Organic Photovoltaics For IoT

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Conventional PV

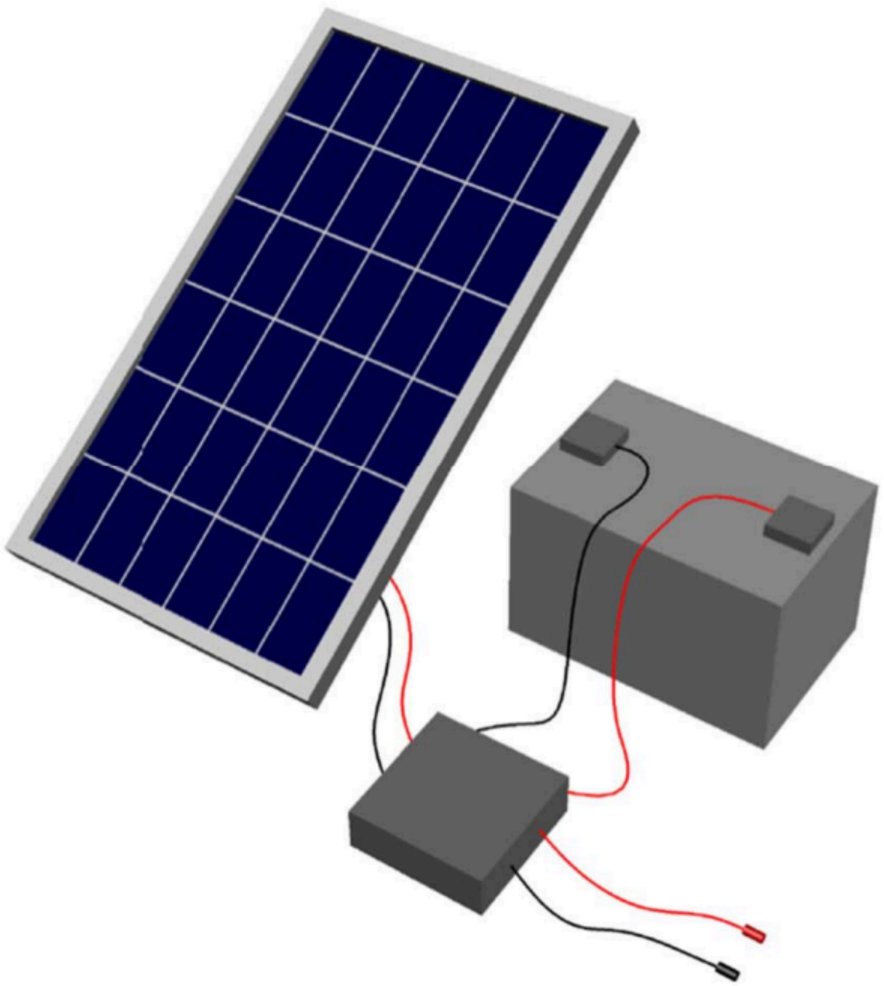
Convert light to electricity directly

Longyangxia Dam Solar Park (850 MW)

Grid parity achieved in many areas.
500 GW deployed, forecast of 6000GW by 2040 (IEA)

Flexible PV for Integrated Systems

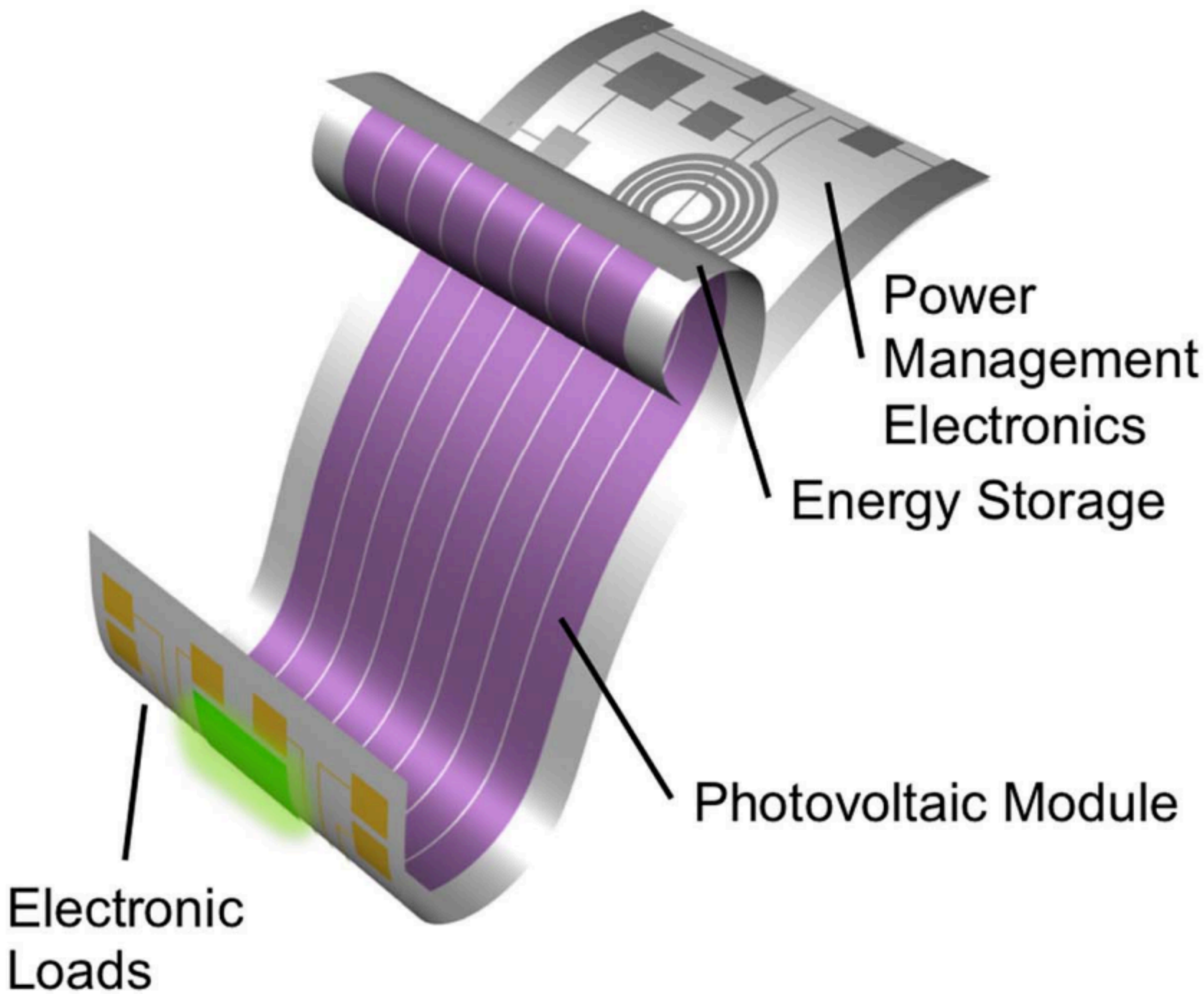
Flex. Print. Electron. 2 (2017) 013001



Large, inflexible, bulky,
not tuneable,
efficient (outdoors)
cheap, long lifetimes

Lightweight, flexible, tuneable,
efficient ?
cheap? lifetimes ?

Materials Criteria

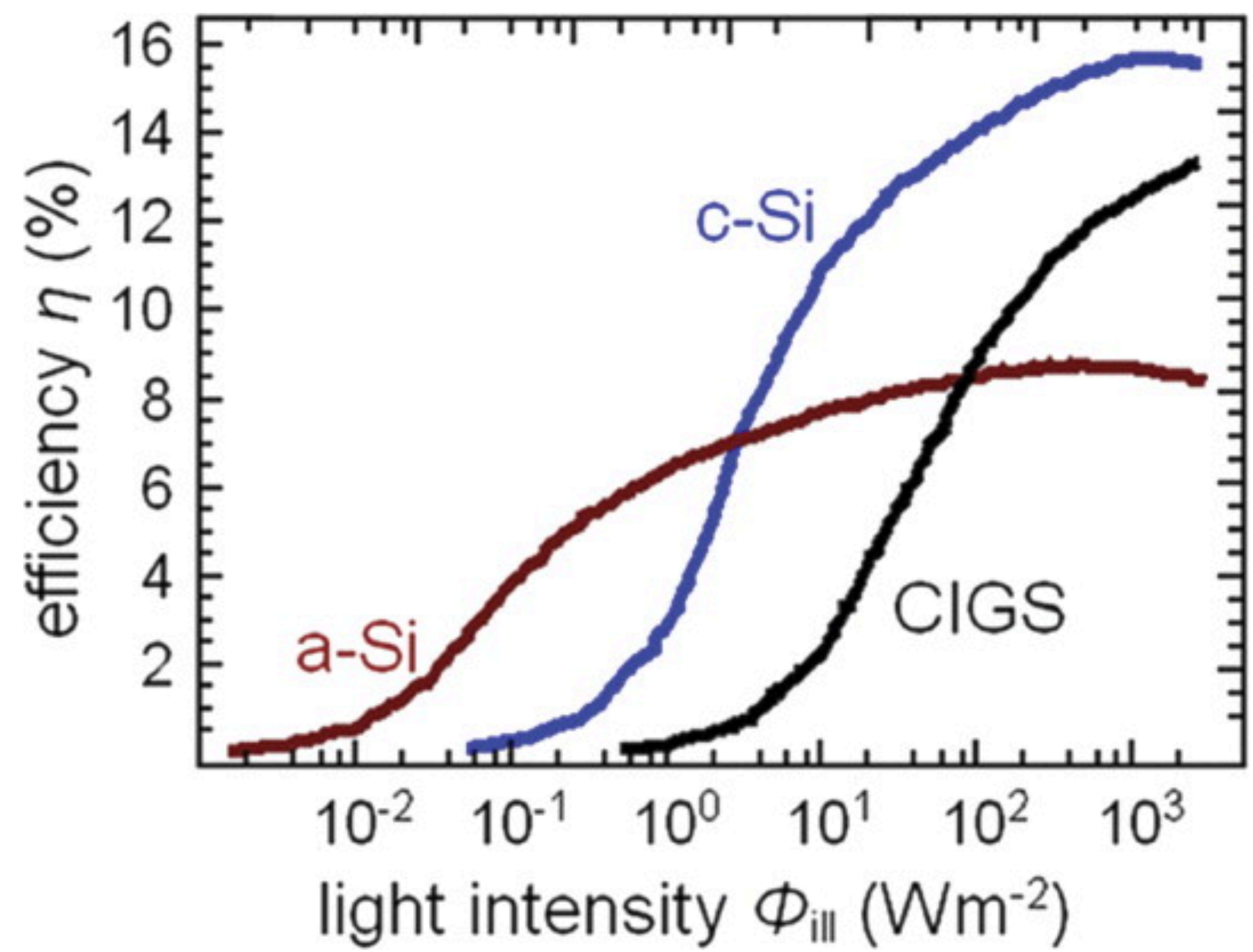


- Lightweight
- Flexible
- Tuneable
- Earth Abundant
- Non-toxic
- Stable
- Cheap

For indoor applications - good low light performance

Low-Light Performance

- Solar : 32000 -100000 Lux
- Factory floor: 500-1000 Lux
- Office : 500 Lux
- Home : 50-200 Lux



Schubert et.al, Materials Today, 9, 42, 2006

Semiconductor Options

Amorphous Si

Metal-Halide Perovskites

Organics

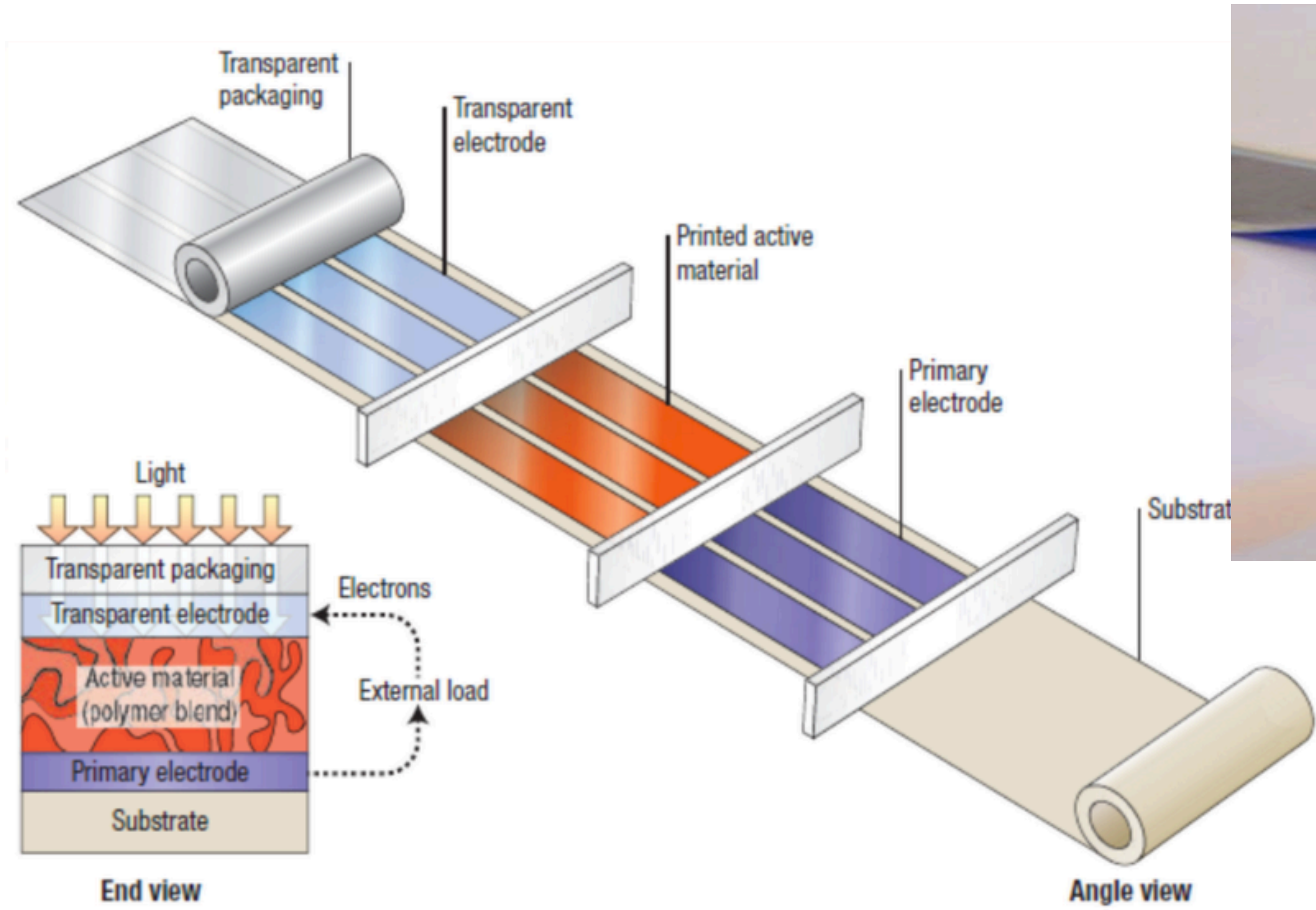
- Lightweight
- Flexible
- Tuneable
- Earth Abundant
- Non-toxic
- Stable
- Cheap

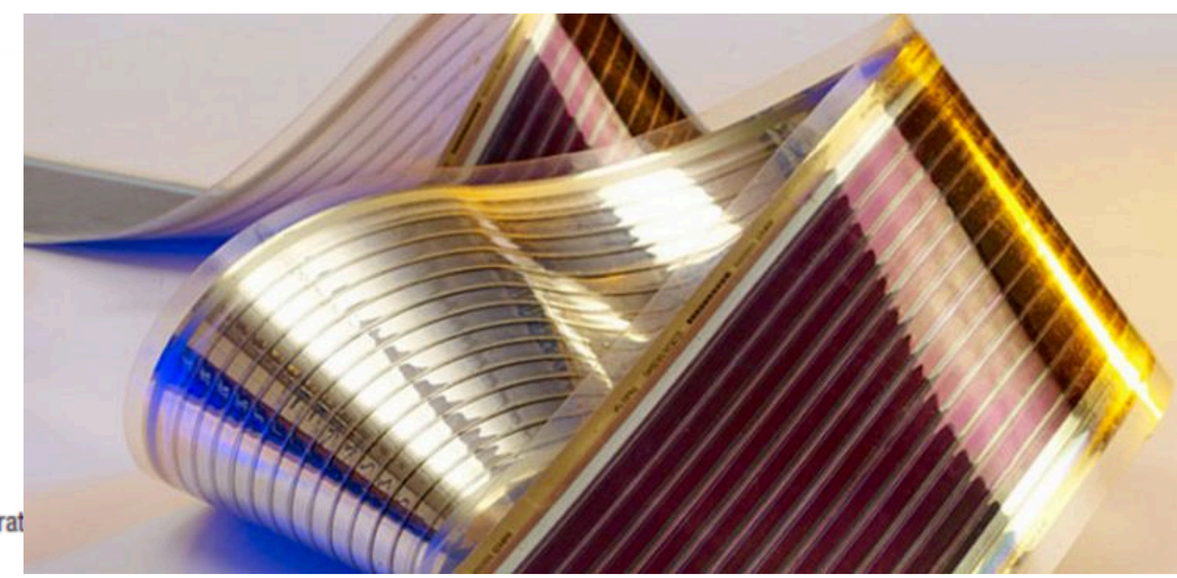
For indoor applications - good low light performance

Organic Electronics

Organic Photovoltaics (OPV)

- Sequential layer deposition
- Multiple printing and coating methods
- Printing speed of several ms per min
- Small volume coating





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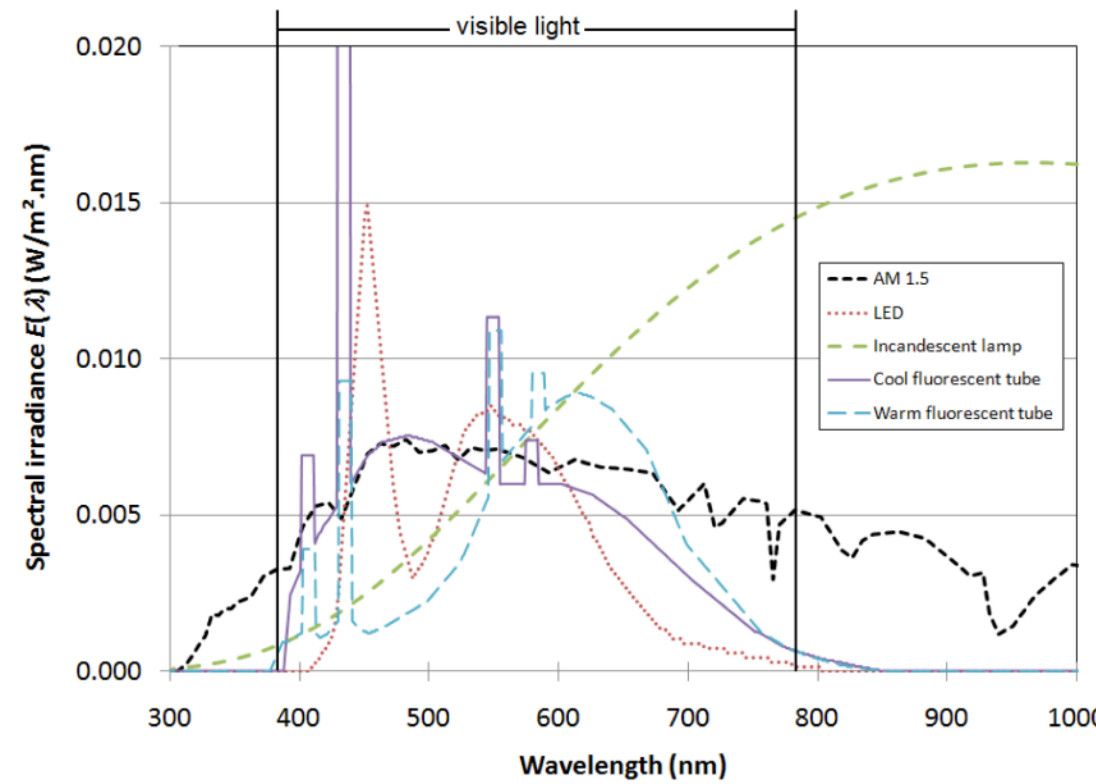
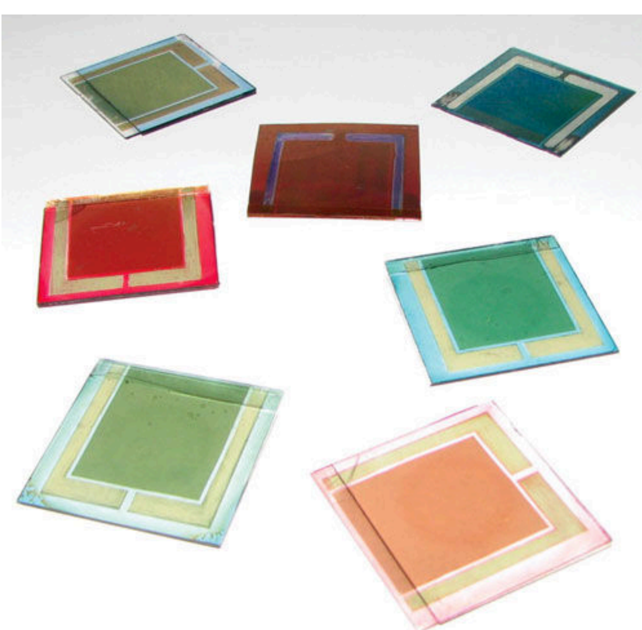
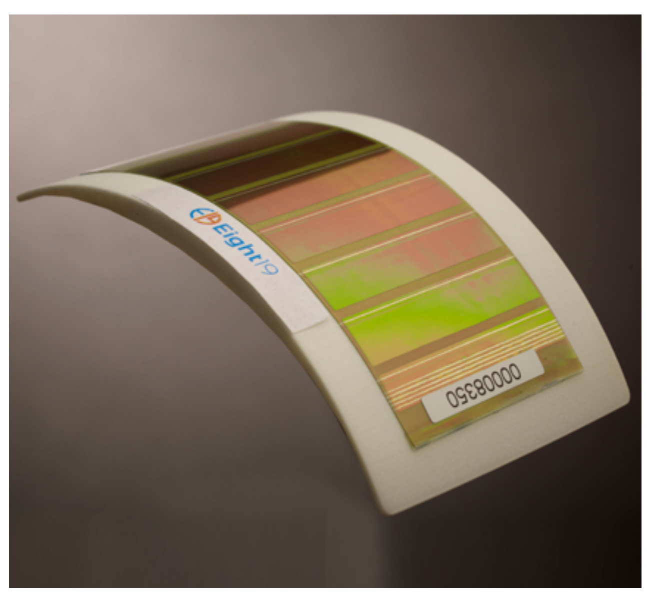
OPV - Advantages

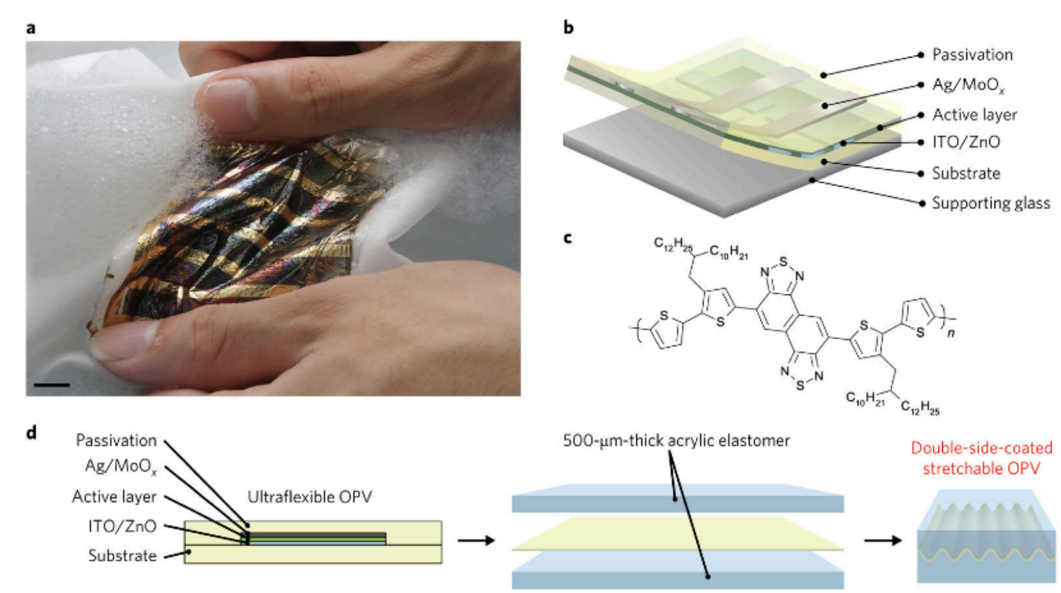
- Tuneable form factor
- Tuneable bandgap
- Tuneable colour, transparency
- Flexible, stretchable
- Very low energy payback time



Minnaert et.al. SPIE Proceedings







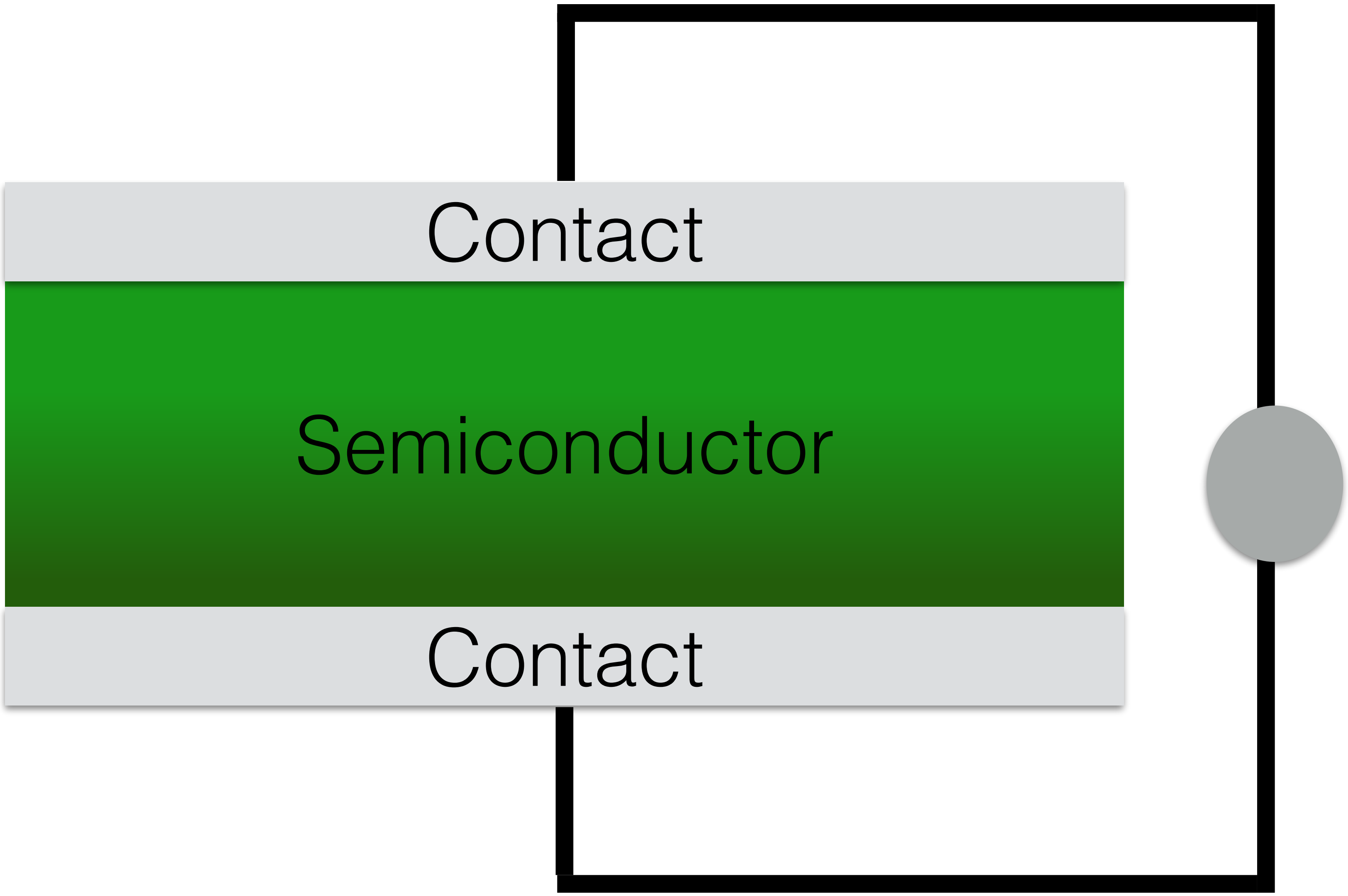
Nature Photonics 3, 447 (2009)

Nature Energy. 2, 780 (2017)

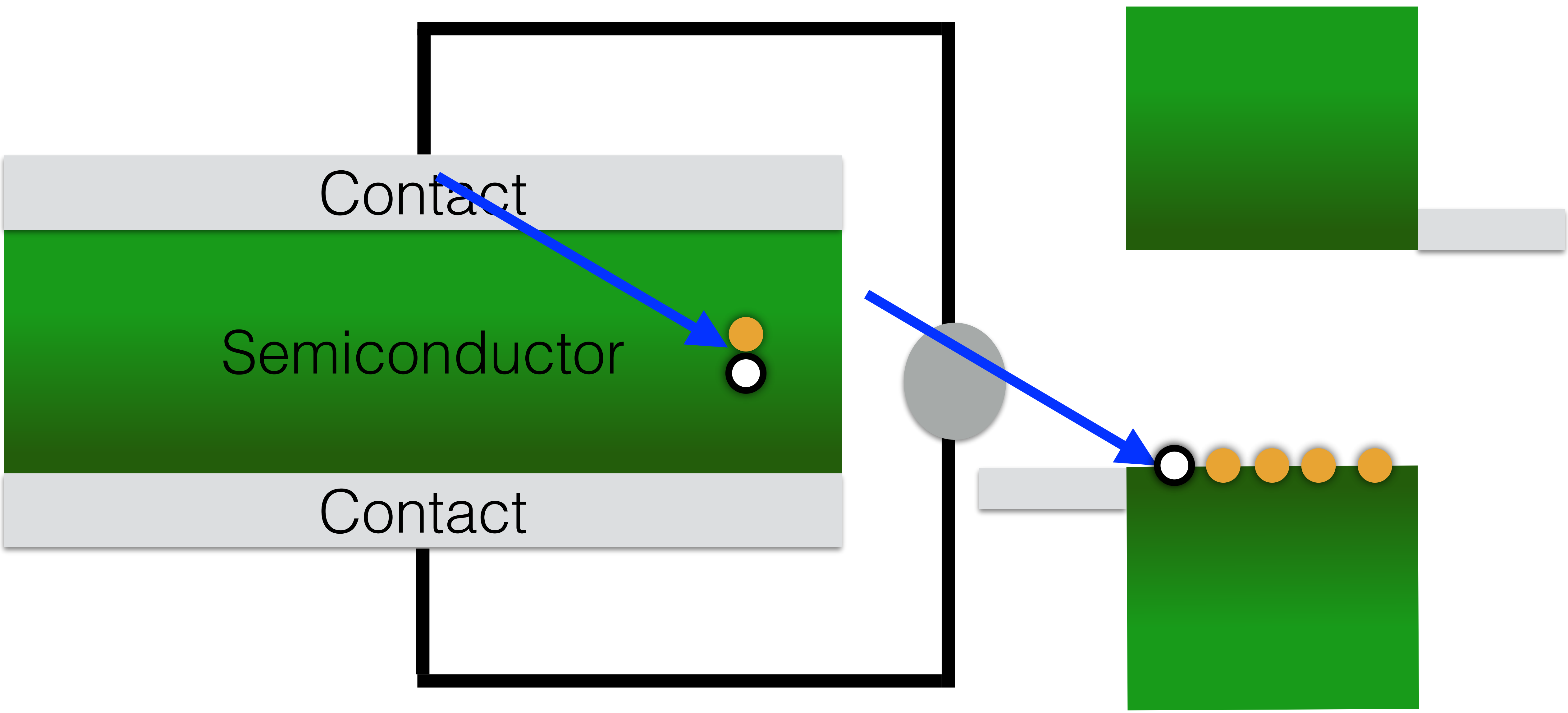
OPV - Challenges

- Efficiency
- Efficiency under low light conditions
- Stability
- Overall cost

How do Photovoltaics Work?

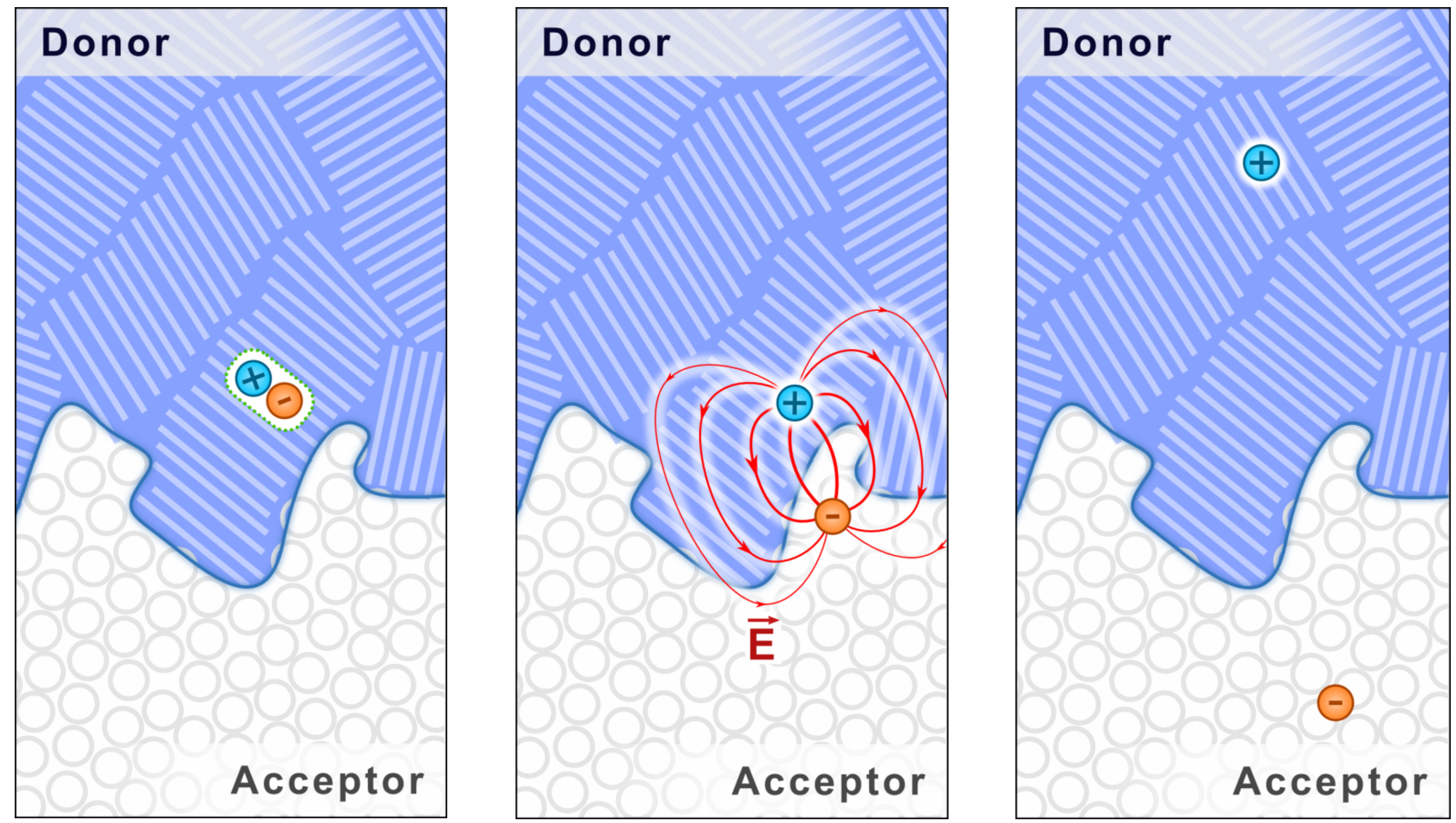


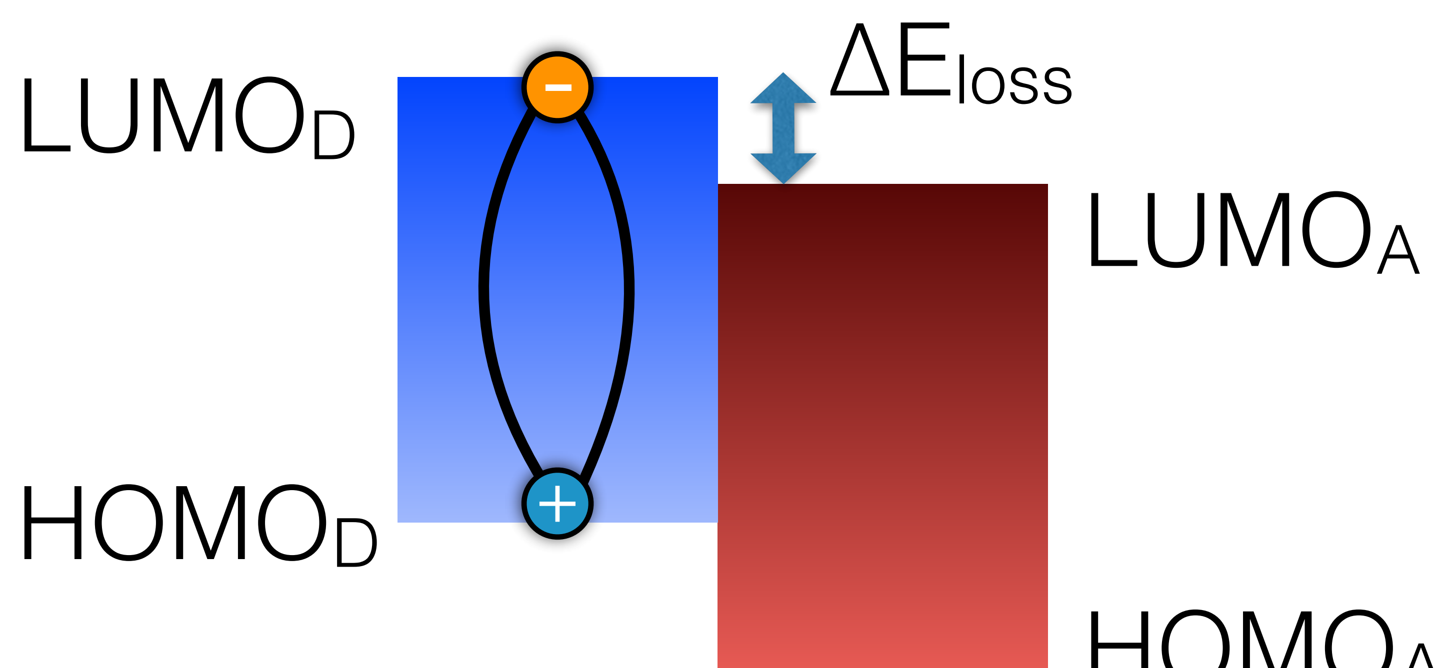
How do Photovoltaics Work?



OPV Physics

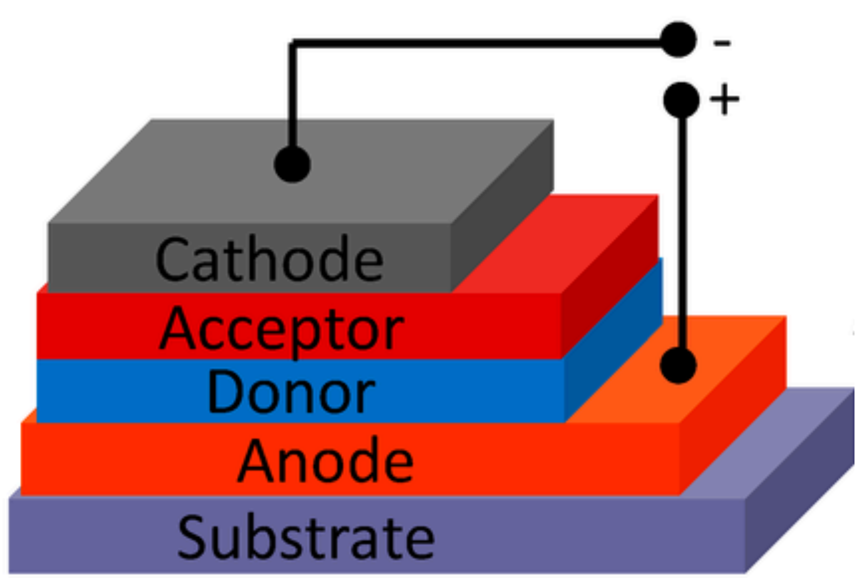
- Photon absorption forms tightly bound e-h pair, an exciton
- Dissociate exciton at a junction between n and p type material
- Energetic offsets drive charge transfer at junction





1st Generation OPVs

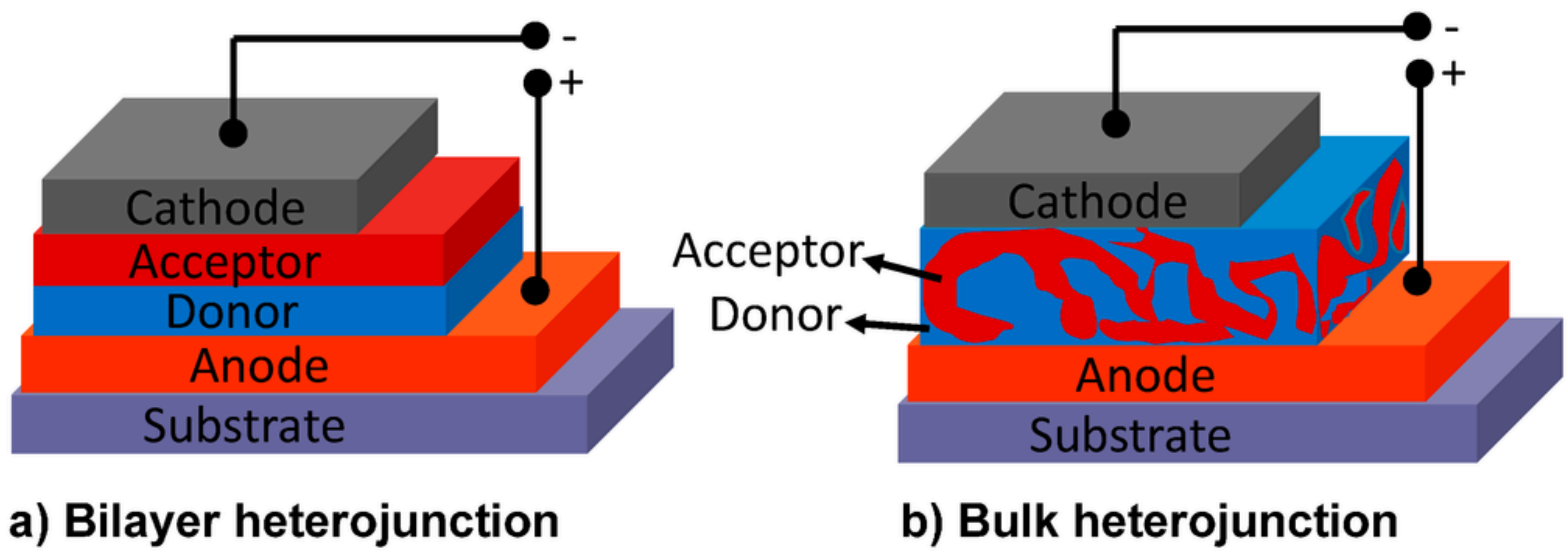
- Simple bilayer devices with donor (p-type) and acceptor (n-type) semiconductor layers
- All excitons don't get to junction to dissociate
- Large energy offset between p and n type material - loss in energy. $\Delta E_{loss} > 500meV$
- Before 1995, efficiency < 2% (AM 1.5G)



a) Bilayer heterojunction

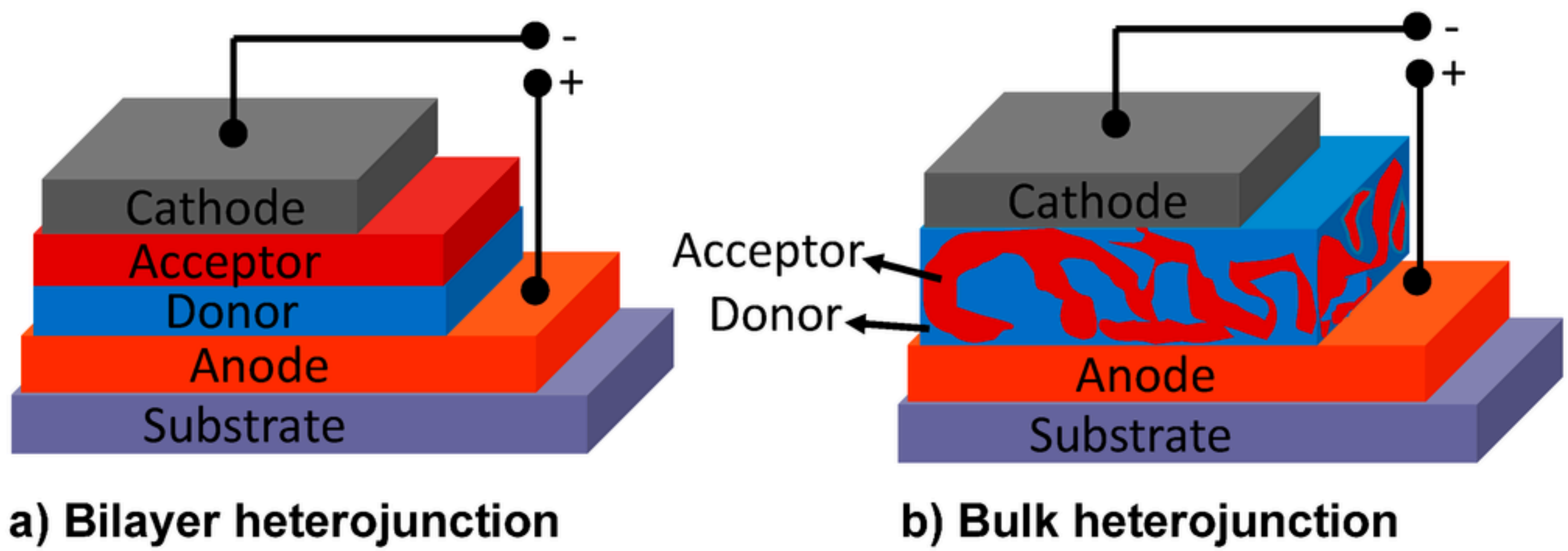
2nd Generation OPVs

- 'Bulk' heterjunction with nanoscale morphology formed via self-assembly. Millions of individual junctions.
- Fullerene (C60) based acceptors
- Large energy offset between p and n type material - loss in energy. ΔE_{loss}> 300meV
- 1995 - 2014, efficiency up to 10% (AM 1.5G)



3rd Generation OPVs

- Still a ‘Bulk’ heterojunction.
- Fullerene (C60) based acceptors replaced with non fullerene acceptors (n-type) materials
- Low or zero energy offset between p and n type material - NO loss in energy. ΔE_{loss} = 0 meV
- 2014 onwards, efficiency currently at 14% (AM 1.5G)



Indoor Efficiency

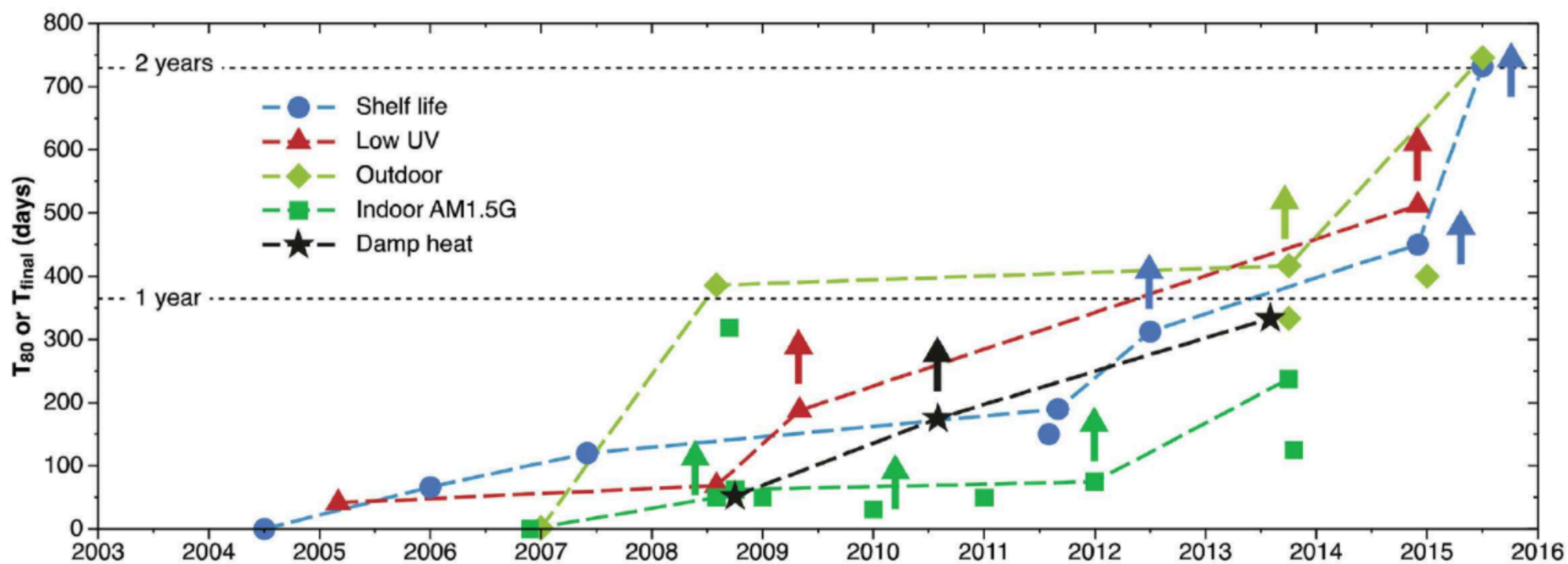
- **Efficiency**
  - 25% under white LED, 2700K. 14% under AM 1.5G
  - 45μW/cm^2 under 1000 Lux.
  - 8μW/cm^2 under 200 Lux.

- Above is for Gen2 OPV materials - fullerene based. Not much data on new more efficient non-fullerene systems.

- **Open questions and Opportunities** - what the nature of losses in OPVs under low light conditions? How are the intercede effected by trapping phenomena? Unexplored area. New device physics models, new materials needed.

Other Considerations

- Stability: 3rd Gen materials have much improved stability. Several year lifetime even under AM 1.5G
- Cost - could be cheap at high volume. But how to get to high volumes?



Adv. Energy Mater. 2016, 6, 1501208

Outlook

- OPV is well suited for IoT power systems
- Many unique properties not matched by other materials
- Large advances in materials design and efficiency in recent years
- Low light performance could be improved a lot. Has not received enough attention yet.
- OPV awaits the killer app - is is IoT?