Quantum Dots as a New Generation of Emitting Materials in OLEDs
Development of Next Generation Display Technologies – Materials, Device Design, Application

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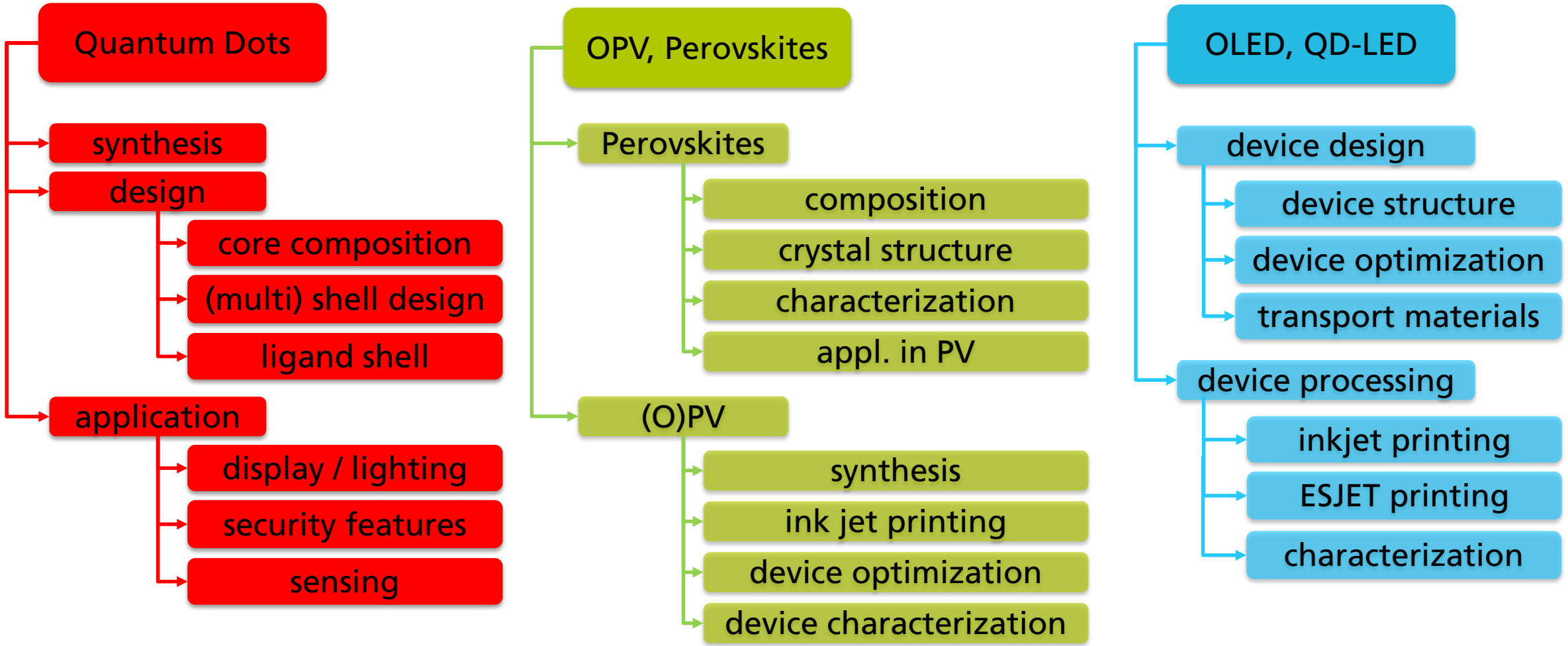
Outline

- **Introduction to Fraunhofer Society and the Fraunhofer IAP**
- Contributions to OLED development
- QD design, synthesis and applications
- QD-LED devices
- Active matrix OLED (AMOLED)
- Summary

Topics @ Fraunhofer IAP



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- First Polymer OLED (1994)
- Organic Electronic (1999)
- Passive Matrix OLEDs (2001)
- OLED Printing (2006)
- **Indium Phosphid Quantum Dots (2009)**
- Pilot Line (2012)

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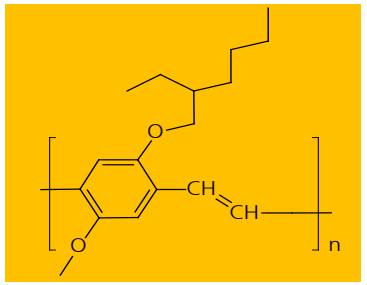
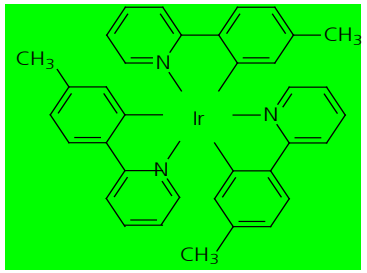
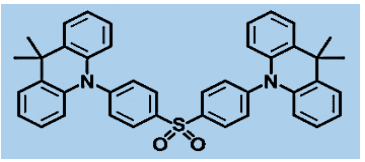
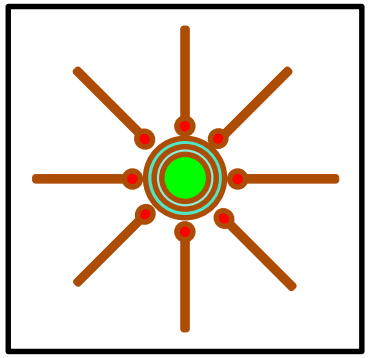
From OLEDs to the next generation: QD-LEDs

- **Singlet-emitters (PLED)**
  - Conjugated polymers MEH-PPV, low efficiency
- **Triplet-emitters (PhOLED)**
  - $Ir(ppy)_3$ as component, high efficiency, evaporate or soluble based
- **TADF Emitter**
  - Thermally activated delayed fluorescence
- **Quantum Dots (QD-LED)**
  - Semiconductor nanoparticle with inorganic core/shell and organic ligand, tunable color and narrow FWHM









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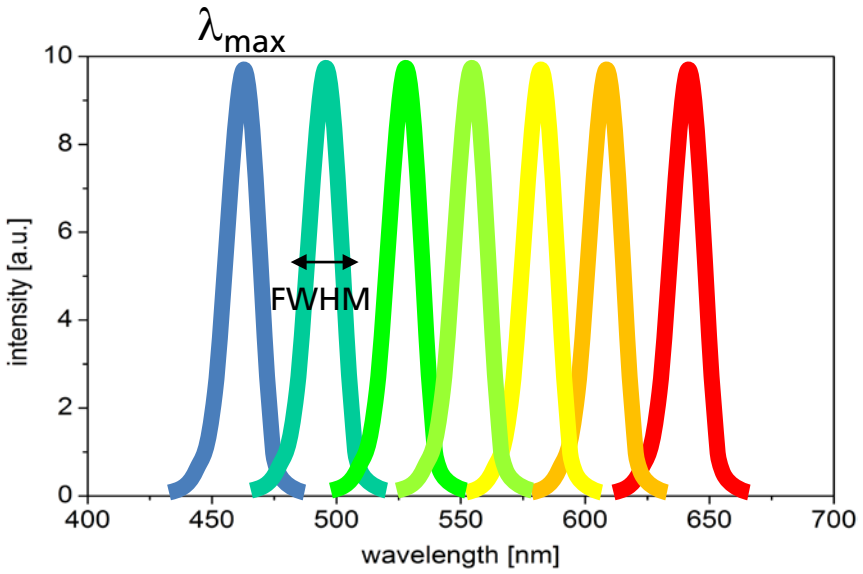
Outline

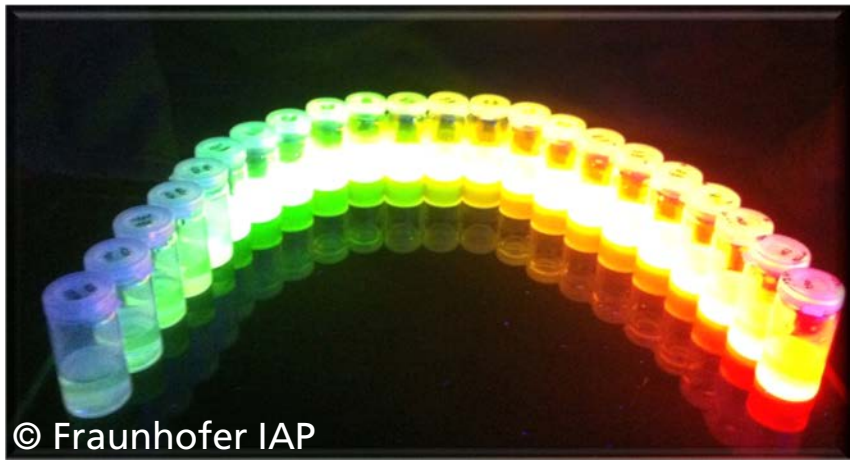
- Introduction
- Multilayer OLED solvent processing with polymers
- **QDs: synthesis approaches and design principles**
- QD-LED devices
- Active matrix OLED (AMOLED)
- Summary

Quantum Dots – special semiconductor nanoparticles

Optical properties are depending on the following parameters:

- **Absorption- and emission properties** (λ_{max} [nm]) are depending on the particle size
- **The full width at half maximum** (FWHM [nm]) is depending on the particle size distribution
- The **Luminescence and Quantum Efficiency** (QY [%]) is depending on the surface defects of the nanocrystal





CdSe-QDs

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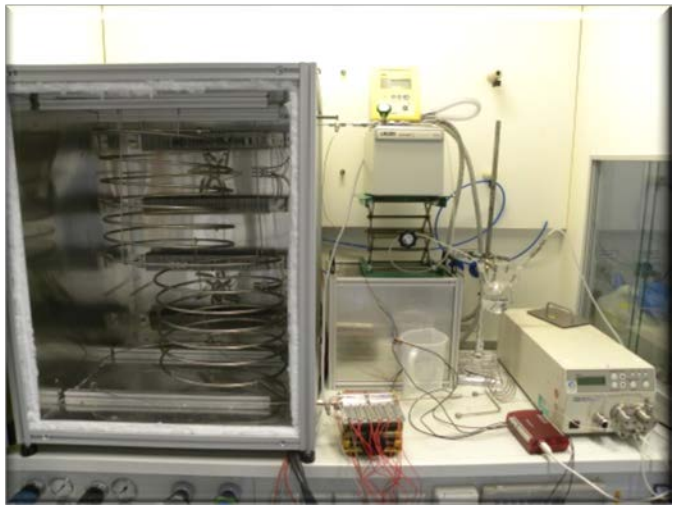
QDs at Fraunhofer IAP - Synthesis

- Synthesis of QDs of various materials
  - CdSe, **InP**, ZnSe, $CuInS_2$, PbSe
  - Color tuning via reaction conditions
  - Ligand tuning to adjust solubility
- Scale up in batches up to 10 – 20 g
- Scale up with flow reactor for larger quantities and reproducibility (Fraunhofer CAN)
- **Special expertise: cadmium free InP based QDs with multi and giant shell configuration**



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Status QD synthesis @ Fraunhofer IAP | Focus on InP and ZnSe

- **CdSe**
  - Best performance for green and red
- **Cd free QDs (green and red)[1]**
  - QY comparable for green and red
  - FWHM to be improved
- **Cd free blue QDs[2]**
  - ZnSe for blue in development
  - QY about 30%, FWHM < 30 nm
- **General approaches**
  - Color tuning via reaction conditions
  - Ligand tuning to adjust solubility

CdSe	green	red
QY (%)*	> 81	> 85
FWHM (nm)*	< 26	< 34

InP	green	red
QY (%)*	> 85	> 77
FWHM (nm)*	< 42	< 58

ZnSe	blue
QY (%)*	~ 30%
FWHM (nm)*	< 20

*all data measured in solution

[1] DE 102012203036 A1
[2] DE 102013206077, EP 2 787 057 A1, US 2014/0353579 A1

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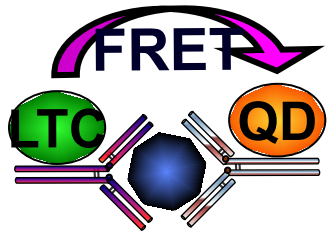
QDs @ Fraunhofer IAP - Technology and Application

- **QD based OLED**
  - OLED set-up and 4th generation of emitting materials
- **QD as converting material for lighting application**
  - QD based enhancement films (QDEF) for display application in LED backlights
- **QD as special material for security application**
  - QDs printed on paper or plastics
- **QD as highly sensitive sensor materials** for bioanalytical applications



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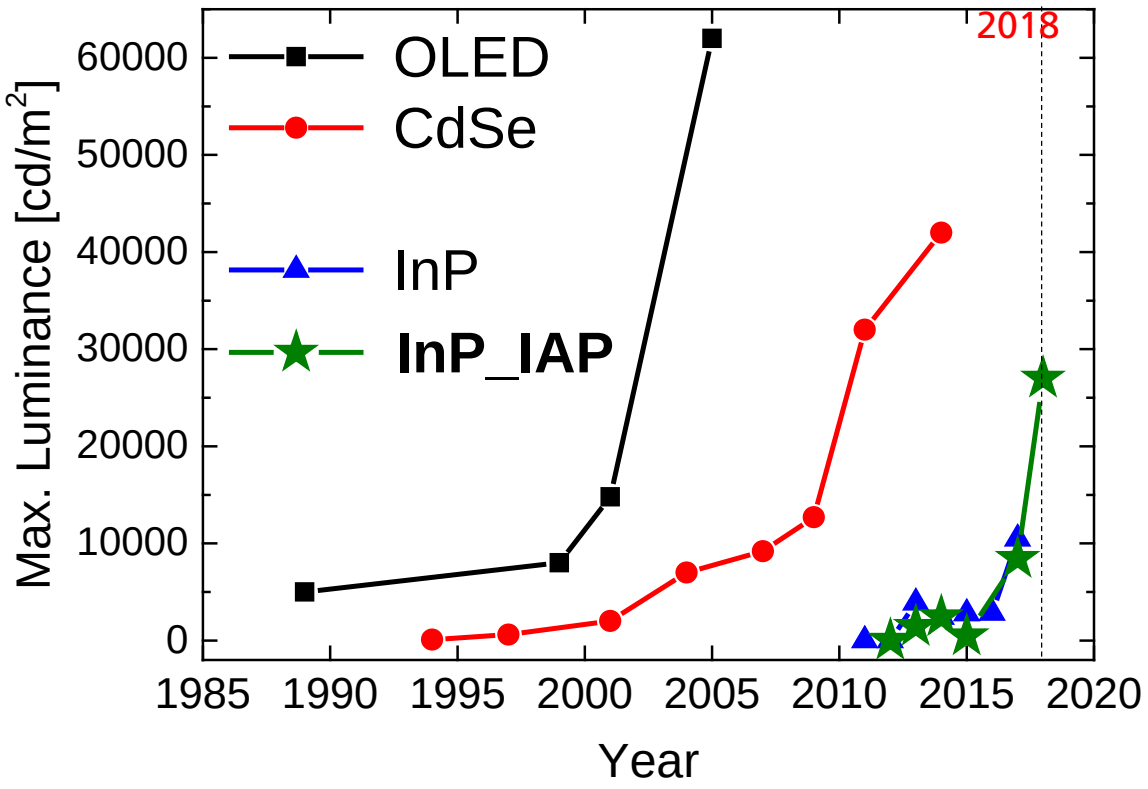
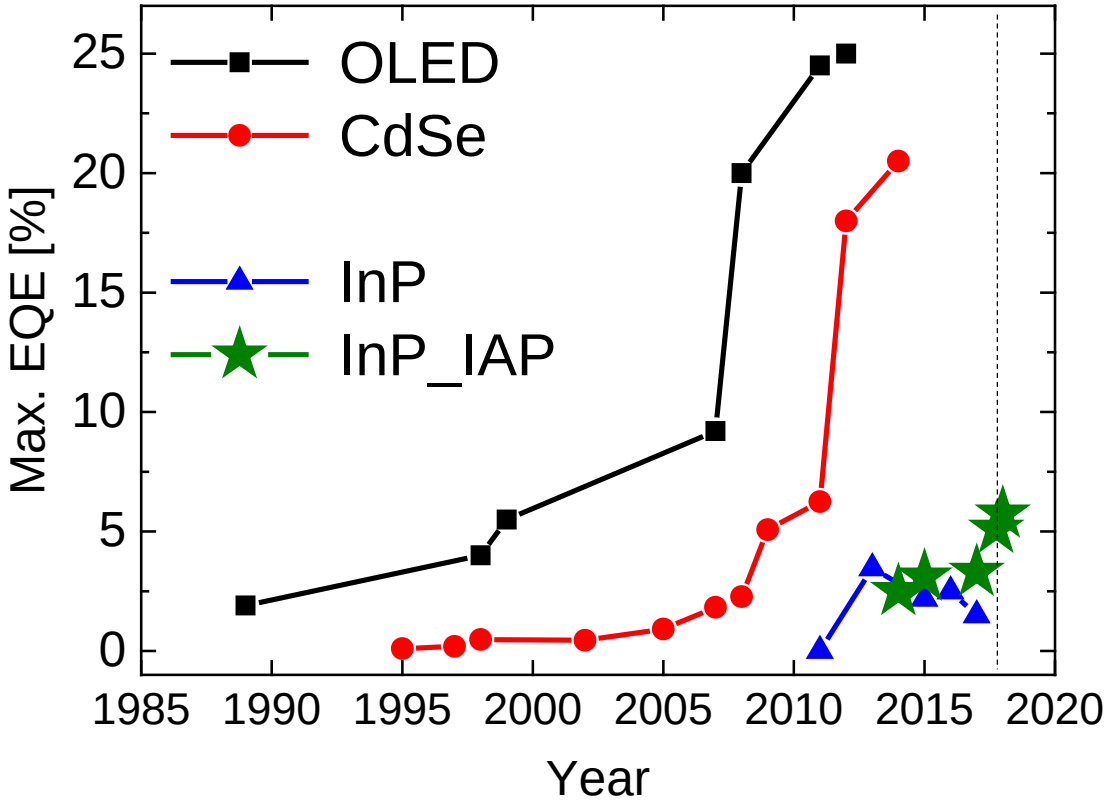
Performance history : CdSe vs. InP





Improved performance for InP QD-LEDs

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IAP @ SID 2018 | Booth

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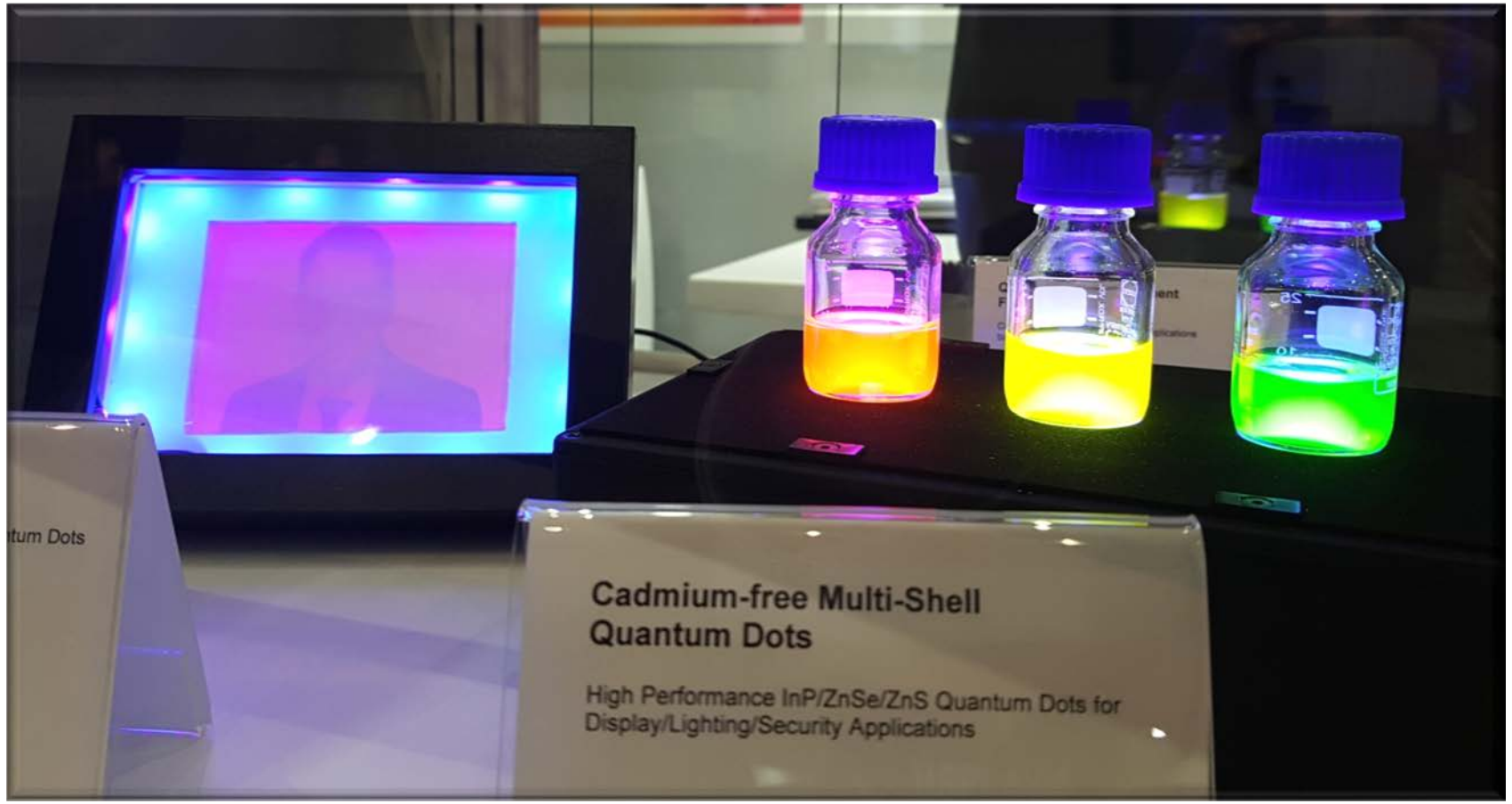
IAP @ SID 2018 | InP QDs and Inkjet Printed QD Picture



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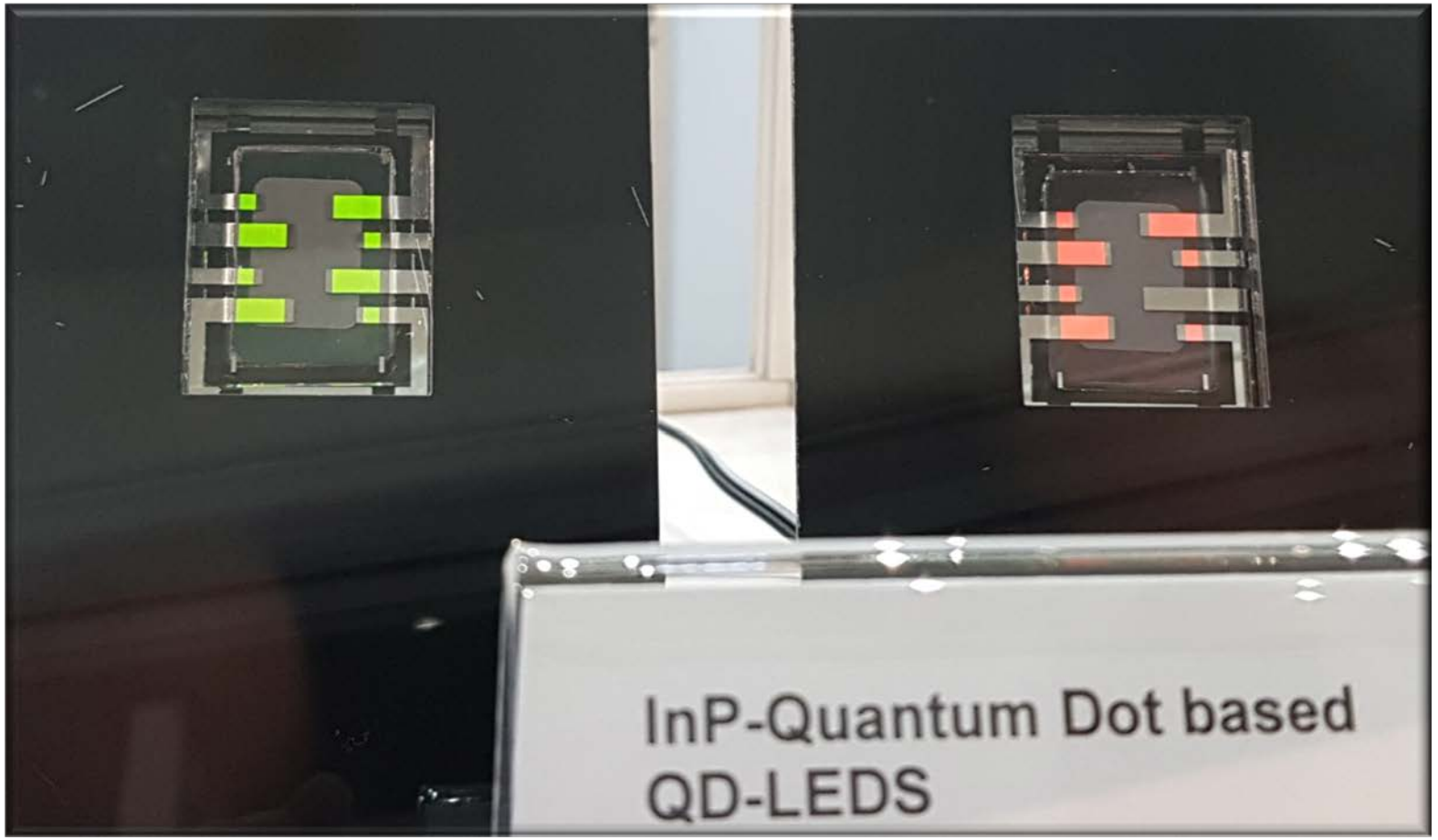
IAP @ SID 2018 | Devices running for days…



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Thank you for your attention!

Want to know more?

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