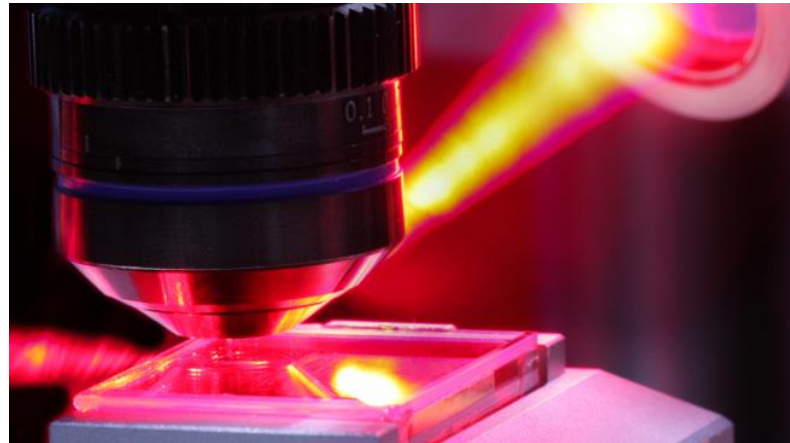


wikimedia.org



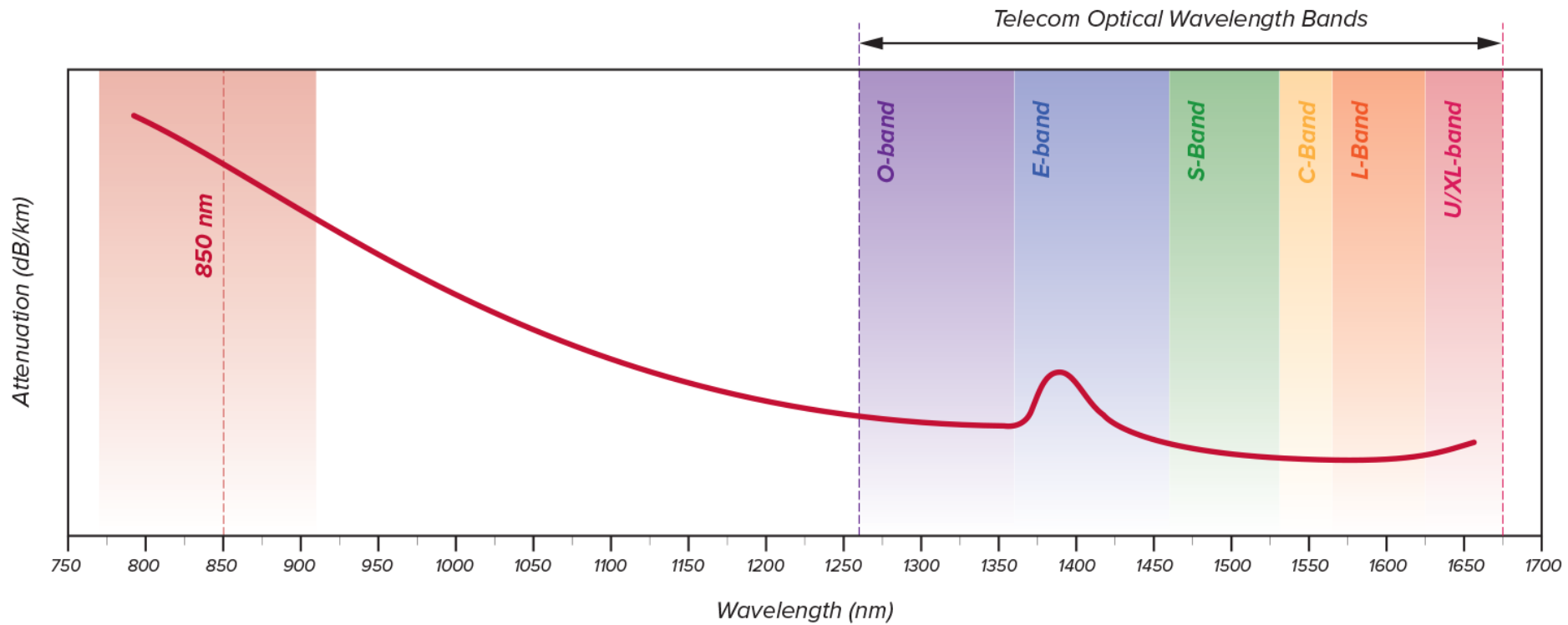
livescience.com

vibrations: phonons  
angular momentum: spin  
...



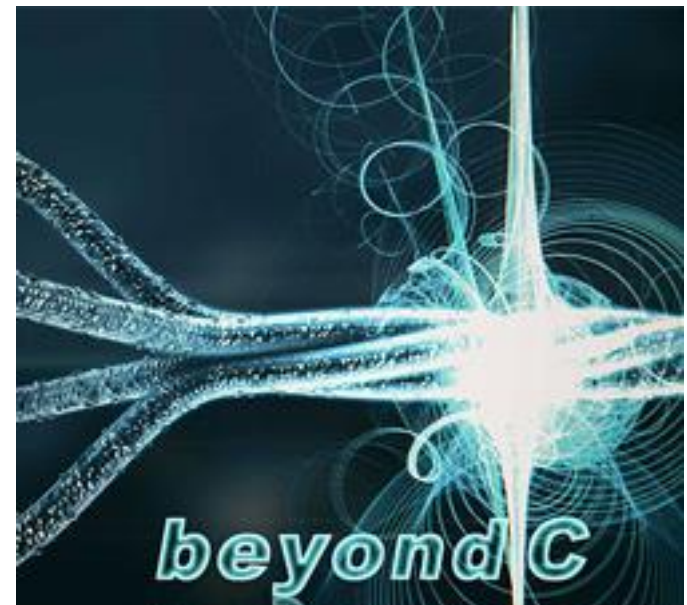
light particles: photons

# Telecom band

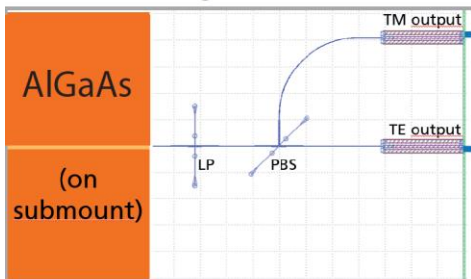




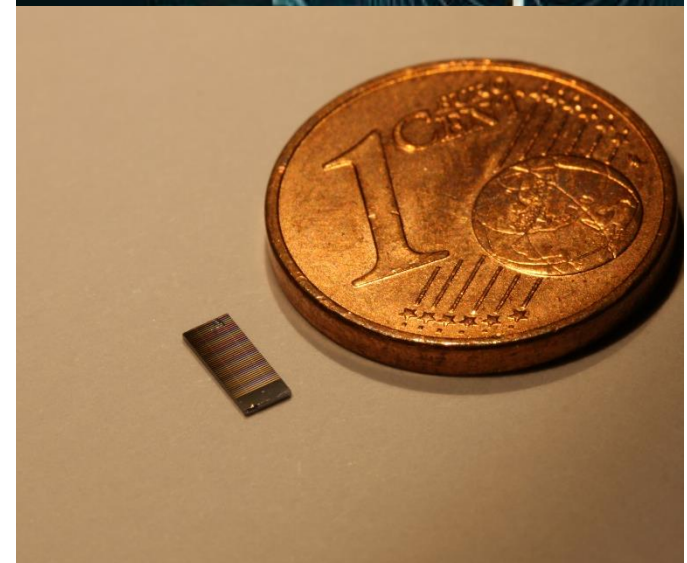
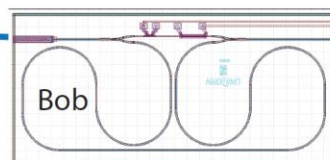
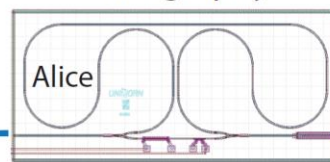
# Outlook



Electrically pumped  
time-bin entangled  
state generation

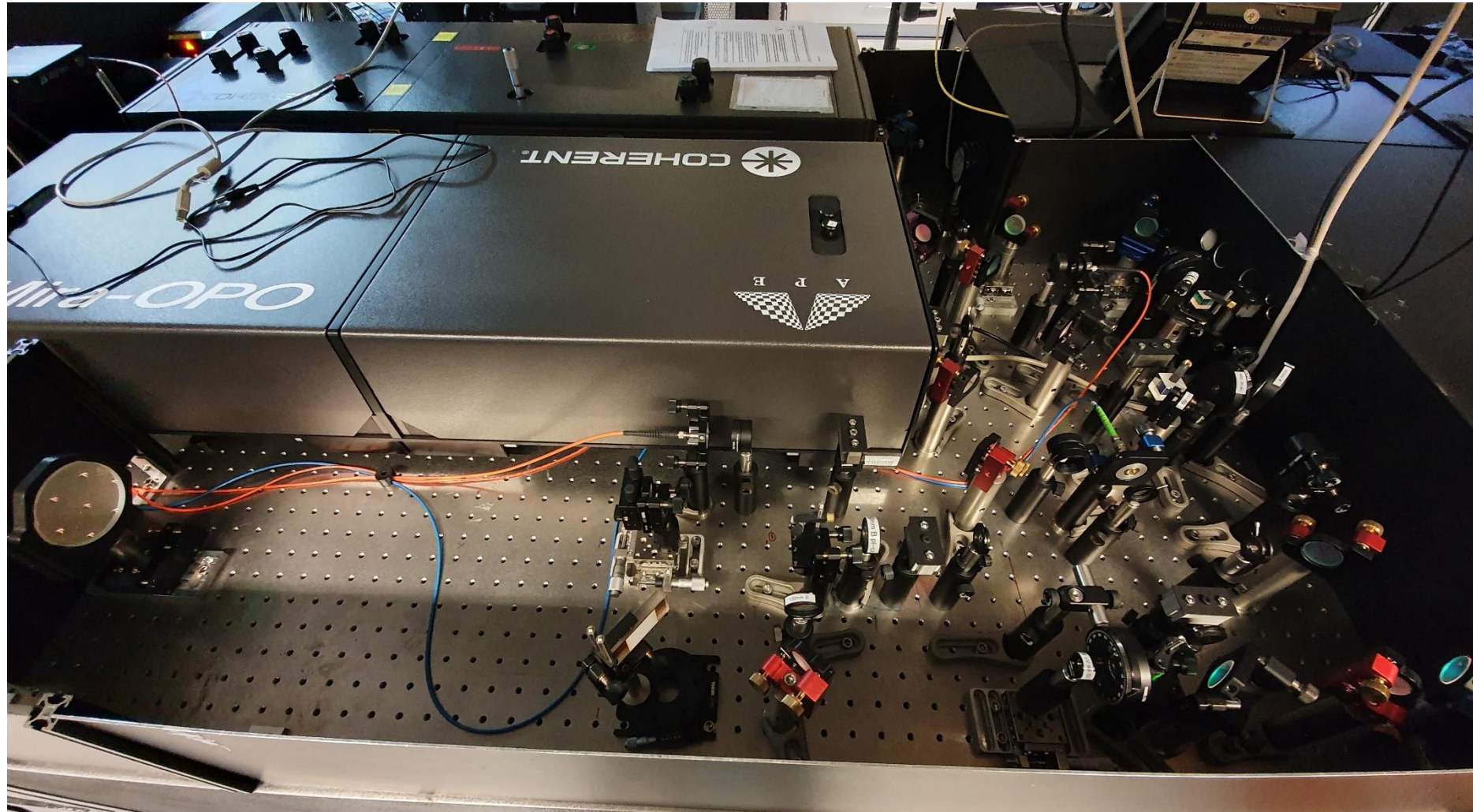


Time-bin state  
tomography





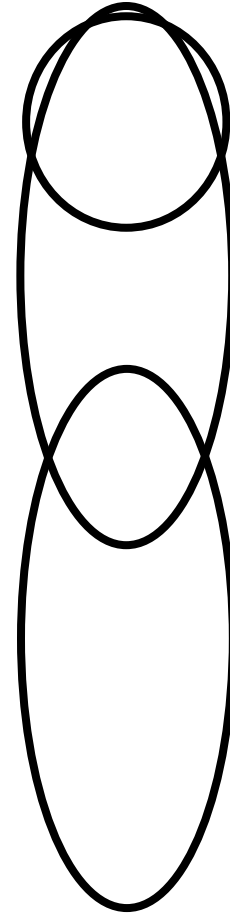
# Big Lasers



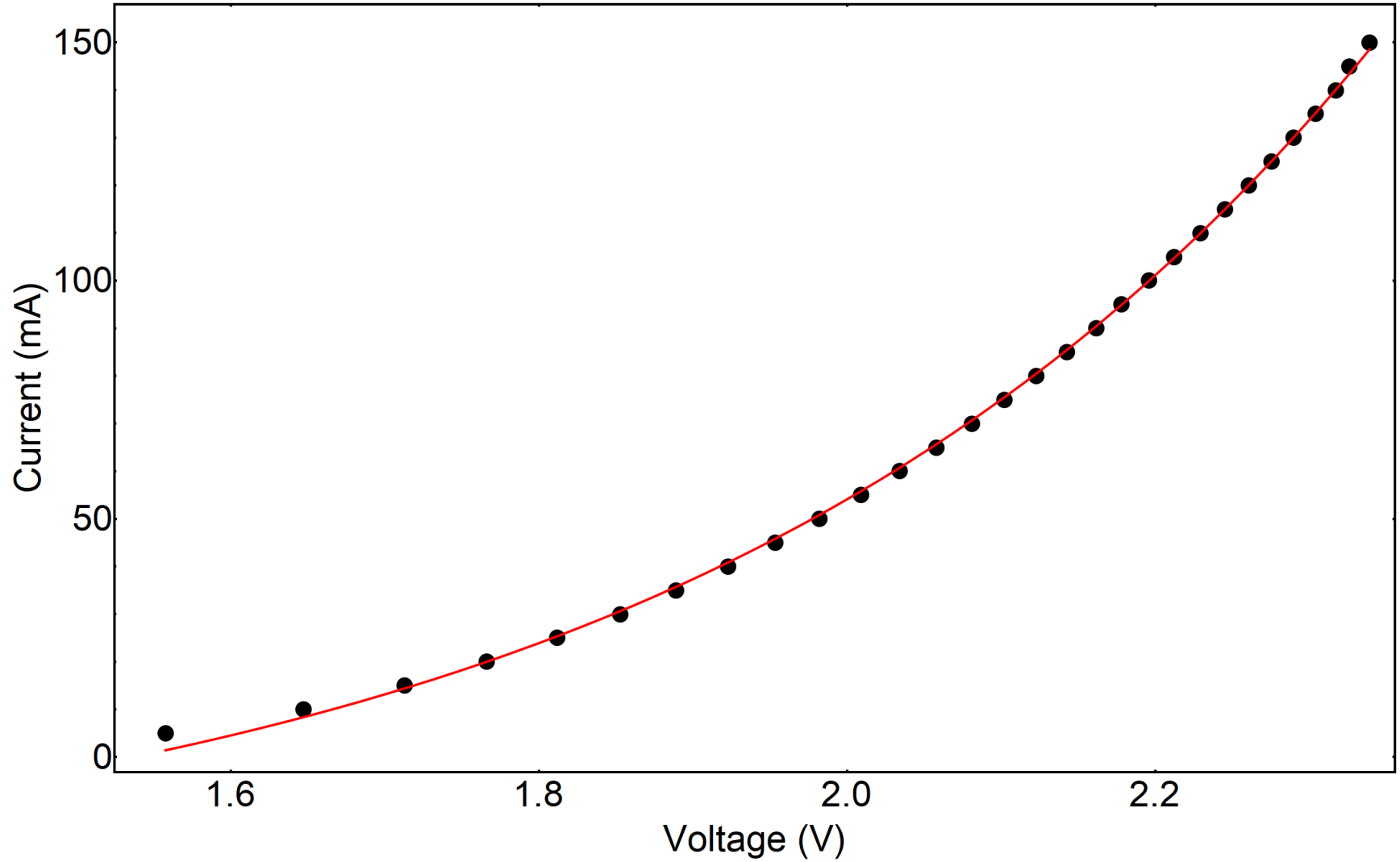
# Photon Pairs



Photon pairs  
→ Heralding  
→ Entanglement



# I-V curve





# DC vs. Pulsed

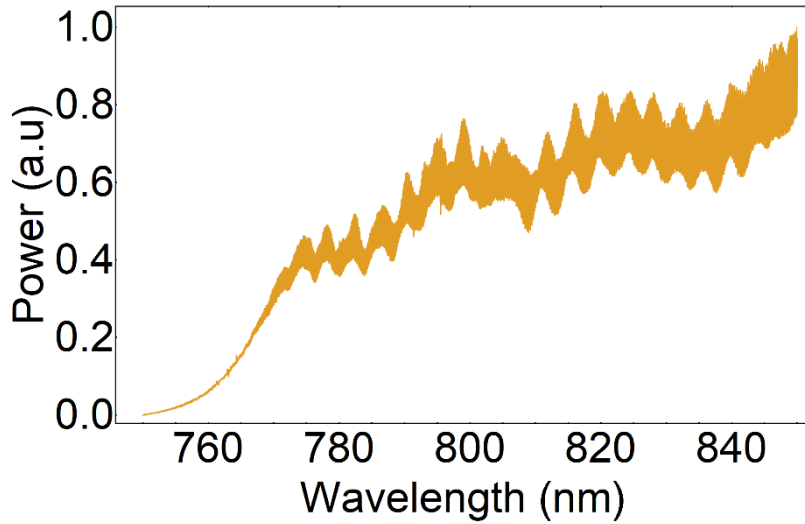
DC: 50 to 140mA

Pulsed: 22.5 to 30 V  
about 700 to 950 mA

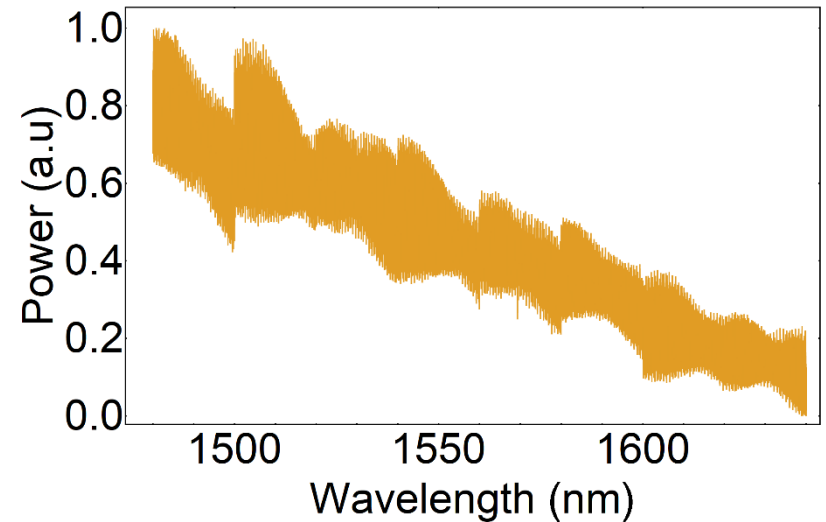
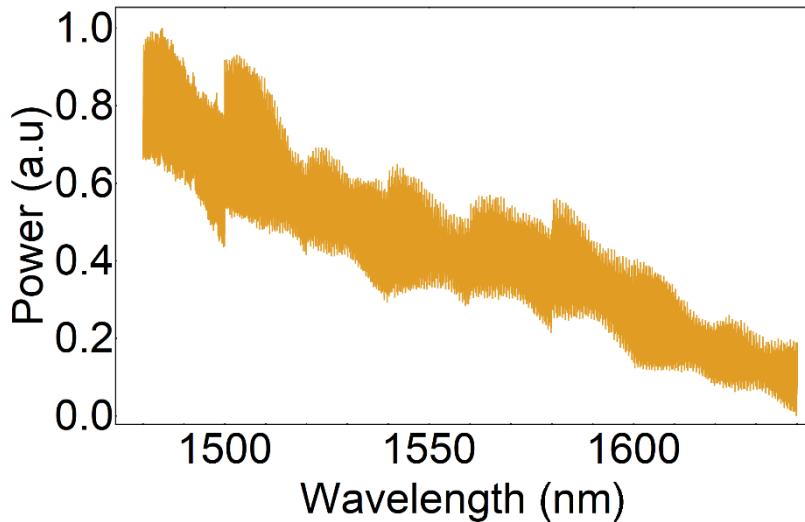
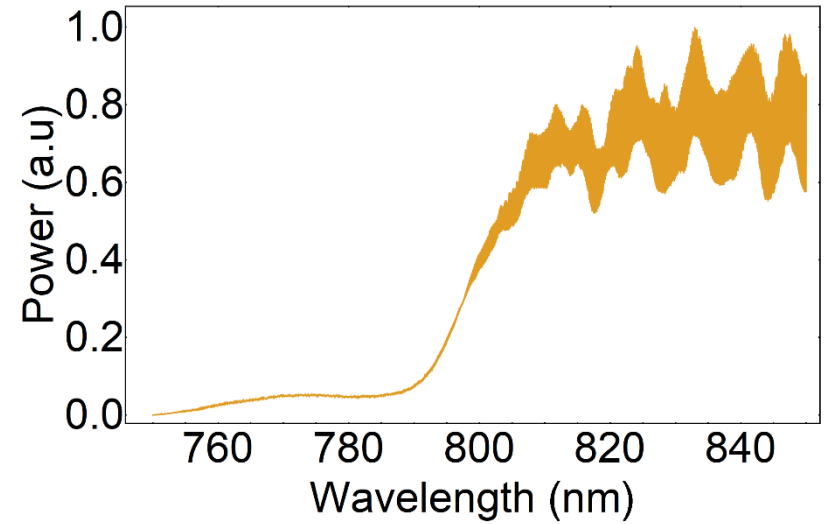


# Transmission Spectroscopy

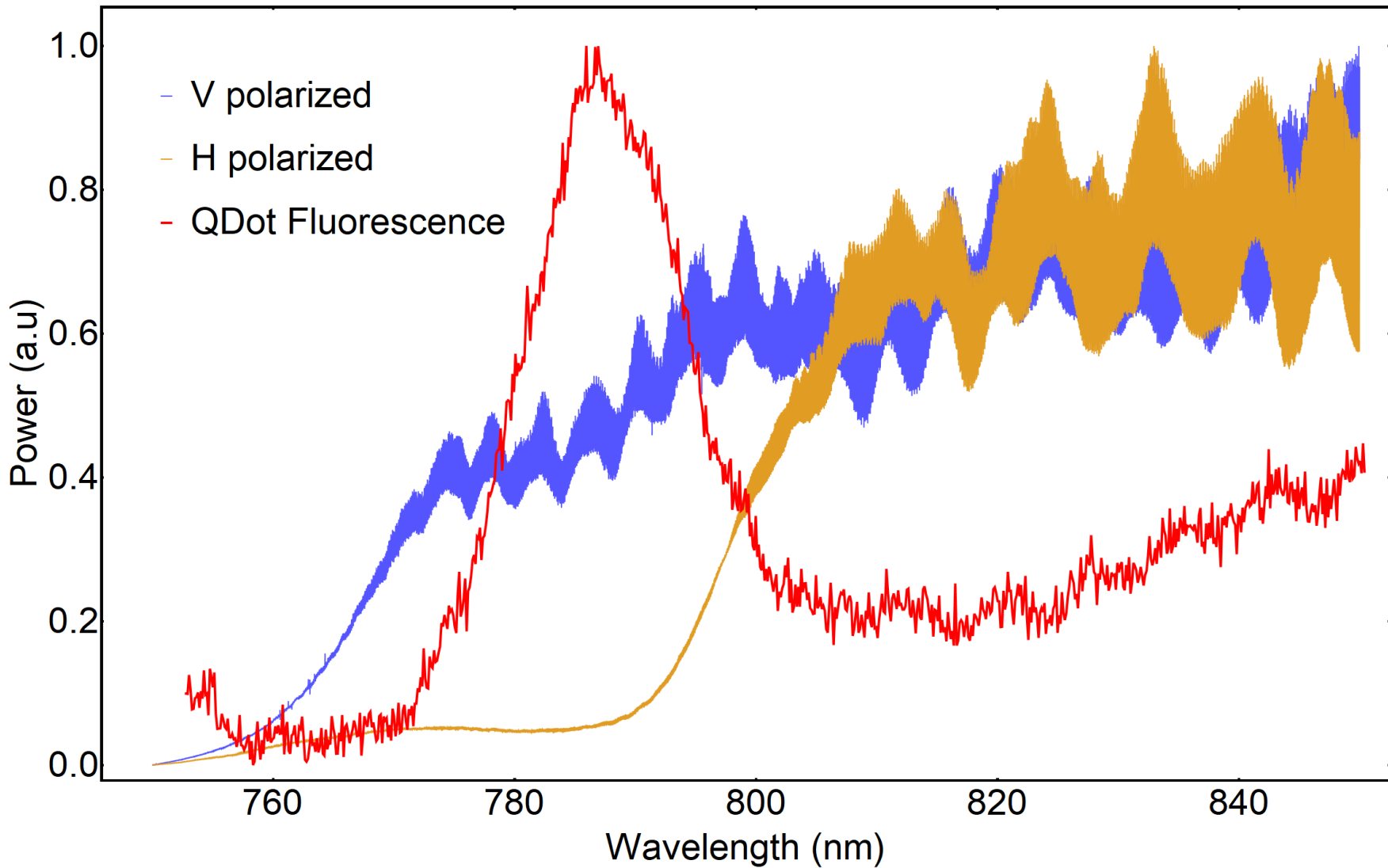
V polarized



H polarized

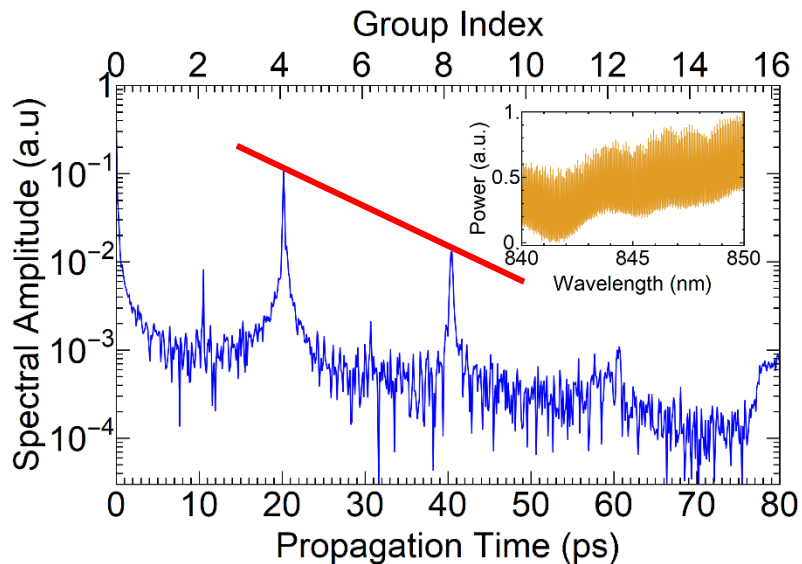


# Quantum Dot Fluorescence



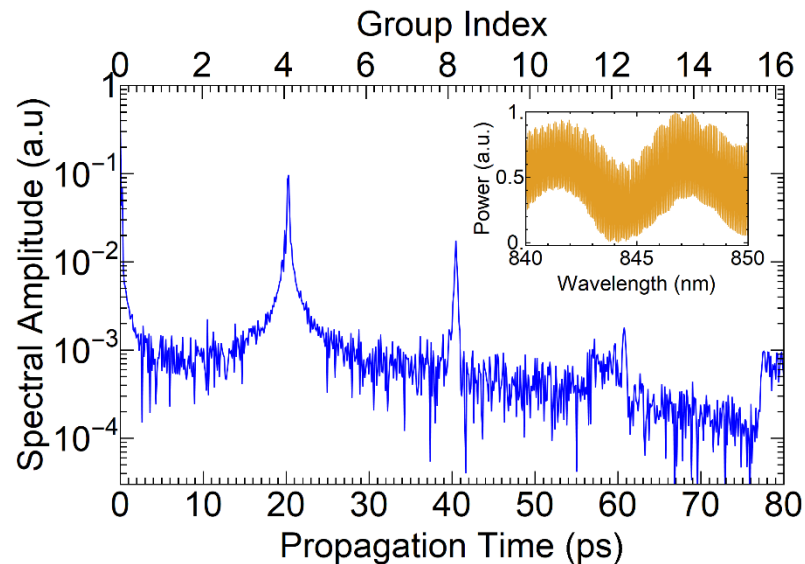
# Fabry Perot Spectroscopy

V polarized

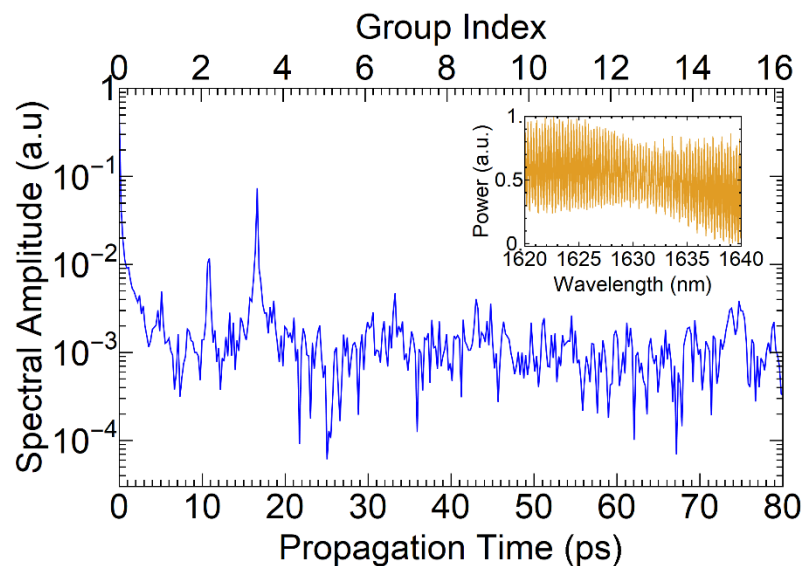
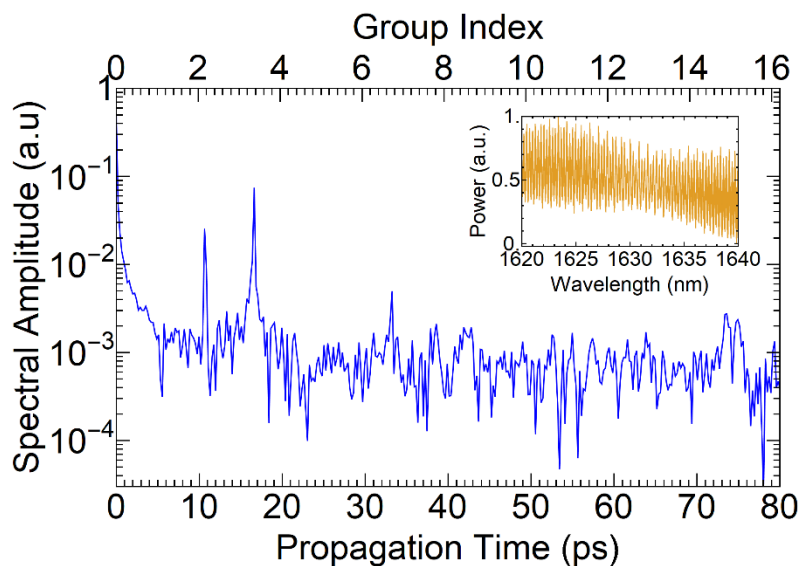


NIR

H polarized

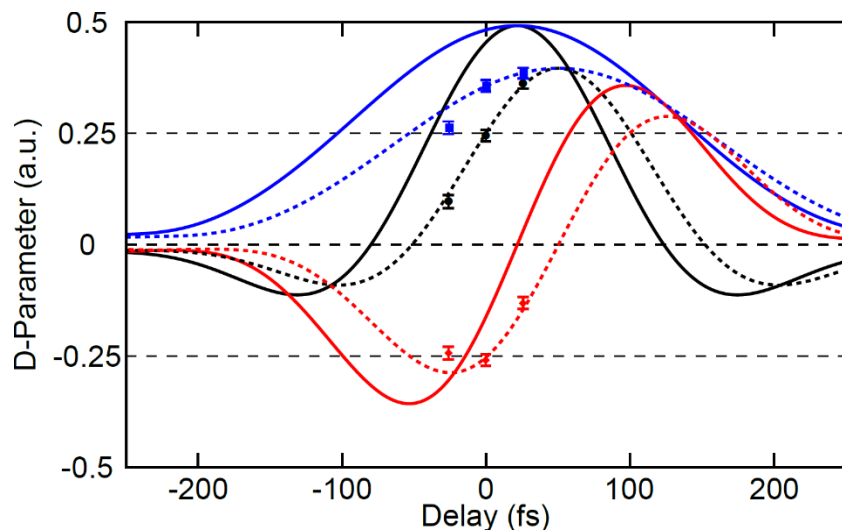


TC

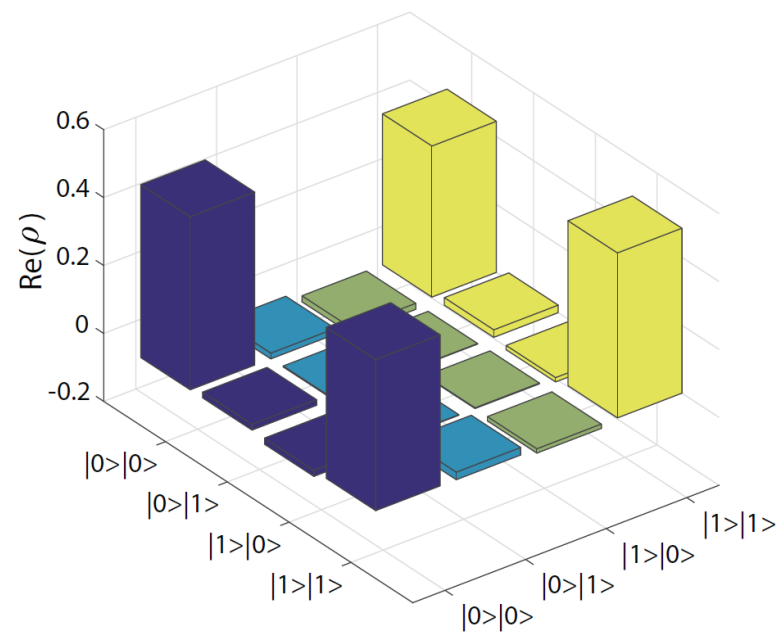


# Entanglement

## Temporal control of polarization entanglement<sup>1</sup>



## Time-bin entanglement<sup>2</sup>

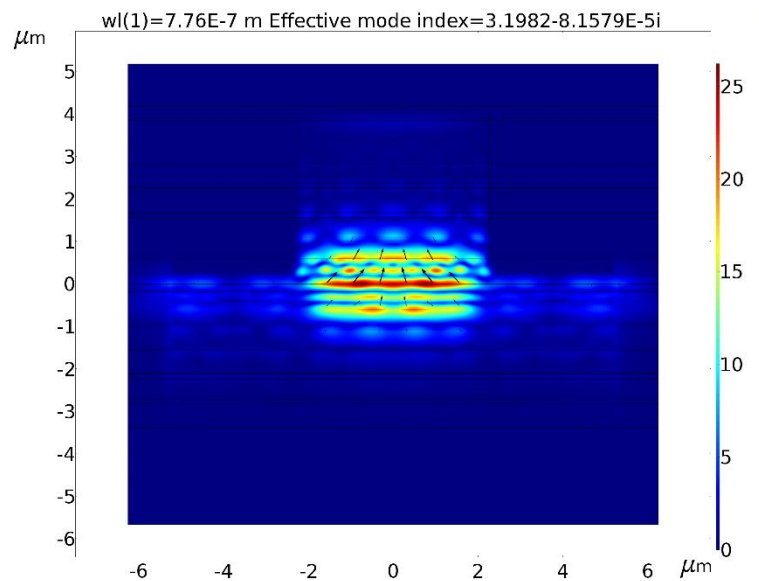
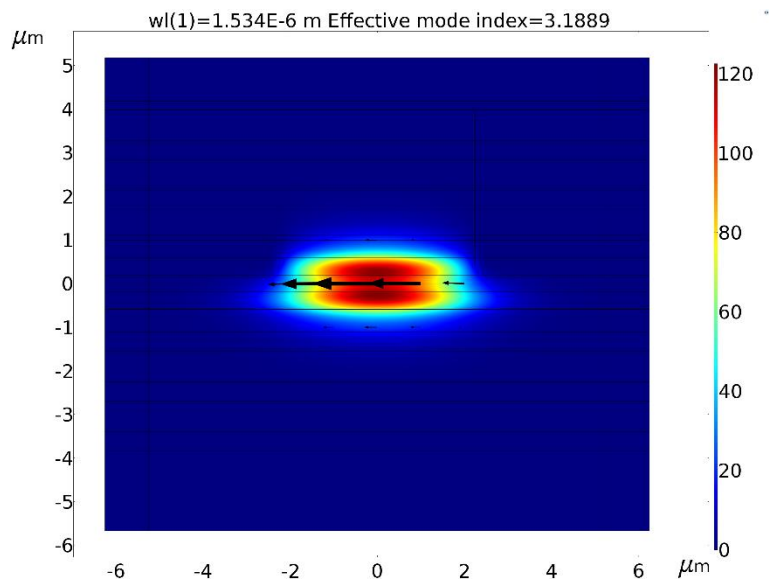
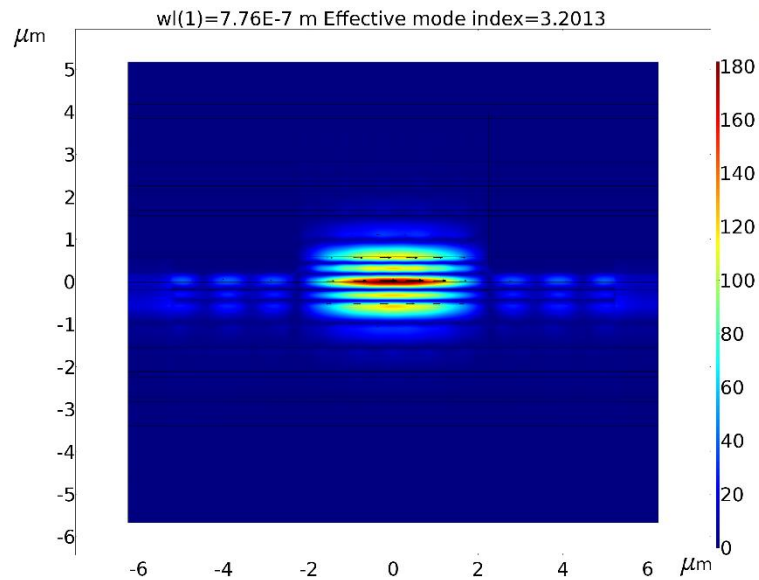
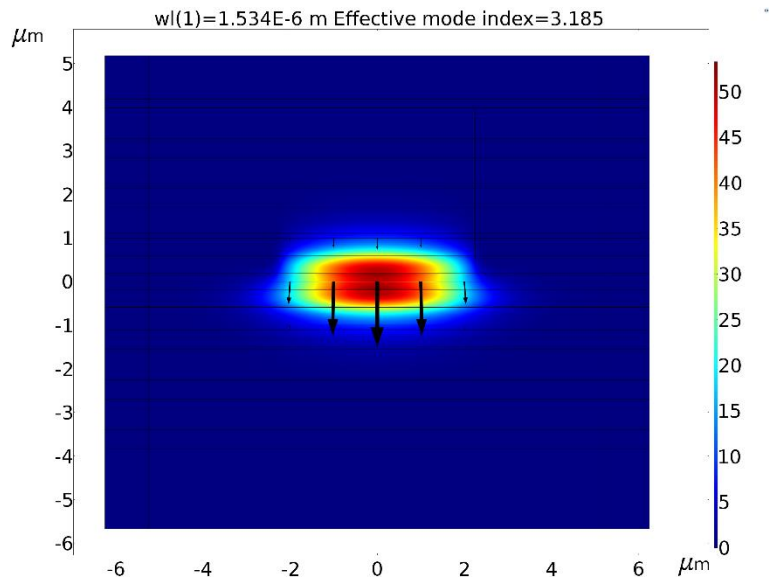


<sup>1</sup>A. Schlager et al., *Optics Letters*, **42**.11 (2017): 2102-2105

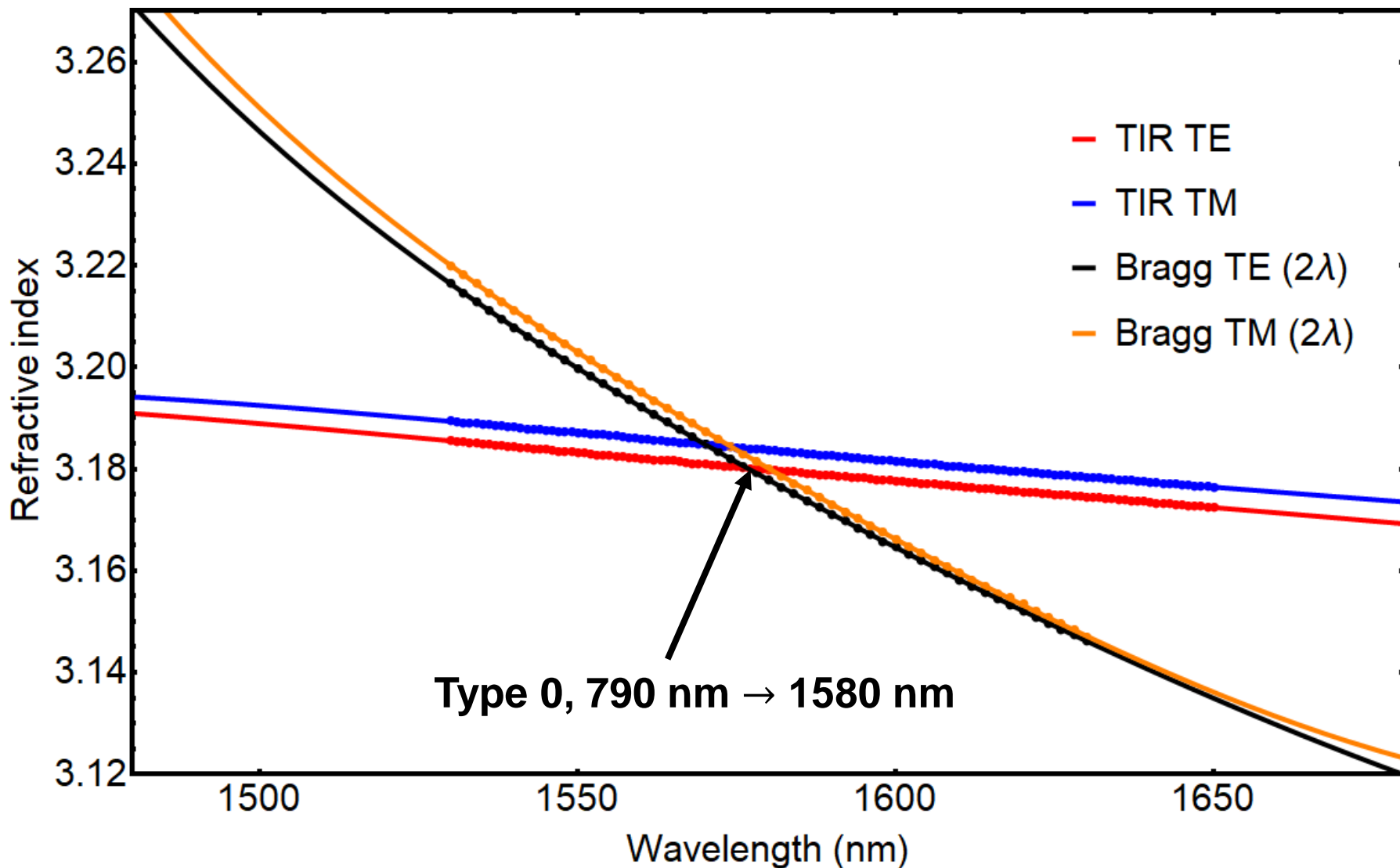
<sup>2</sup>H. Chen et al., accepted in *APL Photonics* (2018)



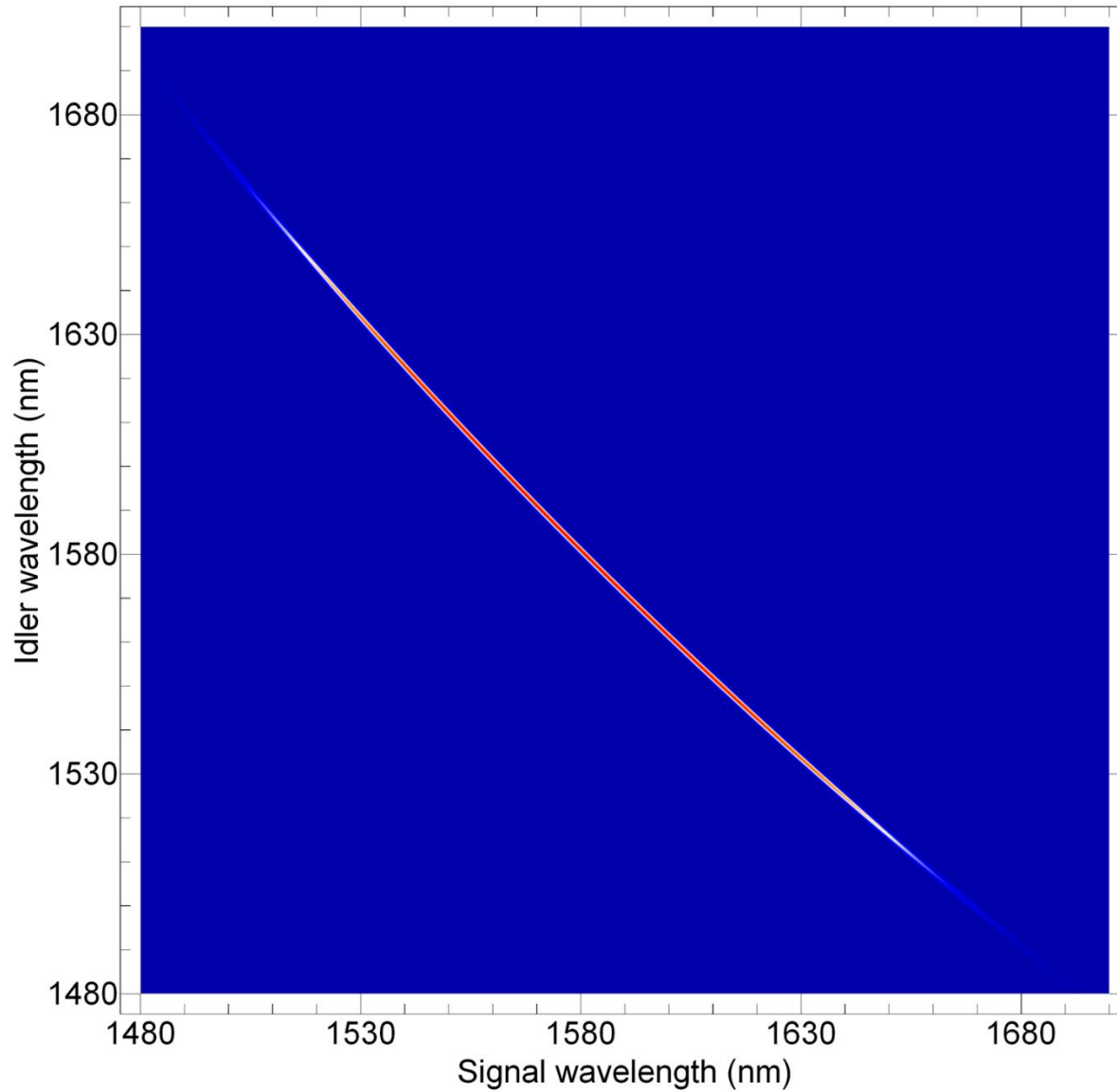
# Simulated Modes



# Refractive indices

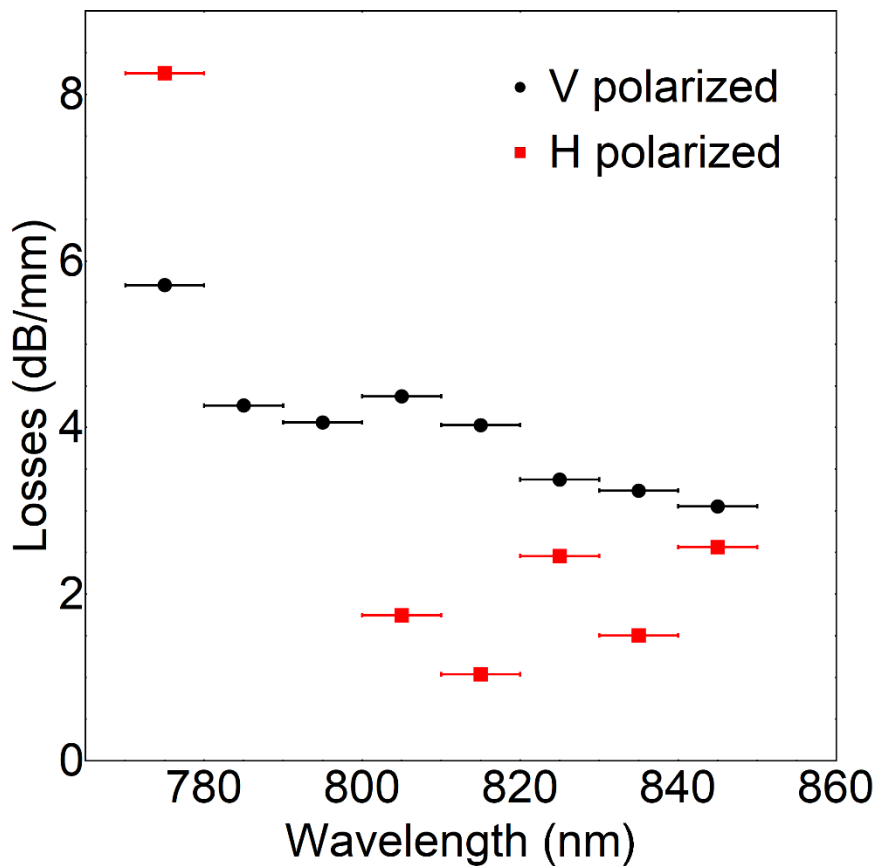


# Joint Spectrum

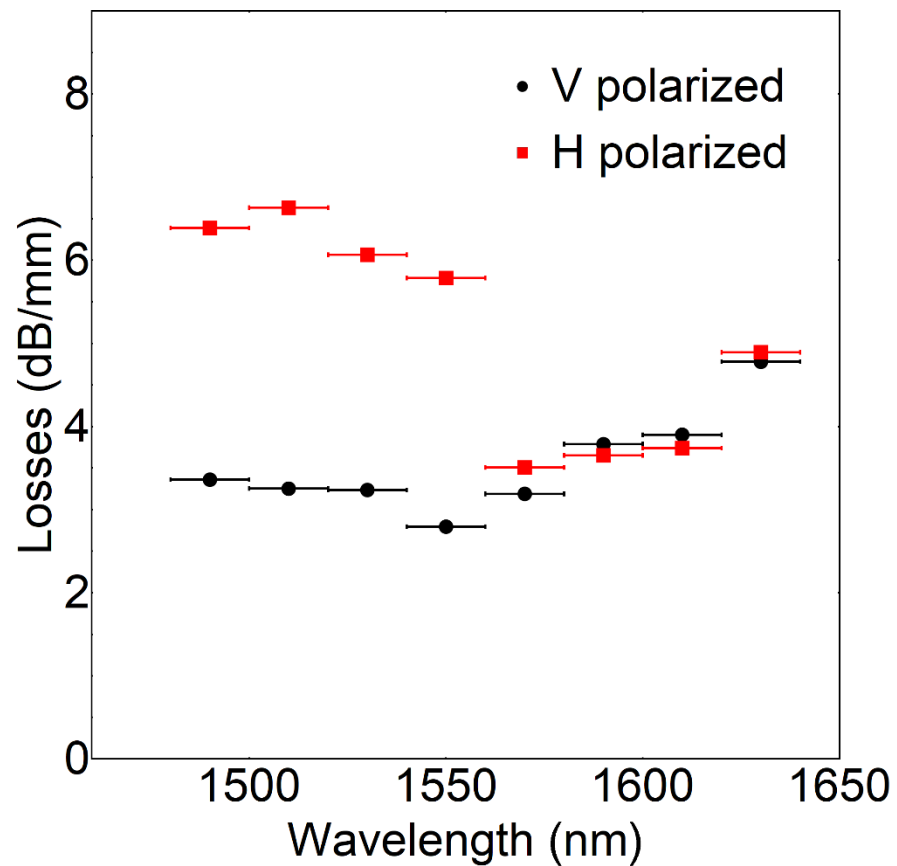


# Losses for 4.5 $\mu\text{m}$ Ridge

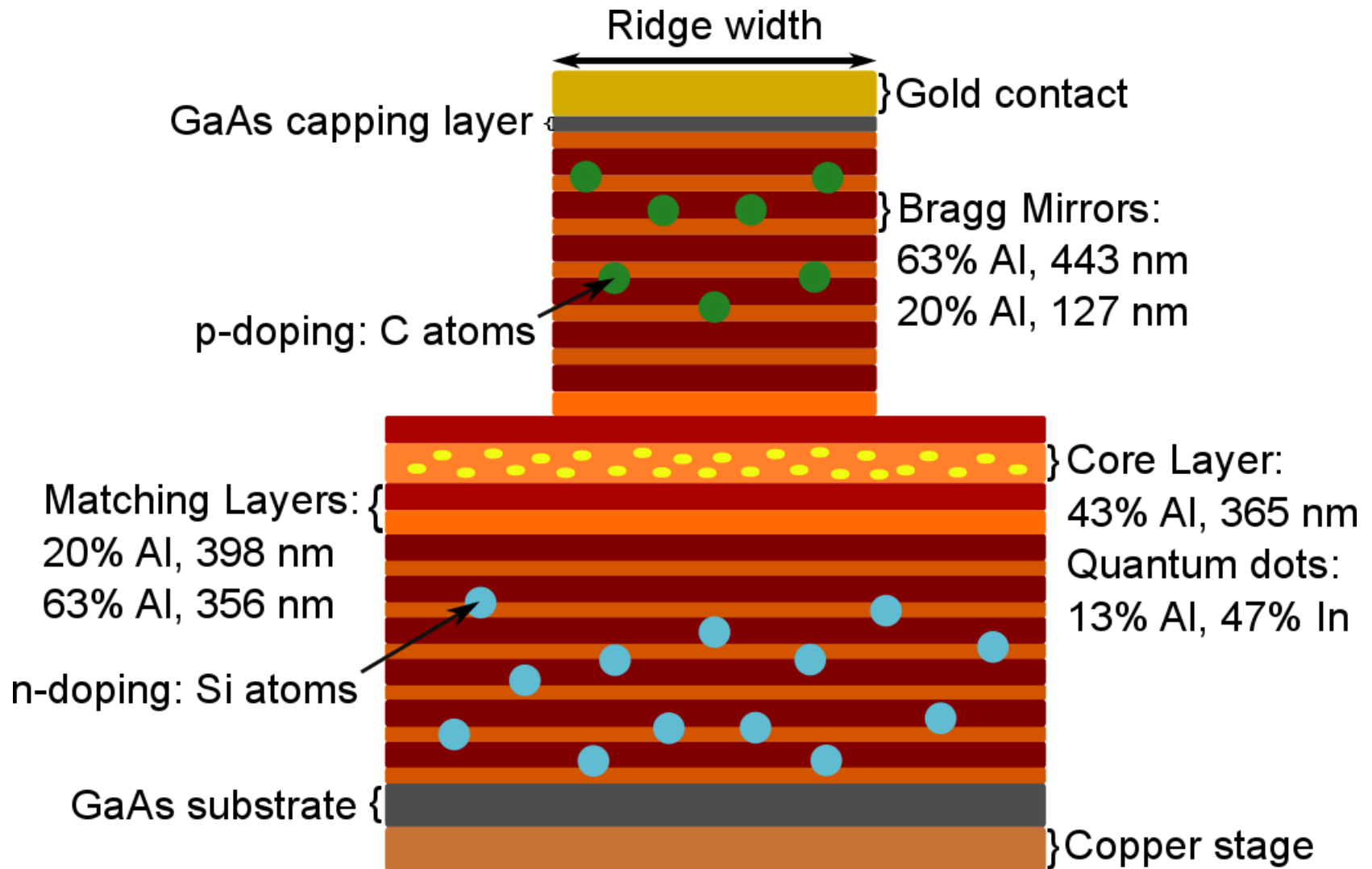
NIR



TC

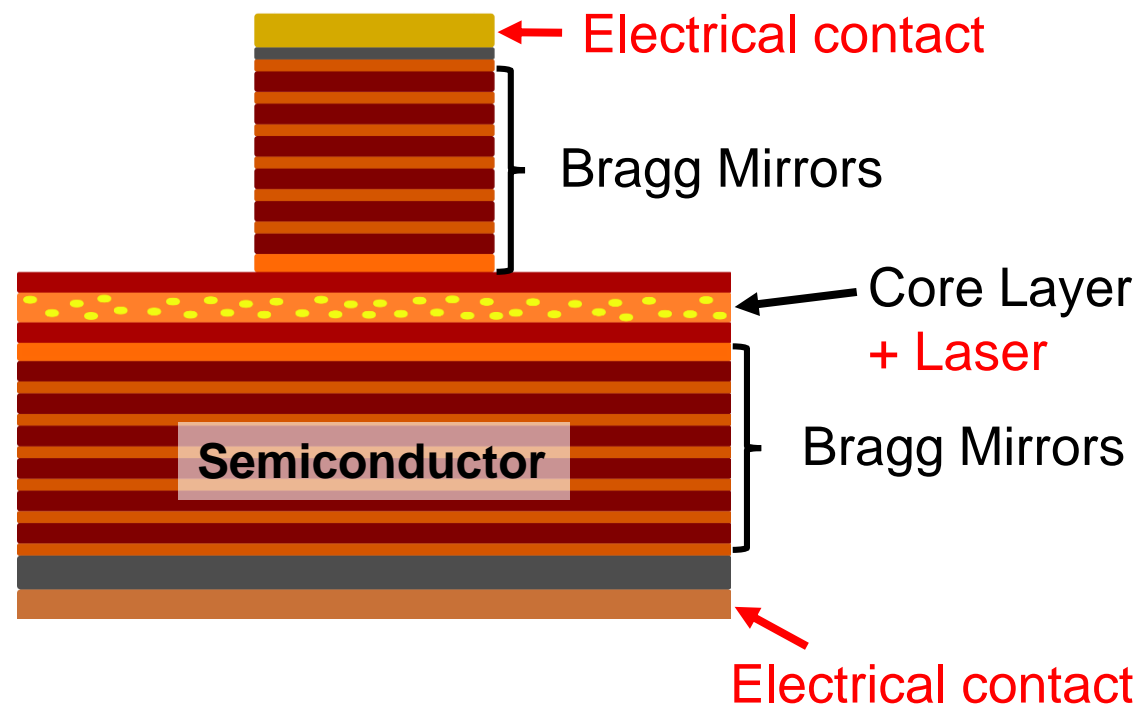
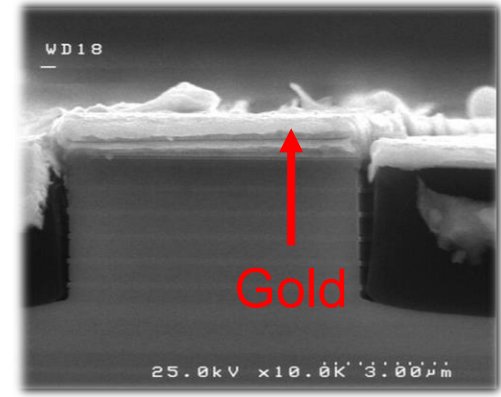
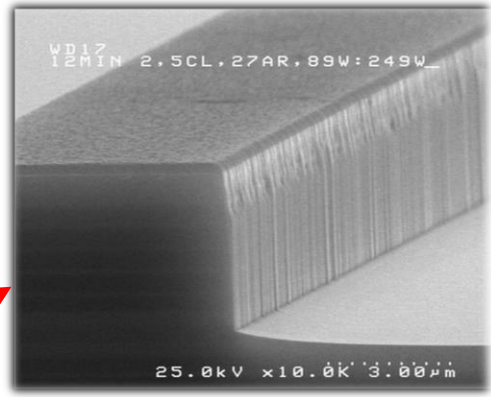
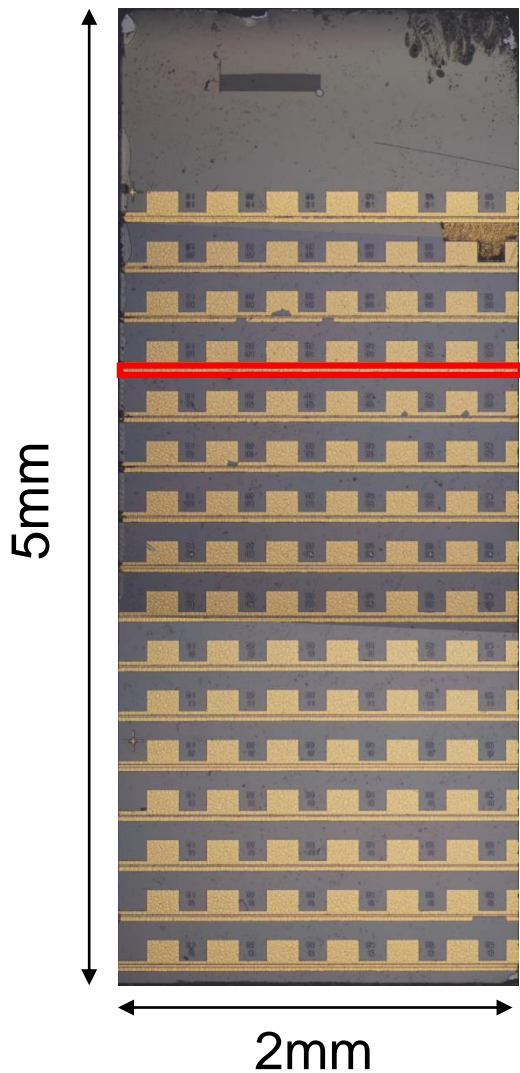


# AlGaAs Bragg-Reflection Waveguide

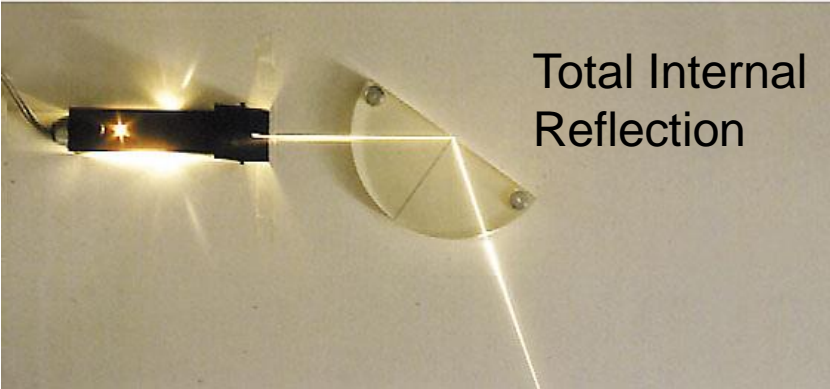
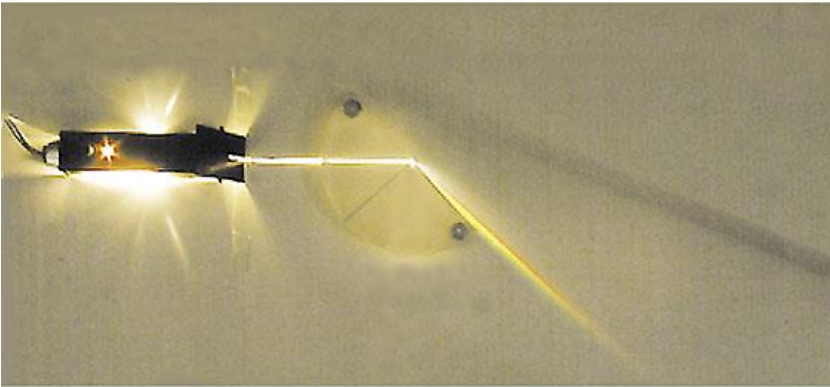
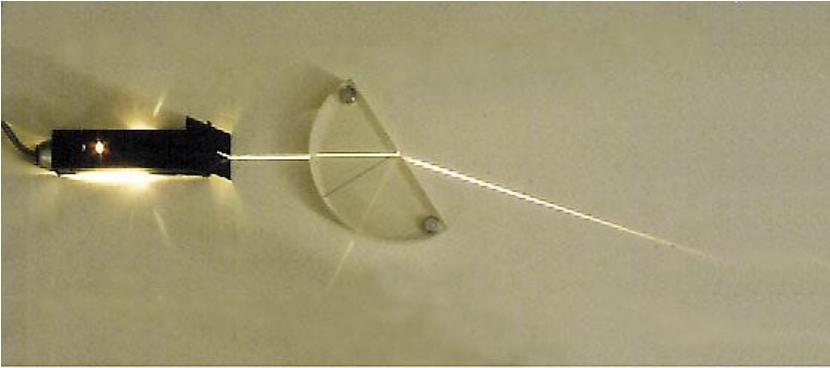




# Internal Laser



# Basic Principles of Waveguides



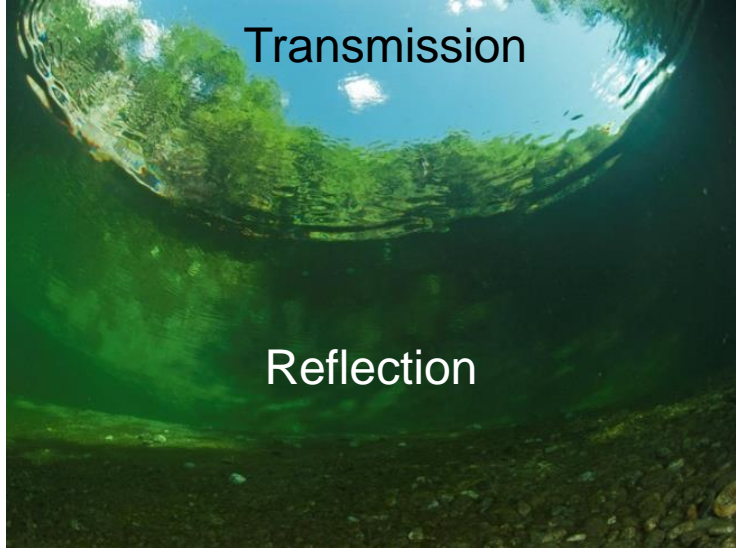
Total Internal Reflection

[lernhelfer.de](http://lernhelfer.de)



Reflection

[britannica.com](http://britannica.com)



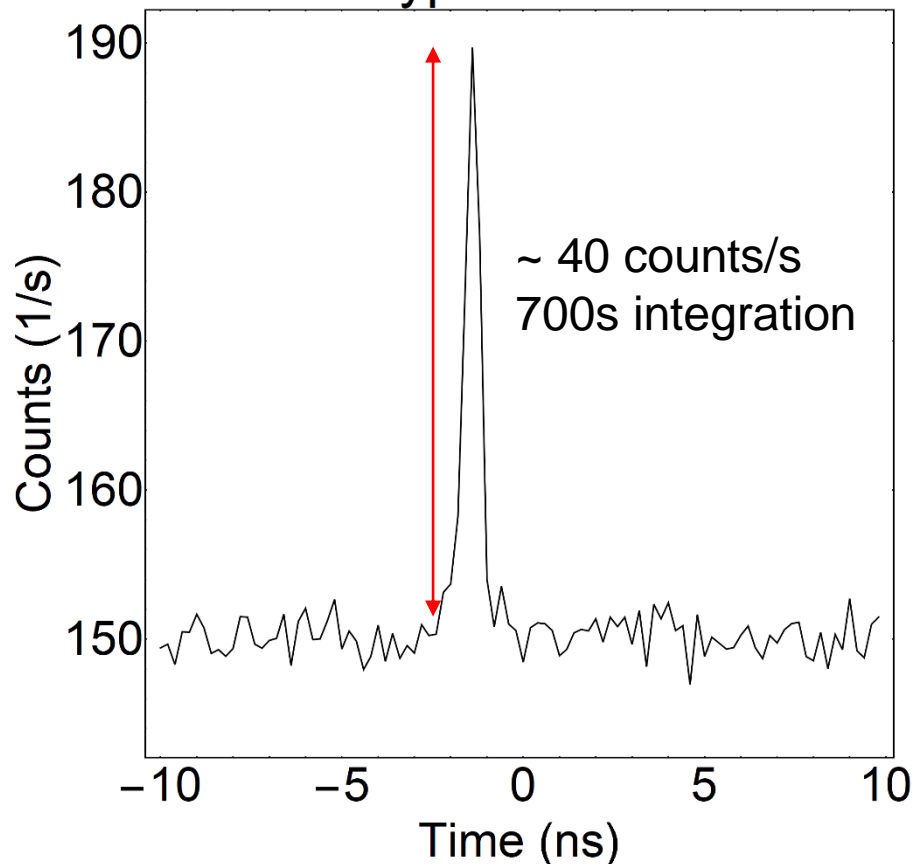
Transmission

Reflection

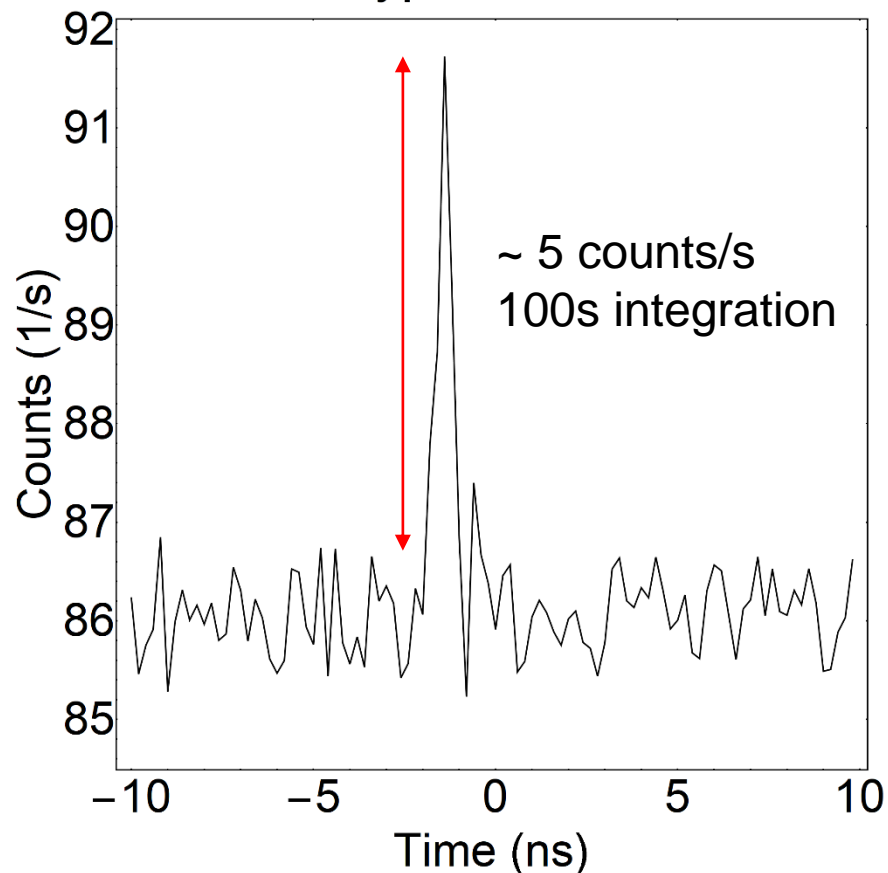
[nies.ch](http://nies.ch)

# Optically pumped PDC

## Type 0 PDC



## Type 1 PDC



Previous experiments<sup>1-3</sup> (w/o the internal laser) >3000 counts/s

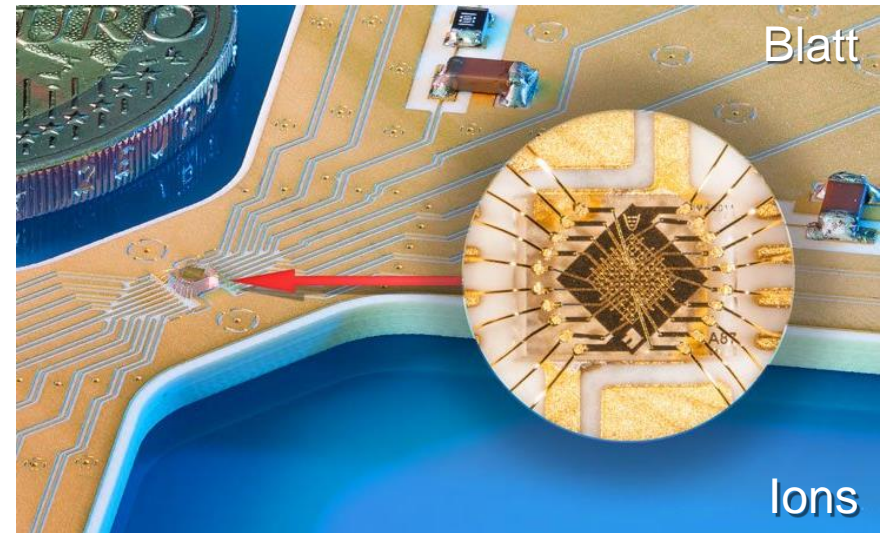
<sup>1</sup>K. Laiho, B. Pressl, A. Schlager et al., *Nanotechnology* **27** (2016)

<sup>2</sup>A. Schlager, B. Pressl, K. Laiho et al., *Optics Letters* **42.11** (2017)

<sup>3</sup>H. Chen, K. Laiho, B. Pressl, A. Schlager et al., *APL Photonics* **3** (2018)



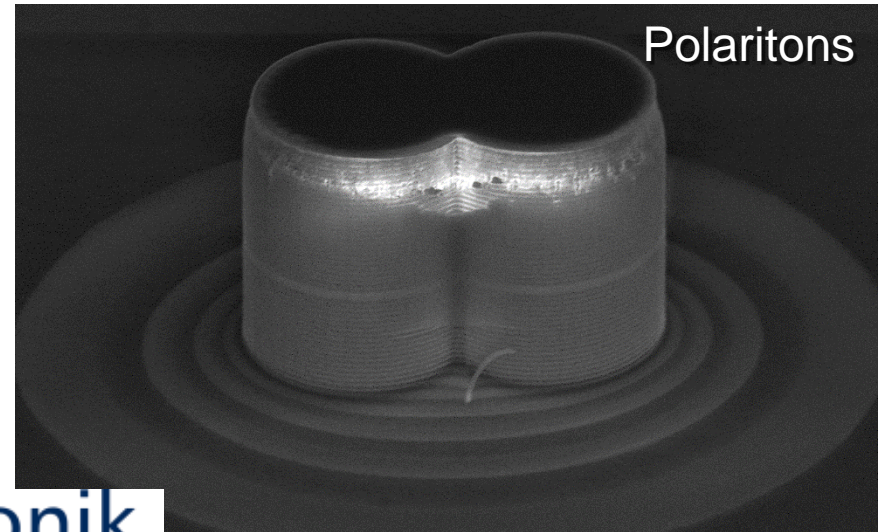
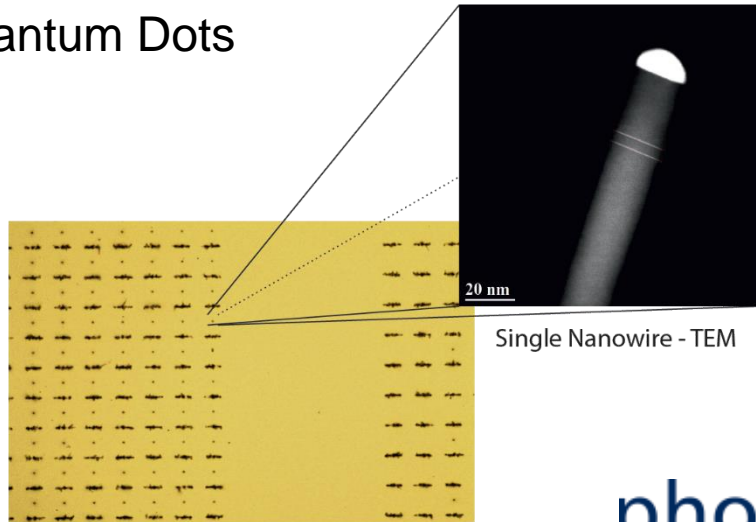
# On-chip Quantum Experiments





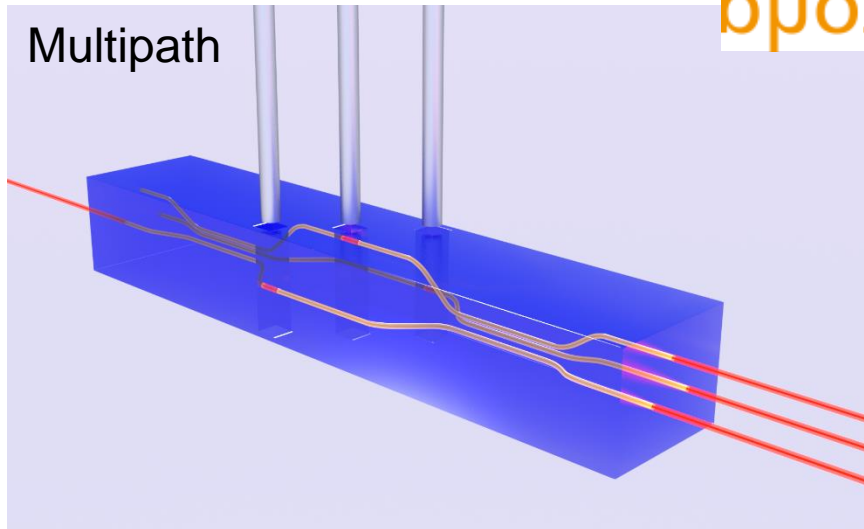
# Photonics Projects

Quantum Dots



photonik  
bionics

Multipath



Waveguides

