Hibrid Halide Perovskite: A game changer for telecommunication?

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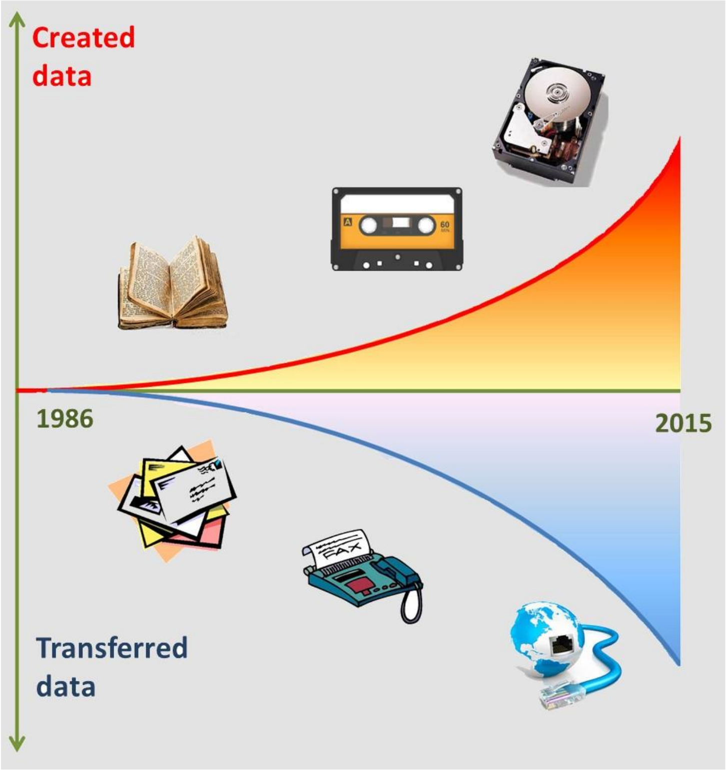
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Motivation

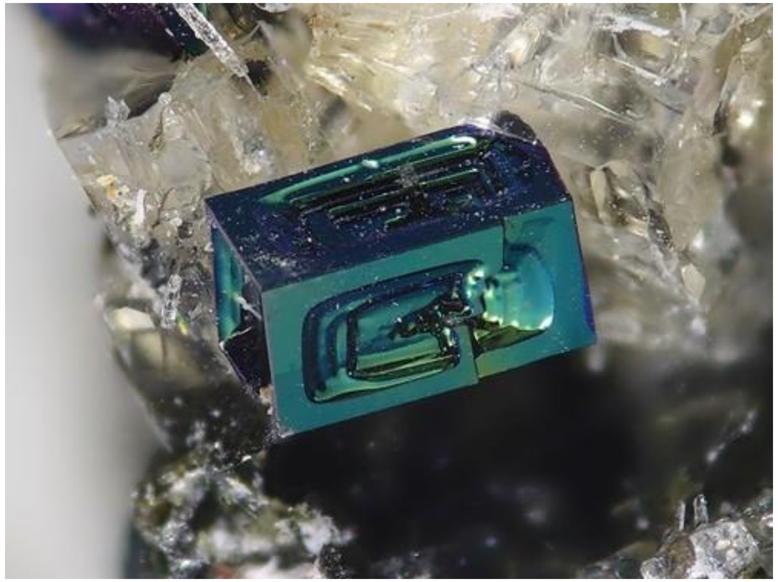
- Digital Universe:
- Today: 12 trillion gigabytes
- In 2020: 44 trillion gigabytes



M. Hilbert and P. López, Science **332** (6025), 60-65

Perovskites

Perovskite $CaTiO_3$

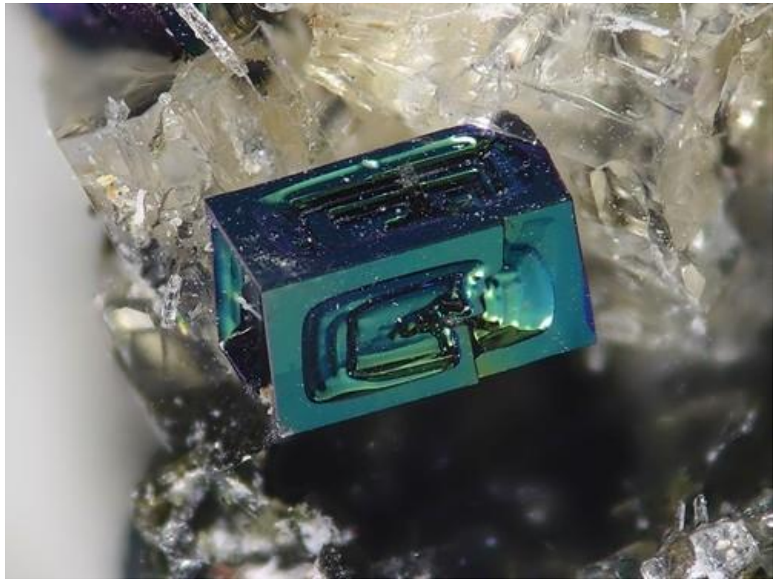


Lev Perovski

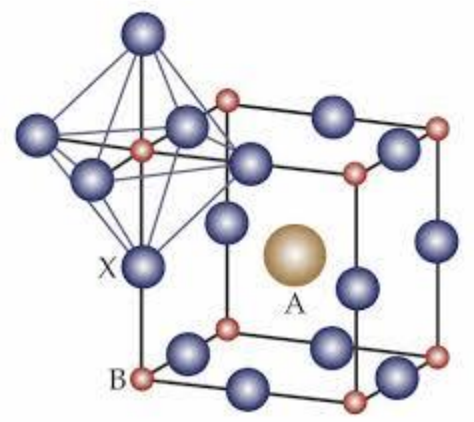
wikipedia

Perovskites

Perovskite $CaTiO_3$



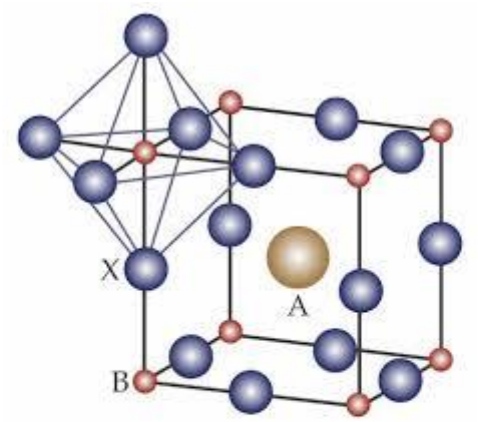
Lev Perovski



ABX$_3$

wikipedia

Hybrid Halide Perovskites



ABX_3

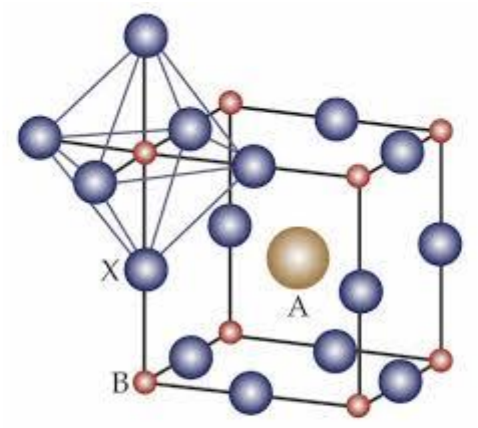
$A = Cs, CH_3NH_3, CH_5N_2$

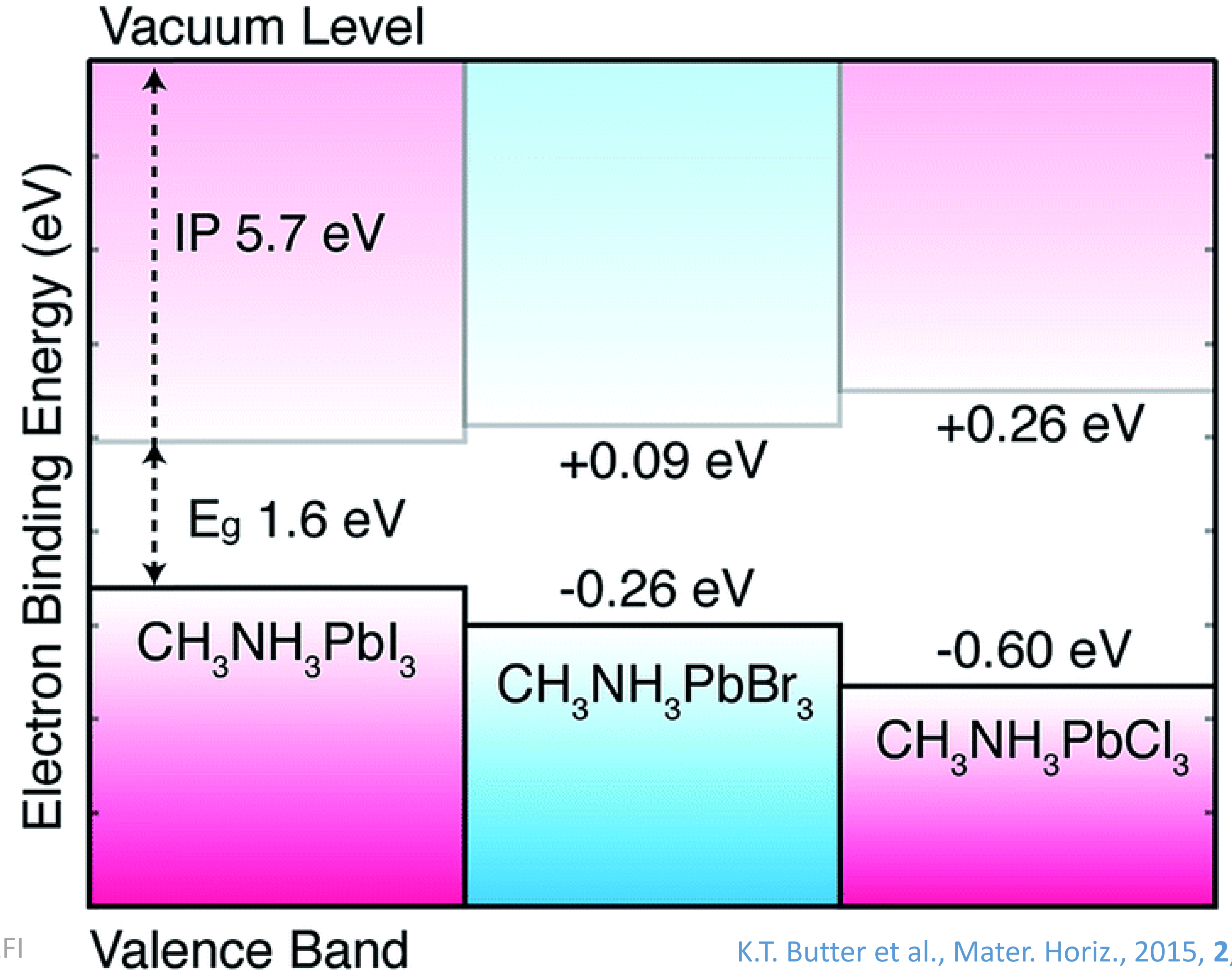
$B = Pb, Sn, Mn, Co, Cr, Fe$

$X = Cl, Br, I$

wikipedia

Hybrid Halide Perovskites





K.T. Butter et al., Mater. Horiz., 2015, **2**, 228-231

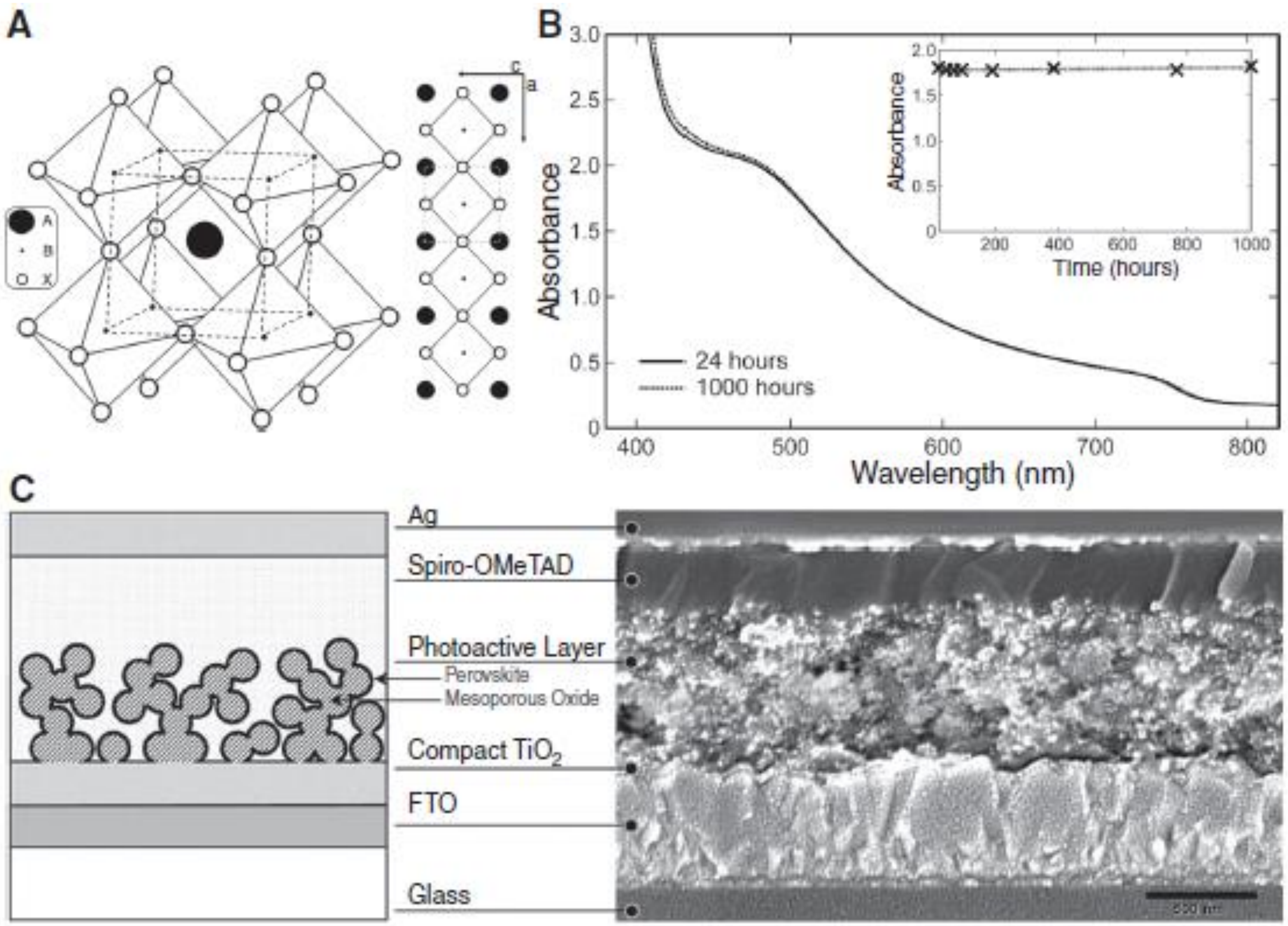
Efficient Hybrid Solar Cells Based on Meso-Superstructured Organometal Halide Perovskites $CH_3NH_3PbI_3$

Michael M. Lee,[1] Joël Teuscher,[1] Tsutomu Miyasaka,[2] Takurou N. Murakami,[2,3] Henry J. Snaith[1]*

The energy costs associated with separating tightly bound excitons (photoinduced electron-hole pairs) and extracting free charges from highly disordered low-mobility networks represent fundamental losses for many low-cost photovoltaic technologies. We report a low-cost, solution-processable solar cell, based on a highly crystalline perovskite absorber with intense visible to near-infrared absorptivity, that has a power conversion efficiency of 10.9% in a single-junction device under simulated full sunlight. This "meso-superstructured solar cell" exhibits exceptionally few fundamental energy losses; it can generate open-circuit photovoltages of more than 1.1 volts, despite the relatively narrow absorber band gap of 1.55 electron volts. The functionality arises from the use of mesoporous alumina as an inert scaffold that structures the absorber and forces electrons to reside in and be transported through the perovskite.

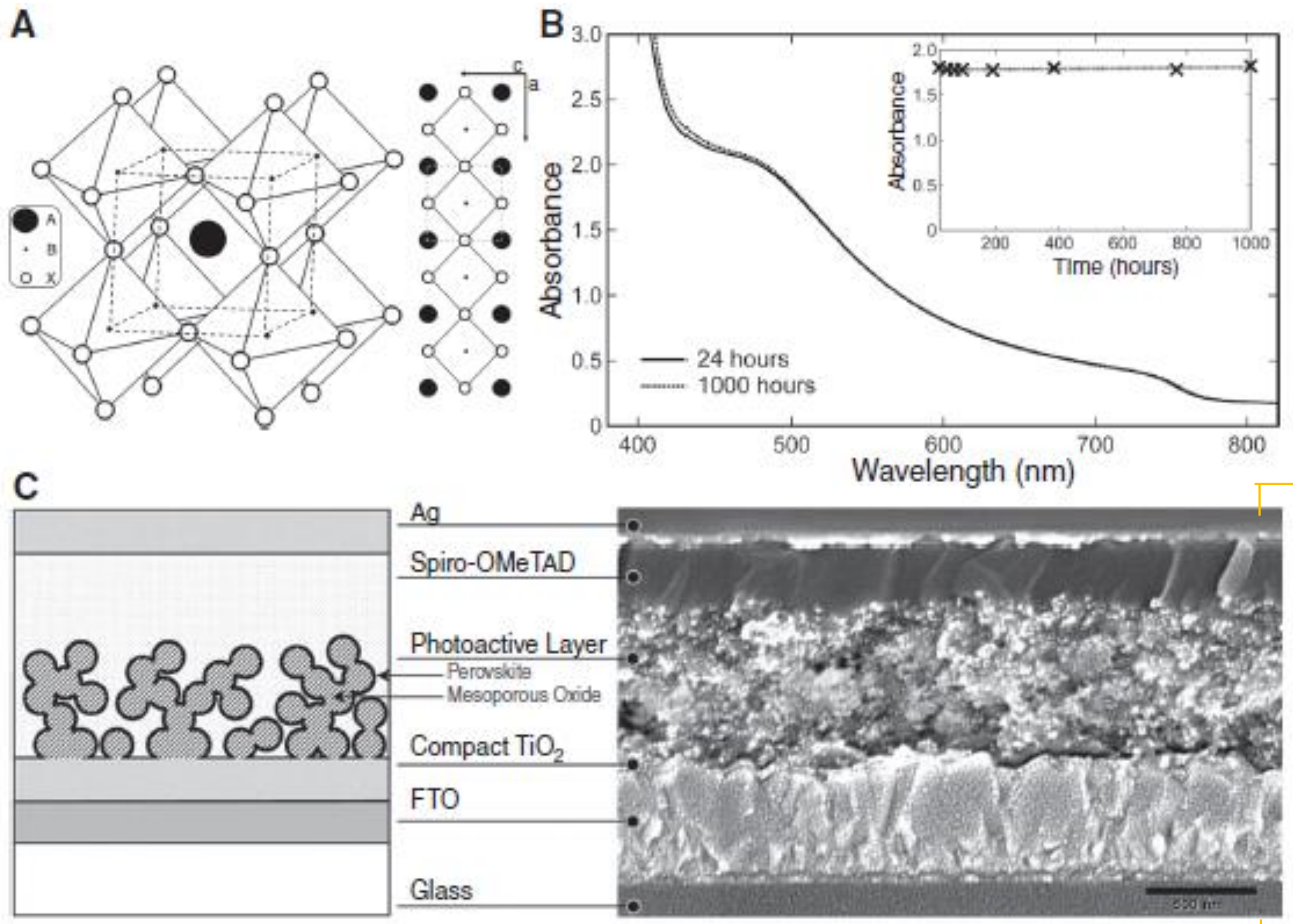
SCIENCE VOL 338 2 NOVEMBER 2012

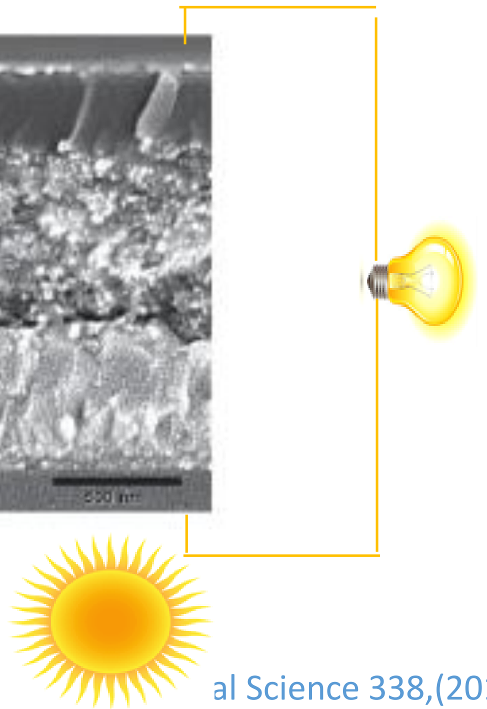
CH_3NH_3
Pb
I



M.M. Lee et al Science 338,(2012)

CH_3NH_3
Pb
I

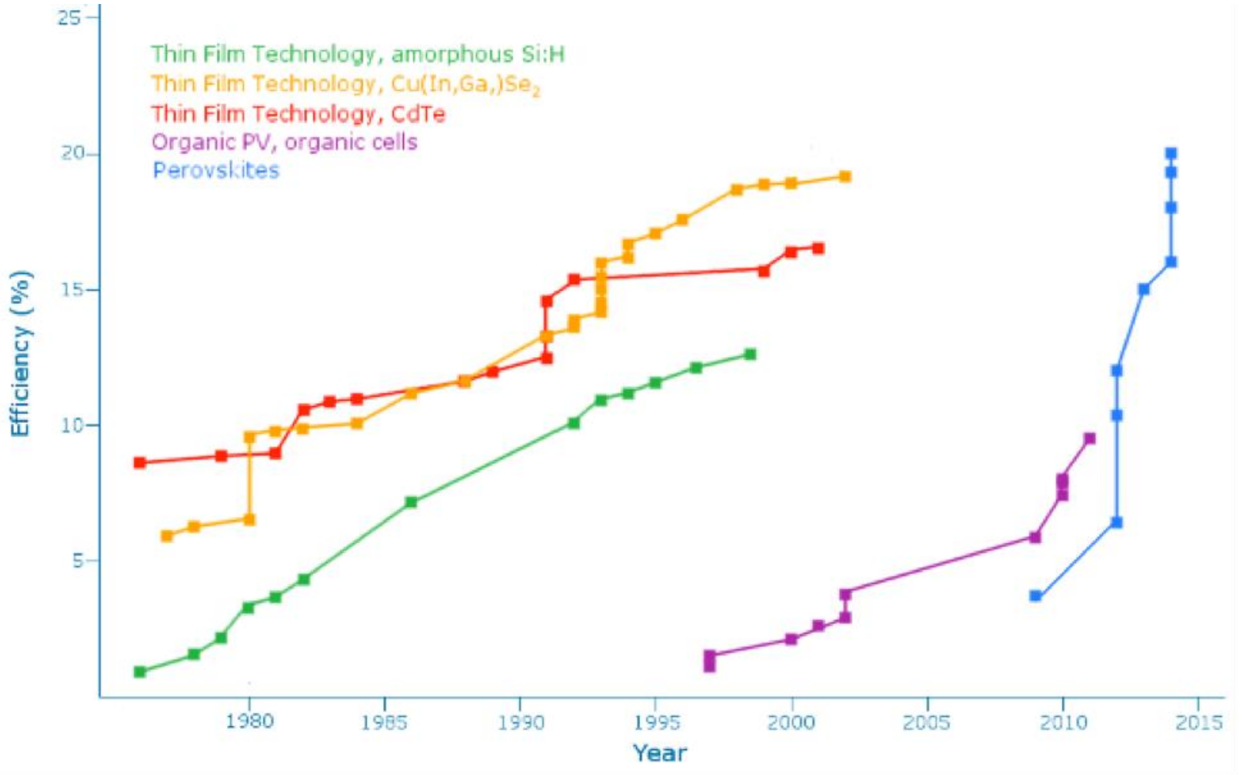




η: 22%

al Science 338,(2012)

It is a gold rush



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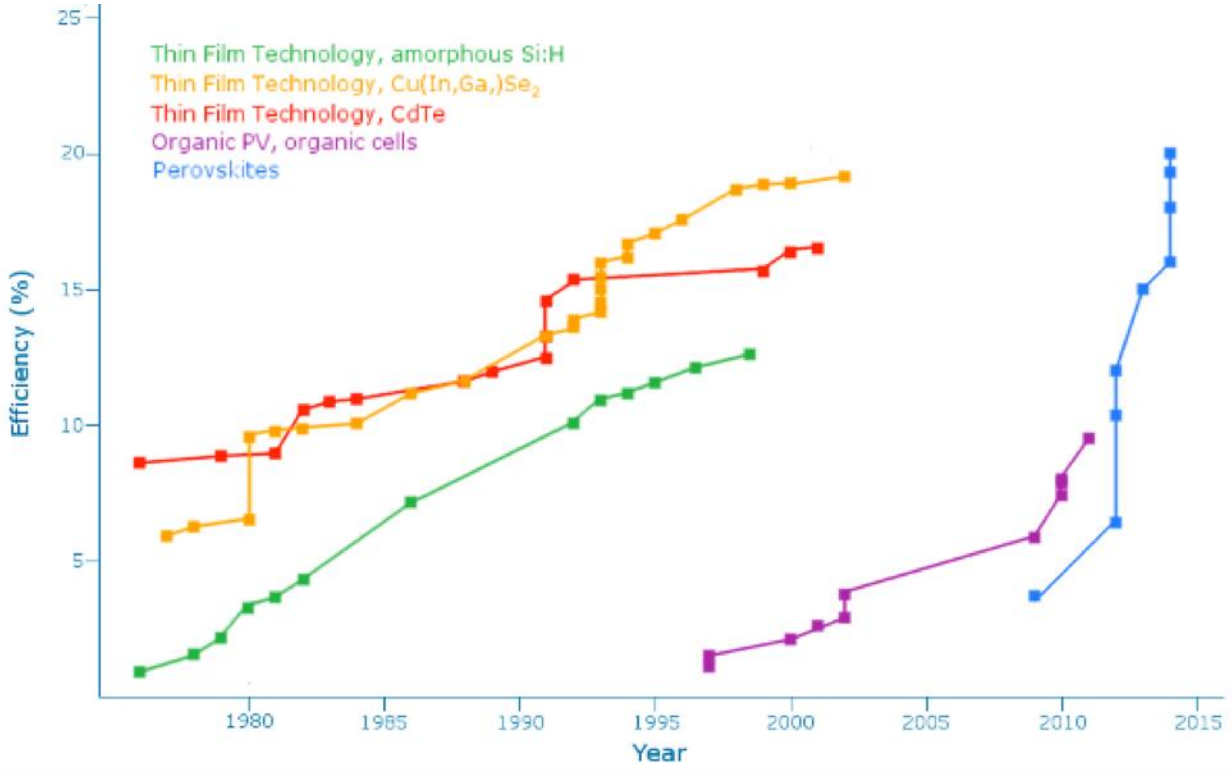
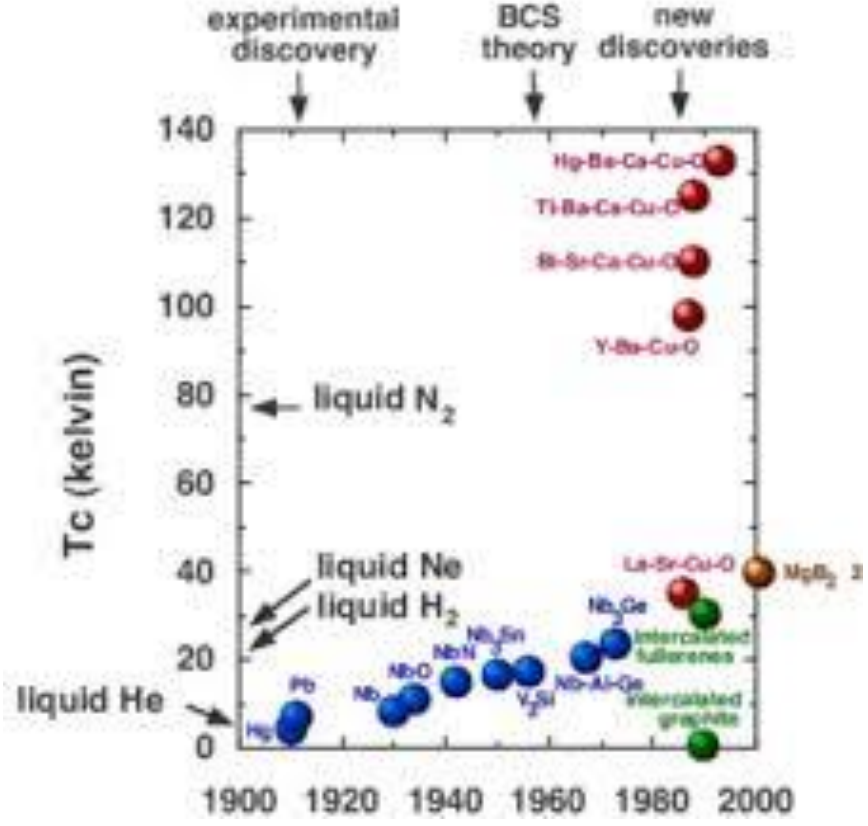




ossila.com; wou.edu

Why is it so good?

Absorption coefficient 10^5 cm^{-1}
Photo electron diffusion length 10-300 μm
mobility 2000 $cm^2(Vs)^{-1}$
lifetime 1-5 μs

L.M. Herz ACS Energy Lett. 2017, 2, 1539

Why is it so good?

Absorption coefficient 10^5 cm^{-1}

Photo electron diffusion length 10-300 μm

mobility 2000 $cm^2(Vs)^{-1}$

lifetime 1-5 μs

Direct- indirect band gap

Ferroelectricity

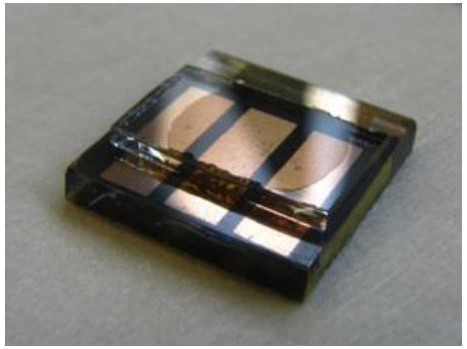
Ionic conduction

polarons

L.M. Herz ACS Energy Lett. 2017, 2, 1539

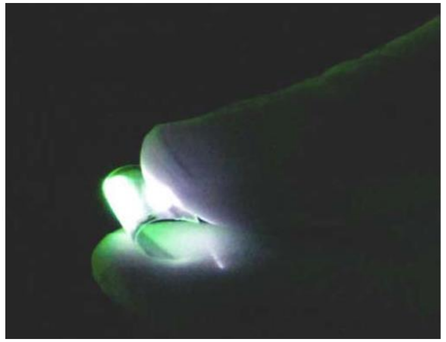
Broad range of applications

Photovoltaics



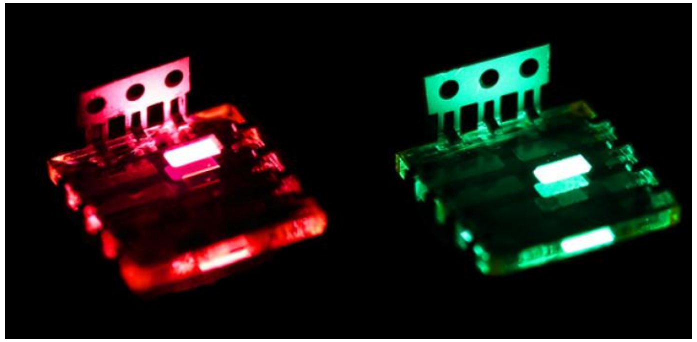
www.rsc.org

Laser



Nature Materials 13, 476–480 (2014)

LEDs

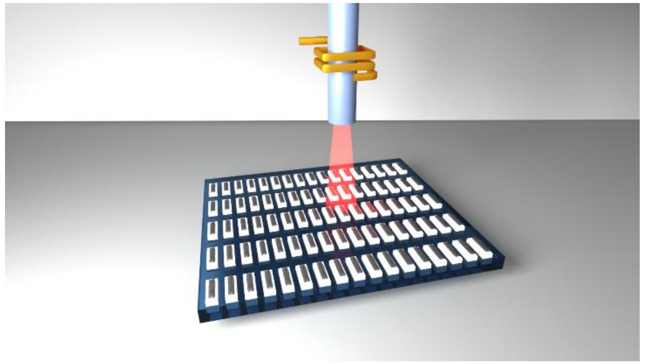


Nature Nanotechnology 9, 687–692 (2014)

Harvesting energy from alternative suns

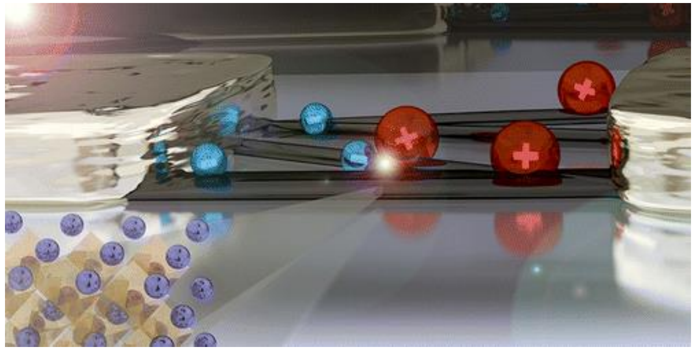
J.Phys.Chem.C. 119, 25204-25208, (2015)

Magnetic data storage



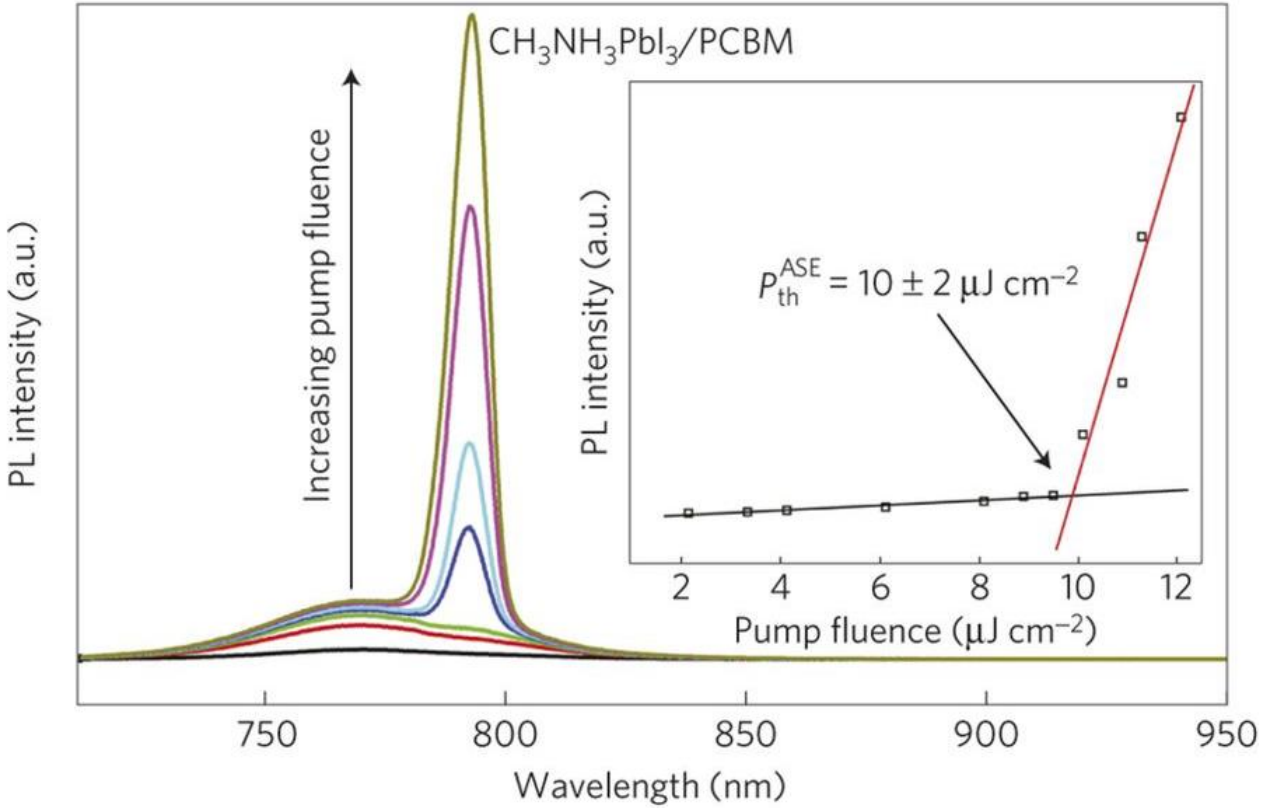
Nature Comm 7, 13406, (2016)

Photodetectors



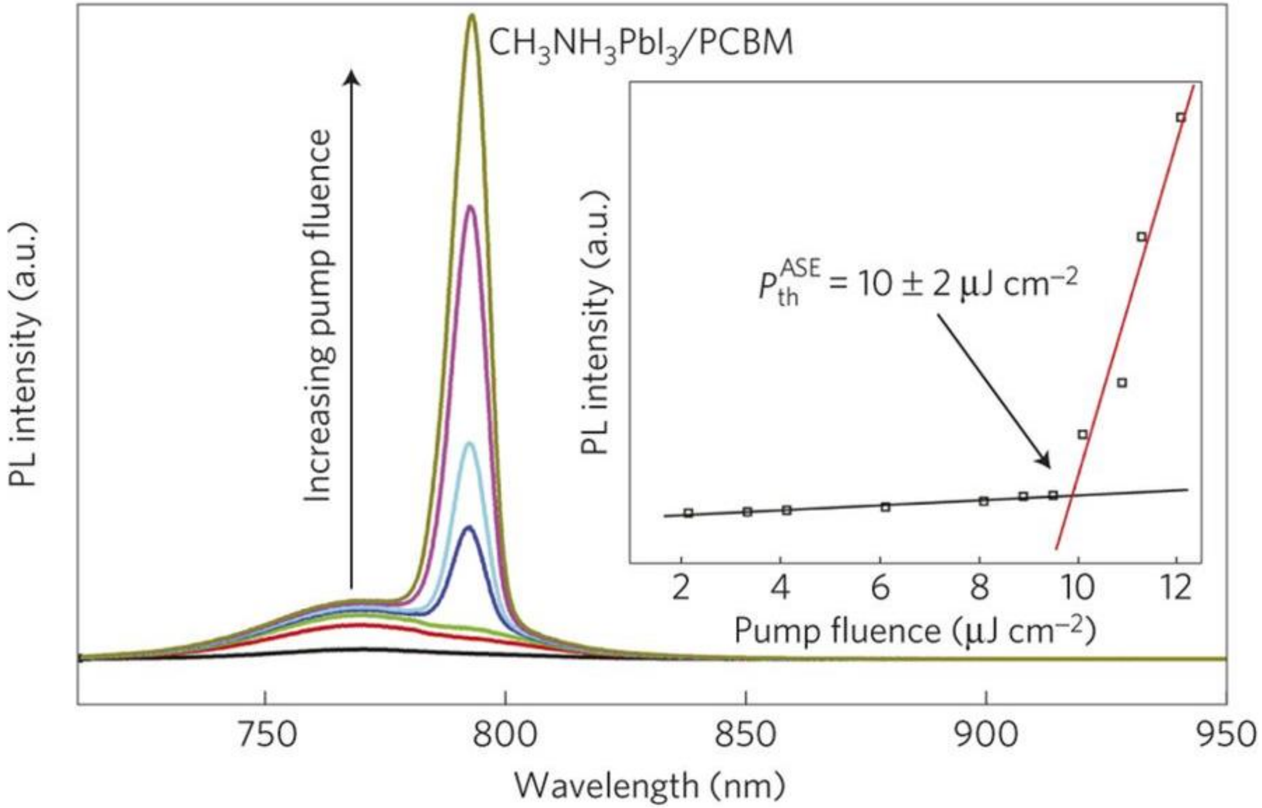
Nano Letters 14 (12), 6761–6766 (2014)

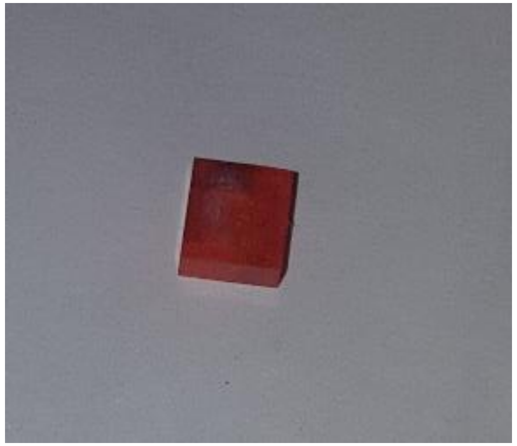
laser



Xing et al Nature Materials **13**, pages 476–480 (2014)

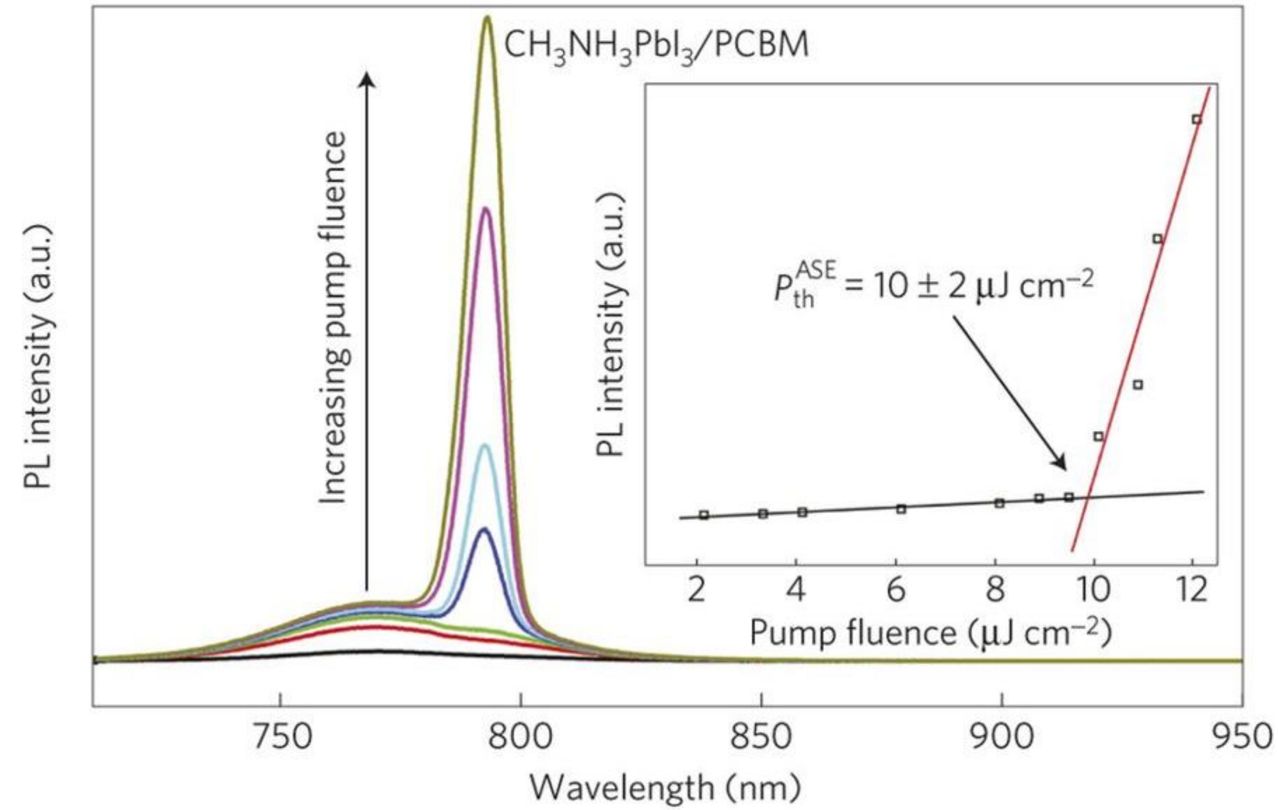
laser

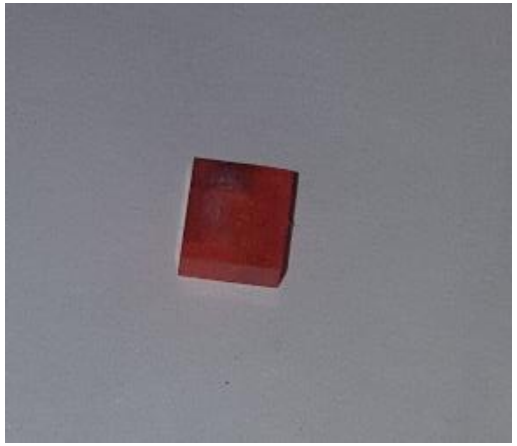


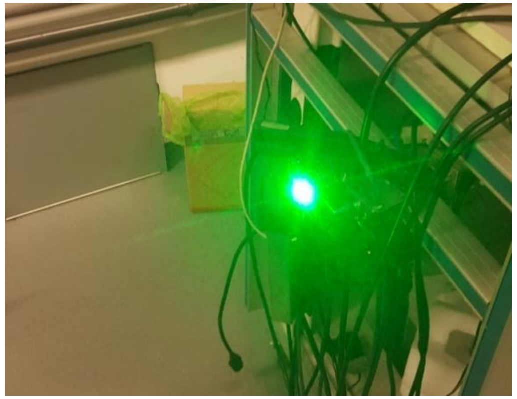


B.N. unpublished
Xing et al Nature Materials **13**, pages 476–480 (2014)

laser







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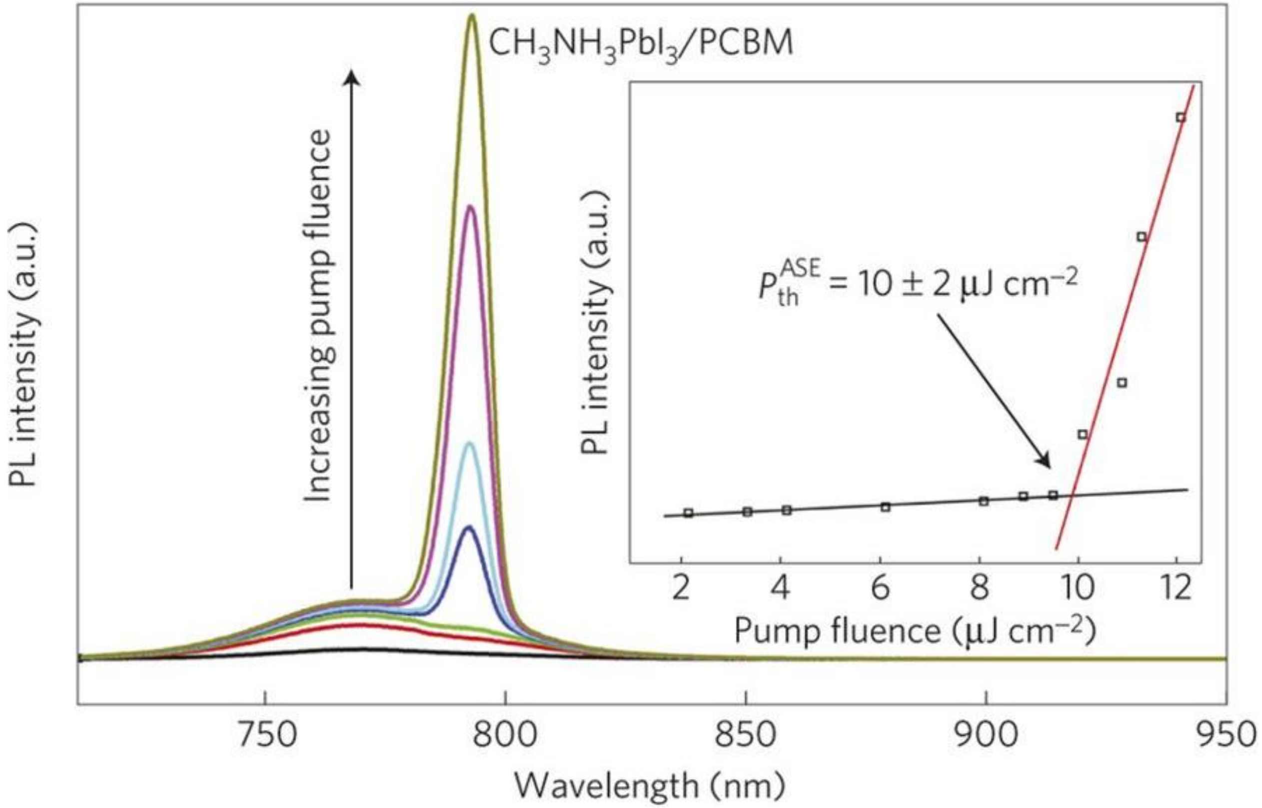
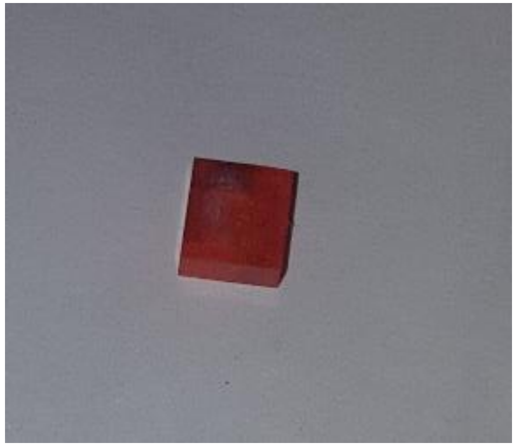
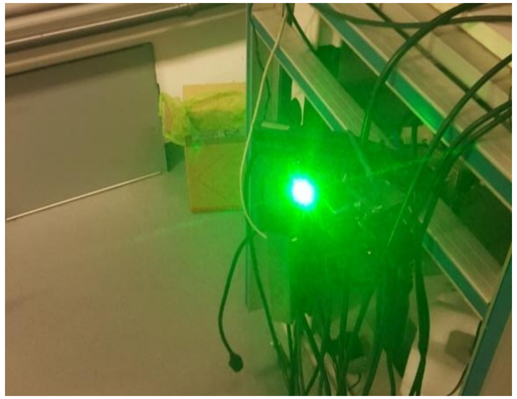


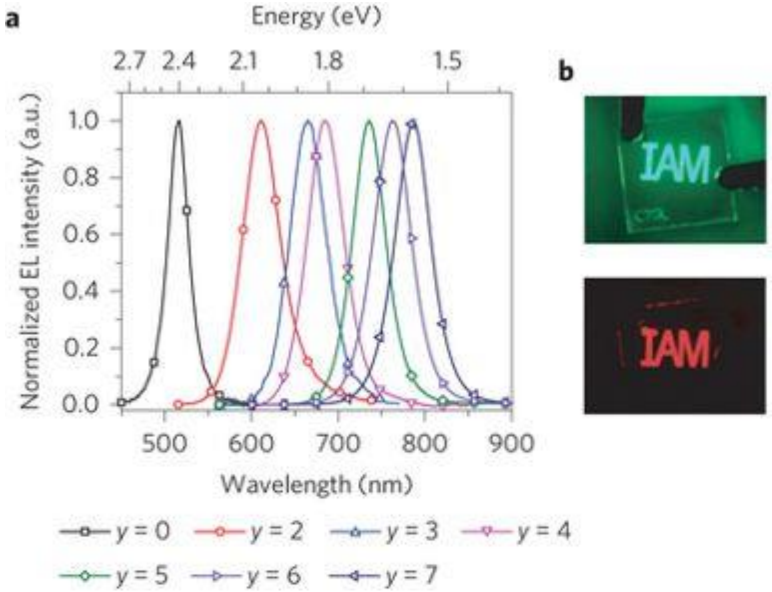




B.N. unpublished

Xing et al Nature Materials **13**, pages 476–480 (2014)

LEDs

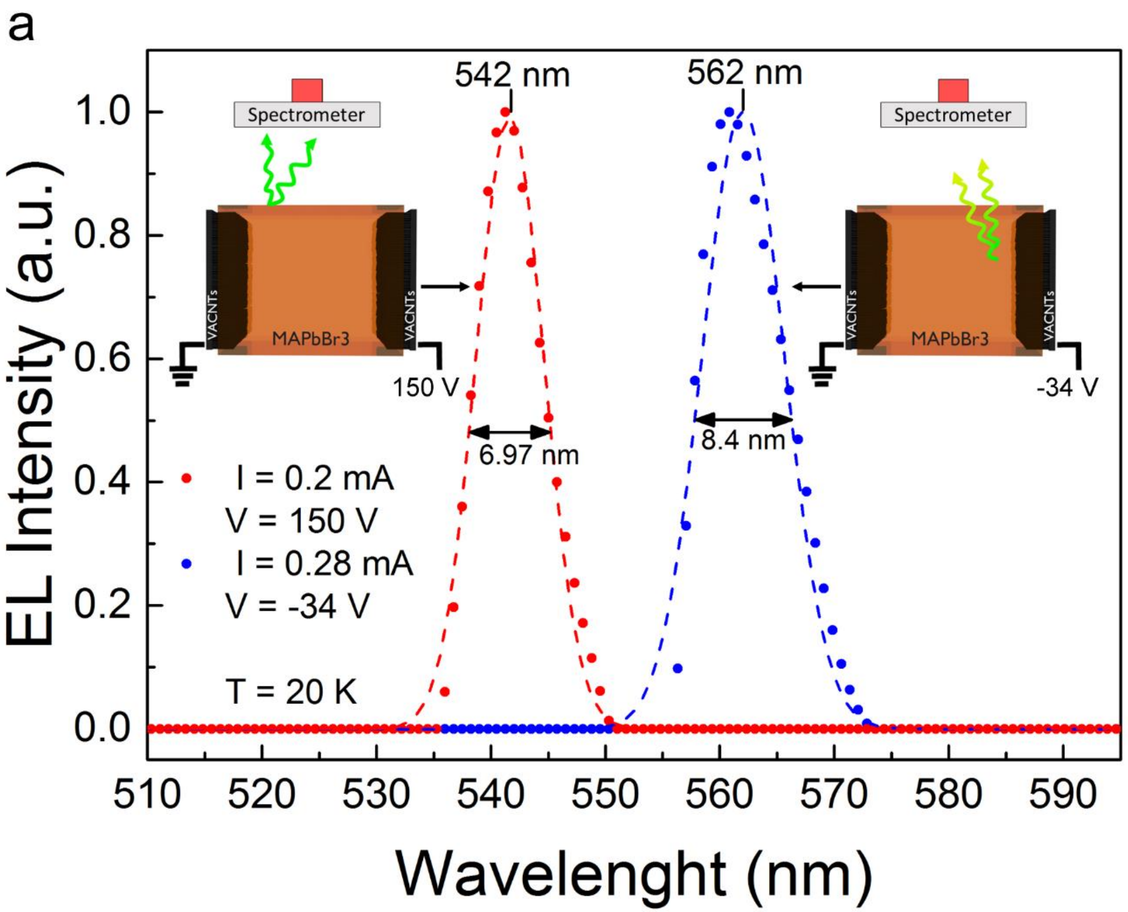


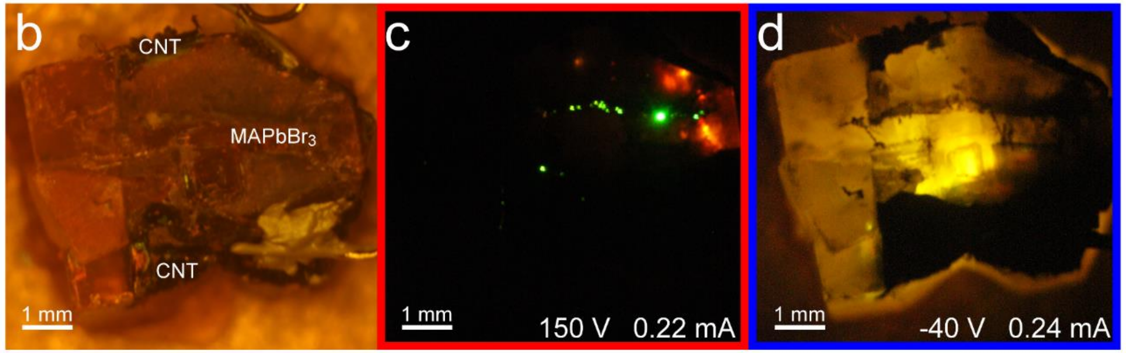
Energy conversion efficiency 5.5%
100 $mAcm^{-2}$

Wang et al Nature Photonics **10**, pages 699–704 (2016)

LEDs

a

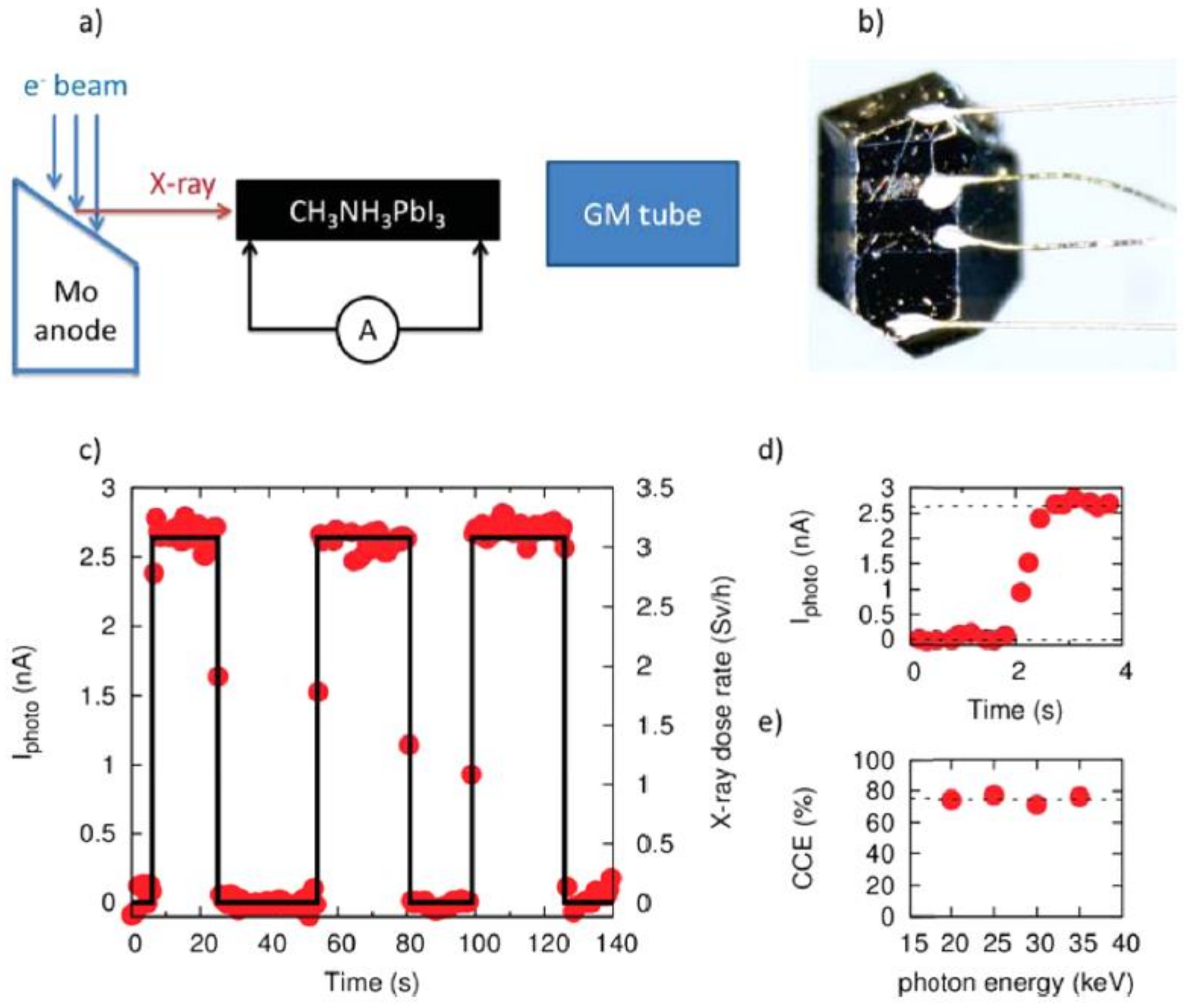


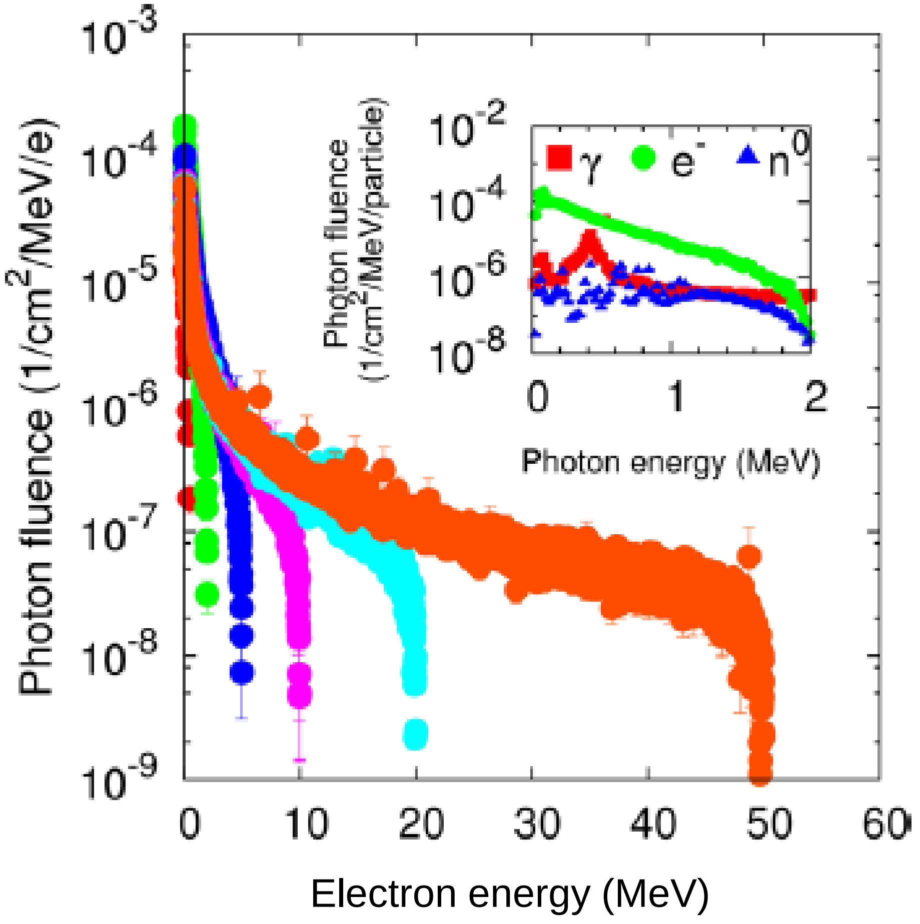


P. Andricevic, BN et al submitted


CAUTION
RADIOACTIVE

Efficient γ, e^-, n^0 to carrier conversion





B. Náfrádi et al J. Phys. Chem. C 2015, 119, 25204–25208

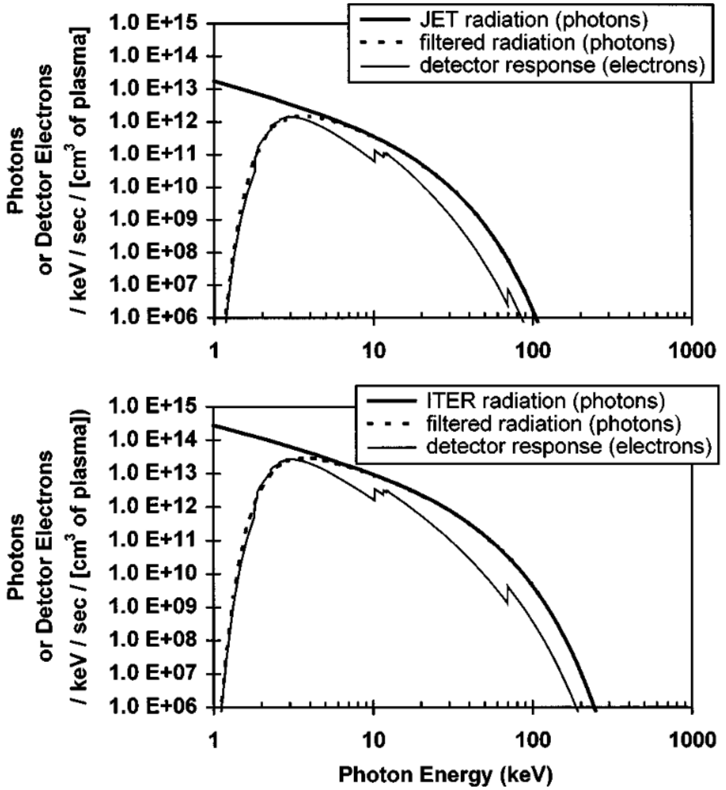
Why is it important?

B. Náfrádi et al J. Phys. Chem. C 2015, 119, 25204–25208

Why is it important?

ITER: 1.24×10^{12} p/cm^2/s @ 1 GW

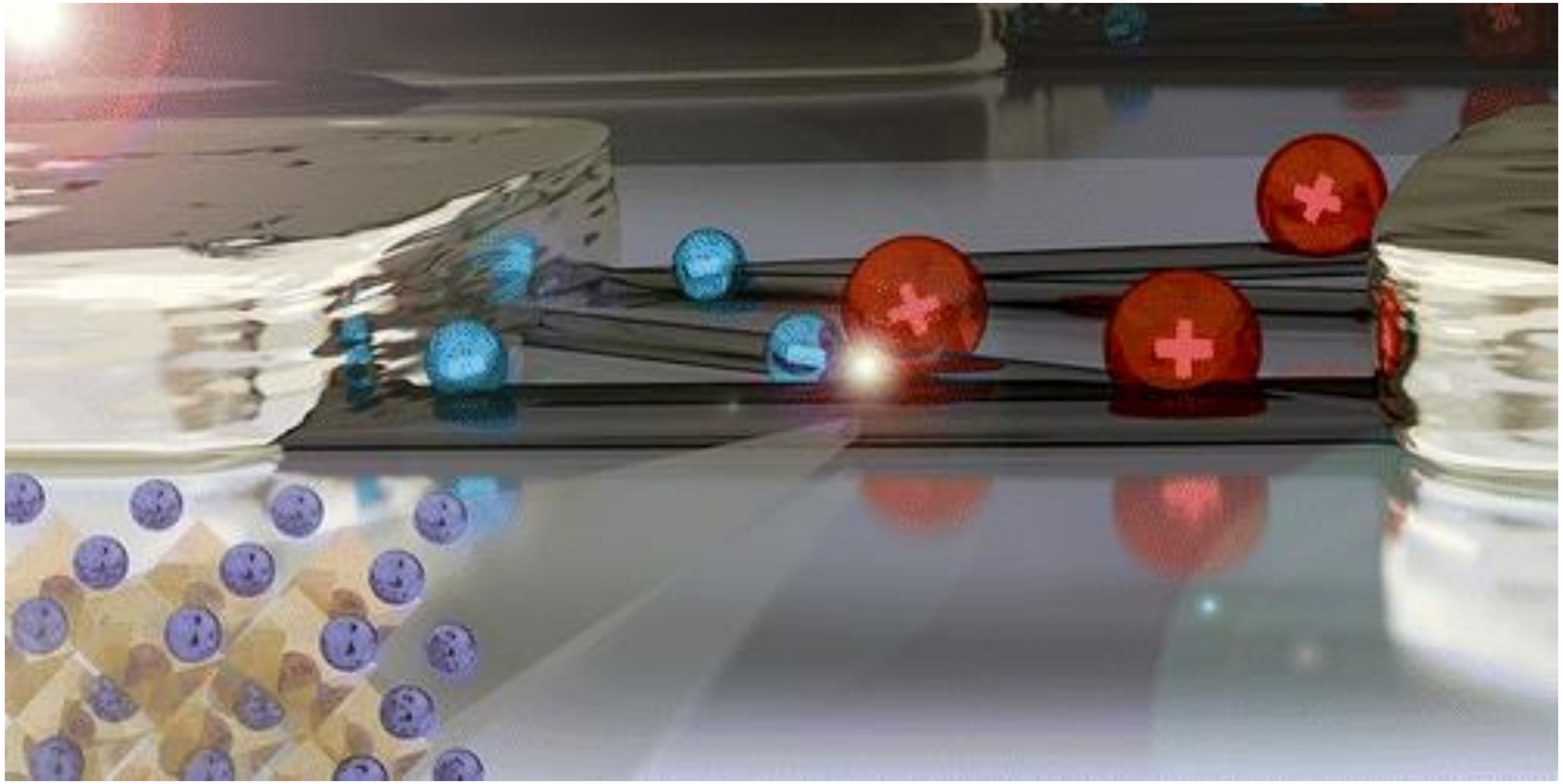
Which means ~450 kW



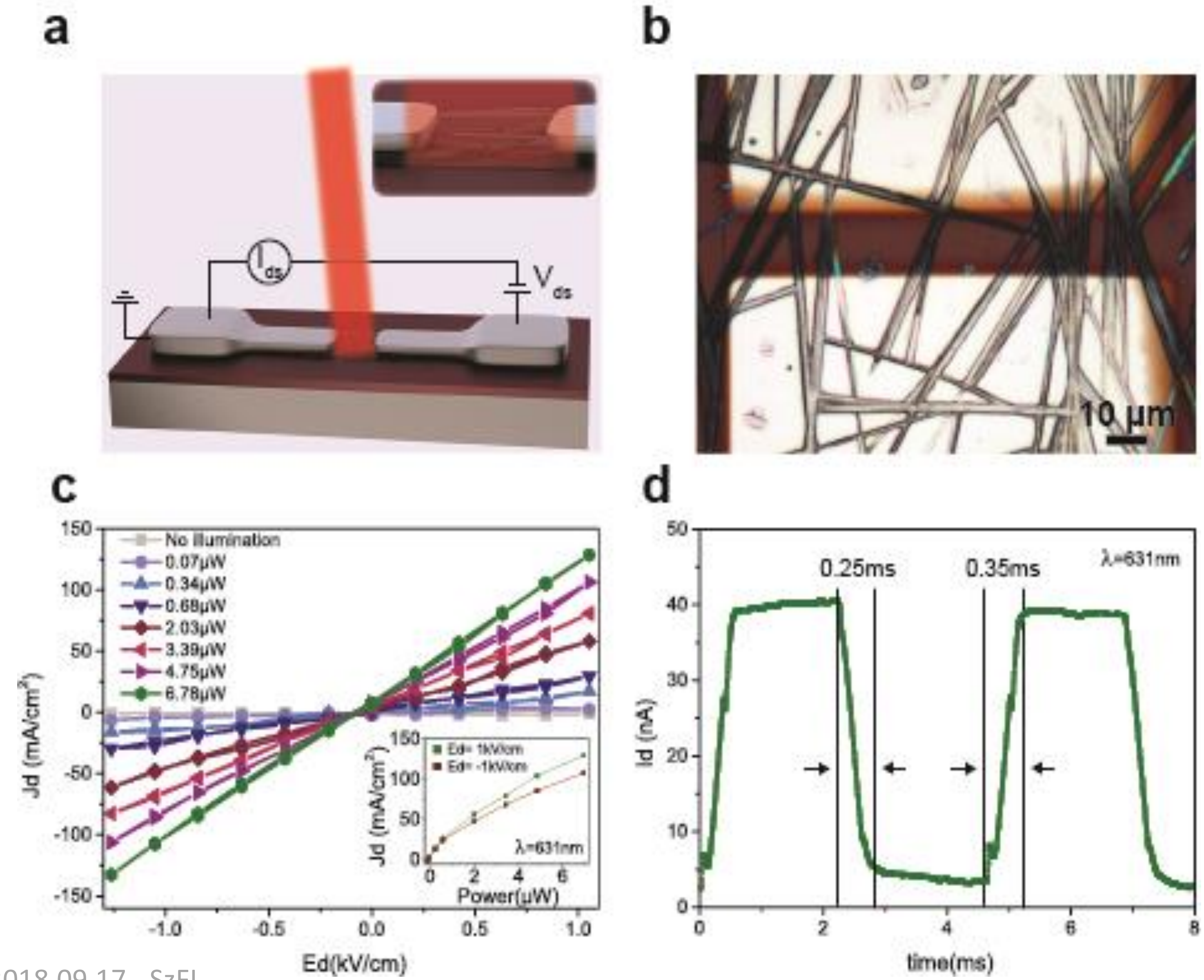
Seguin, F. H.; Petrasso, R. D.; Li, C. K. Radiation-hardened x-ray imaging for burning plasma tokamaks. Review of Scientic Instruments 1997, 68, 753

B. Náfrádi et al J. Phys. Chem. C 2015, 119, 25204–25208

Photodetectors

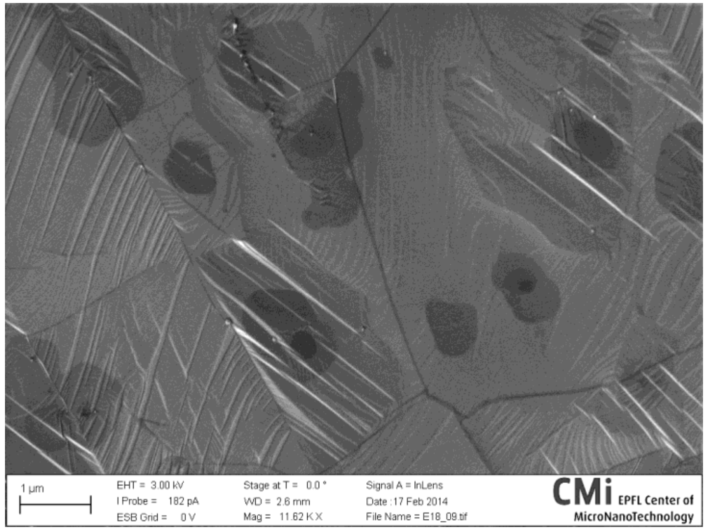


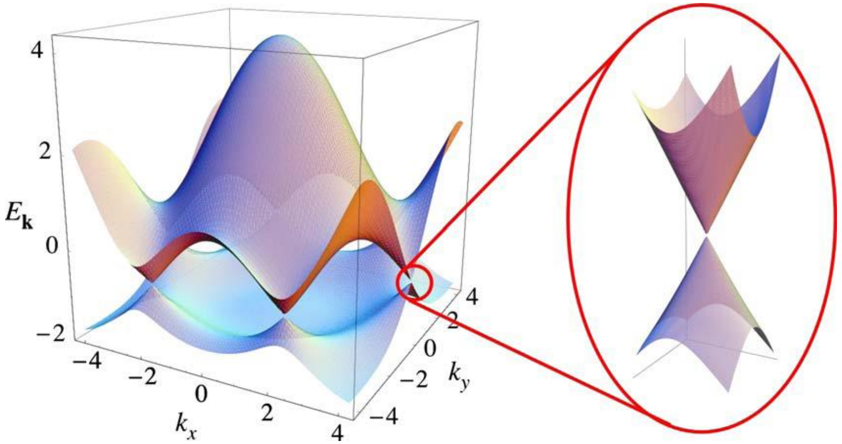
Photodetectors



Responsivity:
10 A/W

E. Horváth et al Nano Letters 14 (12), 6761–6766 (2014)





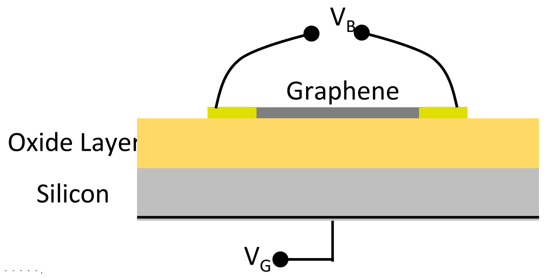
Graphene

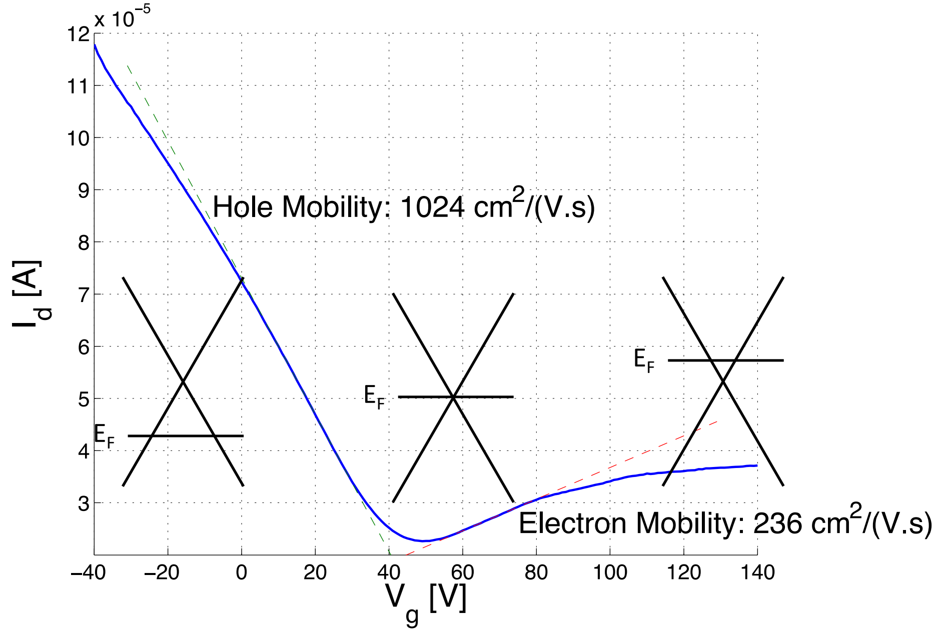
Synthesis:

- Mechanical exfoliation
- Epitaxial growth
- *Chemical vapor deposition (CVD)*

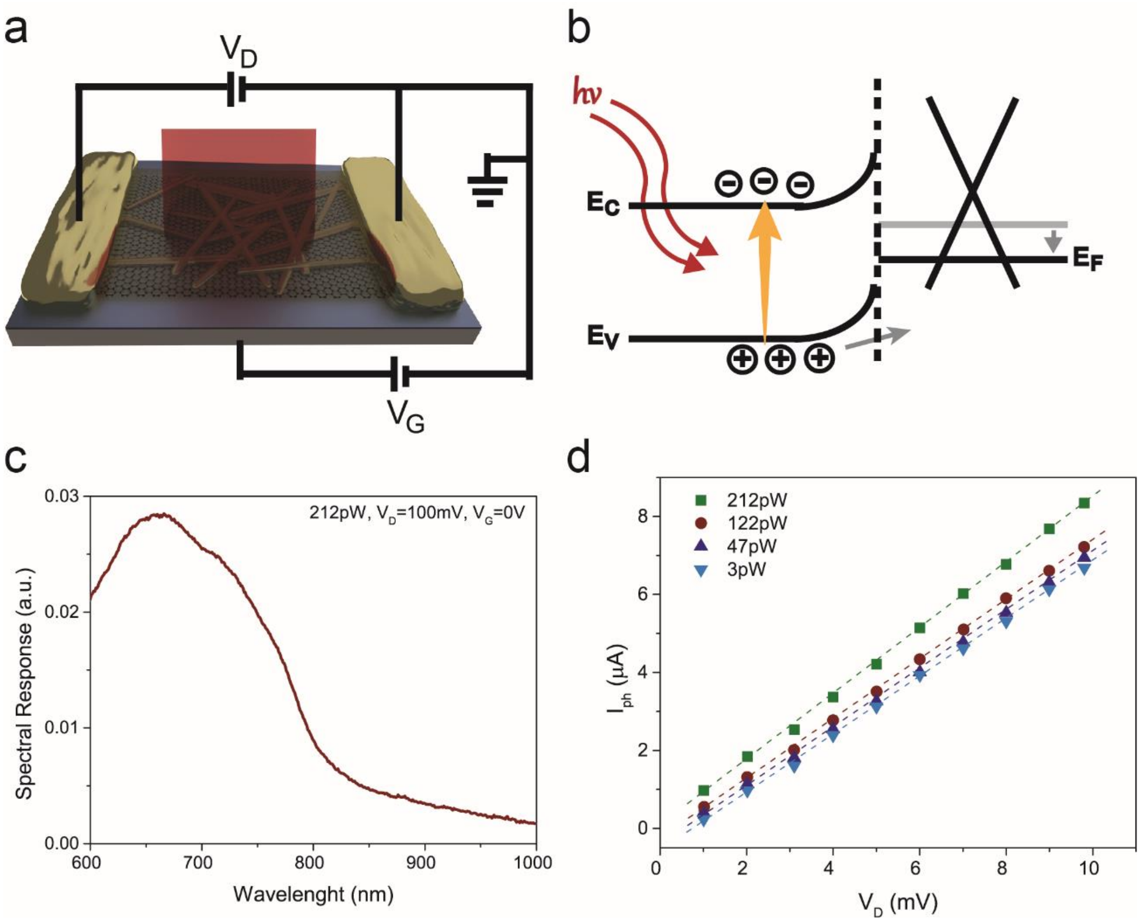
- 2D crystal
- Strong and hard
- Very Stretchable
- Nearly transparent
- High thermal conductivity
- High electrical conductivity

Graphene field effect transistor



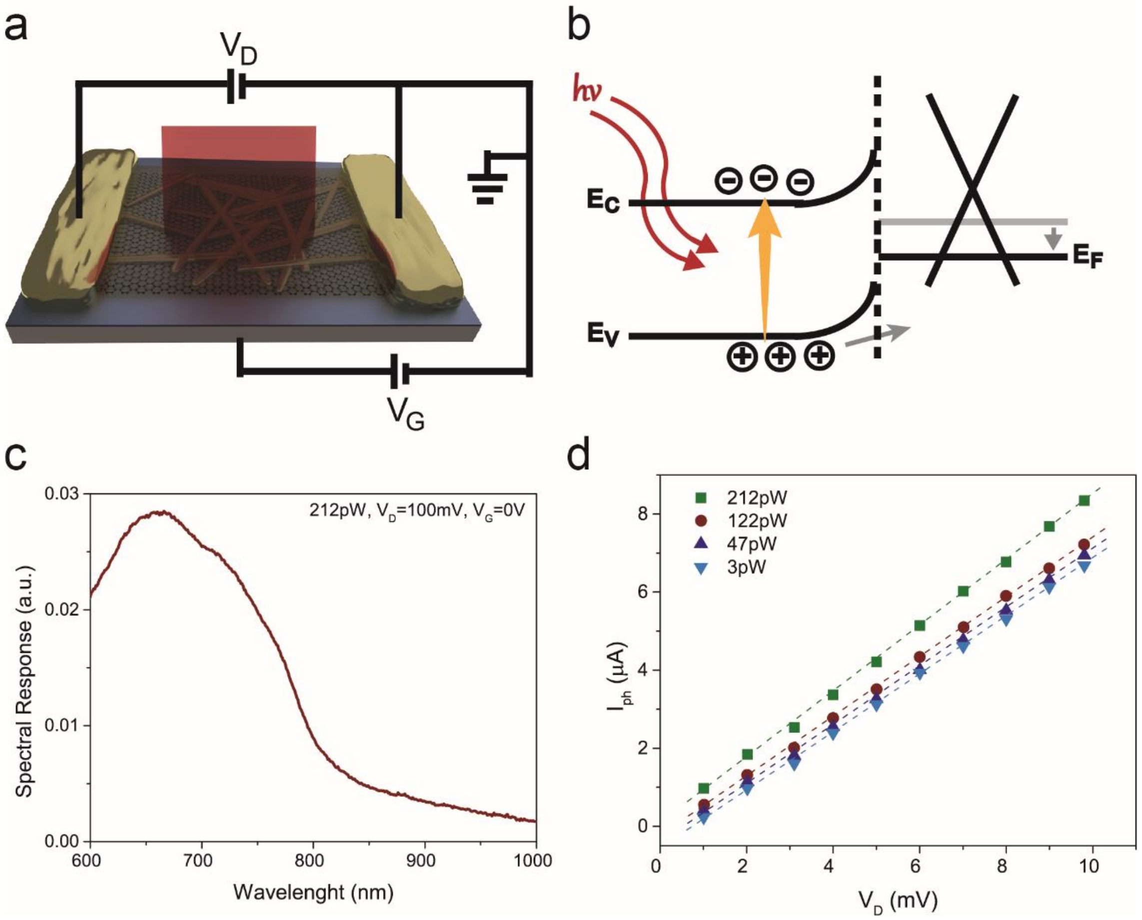


Photogating effect



Small **11**, 4824-4828, (2015); Scientific Reports, **6**, 19834, (2016)

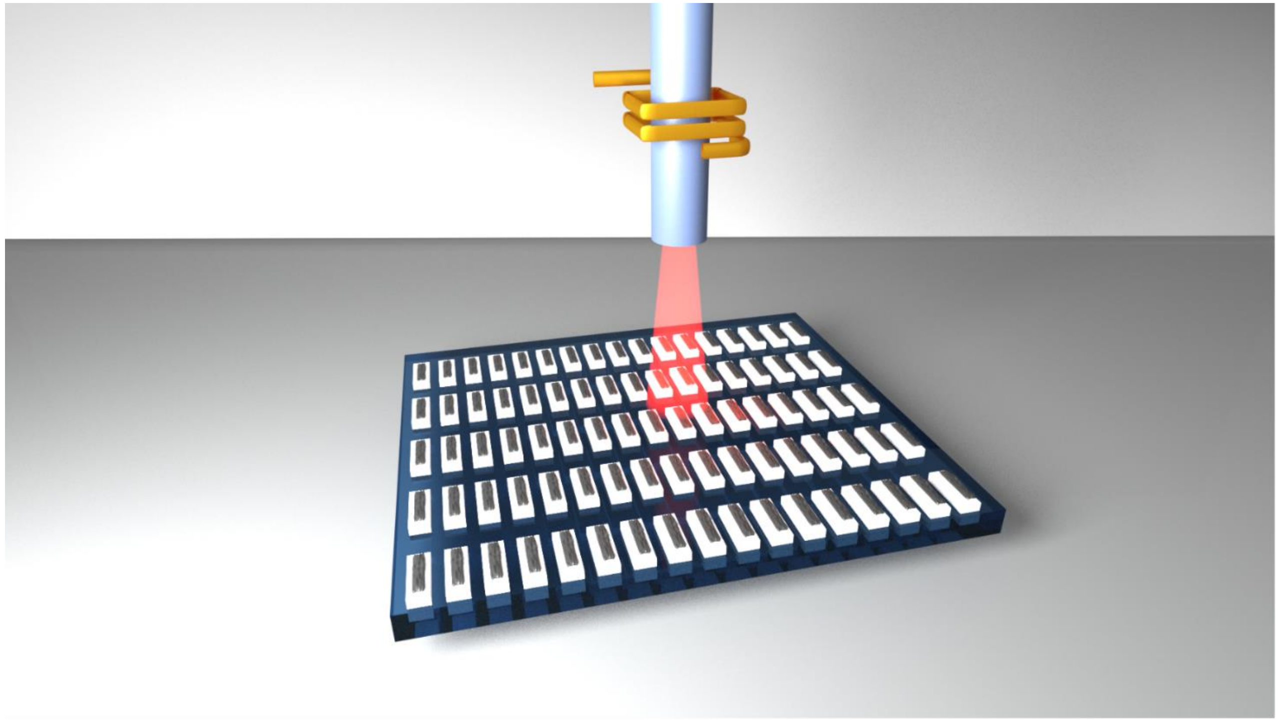
Hope for single photon sensitivity

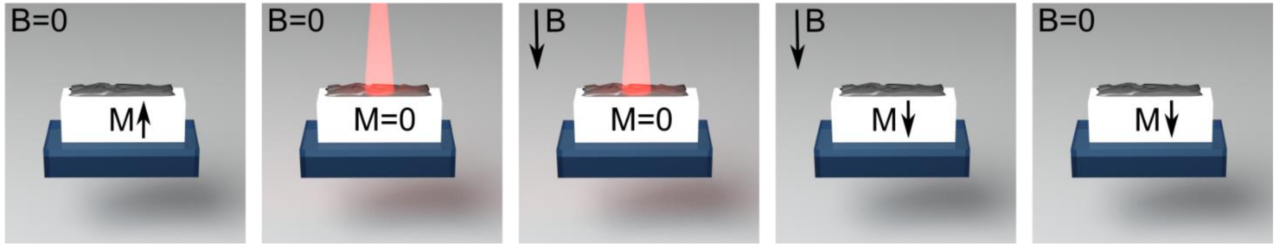


Responsivity: $\approx 2 \times 10^{6}$ A W^{-1}

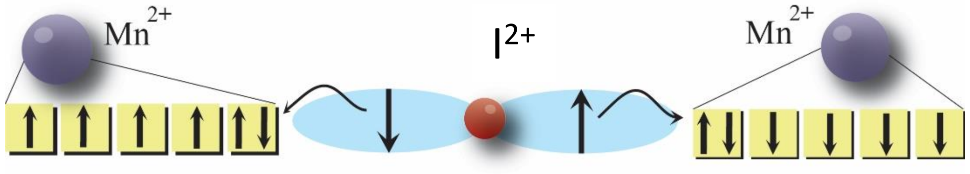
Small **11**, 4824-4828, (2015); Scientific Reports, **6**, 19834, (2016)

Magnetic data storage





Few word about magnets



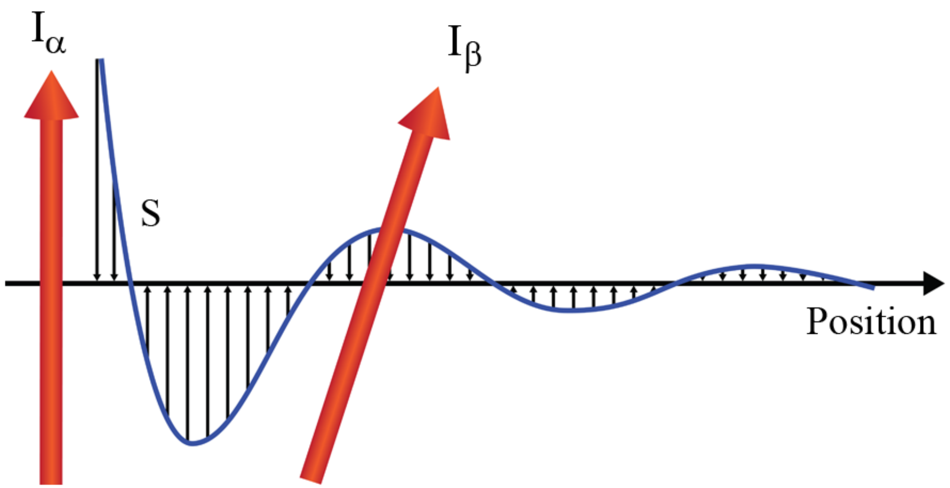
Insulator:

- Super Exchange

$$H_{ij}=2(t^2_{Mn,I}/U)S_i \cdot S_j$$

B. Náfrádi et al Nature Common, 7, 13406, (2016)

Few word about magnets



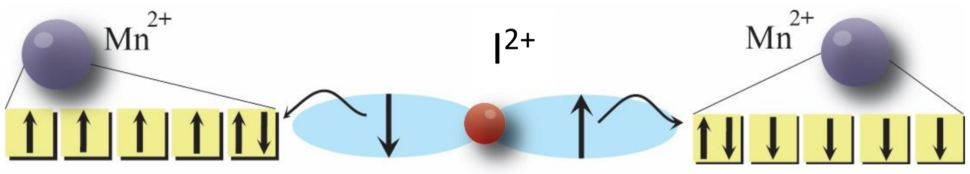
Conductor:

- RKKY

$$H_{ij}=S_i \cdot S_j A R_{ij}^{4}\,(2k_F R_{ij}\cos(2k_F R_{ij})-\sin(2k_F R_{ij}))$$

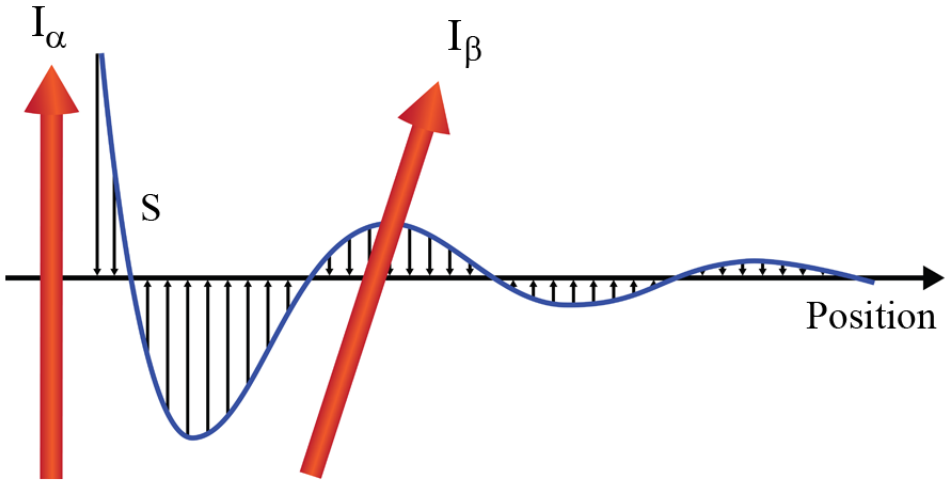
B. Náfrádi et al Nature Common, 7, 13406, (2016)

Magnetic photoconductor $CH_3NH_3(Pb:Mn)I_3$



Insulator (dark):
- Super Exchange

$$H_{ij}=2(t^2_{Mn,I}/U)S_i \cdot S_j$$



Conductor (light):
- RKKY

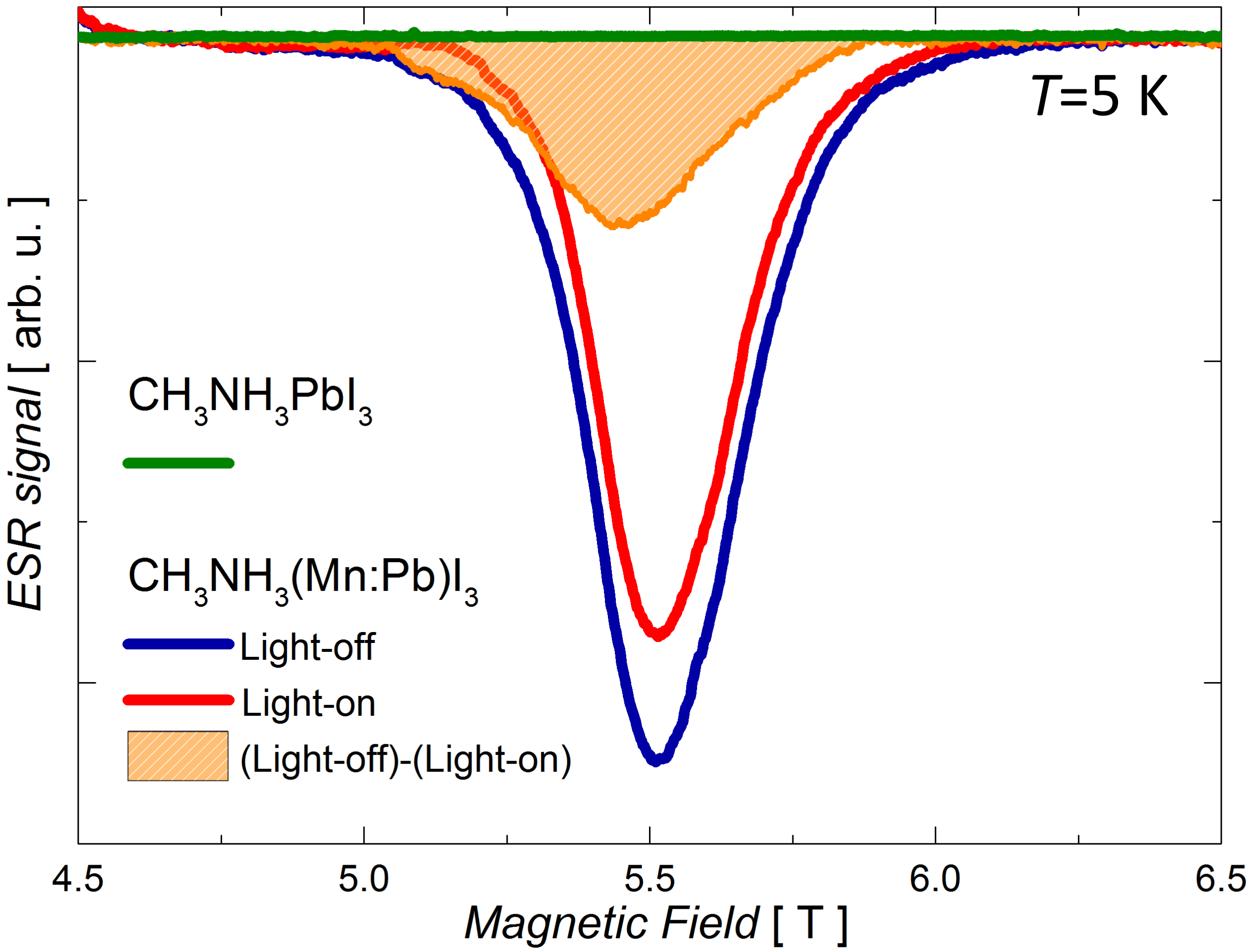
$$H_{ij}=S_i \cdot S_j A R_{ij}^{4} (2k_F R_{ij} cos(2k_F R_{ij}) - sin(2k_F R_{ij}))$$

The competition of the two interactions melts the magnetic order while illuminated.

B. Náfrádi et al Nature Common, 7, 13406, (2016)

Magnetic photoconductor $CH_3NH_3(Pb:Mn)I_3$

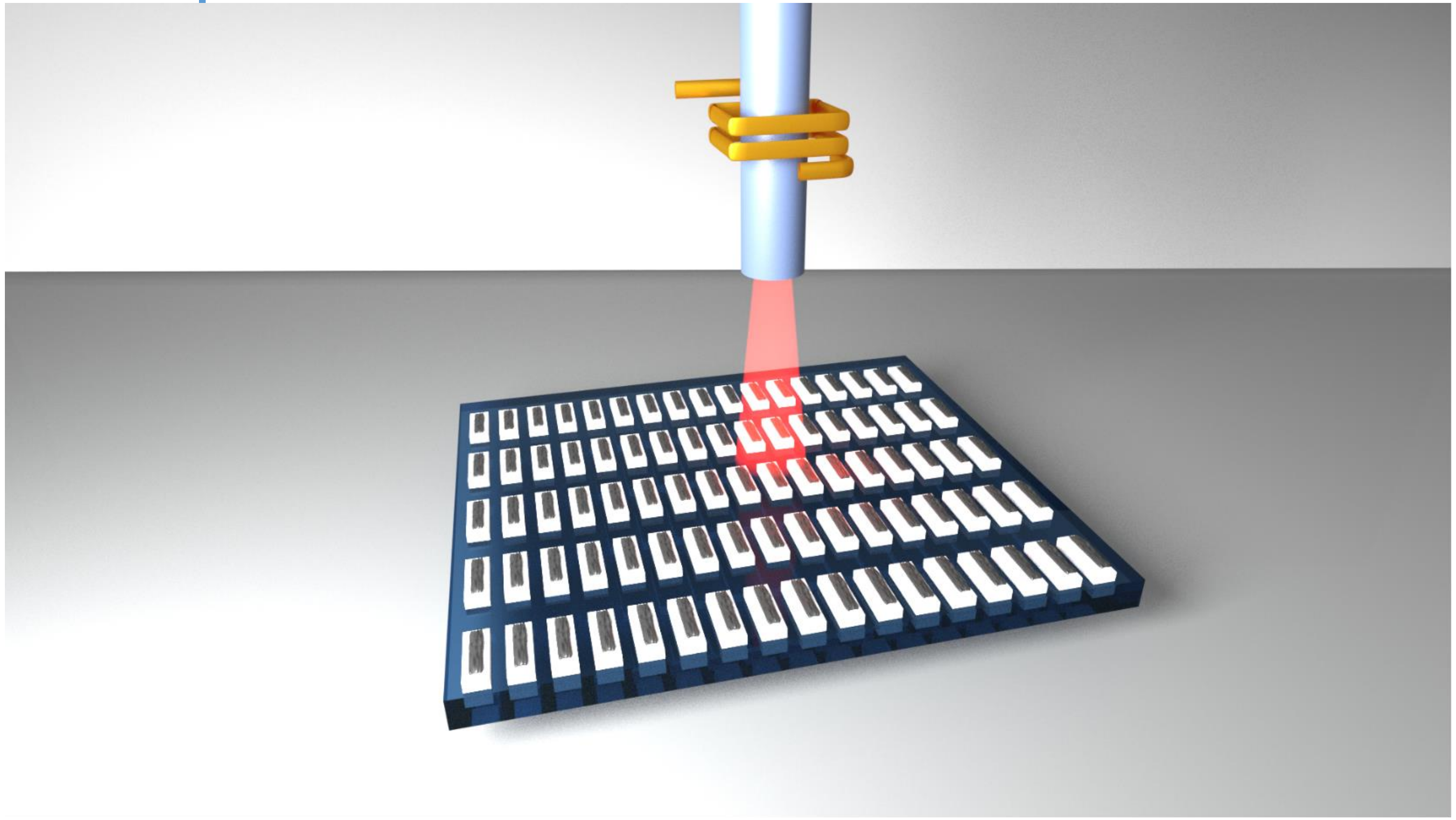
Magnetic properties under illumination

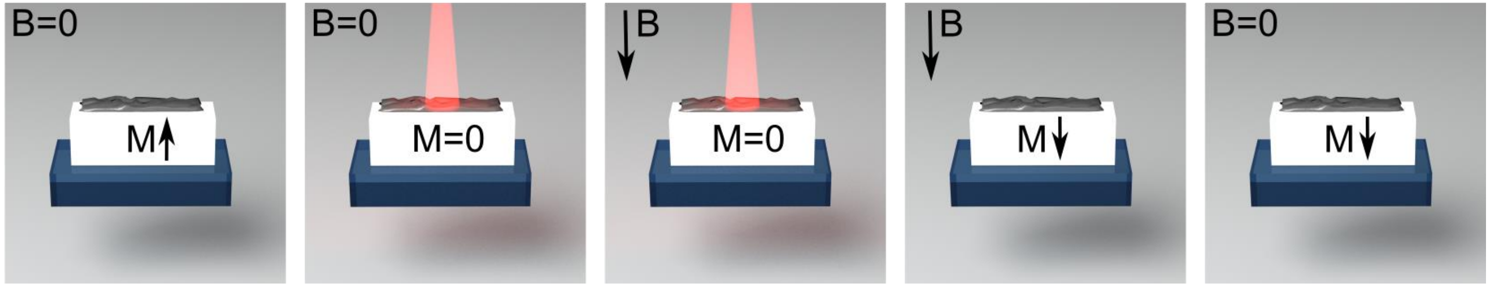


Melting of the ferromagnetic state with weak photoelectron generation

B. Náfrádi et al Nature Common, 7, 13406, (2016)

Magnetic photoconductors for data storage



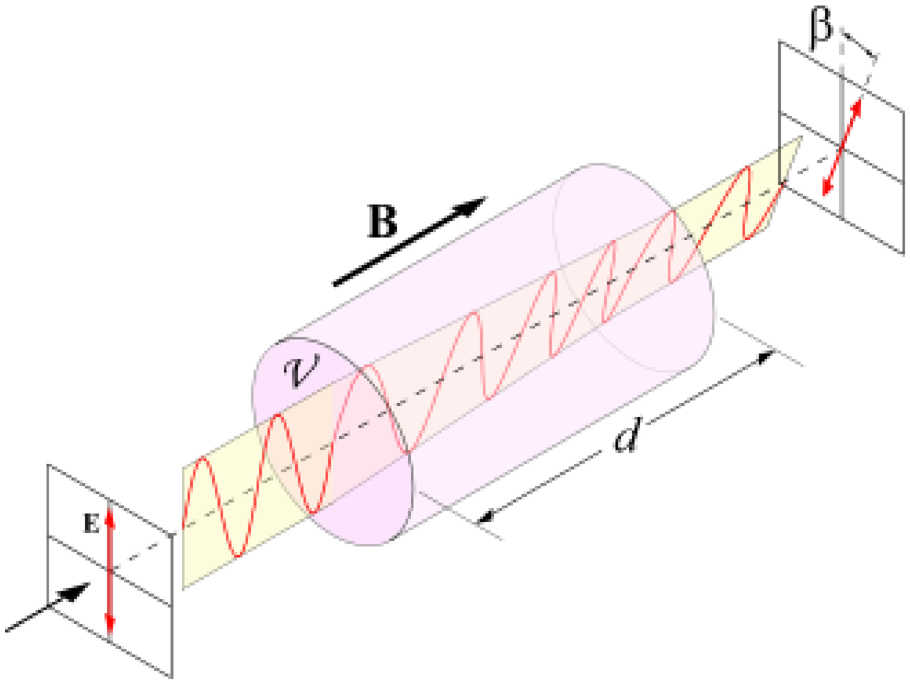


B. Náfrádi et al Nature Common, 7, 13406, (2016)

Magnetic photoconductors for telecommunication

Transmission speed ~ S/N (power/detector quality)
~ **bandwidth**

Faraday rotator:
$\beta = Bd\nu$



P. Szirmai, BN et al in preparation

Magnetic photoconductors for telecommunication

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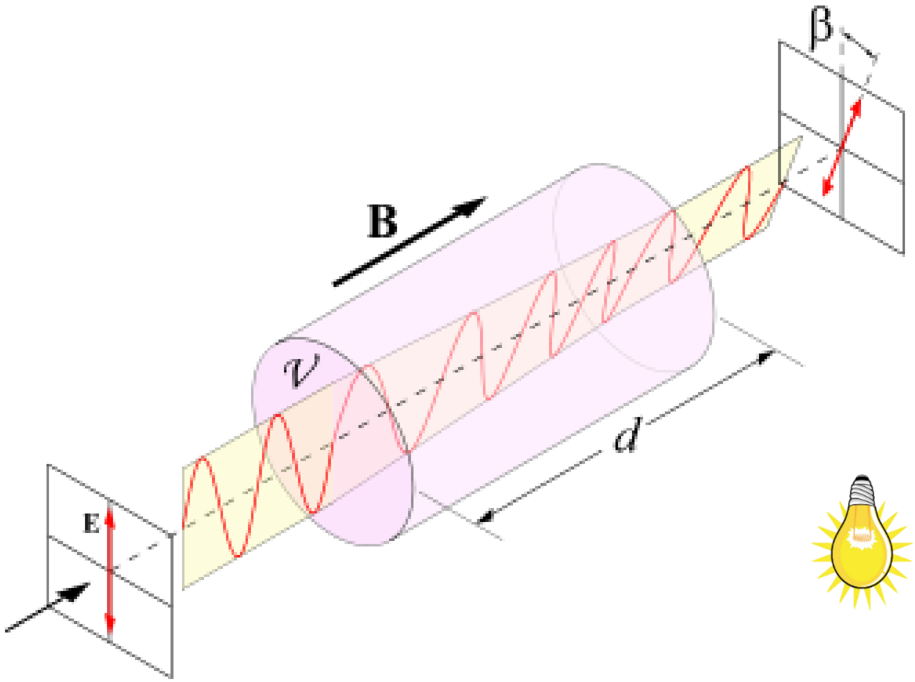

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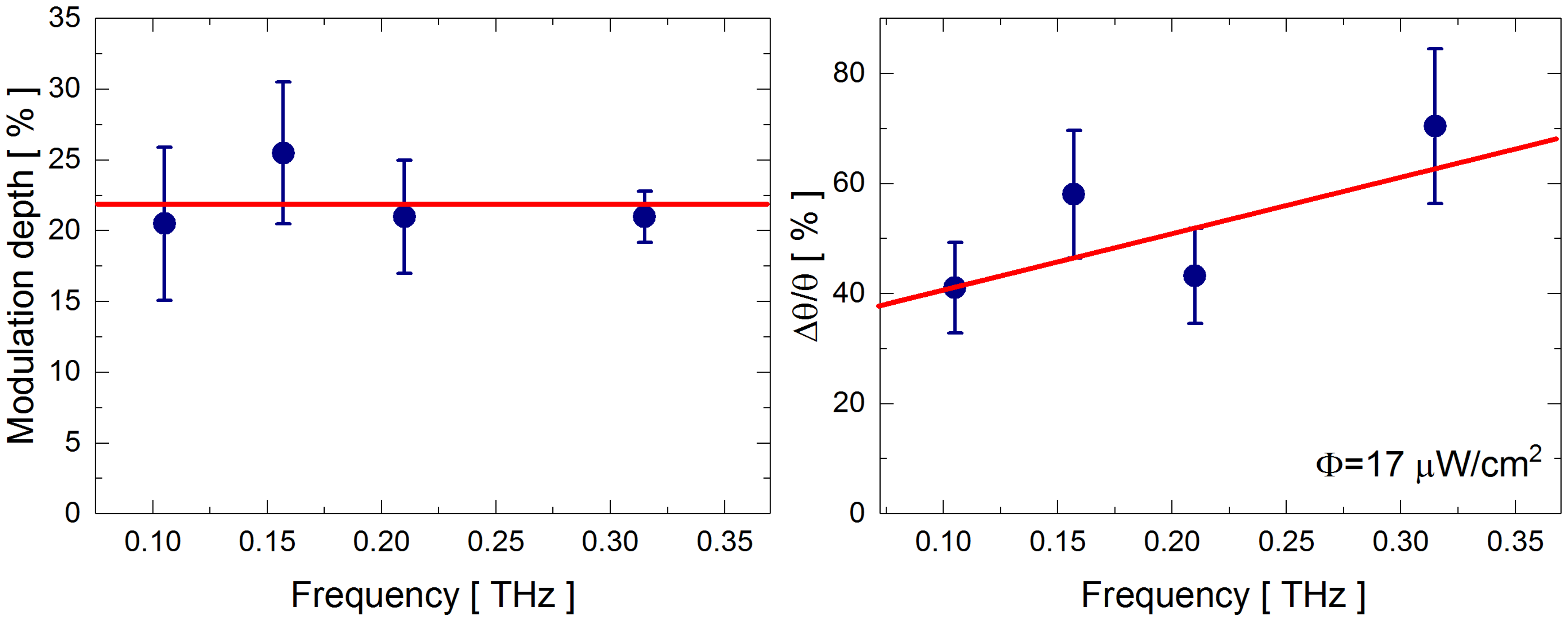

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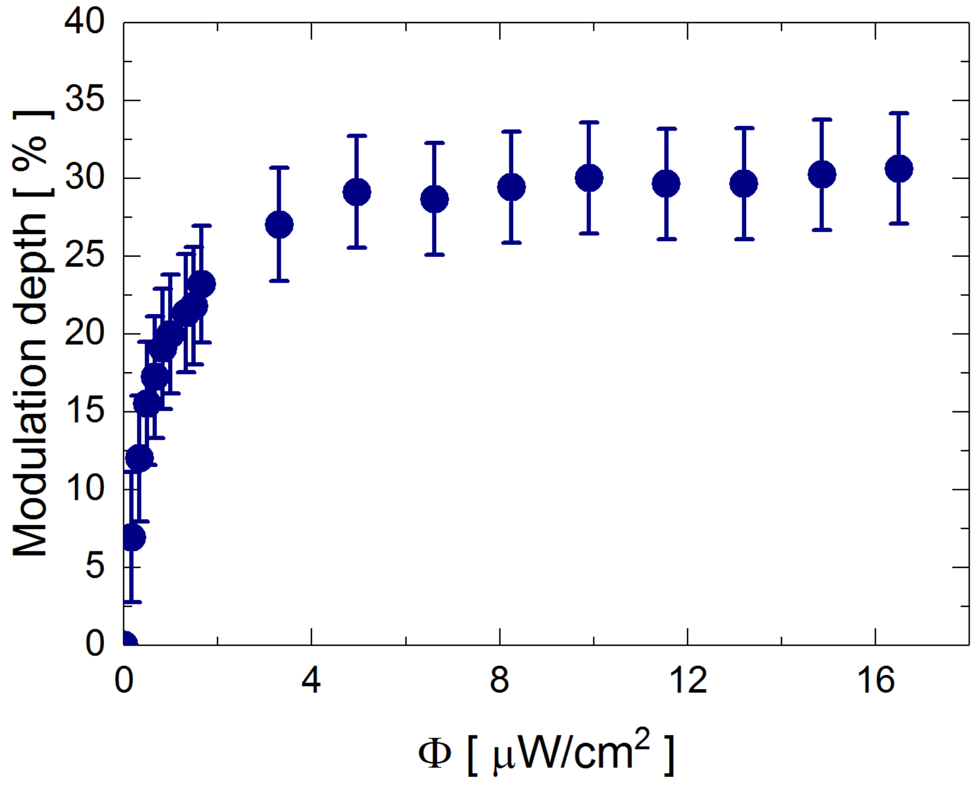
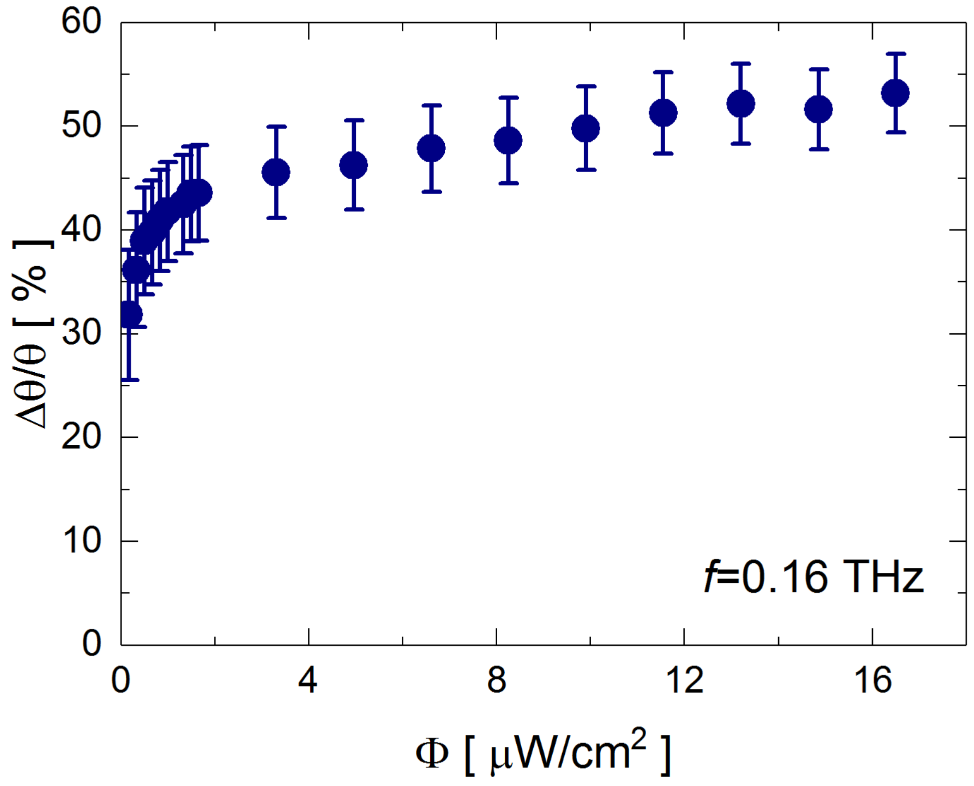




P. Szirmai, BN et al in preparation

Magnetic photoconductors for telecommunication

Transmission speed ~ bandwidth

~ S/N (power/detector quality)

Ultimate detector:

- Single photon sensitivity
- 1 detection efficiency
- fast

Several technologies:

- Photo multiplier tubes
- Superconducting transition edge sensors
- Avalanche photodiodes

Trade-offs for avalanche photodiodes

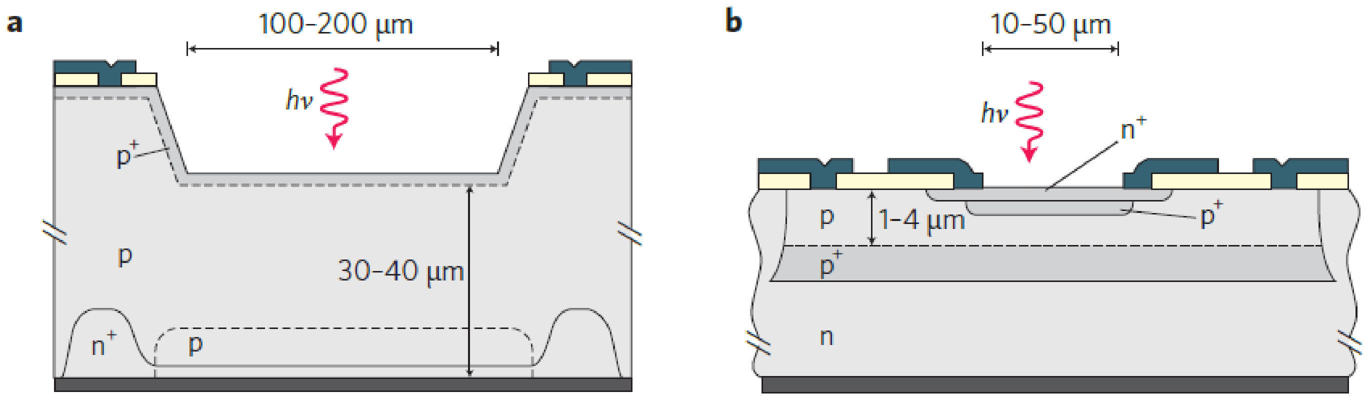
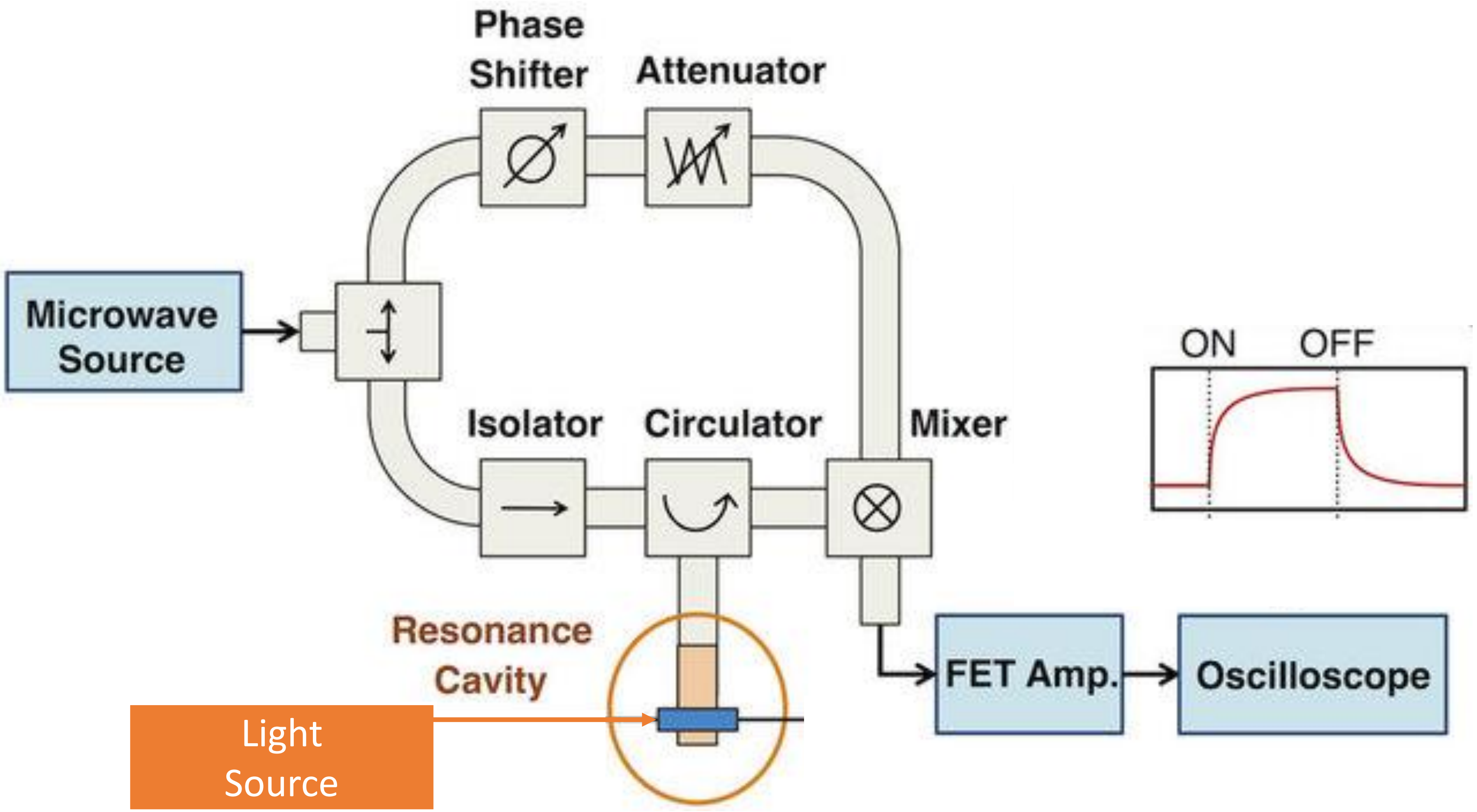


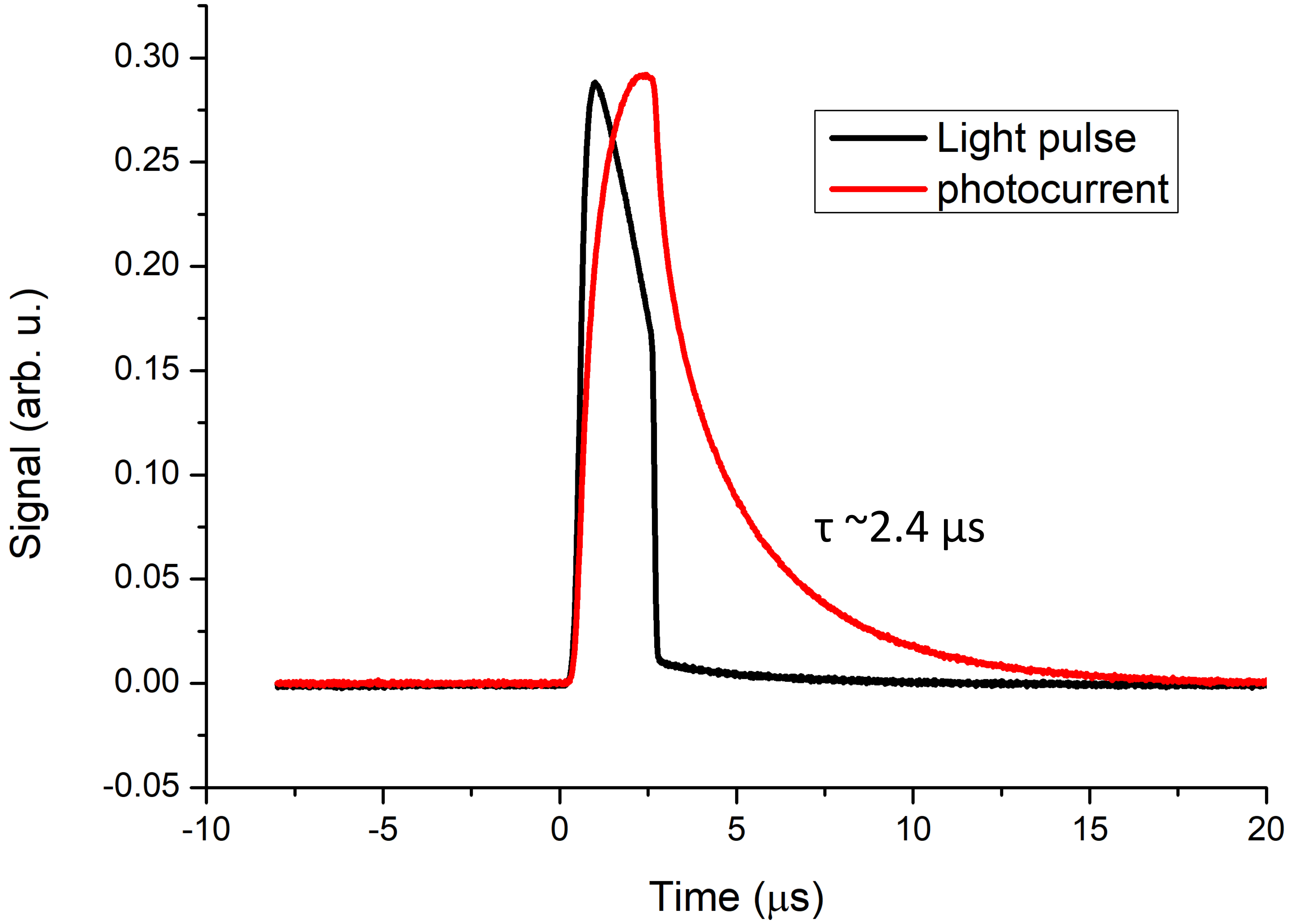
Figure 3 | Established photon-counting technologies based on reverse-biased avalanche photodiodes.

Detection efficiency proportional to the volume
Speed inversely proportional to volume

R.H. Hadfield Nature Photonics **volume 3**, pages 696–705 (2009)

Contactless microwave read out of photocurrnet





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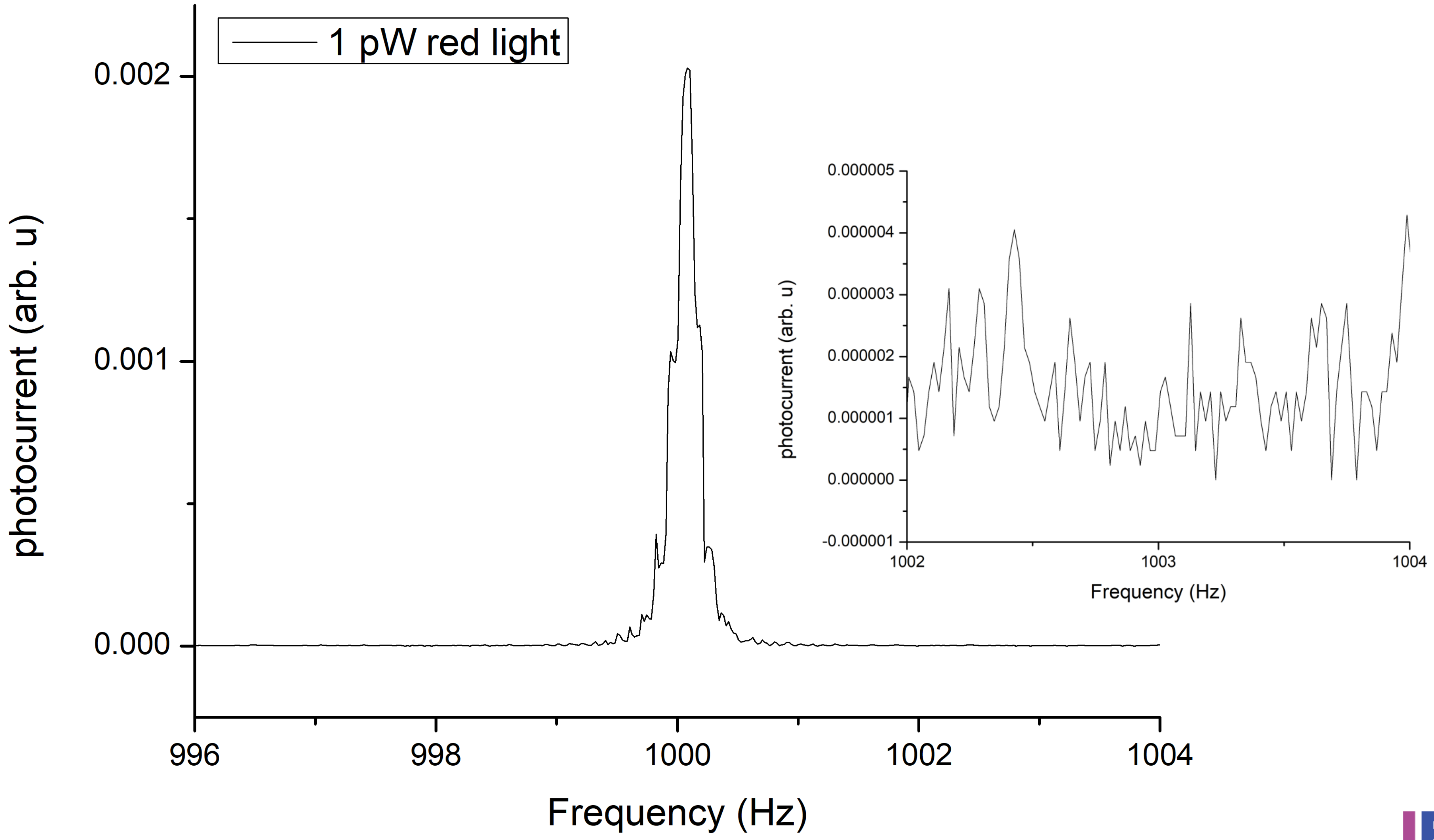

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Summary

- Demonstrated a rapid and easy manipulation of THz amplitude and phase by using photoelectrons generated in $CH_3NH_3(Pb:Mn)I_3$
- Constructed a high sensitivity light detector with contactless microwave readout

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Thank you for your attention!