Optimum Morphology and Performance Gains of Organic Solar Cells

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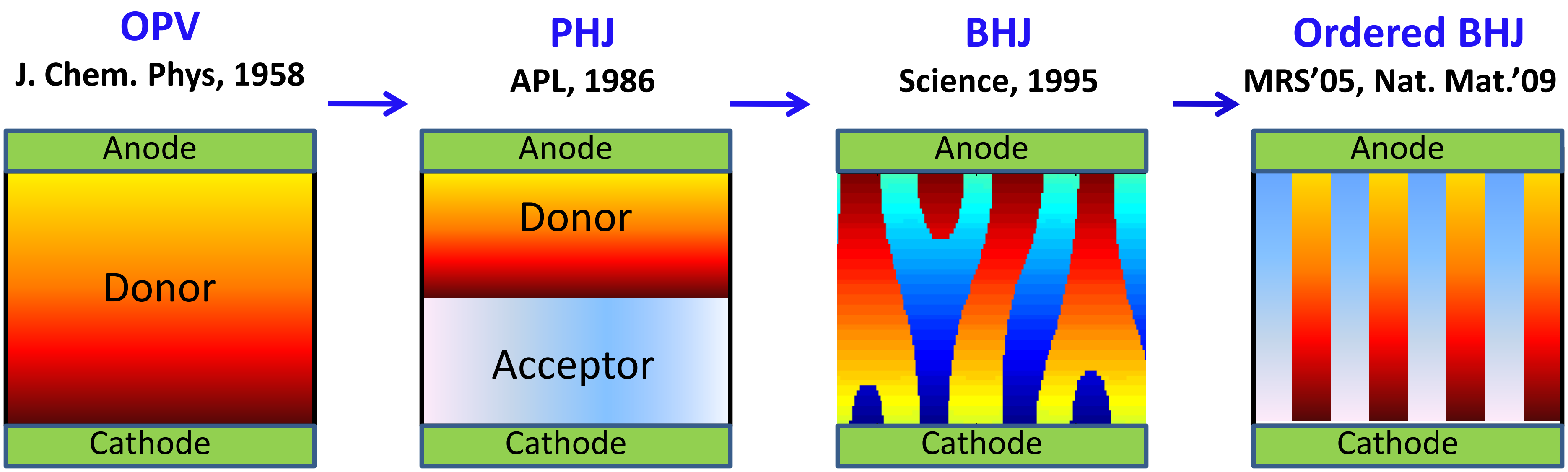
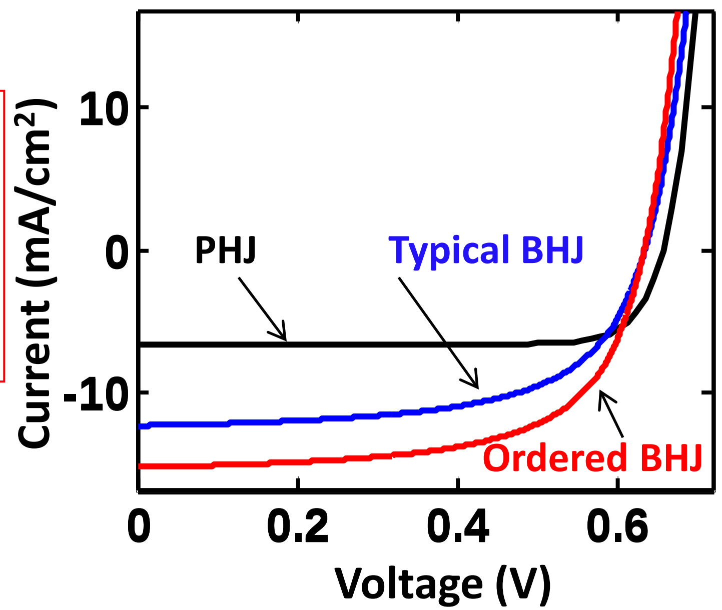
OPV Morphology: Historical Perspective

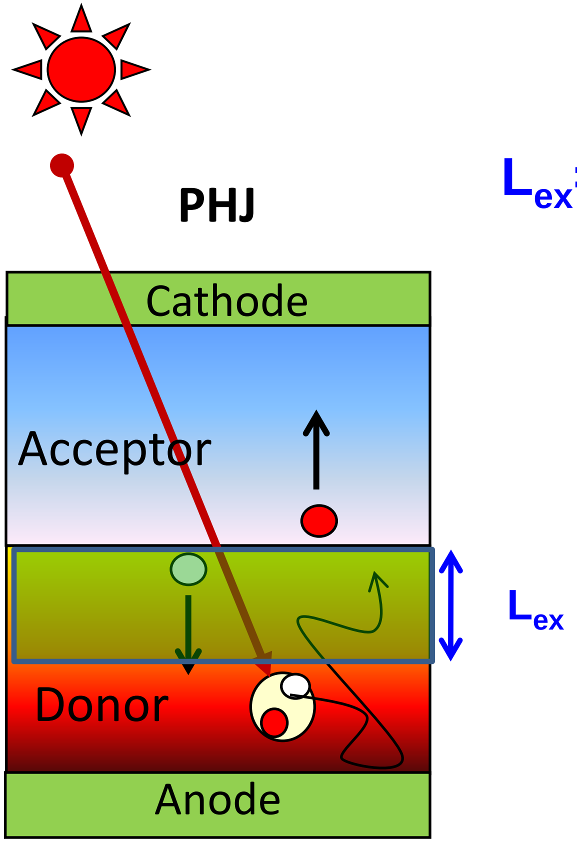


Q. 1
How much is the variability with random morphology?



Q. 2
What is the theoretical optimum morphology ?

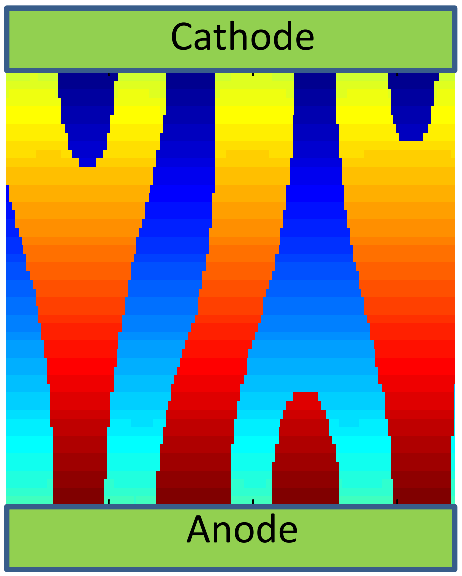
OPV Operation

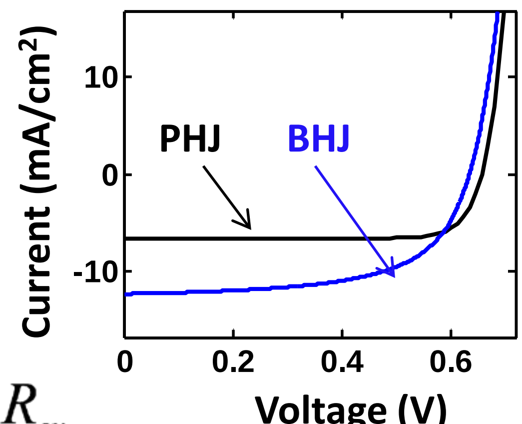


L_{ex}= exciton diffusion length

1) Photon Absorption
2) Exciton Diffusion
3) Charge Separation
4) Carrier Transport

Typical BHJ





Exciton Transport:

$$D_{ex}\nabla^2 n_{ex} = G_{ex} - R_{ex}$$

e/h Transport:

$$J_{e,h} = q\mu n_{e,h} E \pm qD\nabla n_{e,h}$$

Ray et. al.,
Sol. Energy Mat. '11

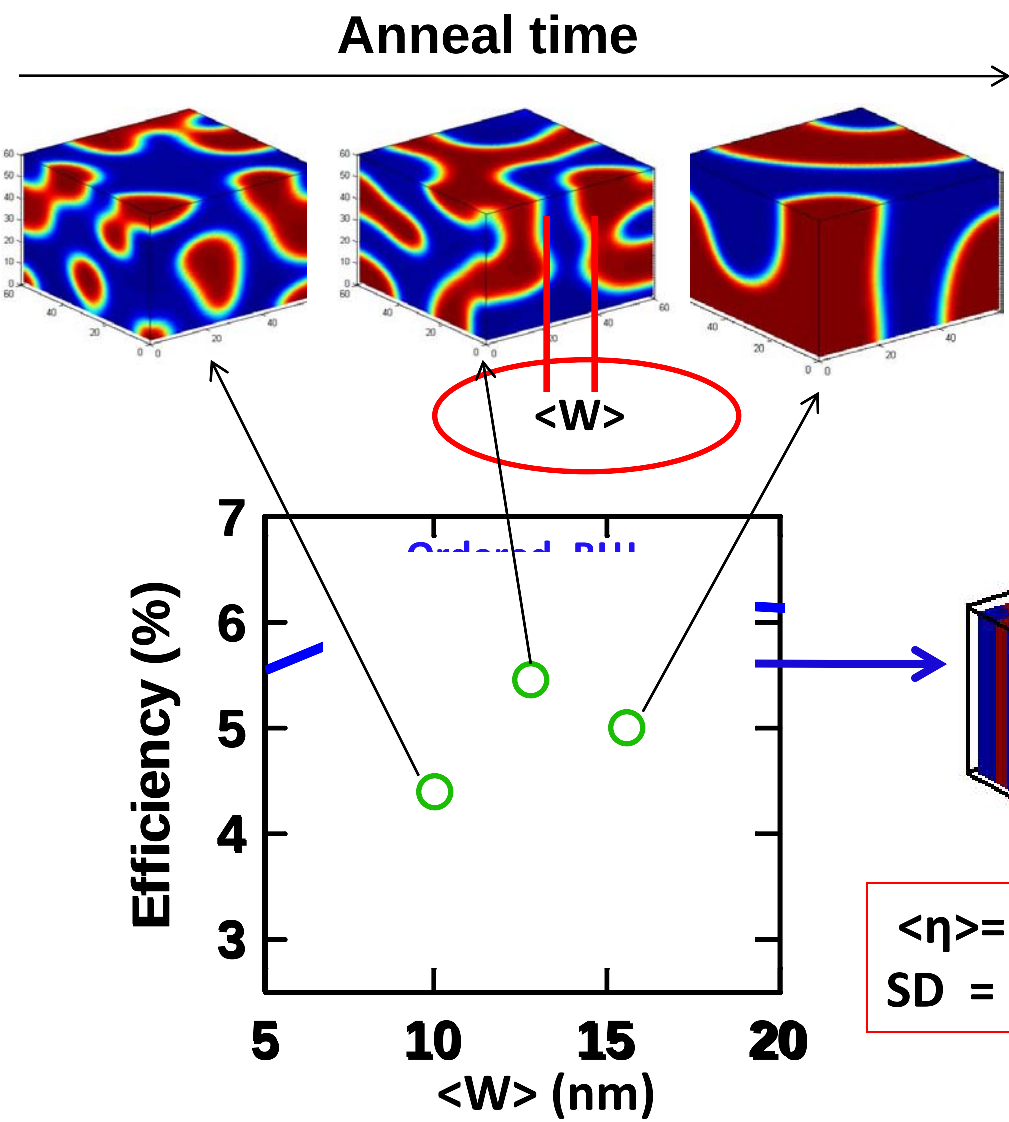
Poisson:

$$\nabla(\varepsilon\nabla\Phi) = q(n_e - n_h)$$

Continuity Eq:

$$\nabla J_{e,h} = \pm q(G_{e,h} - R_{e,h})$$

Performance Variability



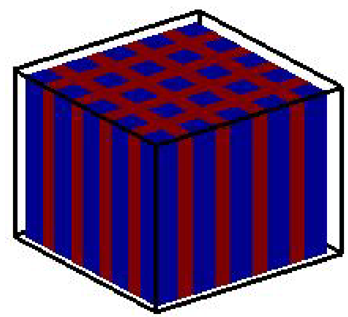
Ray et. al., Sol. Energy Mat. '11

Free Energy of Mixing:

$$f_{mix} = U - TS$$

Cahn-Hilliard Eq:

$$\frac{\partial \varphi}{\partial t} = M_0 \left(\nabla^2 \frac{\partial f}{\partial \varphi} - 2\kappa \nabla^4 \varphi \right)$$

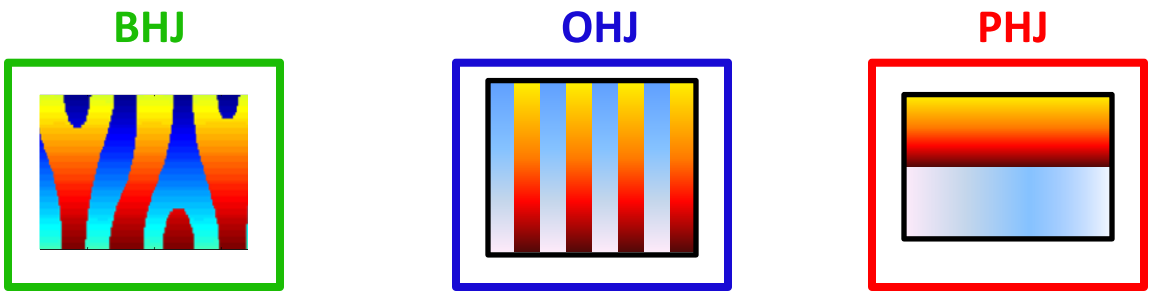


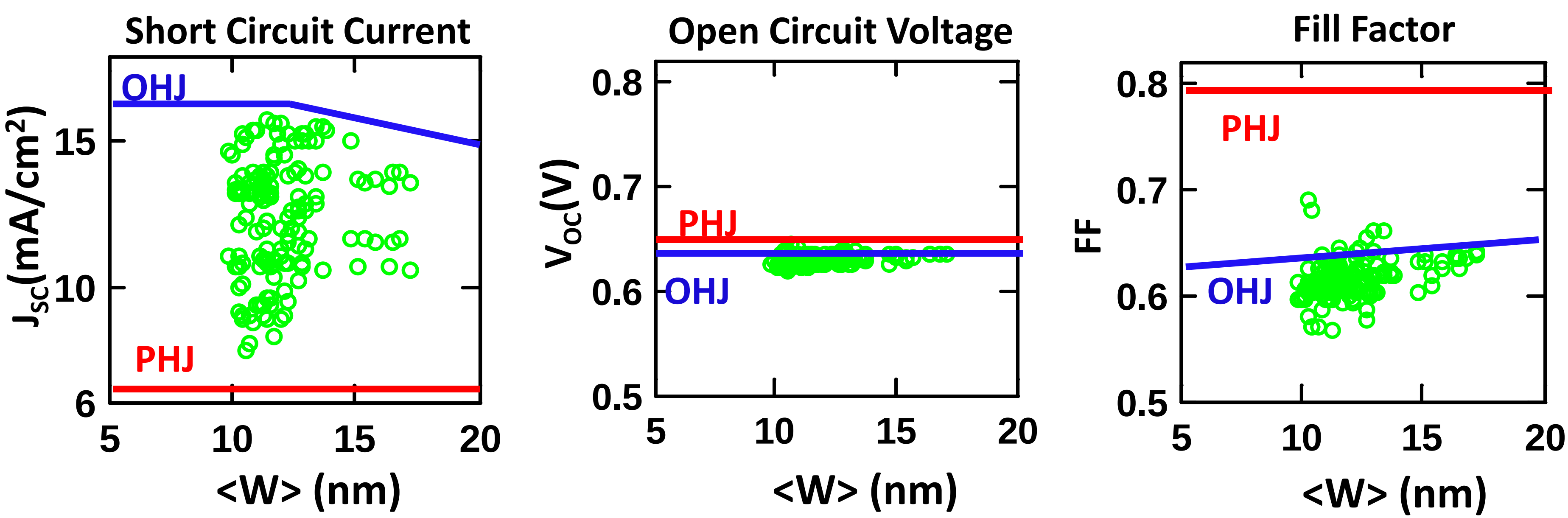
η_{order}= 6.1%

$\langle\eta\rangle$= 4.8%
SD = 0.78%

Regularization improves efficiency and reduces the variability

Performance Variability

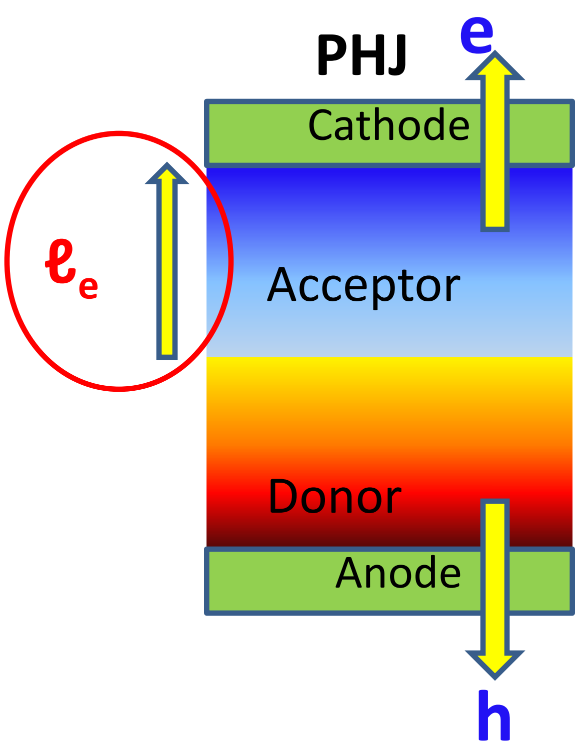




1) V_{oc} is morphology insensitive

2) FF^{PHJ} >> FF^{BHJ}

Why morphology matters ?



Efficiency = J_{SC} x V_{oc} x FF

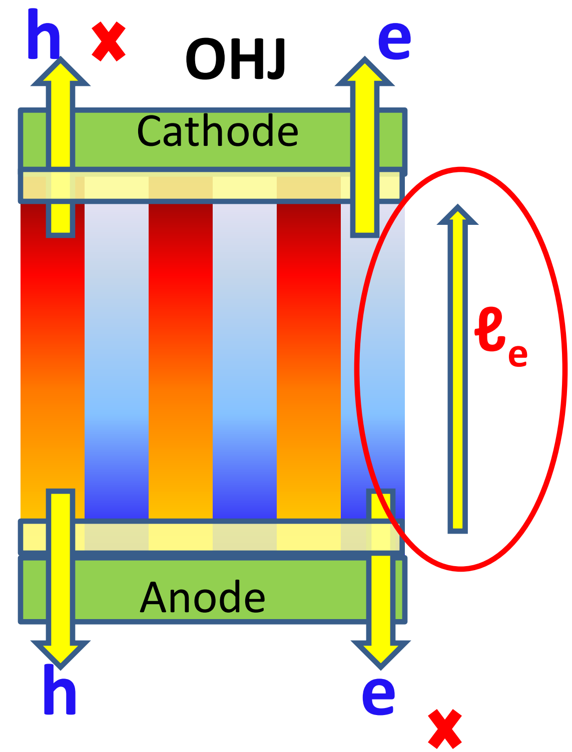
$J_{SC} \propto$ area (Ray *et. al.* APL'11)

V_{oc} : Morphology insensitive

FF :

1) Carrier collection

2) Series resistance $\propto \ell_e$



ℓ_e = $T_{film}/2$

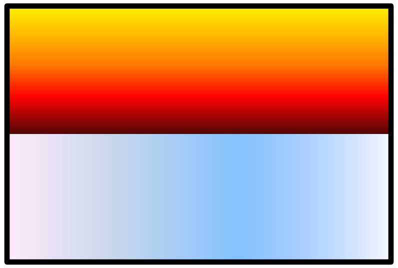
ℓ_e = Average carrier extraction length

ℓ_e > $T_{film}/2$

FF of BHJ is lower than PHJ

Design of Optimum Morphology

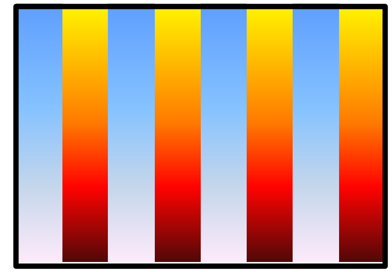
PHJ



$H_{fin} = 0$

OHJ

$H_{fin} = T_{film}$



Electrical transport MOST efficient

Exciton collection LEAST efficient

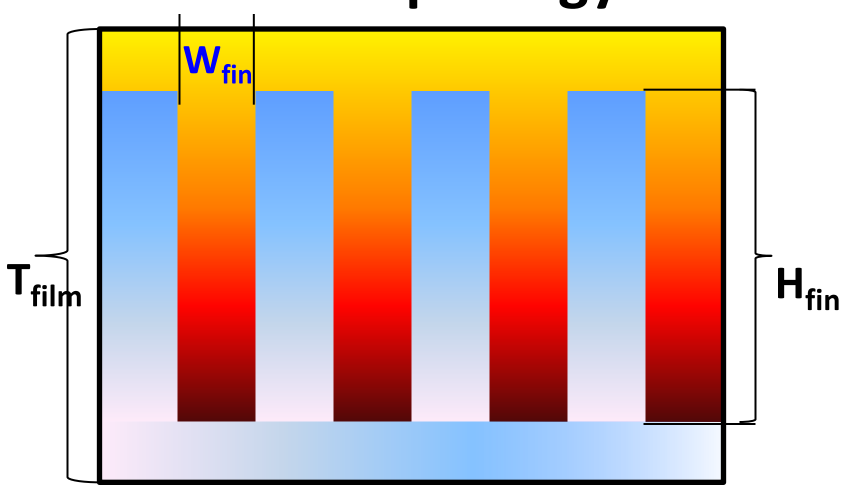
Exciton collection MOST efficient

but NOT electrical transport

Fin Morphology

Fin Width

$W_{fin}\,(opt) \approx 2L_{ex}$

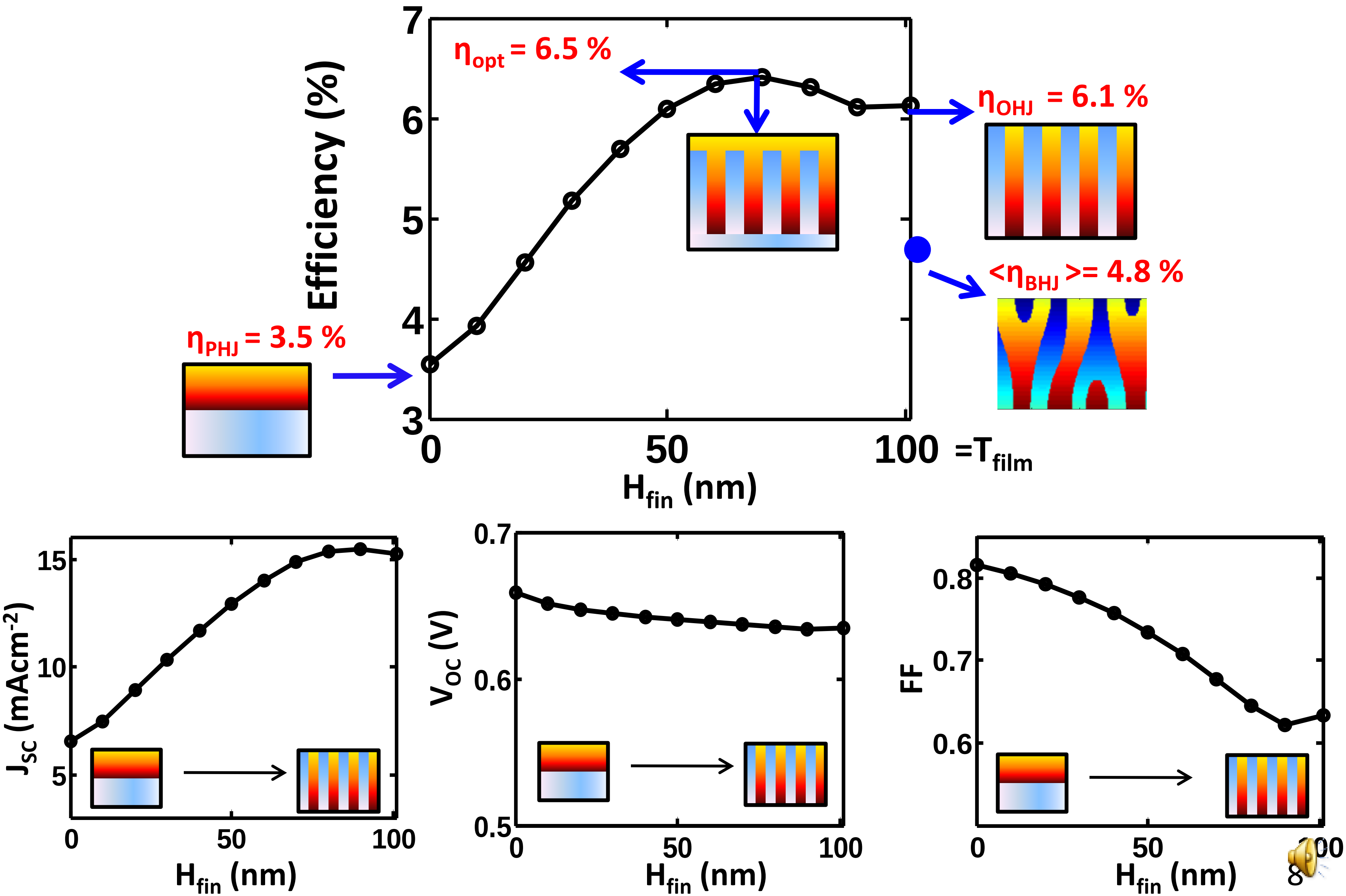


Fin Height

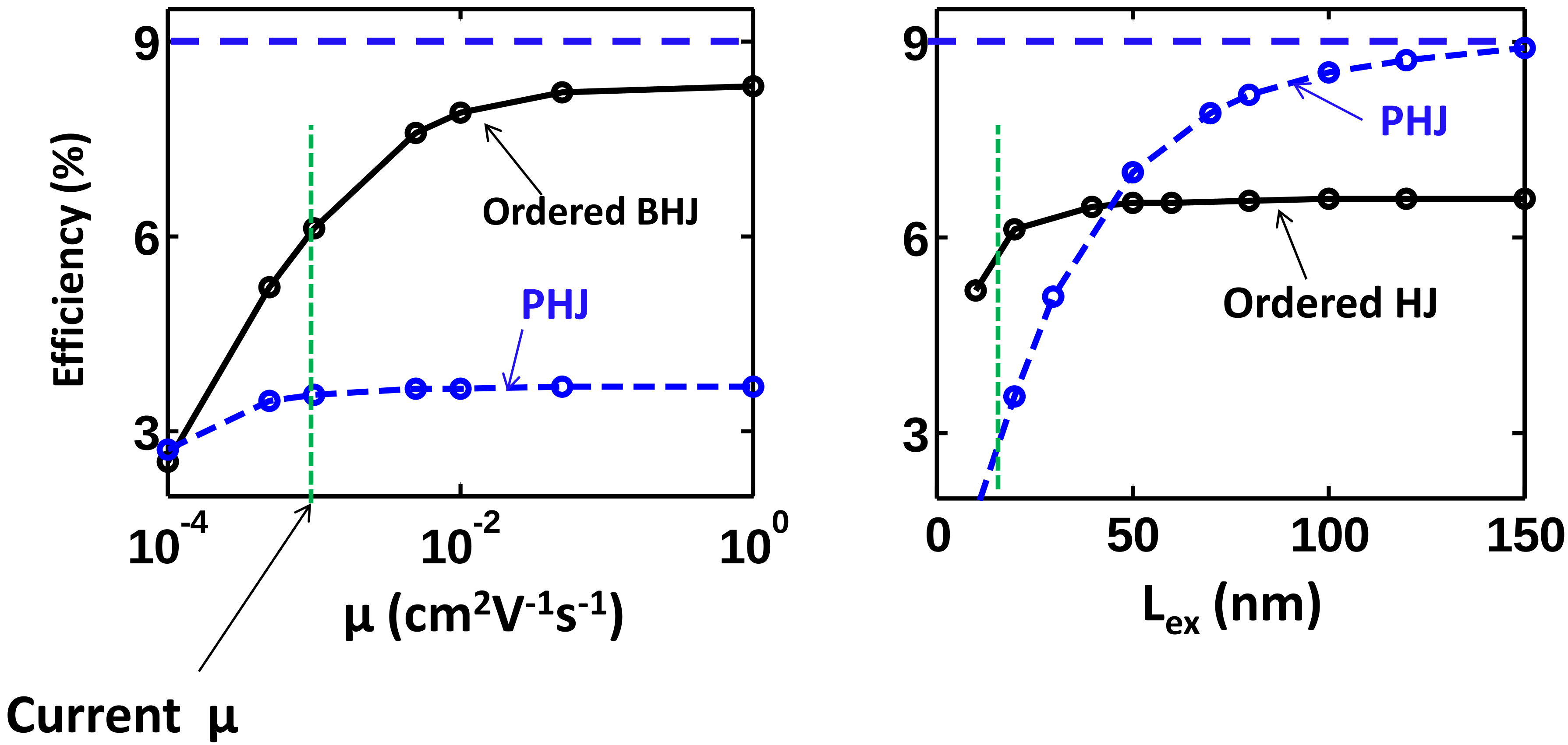
$H_{fin}\,(opt) = f\,(\mu, L_{ex})$

Fin morphology is the optimum

Morphology Dependent Efficiency Space



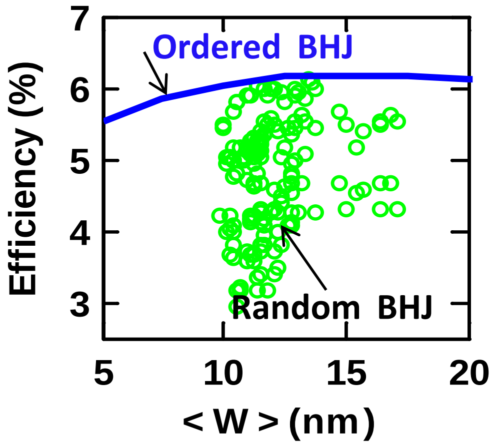
Material Specific Efficiency Limits



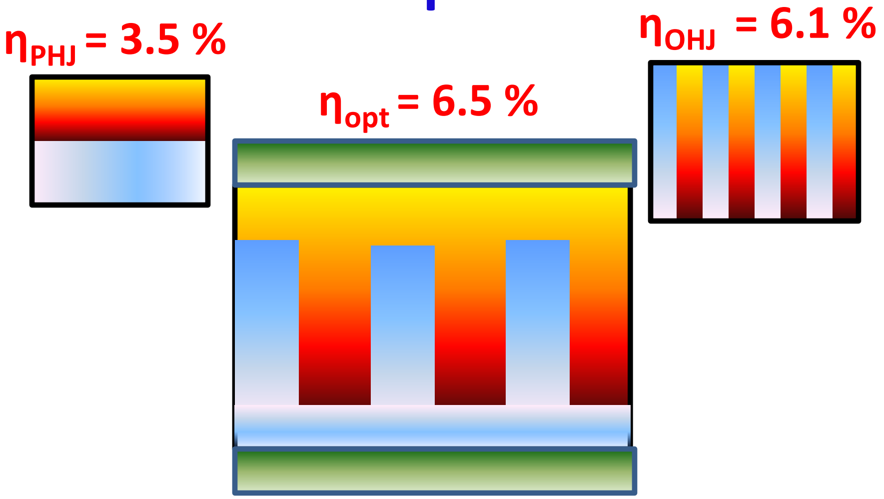
PHJ will be the OPT. for higher L_{ex}

Conclusion

1) Performance variability is inherent in BHJ cell



2) Fin-Like morphology is the optimum



3) PHJ is the optimal for charge carrier transport

$V_{OC}^{PHJ} > V_{OC}^{BHJ}$

$FF^{PHJ} > FF^{BHJ}$