# Green Photonics –

## Greenwashing with photons or exciting scientific field ?

**Peter Seitz**
Prof. em. Optoelectronics, EPFL
Vice President, SATW
Member Sci. Adv. Board, Siemens Found.
Past Managing Director, ieLab, ETH

satw technology for society

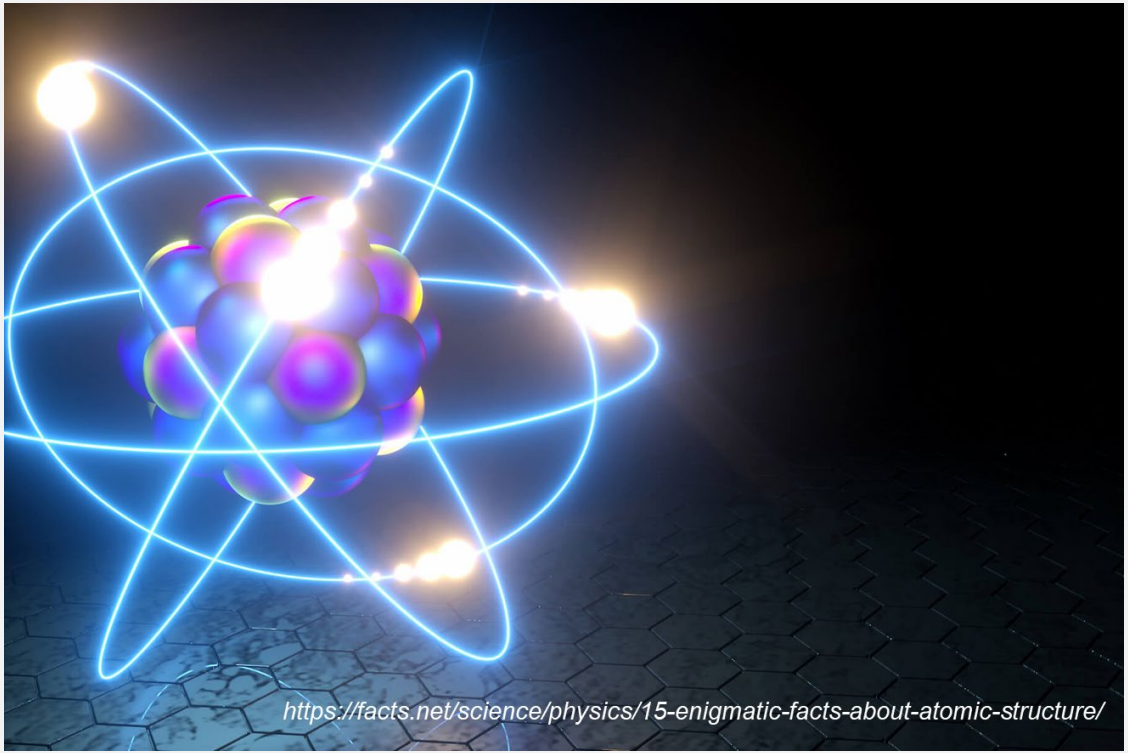
# Green Photonics Sanity Check

*https://www.photonics-austria.at/ausschreibung-green-photonics-2023-national/*



satw

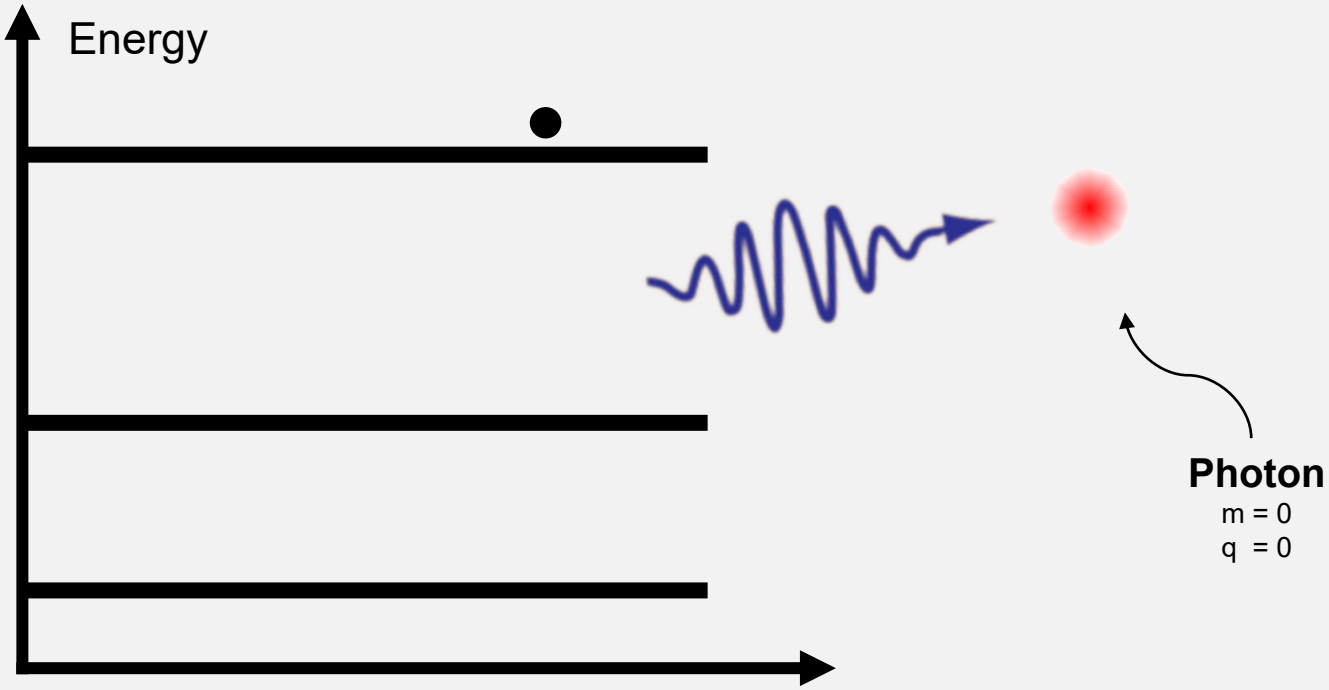
# Green Photonics Sanity Check: Production of Photons?






satw

# Green Photonics Sanity Check: Production of Photons?



# Green Photonics Sanity Check: Efficient Production of Photons?

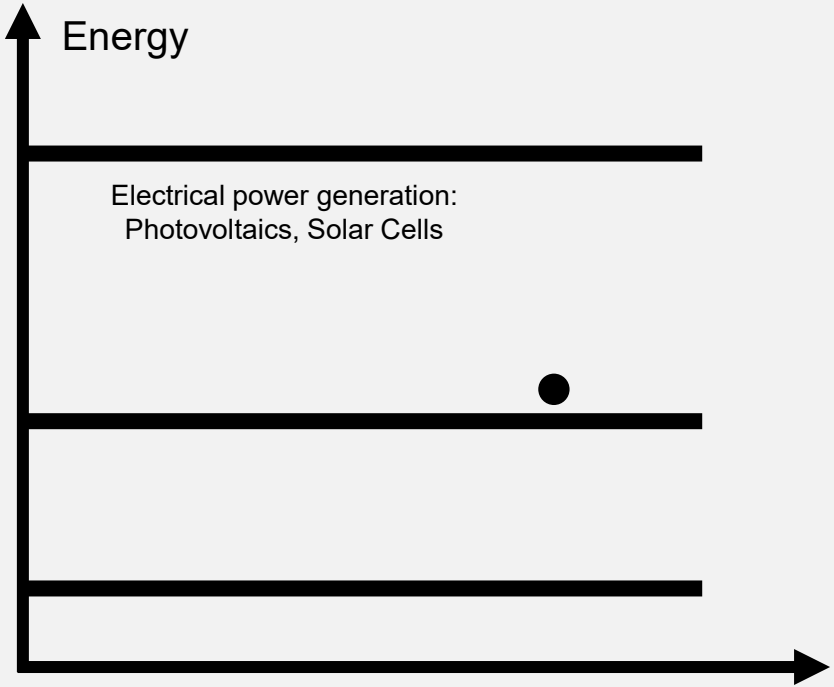
| Assumptions: | | |
|---|---|---|
| | Cost of electricity | € 0.30 / kWh |
| | Photon wavelength | 600nm (red) |
| | LED efficiency | 30% |

For one Euro, one obtains the staggering number of

**10,000,000,000,000,000,000,000,000 photons**

(10 million million million million photons)

# Green Photonics Sanity Check: Sustainable Disposal of Photons?




A photon that was absorbed leaves abso-lutely no trace of its former existence !

**Zero-waste disposal**



satw

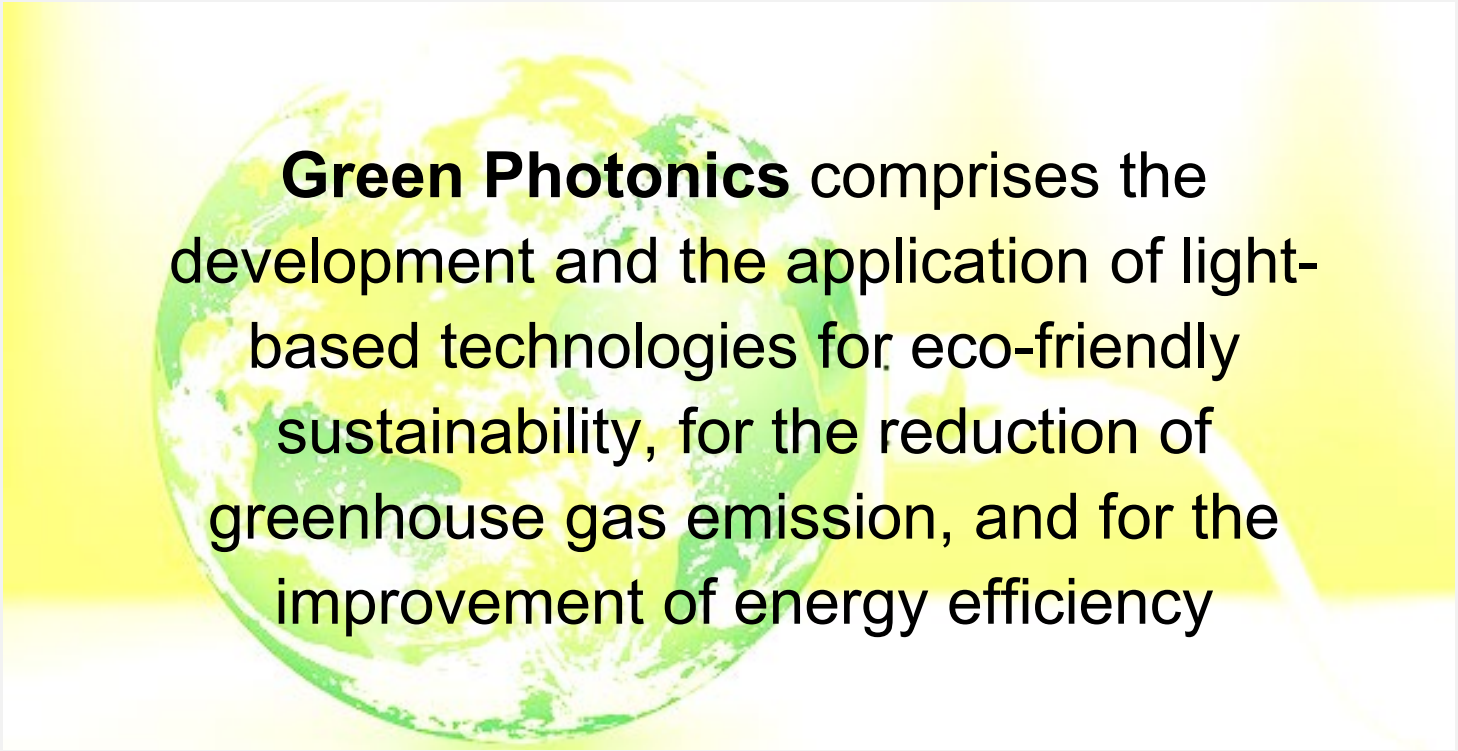
# Conclusion: Green Photonics Might Make Sense …

https://www.photonics.com/Articles/Photonic-Technology-Converts-Greenhouse-Gases/a67708



satw

# Definition of Green Photonics



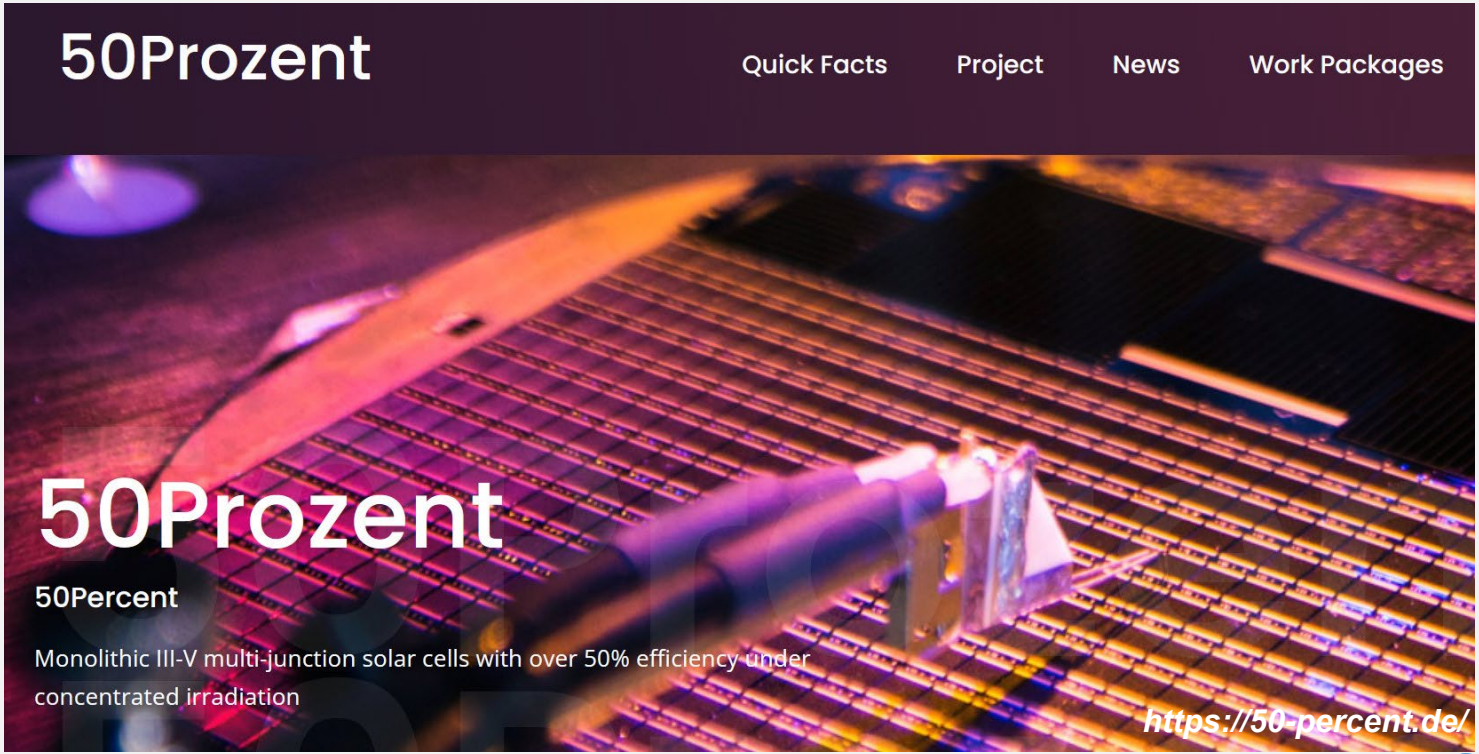
# Core Technologies of Green Photonics

- High-efficiency photovoltaic energy conversion
- High-efficiency versatile lighting
- Eco-friendly, sustainable, cost-effective production
- Environmental and agricultural sensing
- More sustainable opto-electronic materials and measurement techniques
- Fault-tolerant and eco-friendly semiconductors
- Smarter (room-temperature) sensing
- Photonic cooling
- …

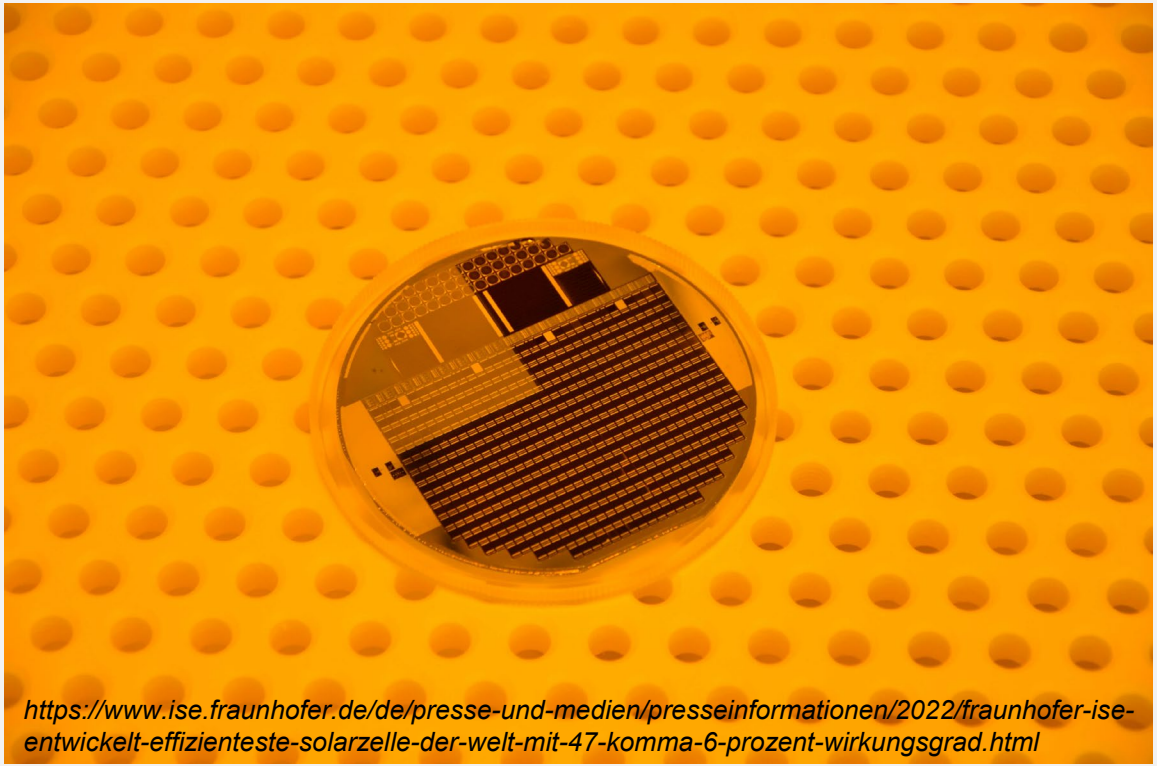
# Core Technologies of Green Photonics

- **High-efficiency photovoltaic energy conversion**
- **High-efficiency versatile lighting**
- Eco-friendly, sustainable, cost-effective production
- Environmental and agricultural sensing
- More sustainable opto-electronic materials and measurement techniques
- **Fault-tolerant and eco-friendly semiconductors**
- **Smarter (room-temperature) sensing**
- Photonic cooling
- …

# Highest Efficiency Photovoltaic Energy Conversion



# World Record Photovoltaics – FhG-ISE (2022): 47.6%

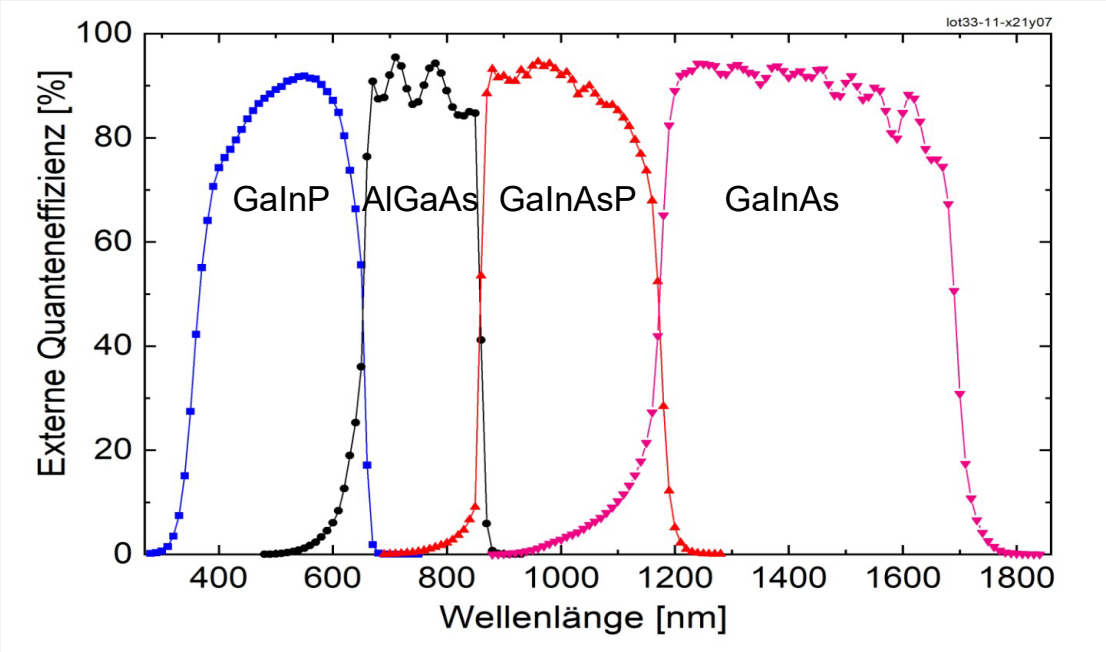


https://www.ise.fraunhofer.de/de/presse-und-medien/presseinformationen/2022/fraunhofer-ise-entwickelt-effizienteste-solarzelle-der-welt-mit-47-komma-6-prozent-wirkungsgrad.html

# Highest Efficiency PV Energy Conversion – What Does It Take?

- Quad compound semiconductor cell
- Broad-band antireflection coating
- Optical concentration
- Micro-PV cell production & assembly
- Precise 2D solar tracking system

# Highest EQE PV: Quad Compound Semiconductor Cell




*https://www.ise.fraunhofer.de/de/presse-und-medien/presseinformationen/2022/fraunhofer-ise-entwickelt-effizienteste-solarzelle-der-welt-mit-47-komma-6-prozent-wirkungsgrad.html*

# Highest EQE PV: Broad-Band Antireflection Coating

https://www.wernersiemens-stiftung.ch/projekte/detail/tandem-photovoltaik/solarzellen-von-hoechster-effizienz



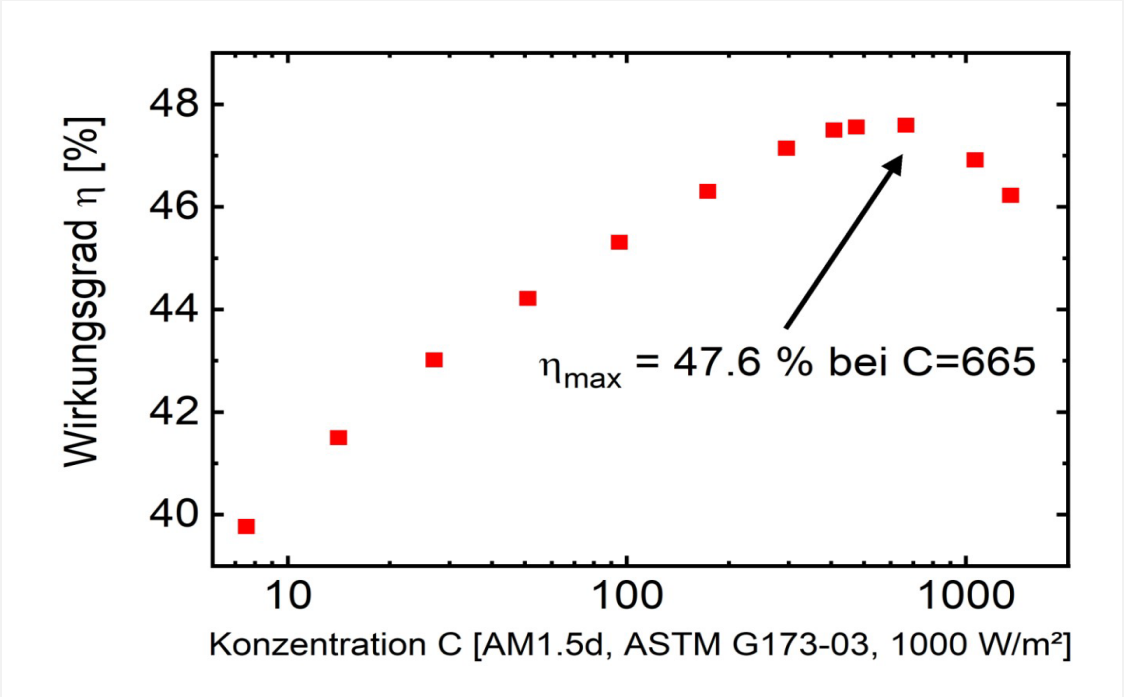
satw

# World Record Photovoltaics – Optical Concentration




satw

# World Record Photovoltaics – Optical Concentration




*https://www.ise.fraunhofer.de/de/presse-und-medien/presseinformationen/2022/fraunhofer-ise-entwickelt-effizienteste-solarzelle-der-welt-mit-47-komma-6-prozent-wirkungsgrad.html*

# World Record Photovoltaics – Micro-PV Production & Assembly

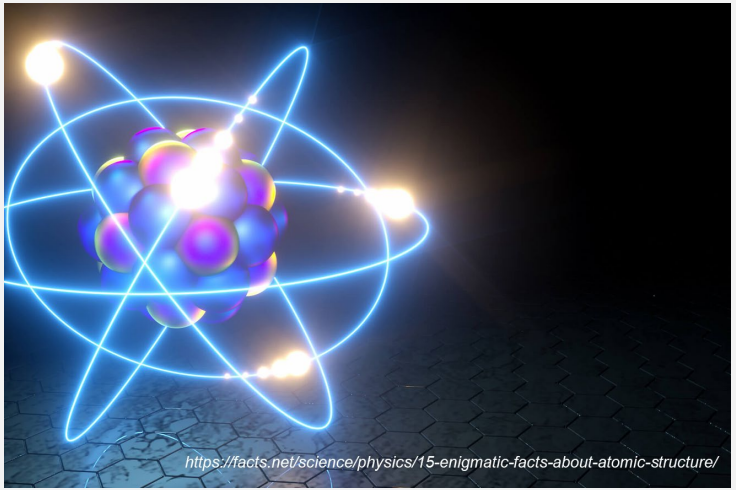
https://www.wernersiemens-stiftung.ch/projekte/detail/tandem-photovoltaik/solarzellen-von-hoechster-effizienz

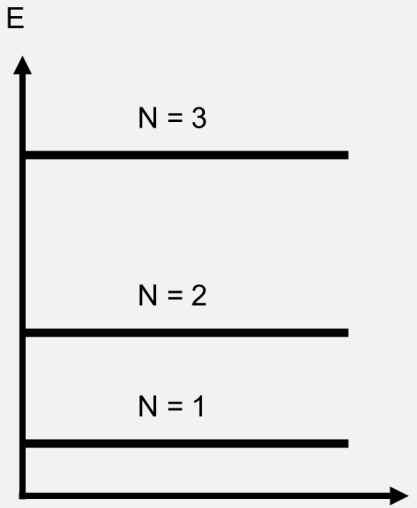


satw

# Highest EQE PV: Dual-Axis Solar Tracking Mechanism

# High-Efficiency Versatile Lighting: Artificial Atoms?



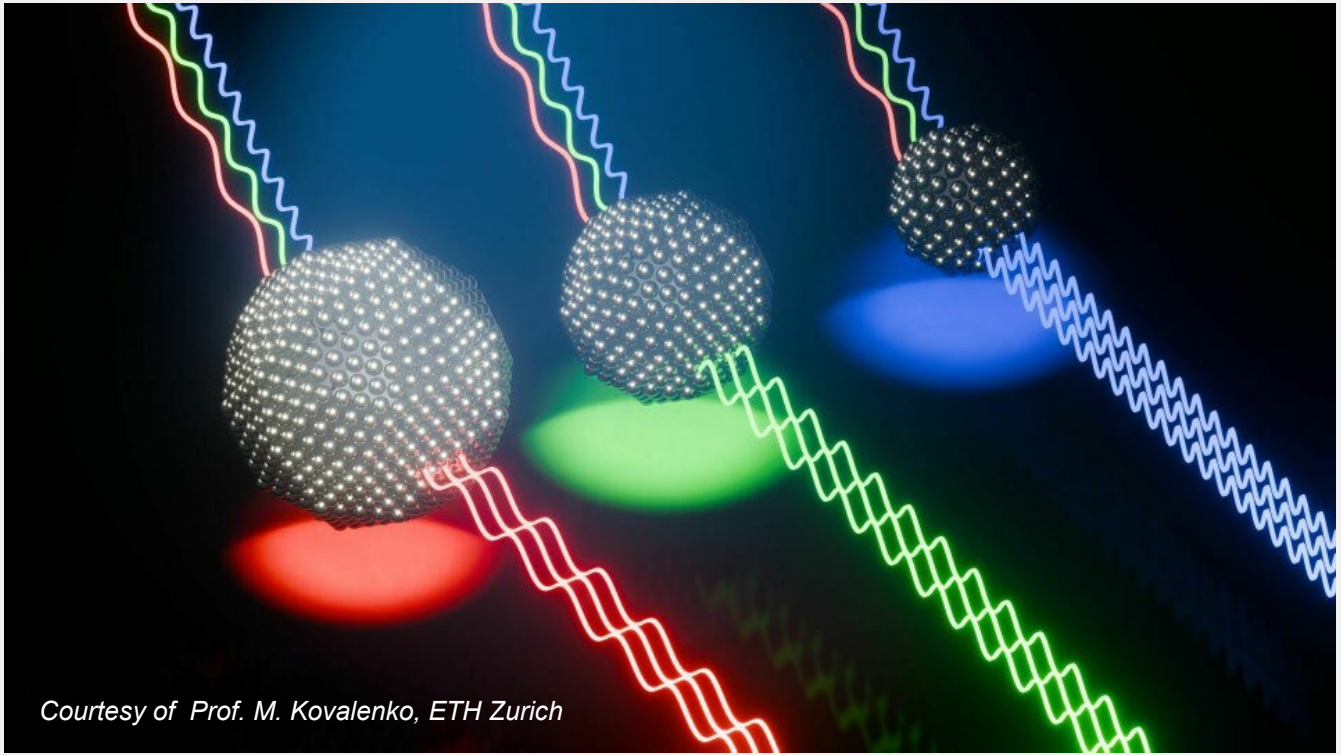

$$E = \frac{h^2}{8\,m\,L^2}\,N^2$$

$h$ : Planck's constant
( $h = 6.6\times10^{-34}$ Js)



satw

# High-Efficiency Versatile Lighting: Quantum Dots?






satw

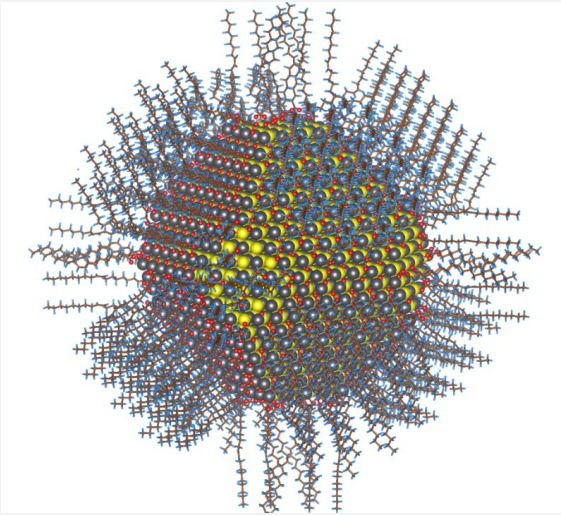
# High-Efficiency Versatile Lighting: The Surface is Devilish…

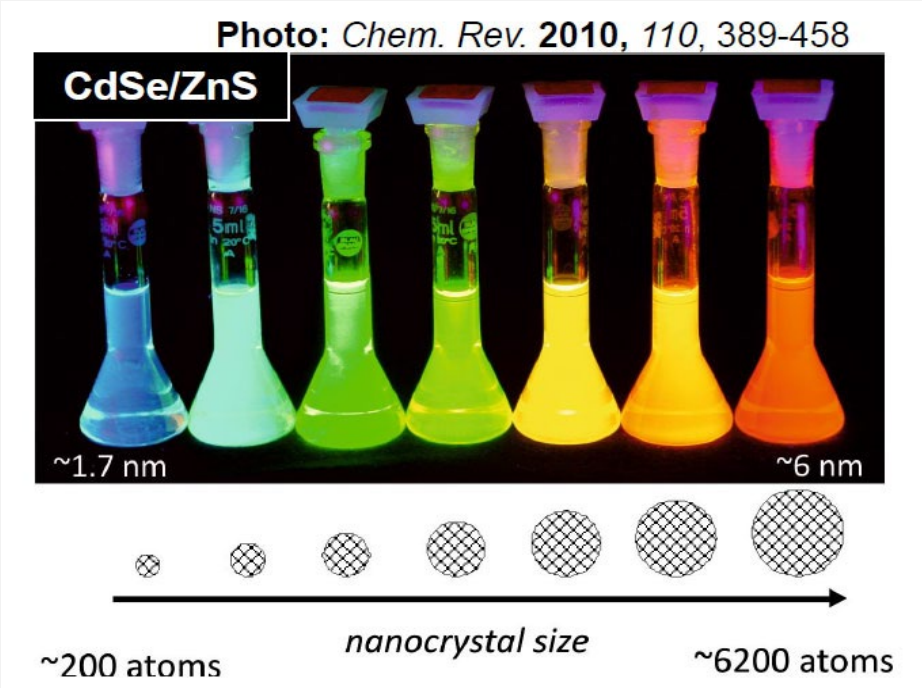
Wolfgang Pauli (1900-1980), ETH Zürich

“Gott schuf das Volumen, der Teufel die Oberfläche“

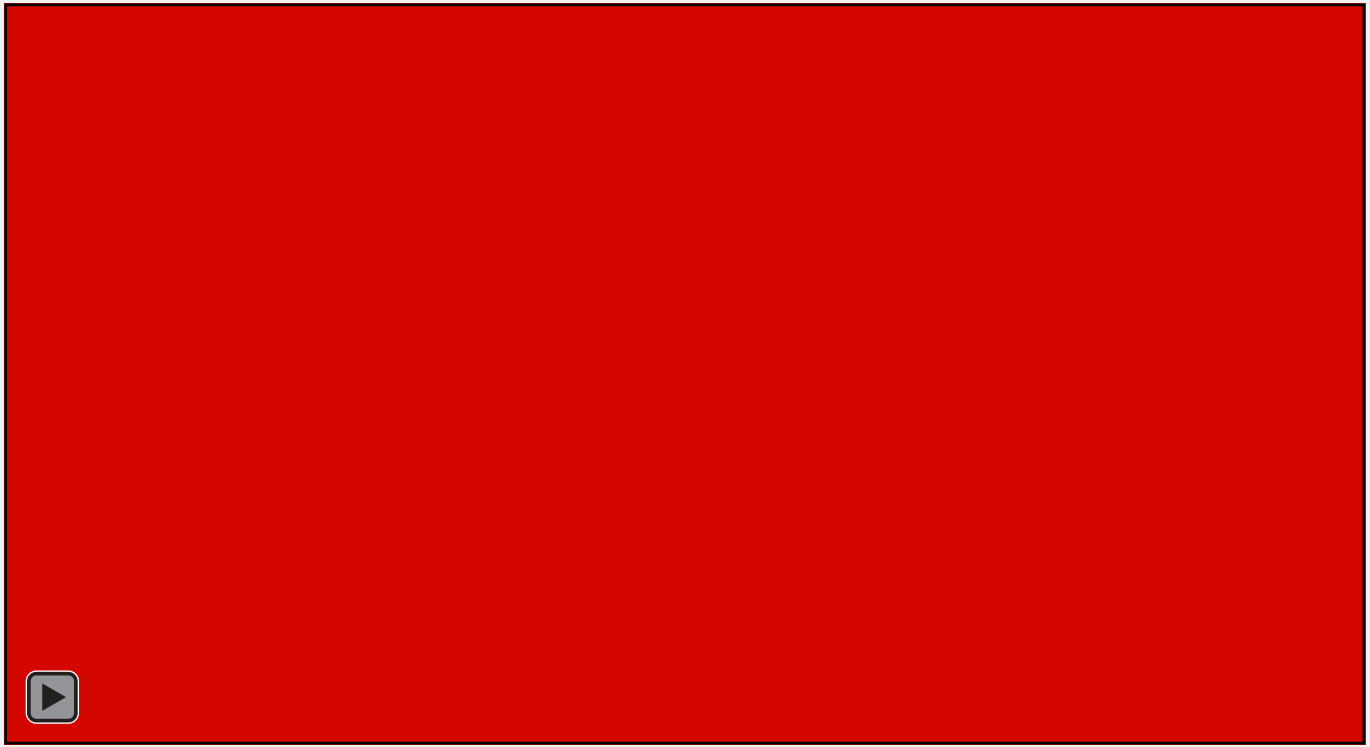
"Über Halbleiter soll man nicht arbeiten, das ist eine Schweinerei; wer weiß, ob es überhaupt Halbleiter gibt"

# Solution: Surface Passivation – Colloidal Quantum Dots





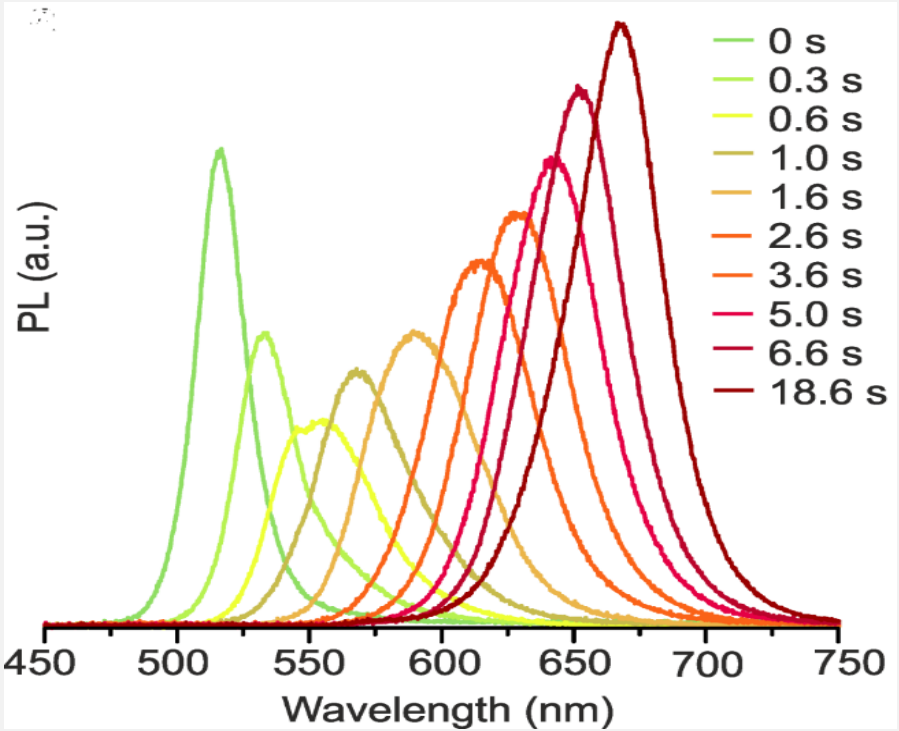
# Fast And Precise Quantum Dot Production





satw

# Fast And Precise Quantum Dot Production

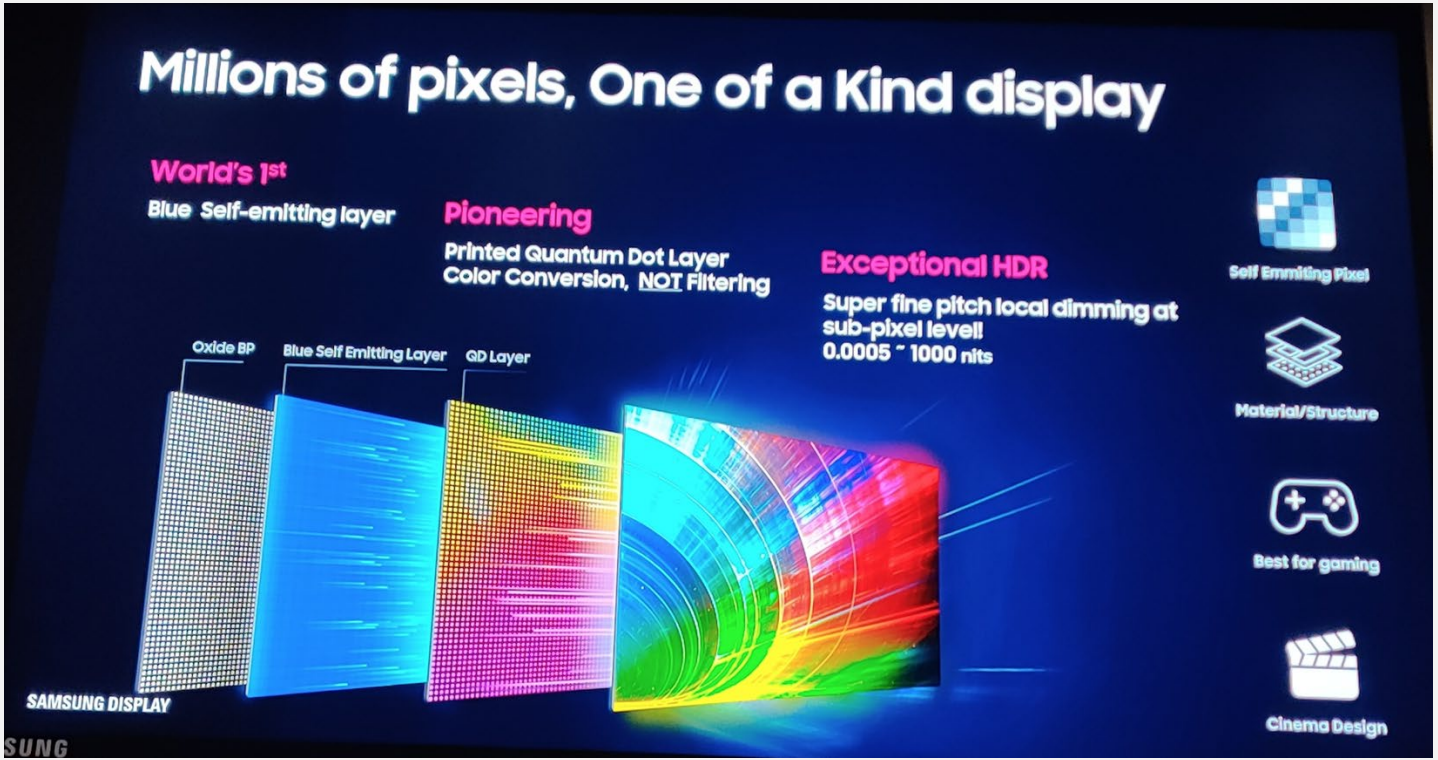



*Courtesy of Maksym Kovalenko, ETH Zurich*

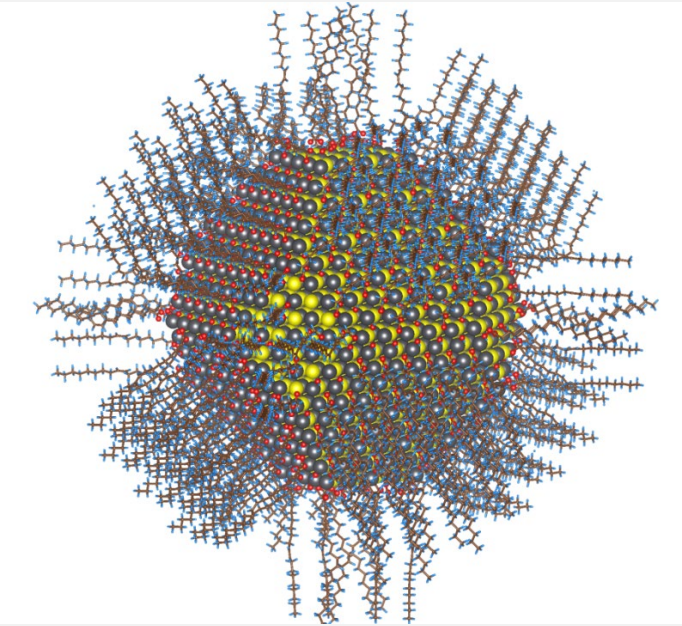


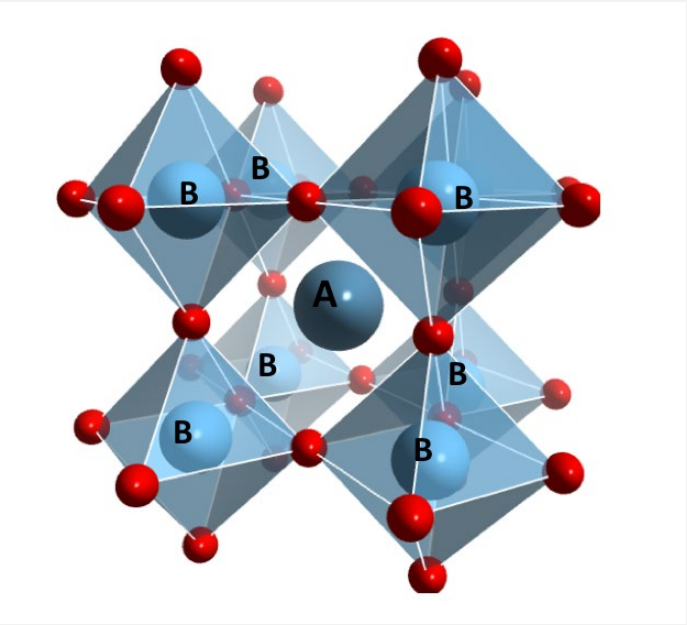
satw

# Quantum Dots Work! Artificial Atoms for the Masses

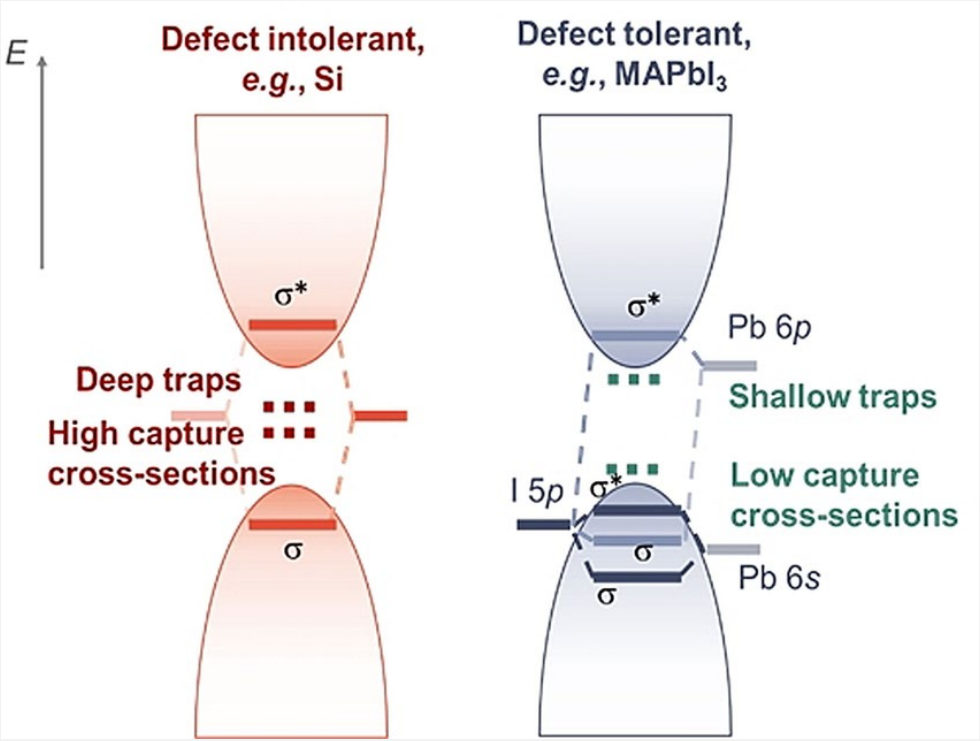


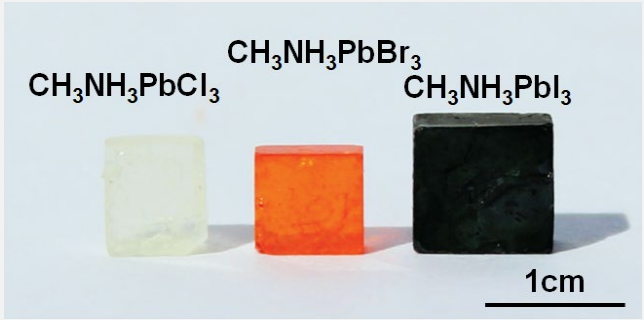
# The Devil Created The Surface … God Gave Us The Perovskite Lattice





# Perovskites: Defect-Tolerant Semiconductors



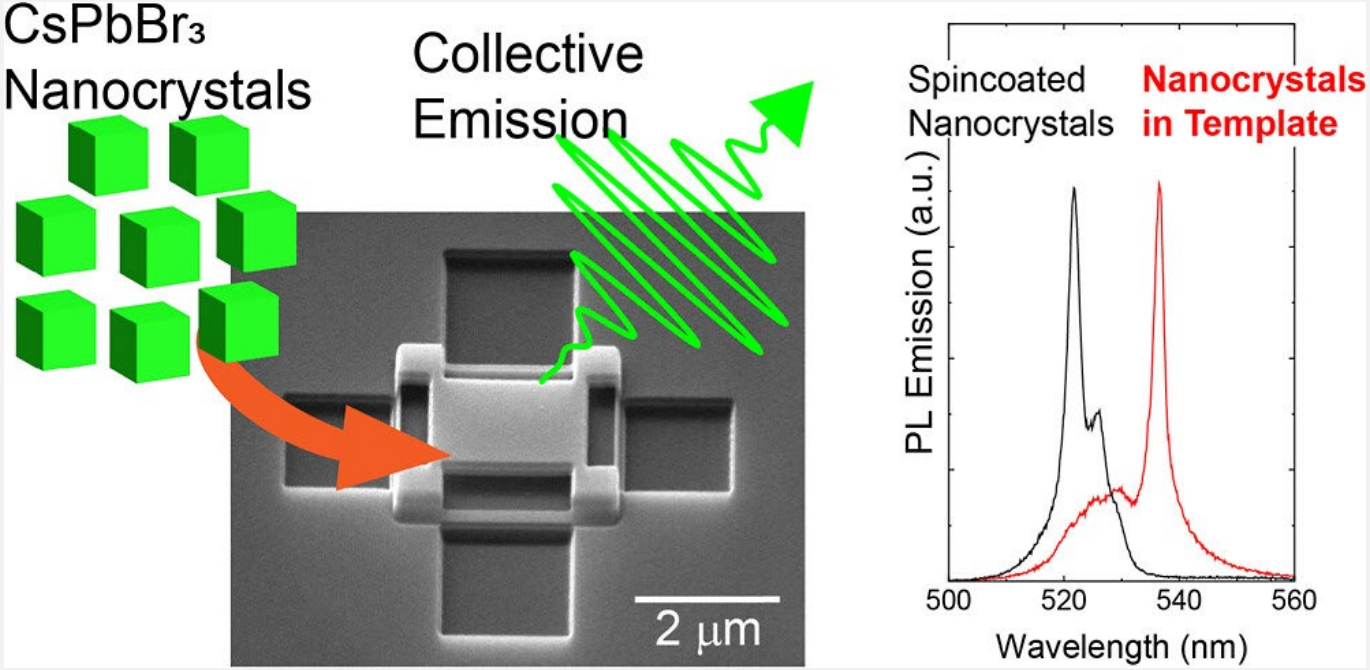




*J. Ye et al., Defect Passivation in Lead-Halide Perovskite Nanocrystals and Thin Films: Toward Efficient LEDs and Solar Cells, Angew.Chem.* ***133****, 2021*



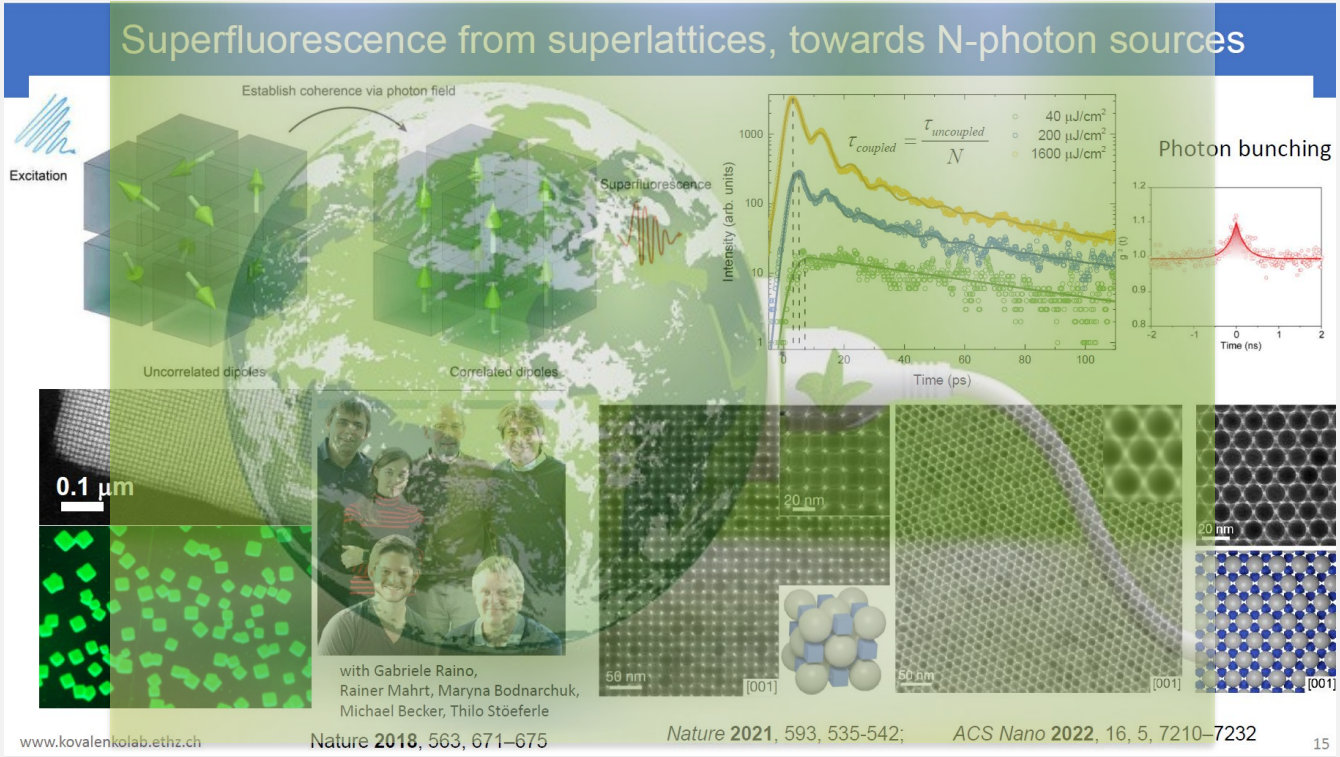
satw

# Perovskites: From Artificial Atoms to Artificial Molecules/Crystals

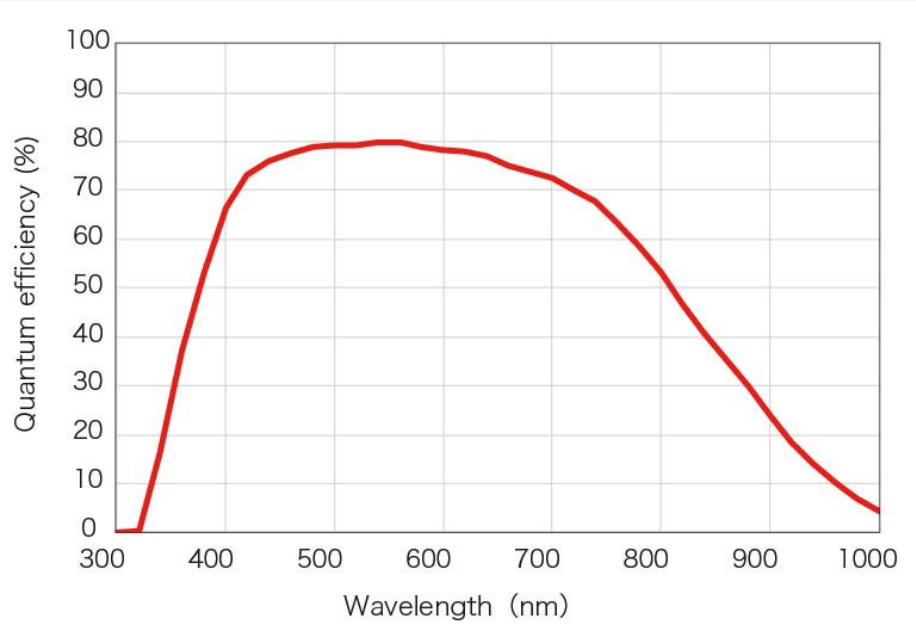



*E. Kobiyama et al., Perovskite Nanocrystal Self-Assemblies in 3D Hollow Templates ACS Nano **19,** 2025*

# Sneak Preview: QD Crystals for Programmable N-Photon Sources



# Room-Temperature Single-Photon Image Sensing




*https://camera.hamamatsu.com/eu/en/product/camera/C14440-20UP.html*

# Room-Temperature Single-Photon Image Sensing

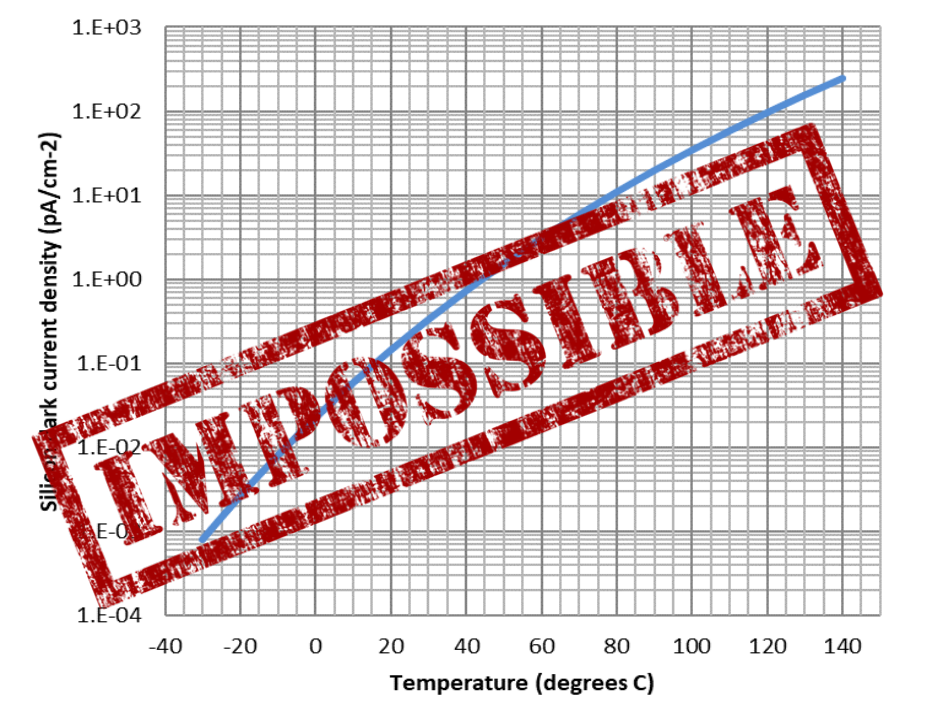
| Product number | | ORCA®-Fusion C14440-20UP | ORCA®-Fusion BT C15440-20UP |
|---|---|---|---|
| Pixel Size | | 6.5 µm (H) × 6.5 µm (V) | |
| Effective number of pixels | | 2304 (H) × 2304 (V) | |
| Effective Area | | 14.976 mm (H) × 14.976 mm (V) | |
| Read noise *1 | Fast scan | 1.4 electrons rms | 1.6 electrons rms |
| | Standard scan | 1.0 electrons rms | 1.0 electrons rms |
| | Ultra quiet scan | 0.7 electrons rms | 0.7 electrons rms |
| Quantum efficiency *1 | @ 400 nm | 65 % | 72 % |
| | @ 550 nm | 80 % | 95 % |
| | @ 700 nm | 70 % | 83 % |
| | @ 800 nm | 50 % | 58 % |
| Full well capacity *1 | | 15 000 electrons | |
| Dynamic range *1 *2 | | 21 400:1 | |
| Conversion factor *1 | | 0.24 electrons / count | |
| Cooling temperature | Forced-air cooled | −5 °C (Ambient temperature: +25 °C) | −8 °C (Ambient temperature: +25 °C) |
| | Water cooled | −5 °C (Water temperature: +25 °C) | −8 °C (Water temperature: +25 °C) |
| | Water cooled (Max cooling) | Less than −15 °C *3 | Less than −15 °C *3 |
| Dark current *1,*4 | cooling temperature: -5 °C | 0.5 electrons/pixel/s | 1.0 electrons/pixel/s |
| | cooling temperature: -15 °C | 0.2 electrons/pixel/s | 0.7 electrons/pixel/s |

*https://camera.hamamatsu.com/eu/en/product/camera/C14440-20UP.html*

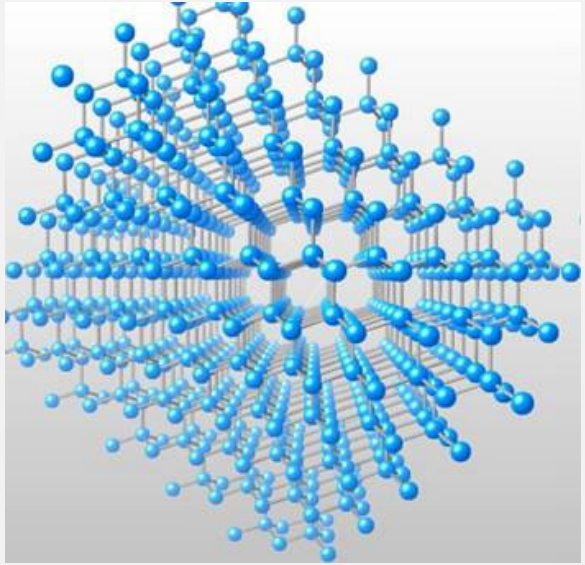
# RT Single-Photon NIR/MIR Image Sensing? Dark Current Density!

$$j \propto T^{\frac{3}{2}} e^{-\frac{E_g}{2kT}}$$

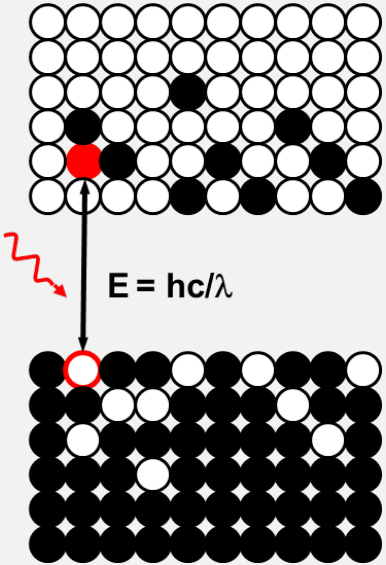
T : Absolute temperature
k : Boltzmann constant
$E_g$: Bandgap energy



# Smarter (Room-Temperature) Image Sensing

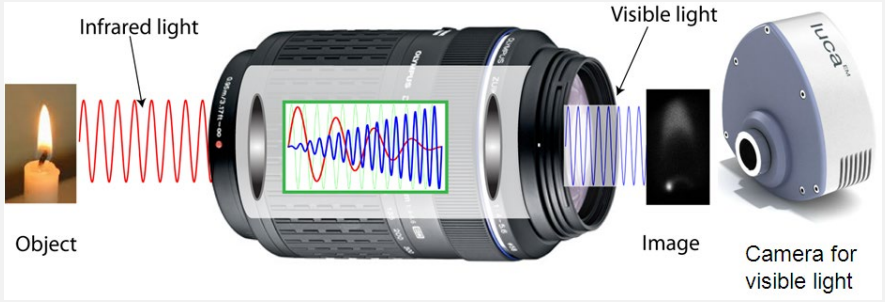


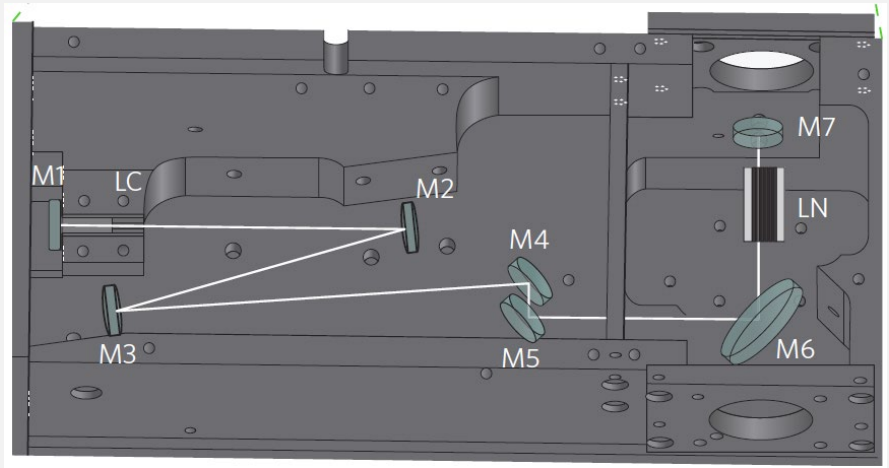
Lattice vibrations (phonons) from all directions…




… and with all energies > $E_{gap}$ contribute to the creation of (thermally excited) dark current!

# Uncooled NIR/MIR Single-Photon Imaging: Directed Upconversion



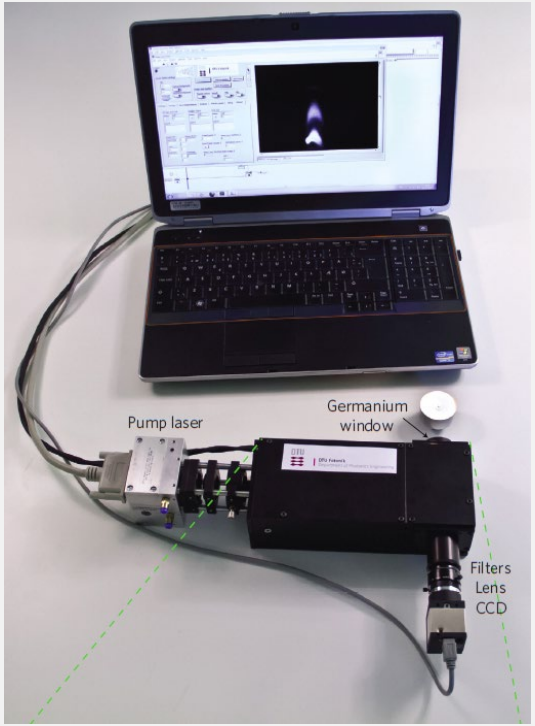




*J.S. Dam et al., Room-temperature mid-infrared single-photon spectral imaging, Nature Photonics, Sept. 2012*



satw

# Uncooled NIR/MIR Single-Photon Imaging: Directed Upconversion




- **Low noise < 0.2 photons/pixel/sec**
- **Uncooled: Room temperature**
- QE = 20% (>50% possible)
- Single-pass upconversion (three-wave mixing): Optically pumped poled Lithium Niobate crystal
- Response speed = speed of light in pp-LN
- Pump laser diode: 4W @ 808 nm
- Upconversion to ~800 nm. Readout with conventional low-noise Si-based camera.
- MIR spectral range up to 5 µm

- **Narrow wavelength bands**: 5 nm @ 2.9 µm, 25 nm @ 3.8 µm, 200 nm @ 4.2 µm
- **Narrow acceptance angle**: ~$1.3^0$ (f/50)

# Green Photonics…

satw technology for society