Ultra-thin Parylene Substrates for Organic Solar Cells

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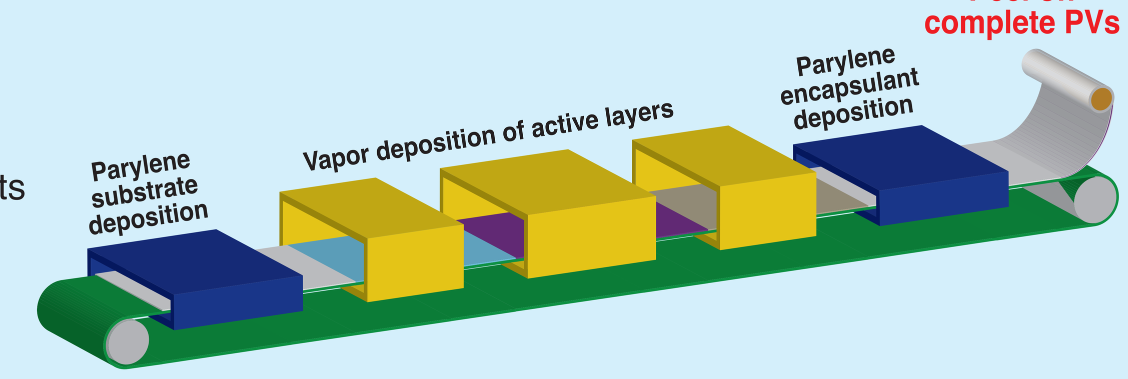
organic and nanostructured electronics

ONE LAB

OPV on glass substrate

Introduction and Research Question

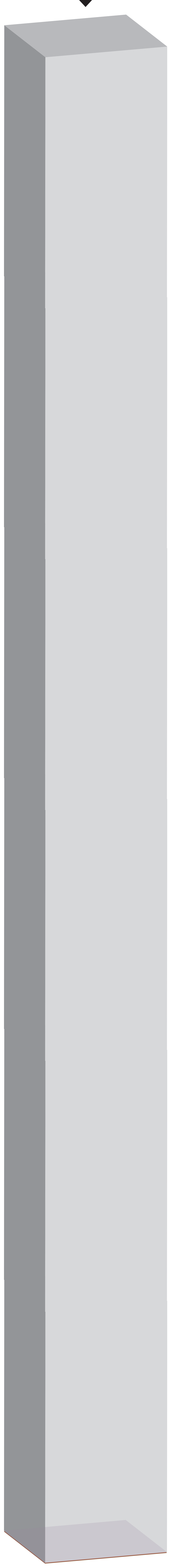
- Heavy glass substrates dominate the weight of conventional thin-film solar photovoltaic (PV) modules
- Small-molecule organic PVs employ thin active layers
- Alternative plastic substrates have large surface defects that may exacerbate shorting in ultra-thin OPVs
- Here we investigate lightweight, flexible, transparent, vapor-deposited polymer films as substrate and encapsulation layers for organic solar cells

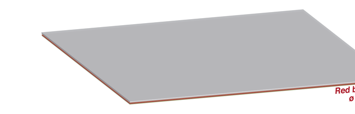


Key Results

- Vapor-deposited parylene C is a viable substrate and encapsulation material for organic solar cells
- Parylene-based devices achieve efficiencies (2.9%) comparable to conventional glass-based cells
- First *in situ* fabrication of a solar cell substrate
- Thinnest solar cell ever demonstrated: 1.3 μm total

OPV on parylene substrate





Motivation

Modern human society uses enormous amounts of energy. Our prodigious consumption has spawned an energy sector that produces two-thirds of global greenhouse gas emissions[1]. Mitigating climate change thus will require a massive shift from conventional fossil-fuel generation to low-carbon technologies, such as solar photovoltaics (PVs).

Global energy consumption
140 PWh/year = ~16 TW_{avg}

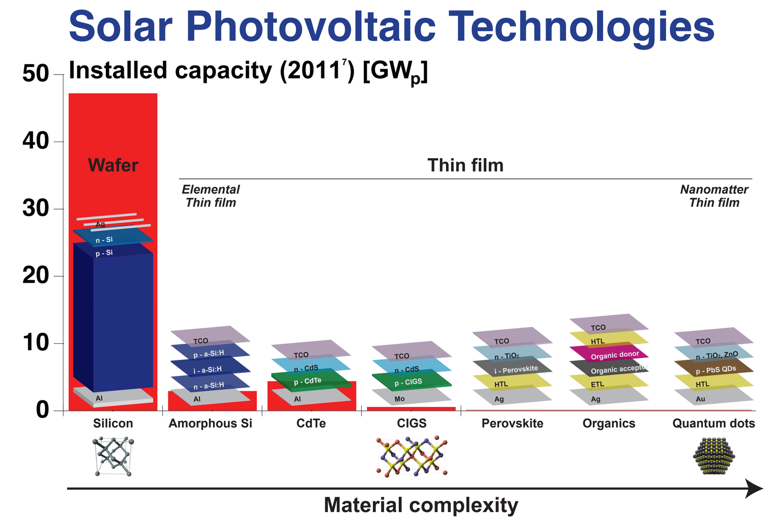
Global solar technical potential[2]
15,000 PWh/year

Global installed PV capacity (2012)[3]
100 GW_p

Thick (3-4 mm) glass substrates dominate the weight and mechanical properties of today's thin-film solar cells, negating their key advantages over crystalline silicon. Conventional plastic substrates can be flexible and lightweight[4,5,6], but unavoidable surface roughness may cause shorting in ultra-thin small-molecule organic PVs.

In this work, we investigate an alternative polymer, Parylene C, which can be deposited *in situ* to form clean, flexible, transparent substrates with tunable thicknesses.

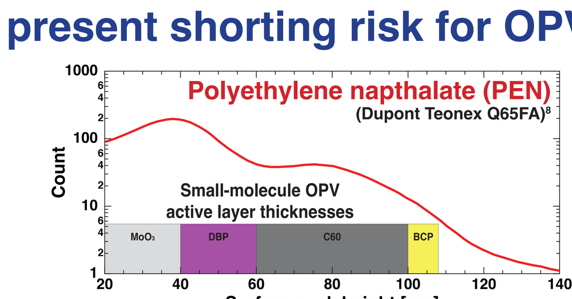
Solar Photovoltaic Technologies



Organic PVs (OPVs)

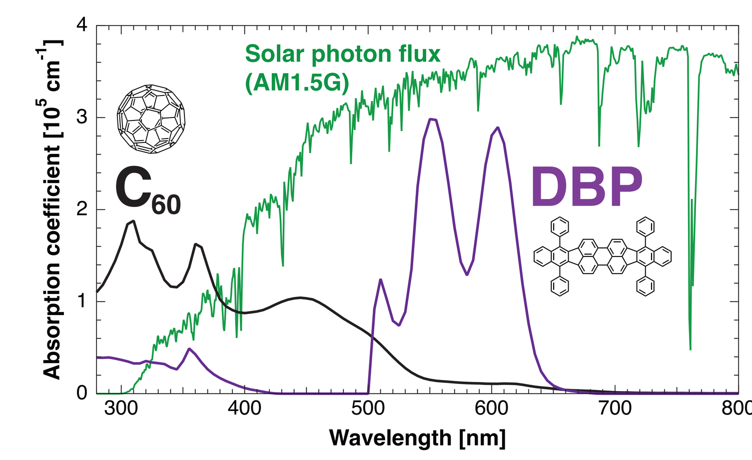
- Low materials usage
- High specific power (W/g)
- Low-temperature deposition
- Flexibility

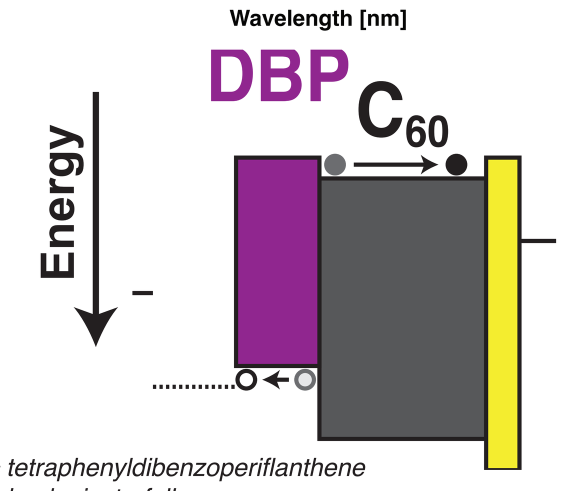
Defects in conventional plastics present shorting risk for OPVs



Device structure and operation

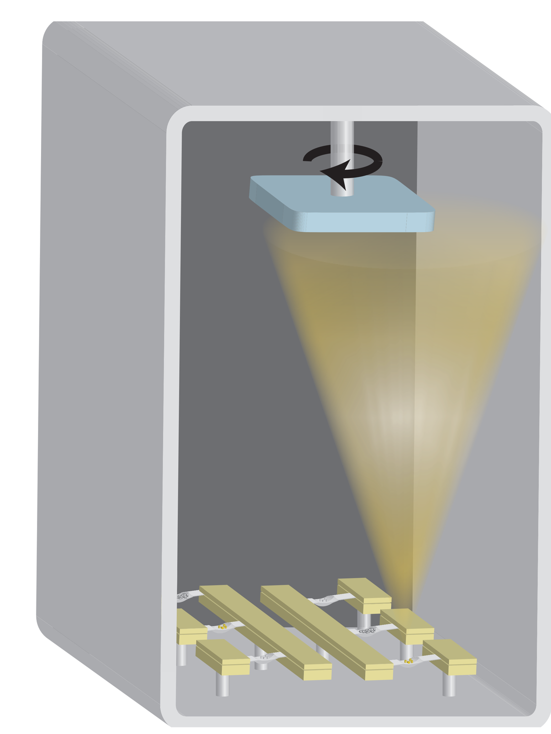
Light is absorbed primarily in the small-molecule organic donor DBP*



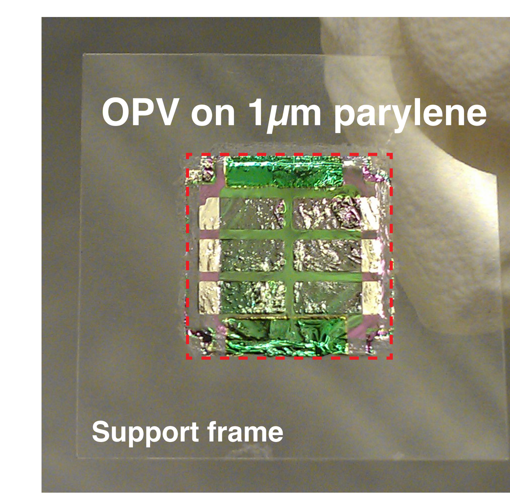


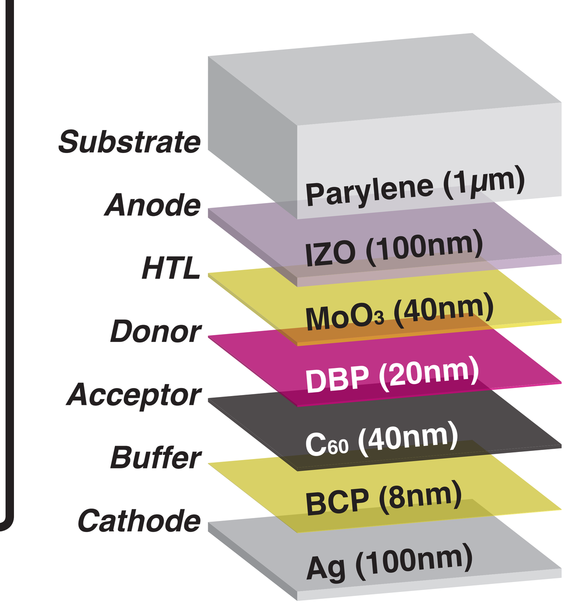
DBP = tetraphenyldibenzoperiflanthene
C_{60} = buckminsterfullerene
BCP = bathocuproine

Thermal evaporation of MoO_3, organic films, and Ag electrode



Devices are peeled off glass carrier after fabrication

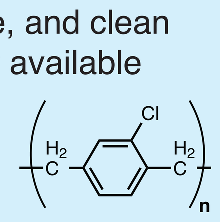




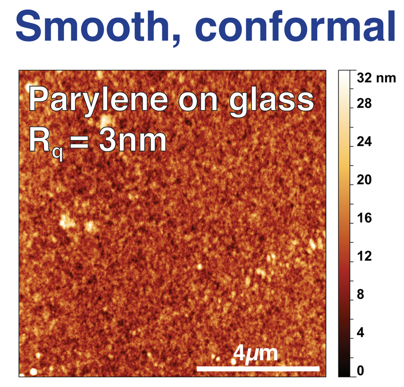
Parylene C: An alternative PV substrate

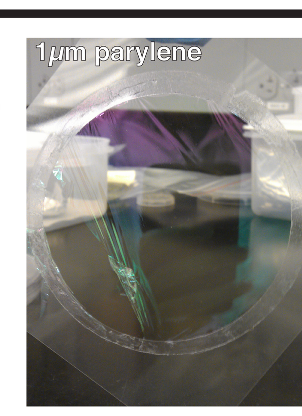
Parylene C = poly(chloro-p-xylylene)

- Room-temp. chemical vapor deposition (CVD)
- Precise nanometer-scale thickness control
- Smooth, conformal, pinhole-free, and clean
- Many variants are commercially available
- Transparent
- Chemically inert
- Biocompatible (USP Class VI)

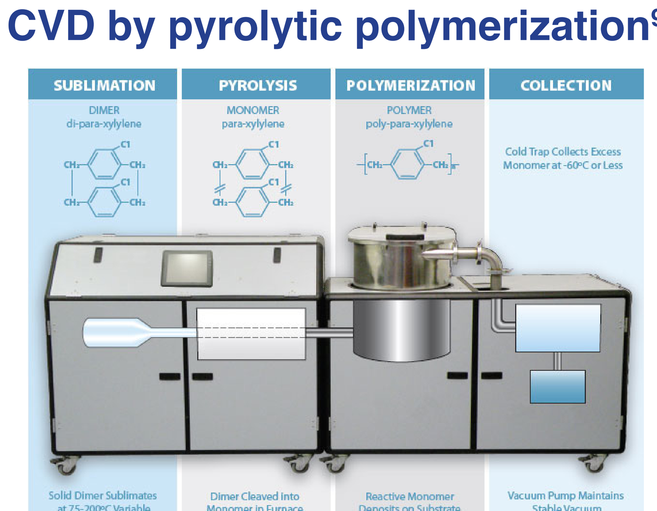


Smooth, conformal

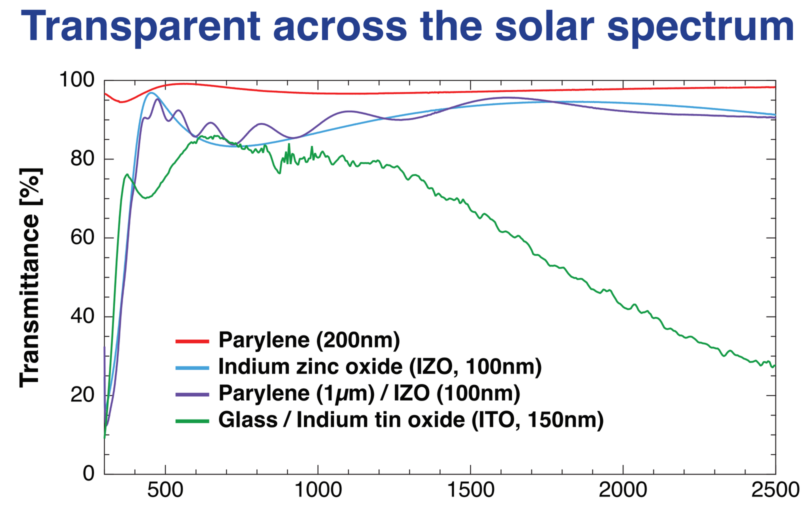




CVD by pyrolytic polymerization[9]

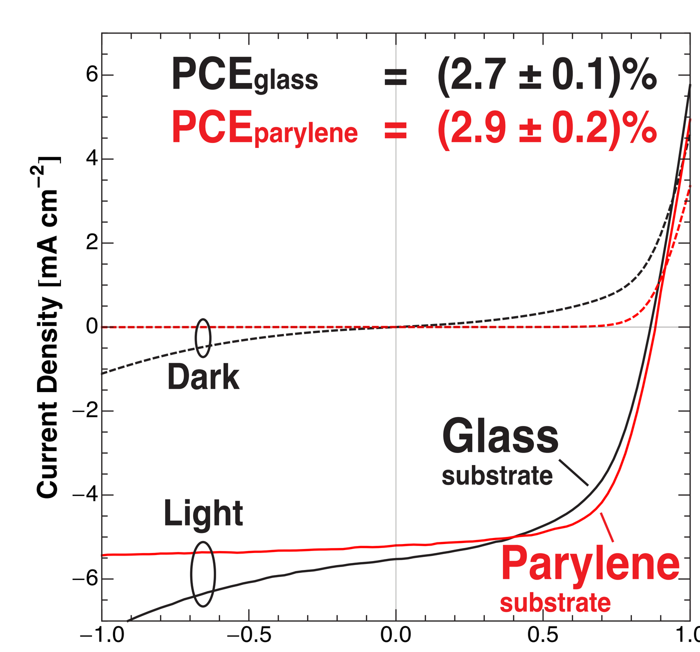


Transparent across the solar spectrum

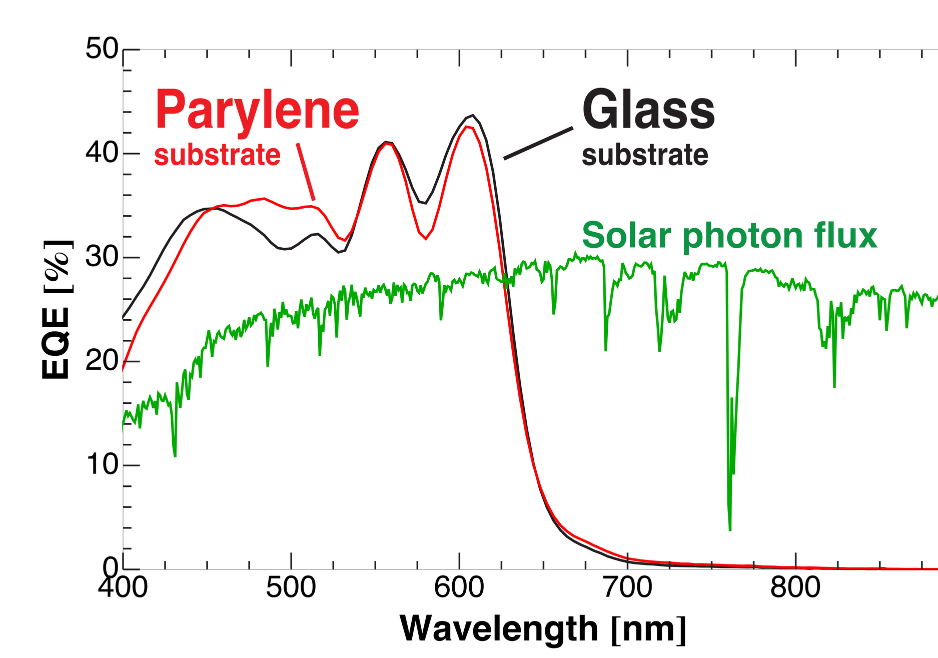


Solar cell performance

Organic solar cells on parylene substrates perform as well as devices on glass

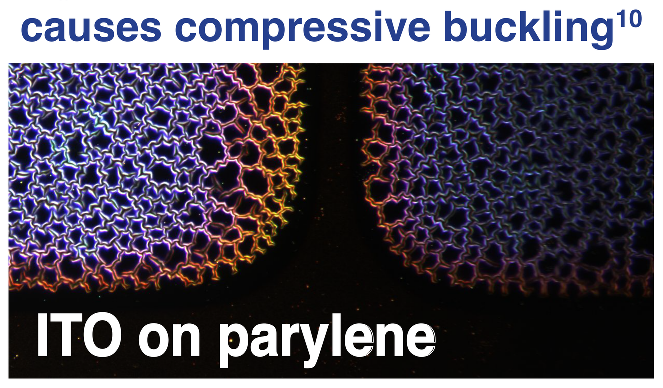


External quantum efficiency (EQE) spectra confirm measured photocurrents



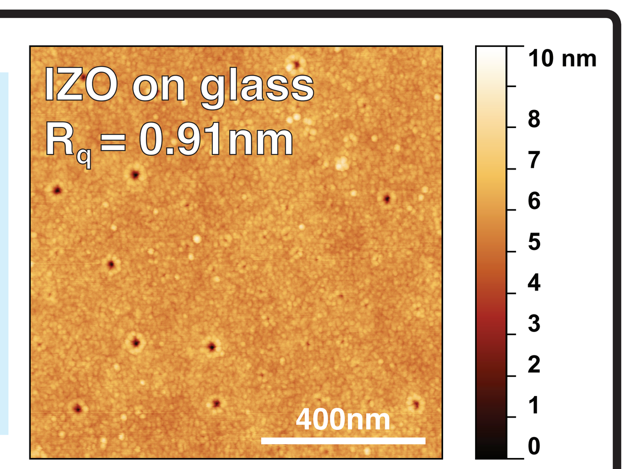
Transparent electrode selection

High intrinsic stress in ITO films causes compressive buckling[10]

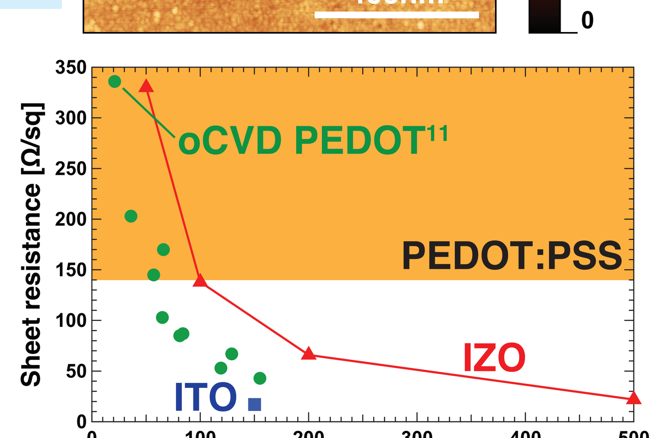


Indium zinc oxide (IZO)

- Sputtered
- Smooth
- Conductive

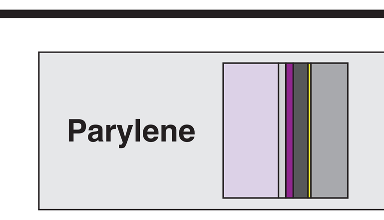


Material	Deposition Method
Indium tin oxide (ITO)	Ion-beam sputtering (IBS)
PEDOT:PSS	Spin-coating
PEDOT	Oxidative CVD (oCVD)
Indium zinc oxide (IZO) (90% In_2O_3 / 10% ZnO)	RF sputtering



Future work

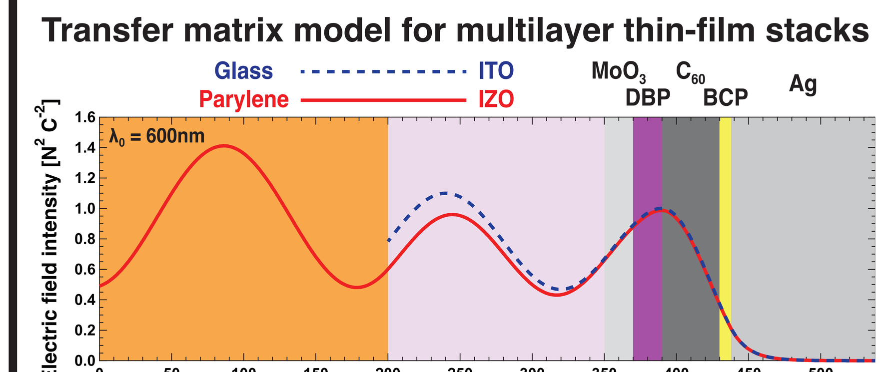
In situ encapsulation of complete device with Parylene C



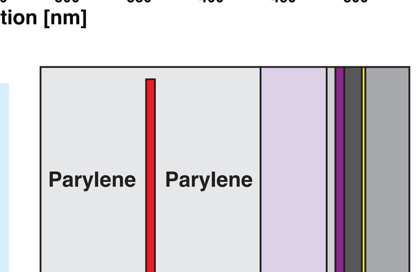
Absorption enhancement

Microcavity tuning: Precise thickness control may allow optimization of optical interference effects

Transfer matrix model for multilayer thin-film stacks

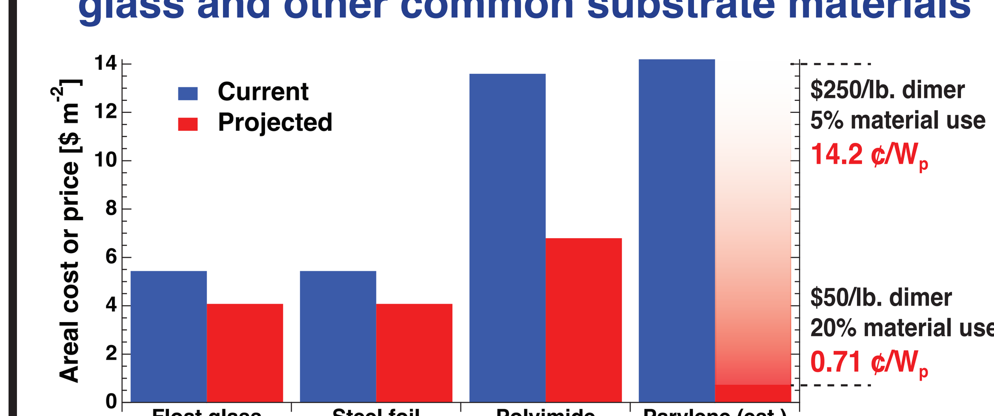


Spectral modification: Vapor deposition enables integration of upconverting or downconverting phosphors



Materials cost estimates

Cost of Parylene C is comparable to that of glass and other common substrate materials



Assumptions: 1μm Parylene C film, 10% power conversion efficiency, 5-20% material use (yield), Glass/steel/polyimide costs[12] adjusted to 2012$, Parylene C dimer (diX-C) price ($250/lb.) from Uniglobe Kisco

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