Structured organic photodetectors via orthogonal photolithography

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28.09.2016

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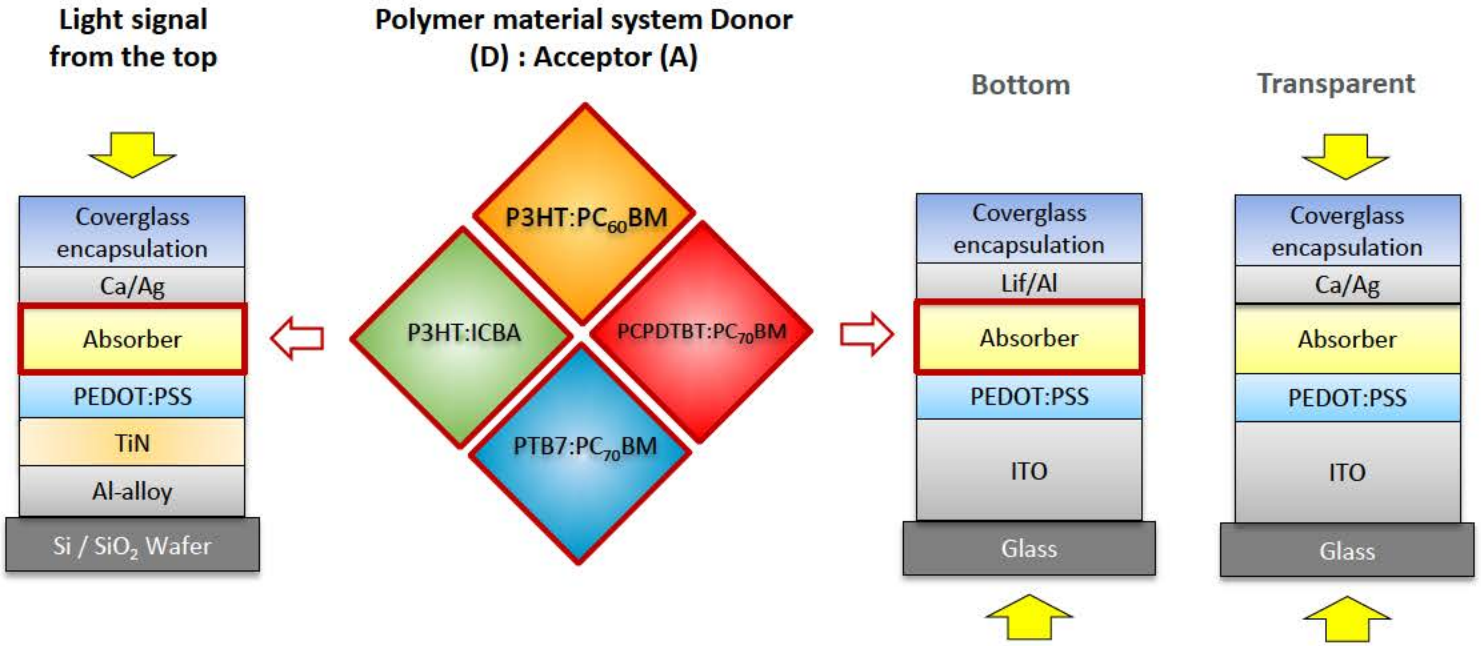
Outline

- Introduction
- Equipment
- OPD Stack & Material
- Process Lithography
- Result / OPD test substrate
- Result / OPD at 8-inch

Organic Photodetector (OPD) design & electronic process



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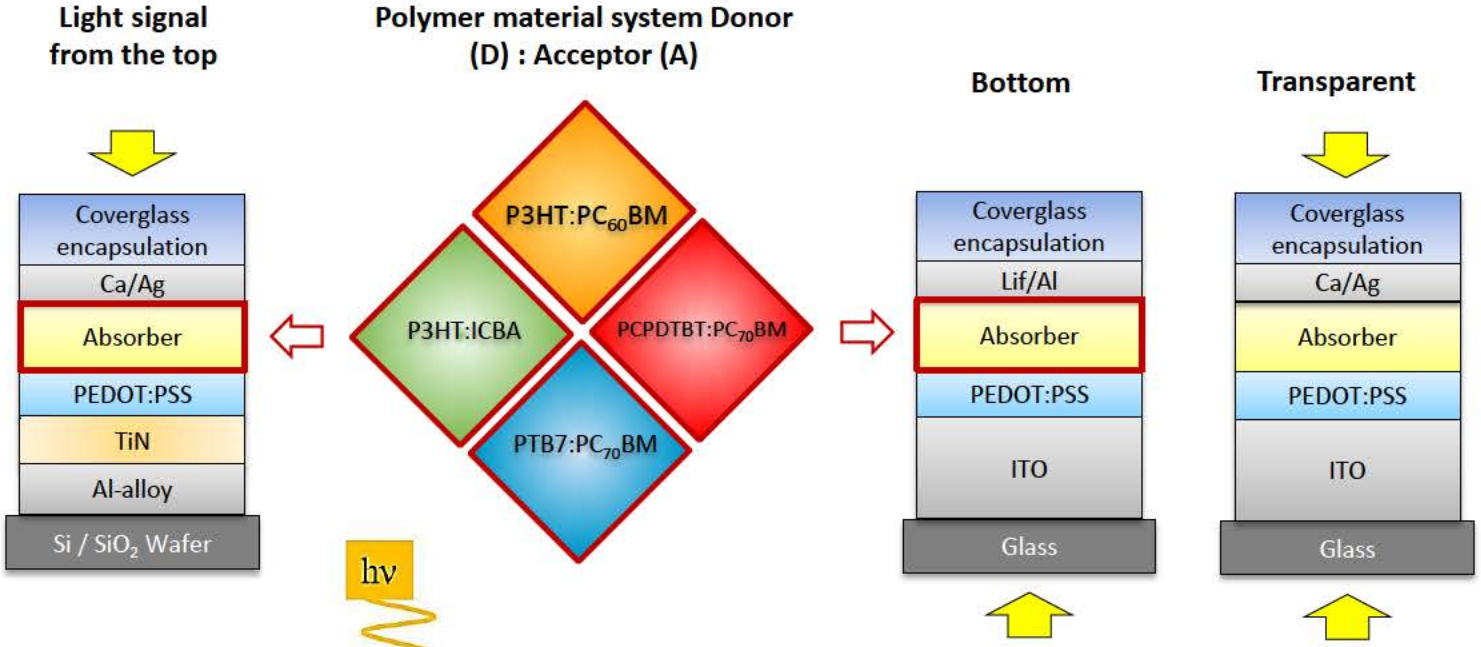
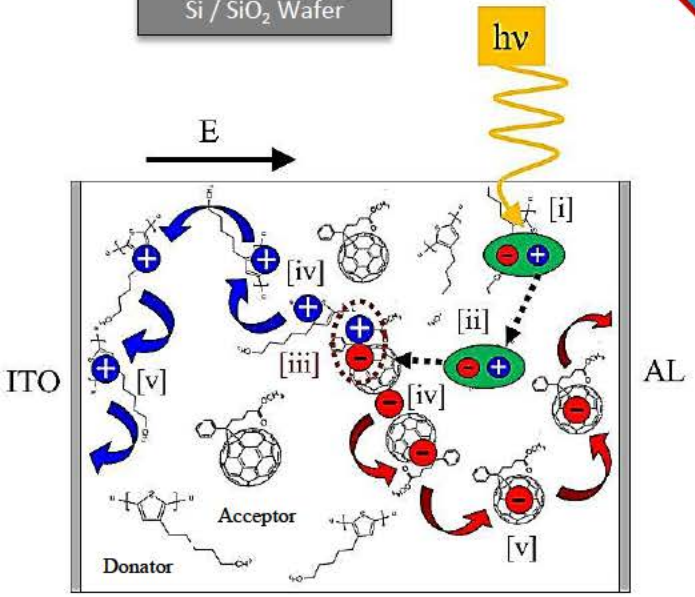
Organic Photodetector (OPD) design & electronic process





Charge generation in bulk heterojunction OPD

i. Light absorption and exciton creation
ii. Excitons diffuse to the donor-acceptor-interface
iii. Exciton dissociation *via* charge transfer (still Coulombically bound) polaron pair
iv. Exciton seperation (polarons pair)
v. Charge carrier transport *via* hopping free polarons

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Applications

Radiation Measurements

Current development

R & D and future

- ❖ Medical applications
- ❖ Healthcare

Applications:
- UV indicator to protect sunburn
- protect and control aging effects of biological organism

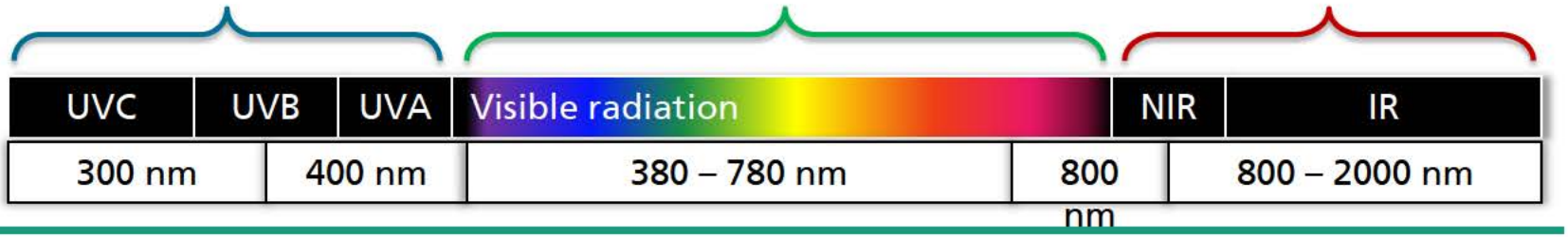
- ❖ industrial process monitoring
- ❖ Healthcare & Life- & Bioscience
- ❖ Optical sensors
- ❖ Interfaces in military, civil, astronomy
- ❖ Data transmission & Presence detect.
- ❖ Object recognition and X-ray detection

Applications:
- chemiluminescence
- non contact and positioning
- wearable applications scintillators
- surface motion detection
- .....

R&D and future

- ❖ Chemical sensing
- ❖ Security
- ❖ Interactive sensing
- ❖ Food and agriculture

Applications:
- Surface characterization
- luminescence detection
- Body radiation
- spectroscopy
- .....



IR – infra red / NIR – near infra red / UVA – ultra violet A / UVB – ultra violet B / UV – ultra violet B

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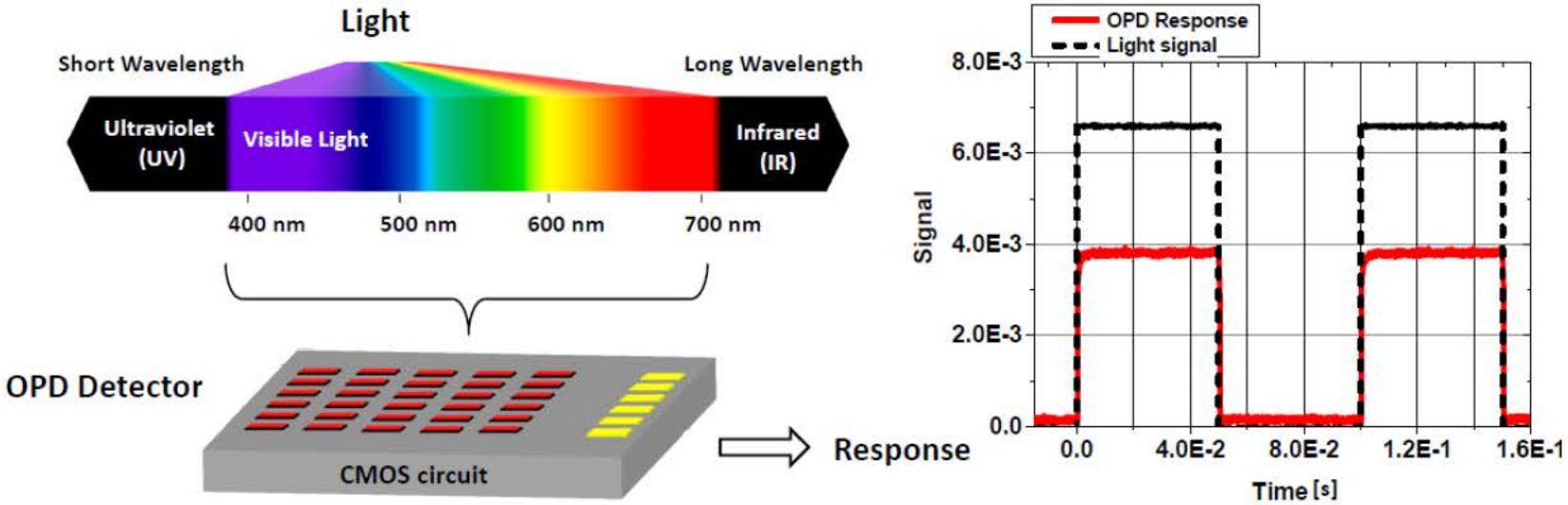
OPD at complementary metal-oxide-semiconductor



Motivation:

- Detector (array architecture), Imaging
- New field of applications NIR / UV
- Stacked architectures (circuit & OPD)
  → high fill factor
- Price reduction to InGaAs-Detektoren
- Large detectors at reasonable price

Challenge:

- **structuring at 8-inch wafer**
- crosstalk between pixel
- light to dark behavior
- absorption materials UV/NIR/IR

IR – infra red / NIR – near infra red / UVA – ultra violet A / UVB – ultra violet B / UV – ultra violet B /InGaAs-Indium-Gallium-Arsenide

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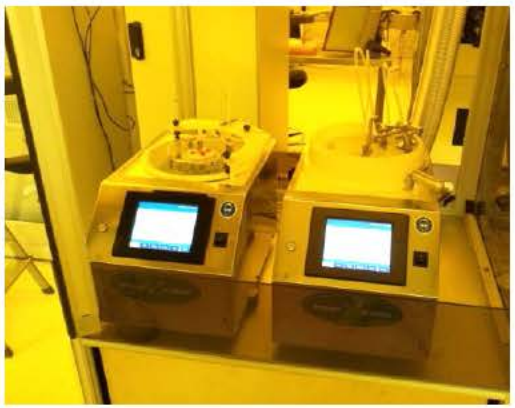
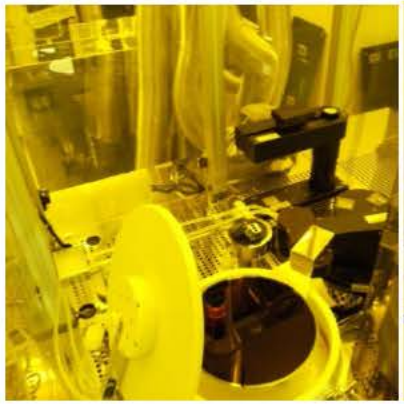
Equipment at FEP

- Process enabled for 200 mm wafers
  - Clean room class 100
  - ANS deposition system
  - Brewer Spincoater for photo resist deposition
  - Brewer Spraycoater for development and strip-off
  - EVG Spincoater for polymer deposition
  - Laurell Spincoater in glovebox
  - EVG wafer aligner / exposure system
  - Leybold Optics vacuum cluster for dry etching via O2 RIE and Ar ion mill
  - Tools for optical inspection: microscopes, particle scanner, ellipsometer and reflectometer





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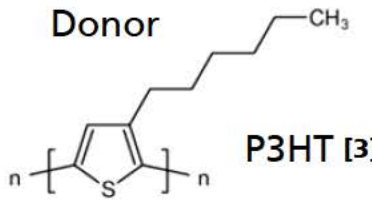
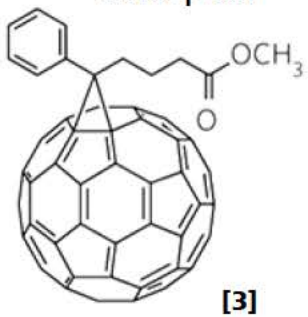
Organic Photodiodes / Stack & Materials

Donor



P3HT [3]

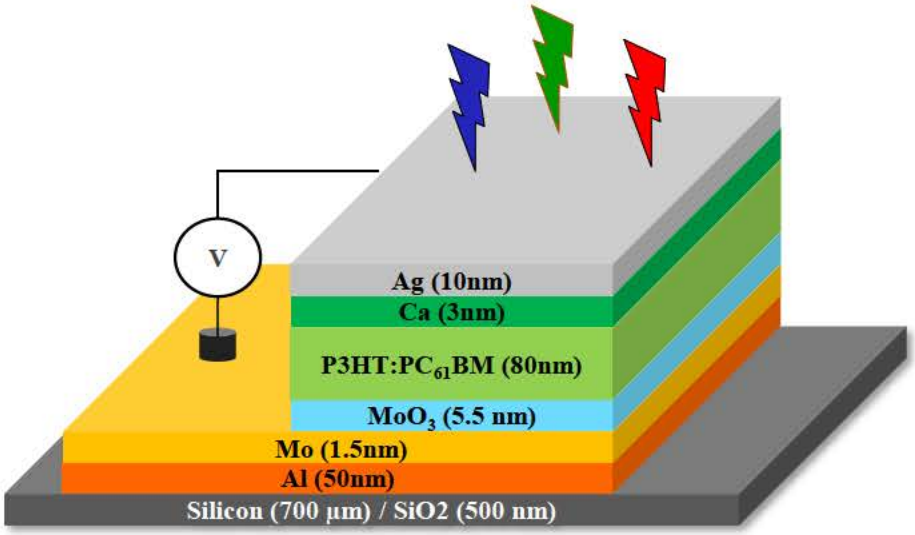
Acceptor



[3]

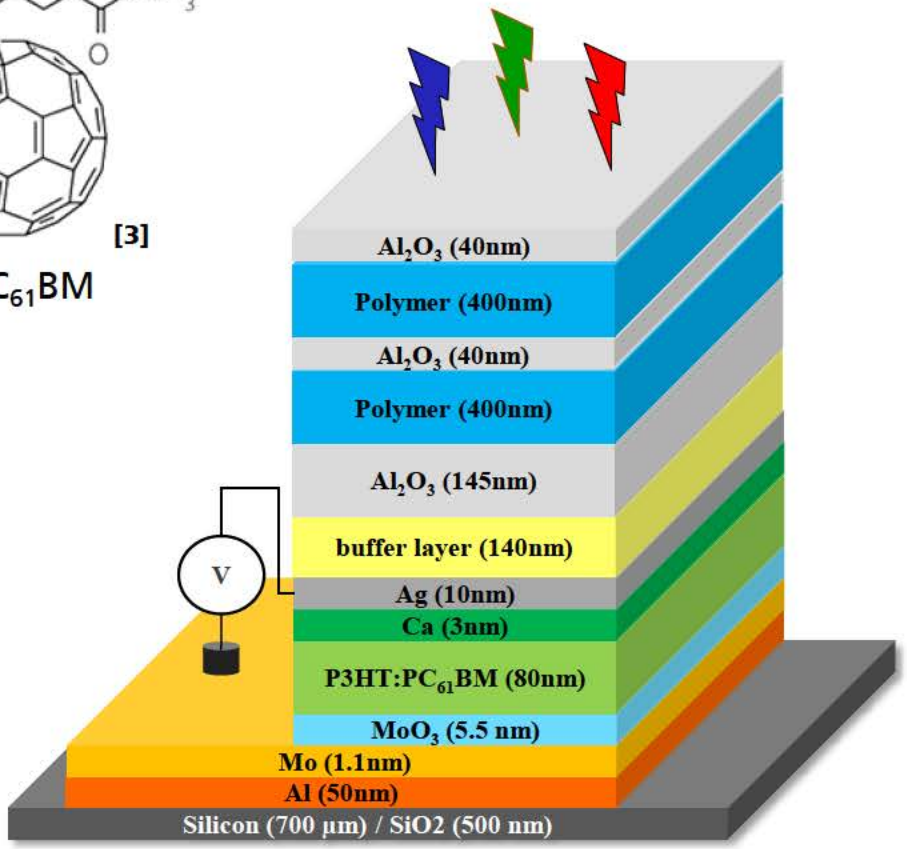
$PC_{61}BM$

h*ν



4F Substrate with cover glass

h*ν



8-inch Wafer with thin-film encapsulation

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[3]Li, G., Zhi, R., and Yang, Y. *Nature Phot.* **6**, 153–161 (2012).

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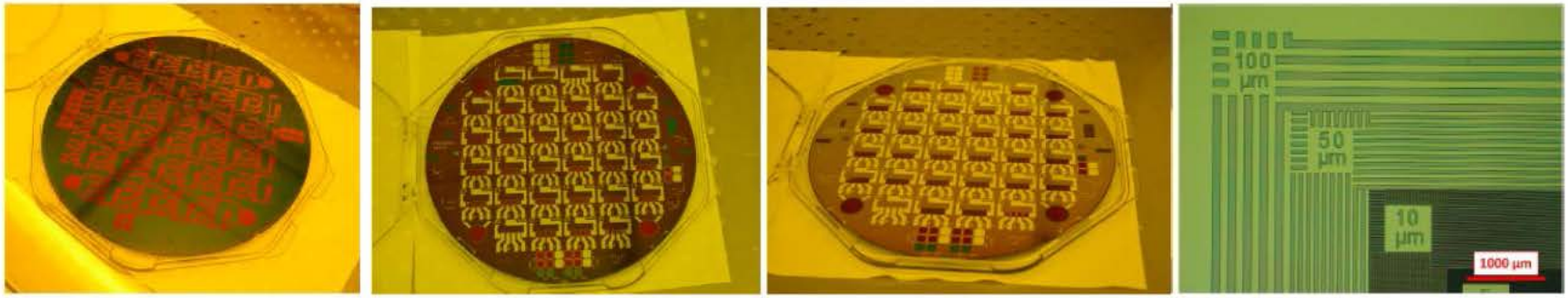
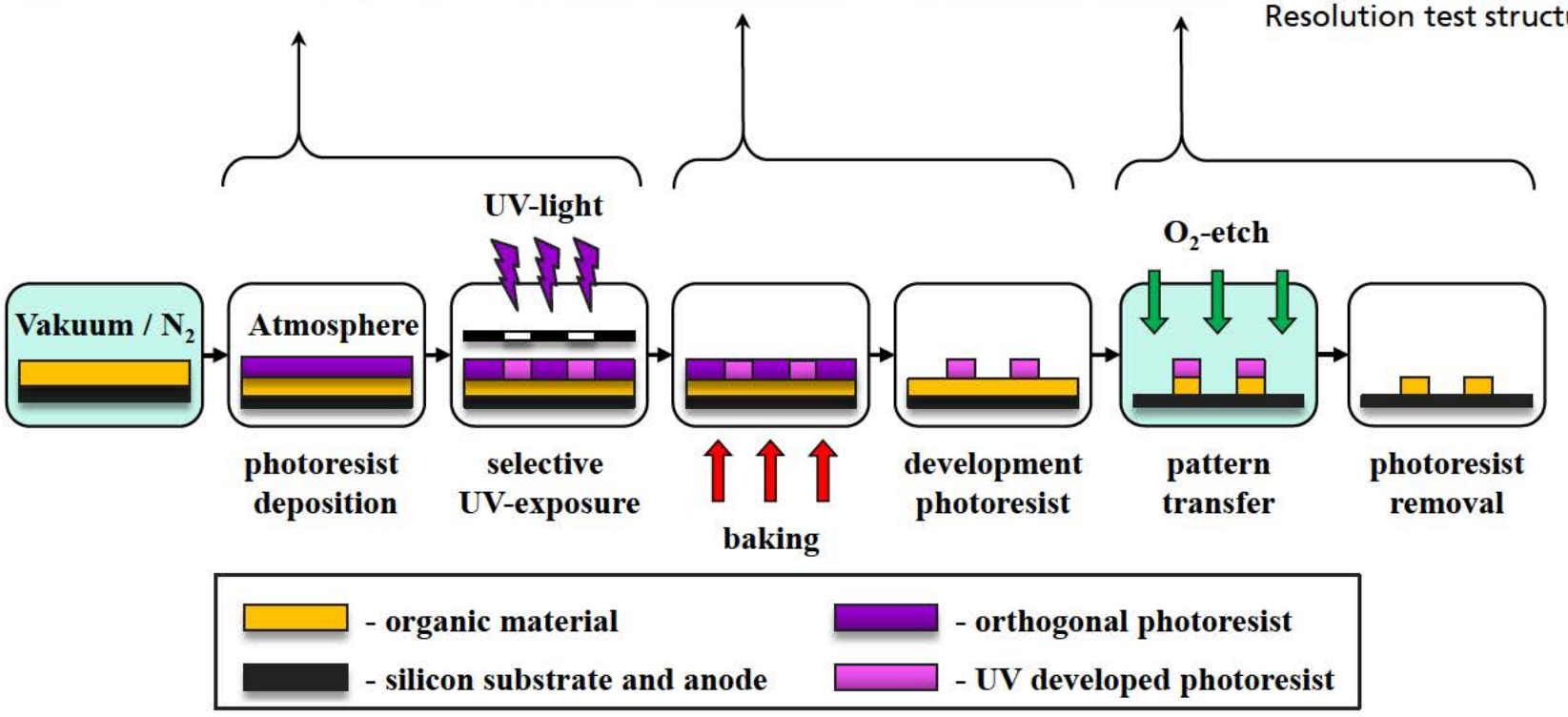
Process of structuring via orthogonal Photolithography



Resolution test structure



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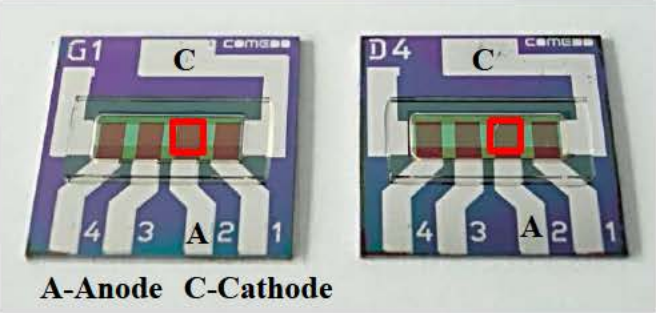
Organic Photodiodes test substrate

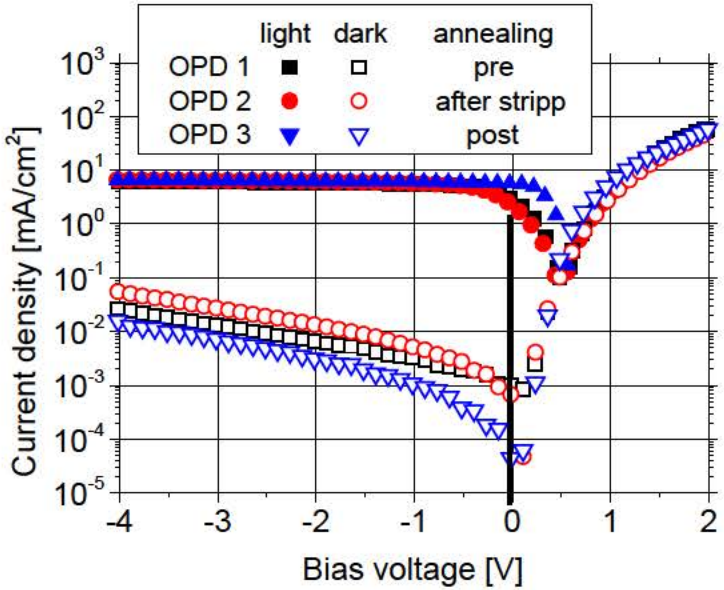
Reference OPD 3
manuelly structured by a cotton bud

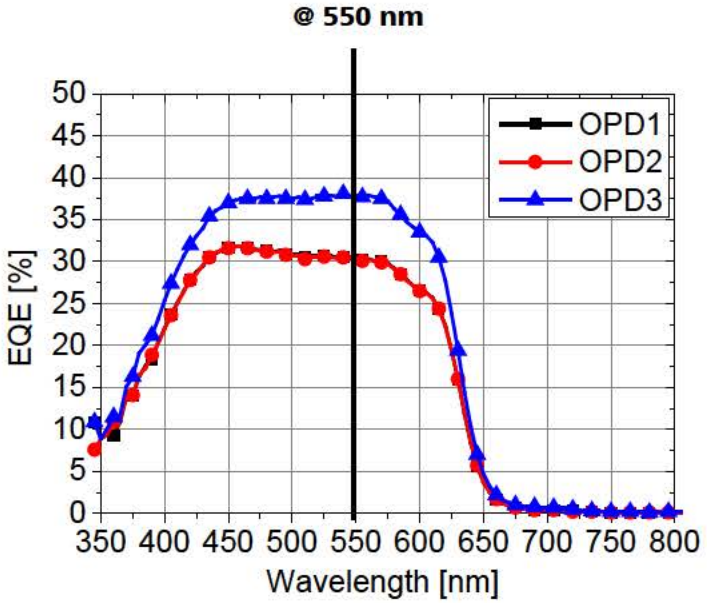
OPD 1 & 2
structured by orthogonal photolithography



We examine the possibility to structure the OPD but achieve different dark current and EQE in comparison.

OPD	J_{Ph} [mA/cm²] (@ -4 V)	J_0 [mA/cm²] (@ -4 V)	V_{OC} [V]	EQE [%] (@ 550 nm)	Sens. [A/W] (@ 550 nm)
OPD 1	6.6	0.06	0.59	37.0	0.167
OPD 2	6.4	0.03	0.52	30.4	0.135
OPD 3	6.5	0.17	0.48	30.3	0.134





Encapsulation with a cavity glass

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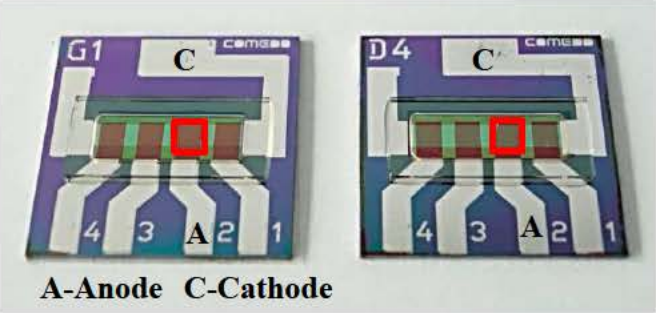
Organic Photodiodes test substrate

Reference OPD 3
manually structured by a cotton bud

OPD 1 & 2
structured by orthogonal photolithography



The result show a difference in open circuit voltage, series resistance and sensitivity.

OPD	J_{Ph} [mA/cm²] (@ -4 V)	J_0 [mA/cm²] (@ -4 V)	V_{OC} [V]	EQE [%] (@ 550 nm)	Sens. [A/W] (@ 550 nm)
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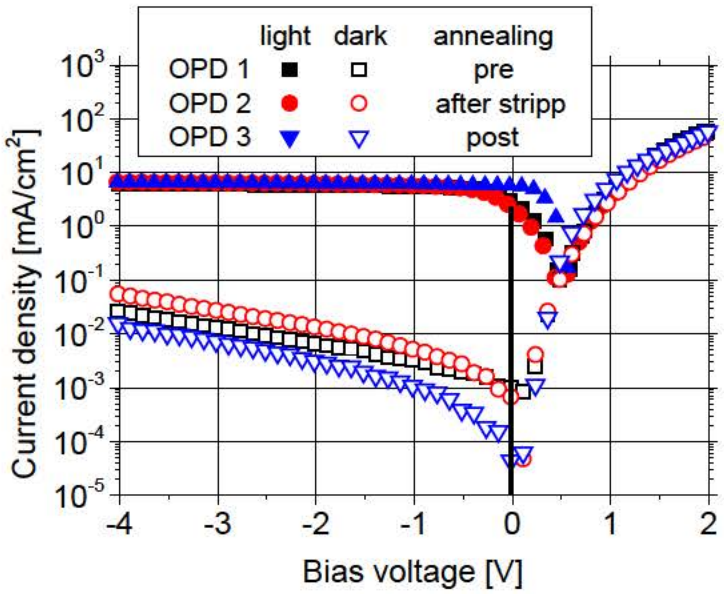

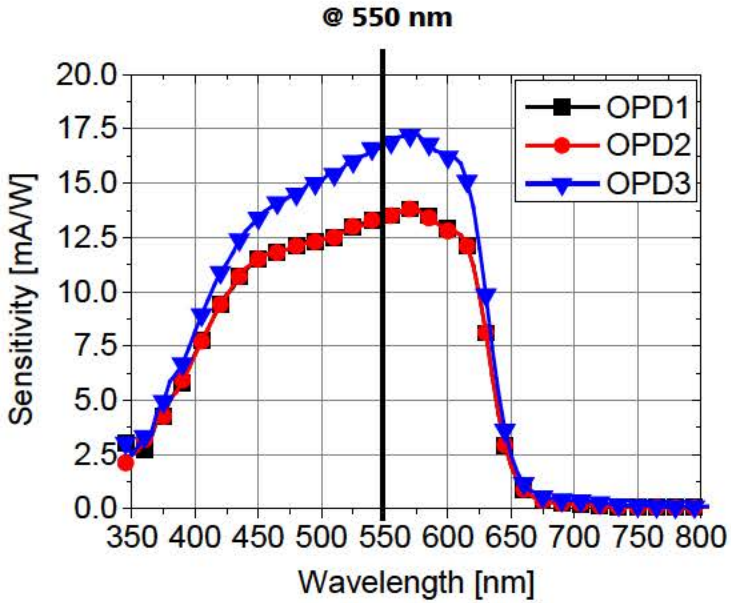

Encapsulation with a cavity glass

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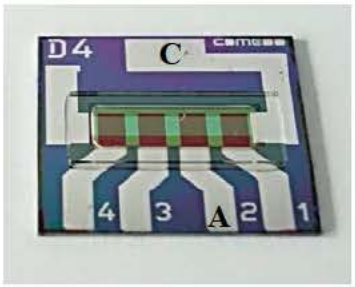
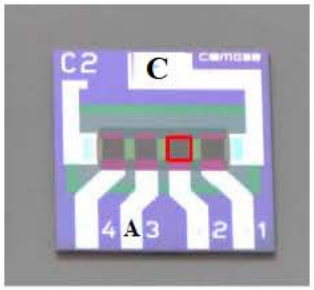
Organic Photodiodes at 8-Inch Wafer

Reference OPD
Substrate



Encapsulation with cavity glass

OPD @ 8-inch
Processed at wafer

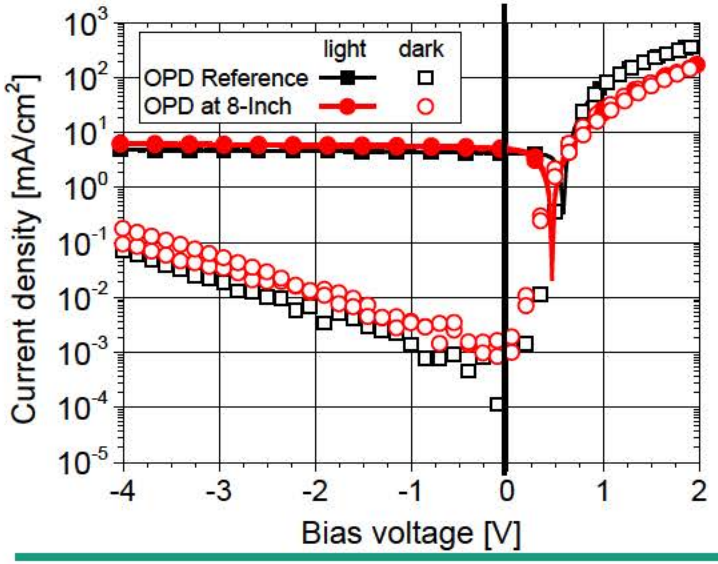


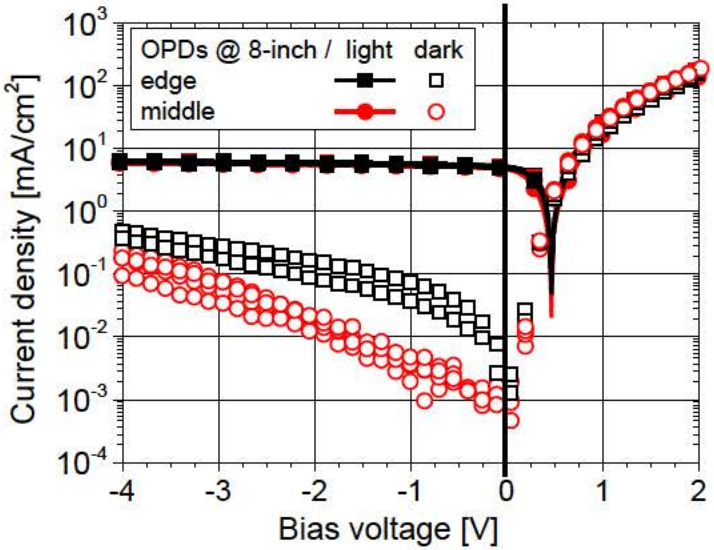
Encapsulation with Thin-films

Different On/Off-characteristics at 8 inch wafer series resistance varied and sensitivity.

OPD	J_{Ph} [mA/cm²] (@ -4 V)	J_0 [mA/cm²] (@ -4 V)	V_{OC} [V]	EQE [%] (@ 550 nm)	Sens. [A/W] (@ 550 nm)
Reference	5.1	0.06	0.59	37.6	0.165
8-Inch	6.1	0.18	0.48	32.8	0.145
8-Inch$_{edge}$	6.3	0.49	0.47	30.2	0.135
8-Inch$_{middle}$	5.7	0.09	0.47	28.9	0.130

A-Anode C-Cathode





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Encapsulation with a thin-film encapsulation

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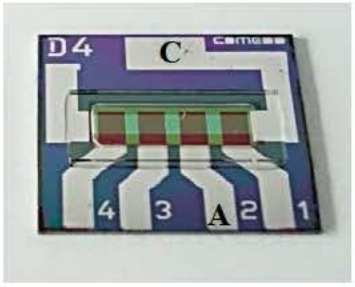
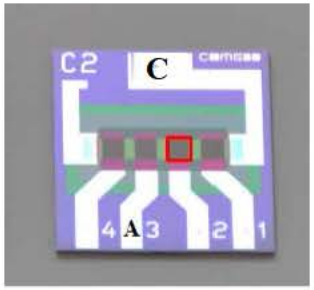
Organic Photodiodes at 8-Inch Wafer

Reference OPD
Substrate



Encapsulation with cavity glass

OPD @ 8-inch
Processed at wafer



Encapsulation with Thin-films

We examine a difference in absorption spectra and in EQE in dependence of thin-film encapsulation.

OPD	J_{Ph} [mA/cm²] (@ -4 V)	J_0 [mA/cm²] (@ -4 V)	V_{OC} [V]	EQE [%] (@ 550 nm)	Sens. [A/W] (@ 550 nm)
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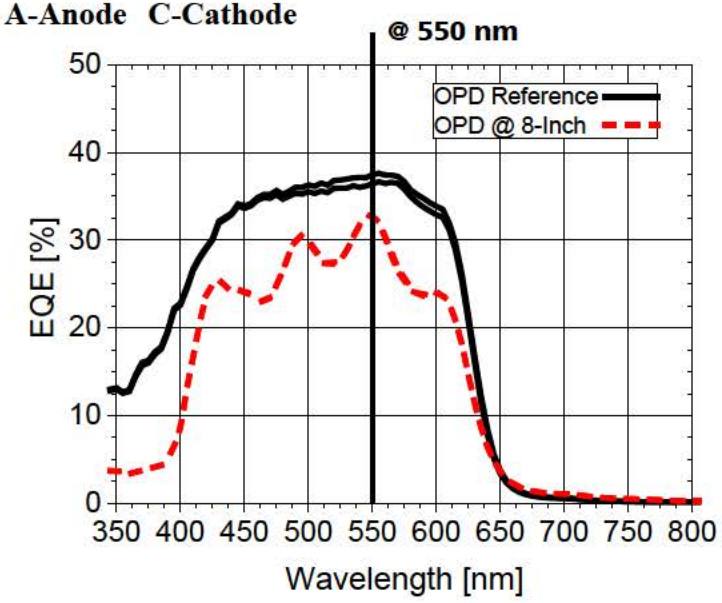

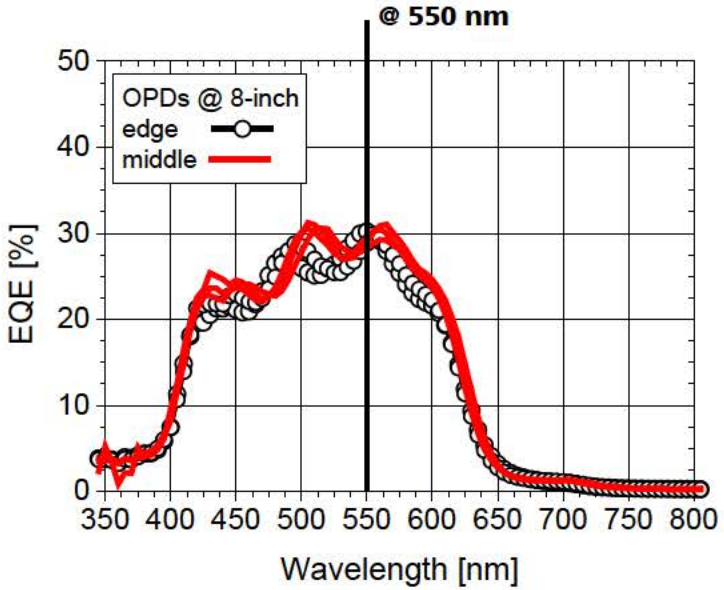

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Encapsulation with a thin-film encapsulation

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Organic Photodiodes at 8-Inch Wafer

Reference OPD
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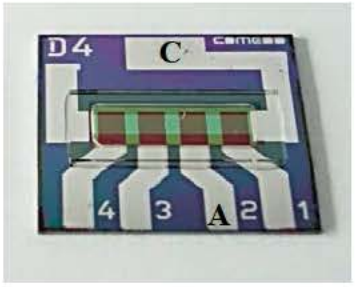
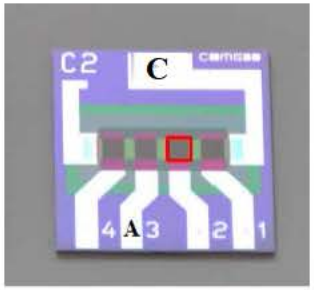


Encapsulation with cavity glass

OPD @ 8-inch
Processed at wafer



Encapsulation with Thin-films

The change in the absorption spectrum results in a change in sensitivity.

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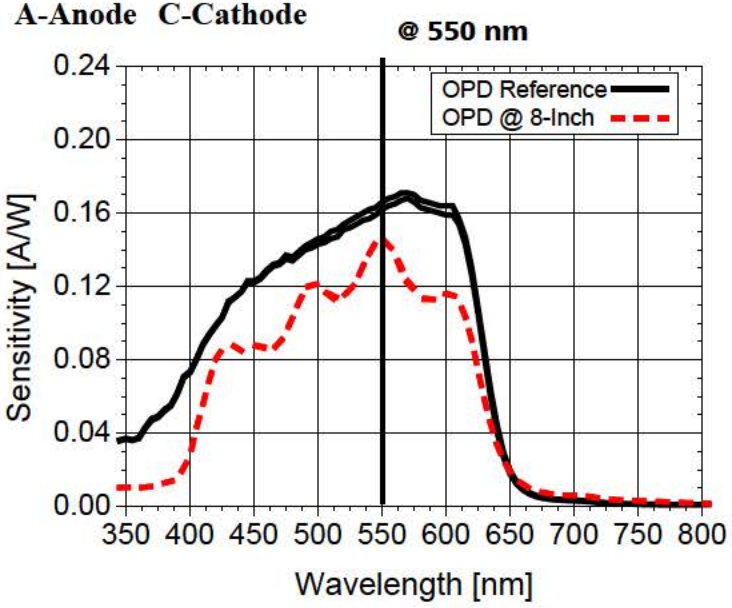

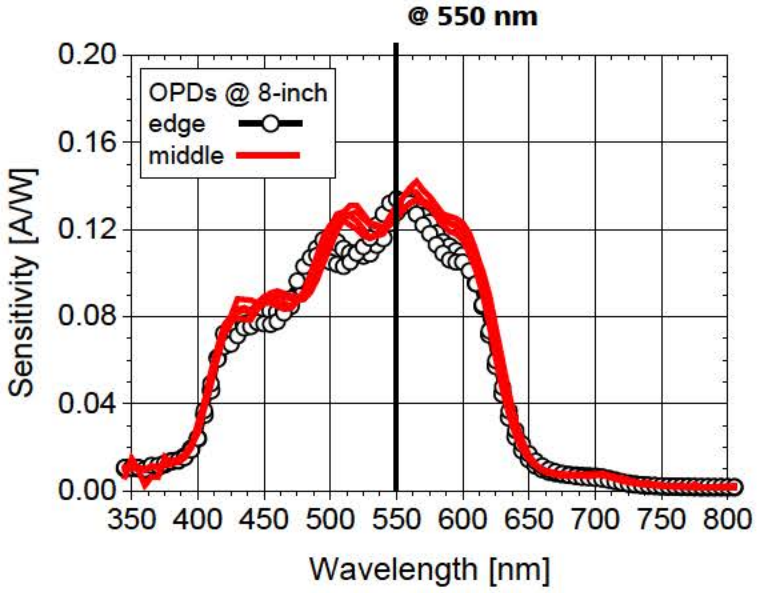

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Encapsulation with a thin-film encapsulation

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Conclusion

- Successful structuring of P3HT:PCBM by orthogonal photolithography.
  (1-inch test substrate and 8-inch wafer)
- We achieve in maximum a resolution of 50 µm with photolithography.
- The j-V-behavior is different in comparison to the OPD reference.
  (This depends on different series resistance for J_{PH} and impurities affecting during the process the J_0.)
- The EQE and sensitivity decreases under the influence of photolithography.
- The spectral shape of EQE change in dependence of thin-film encapsulation.
- The on- / off-ratio is varied by the influence of lithographic process.
- The transfer from 1-inch substrates to 8-inch wafer shows the similar behavior for electronic characteristics.
- Increasing current density at 8-inch because of a faster process due to semi-automated work at wafer-level
- We examine a differences in J-V-behavior at 8-inch wafer with different values for $J_{0,}$middle to edge.

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