

Photovoltaics and Photodetectors - part I

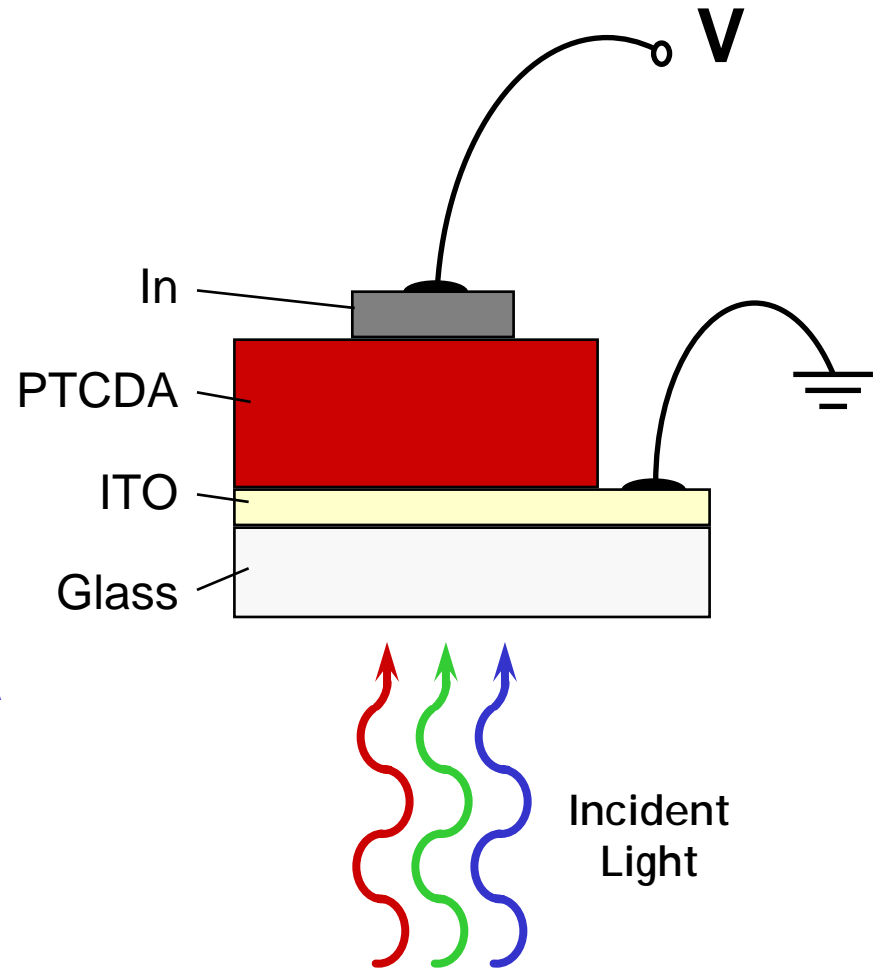
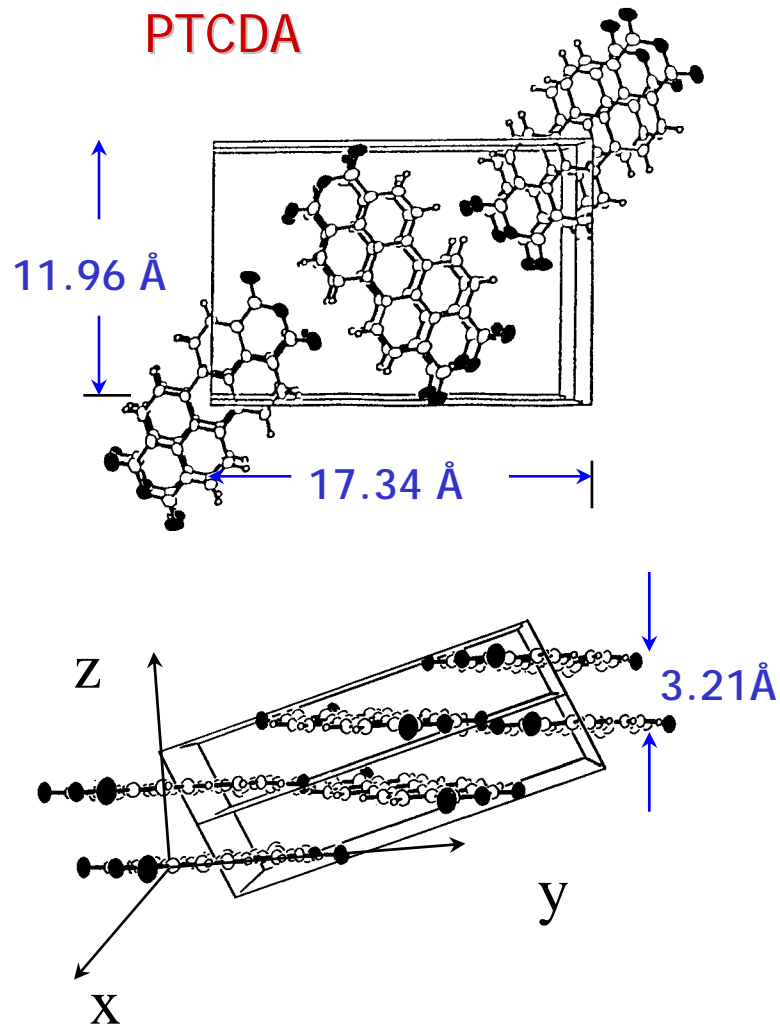
- Photogeneration
 - Organic Heterojunction Photovoltaic Cell
 - Organic Multilayer Photodetector
-

*Recitation Handout: Yu et al., Science 270, 1789 (1995),
Shaheen et al. , Appl. Phys. Lett. 78, 841 (2001).*

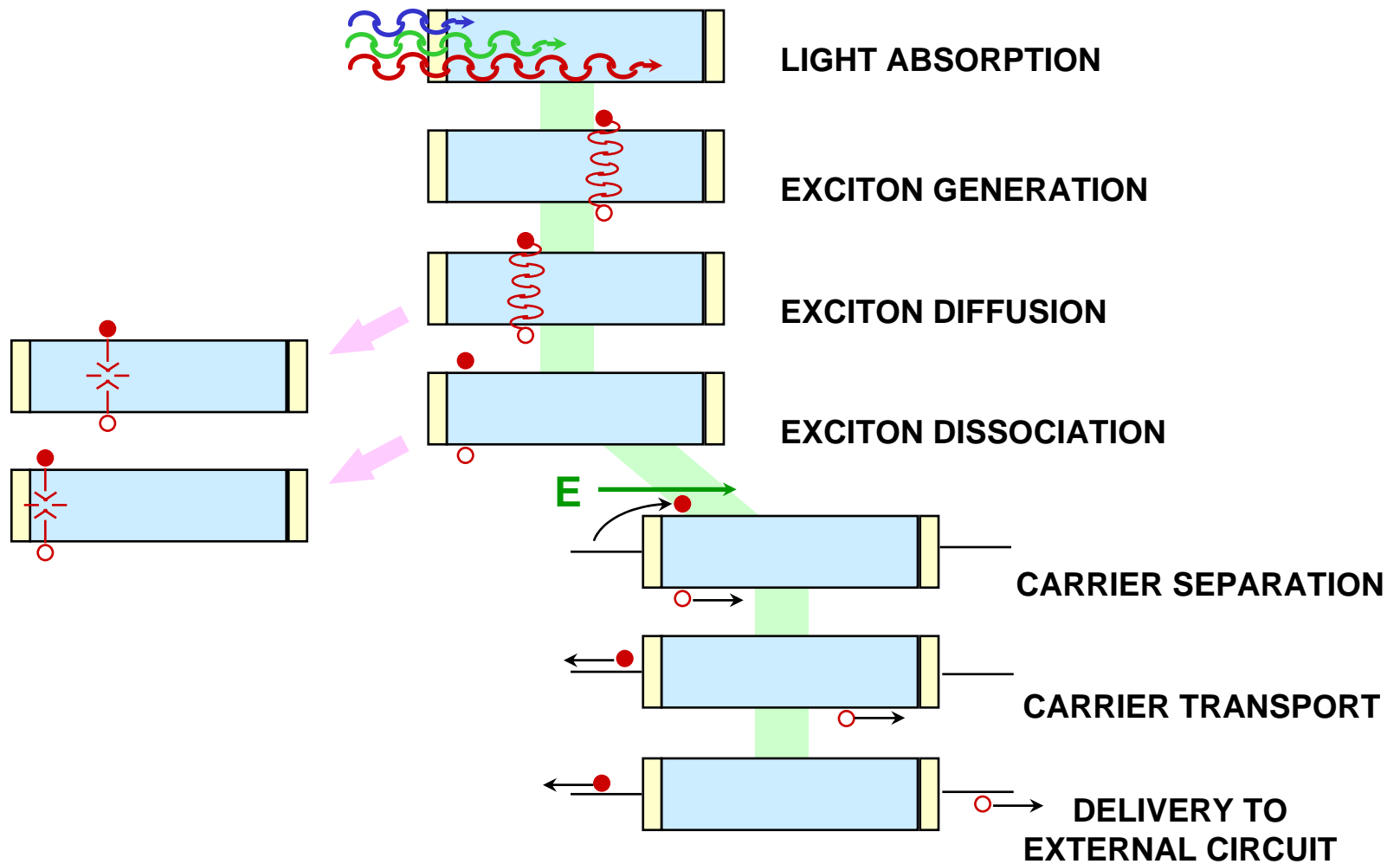
Announcement: Lab #1 write-up is due in class on Tuesday, March 11



Single Layer Organic PV Cells

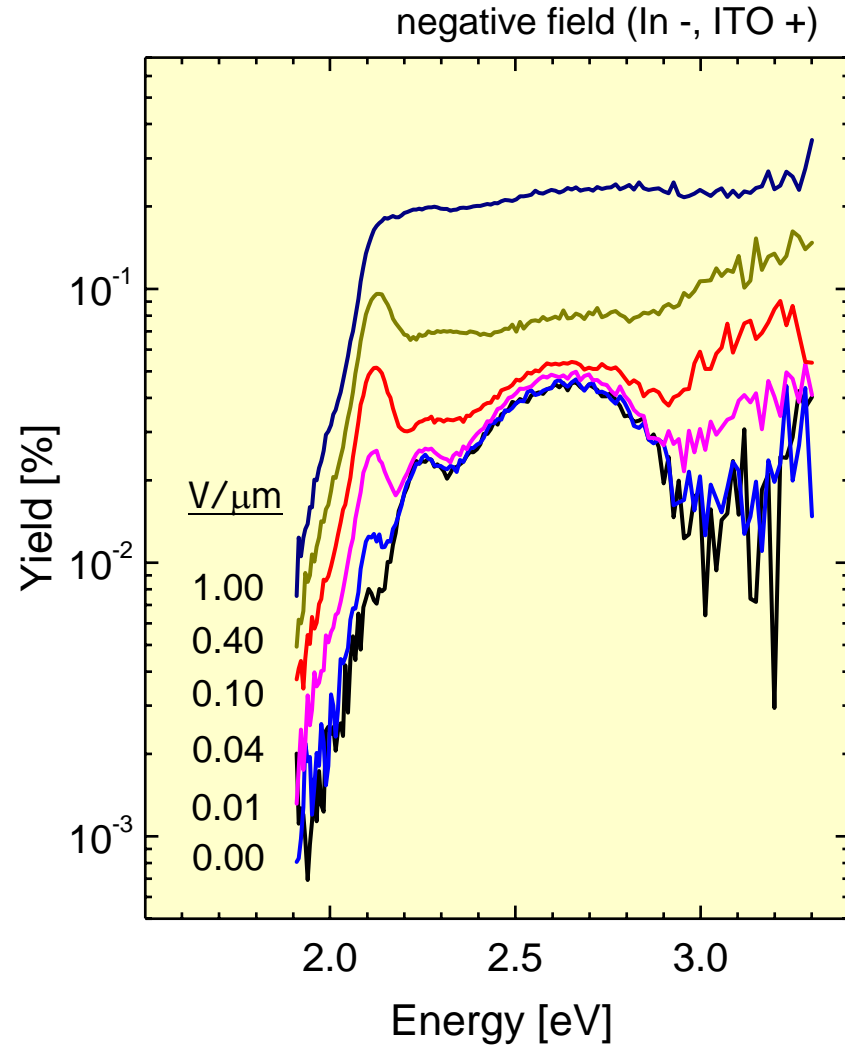
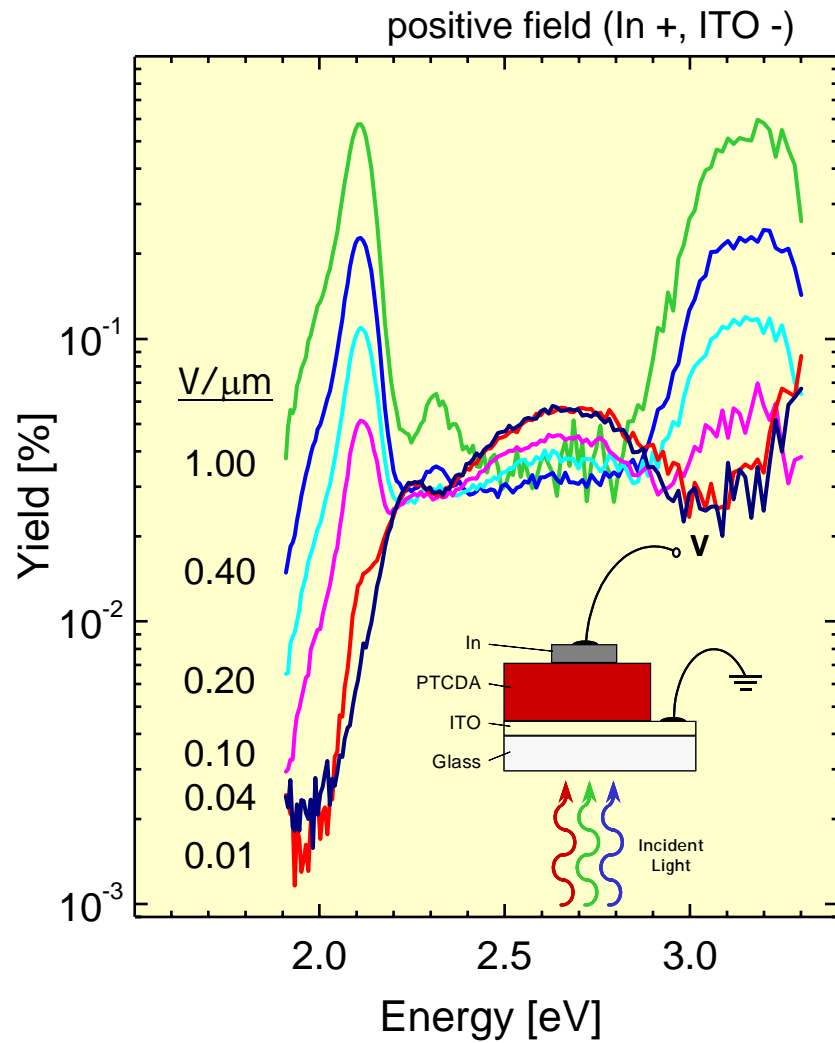


Photocurrent Generation

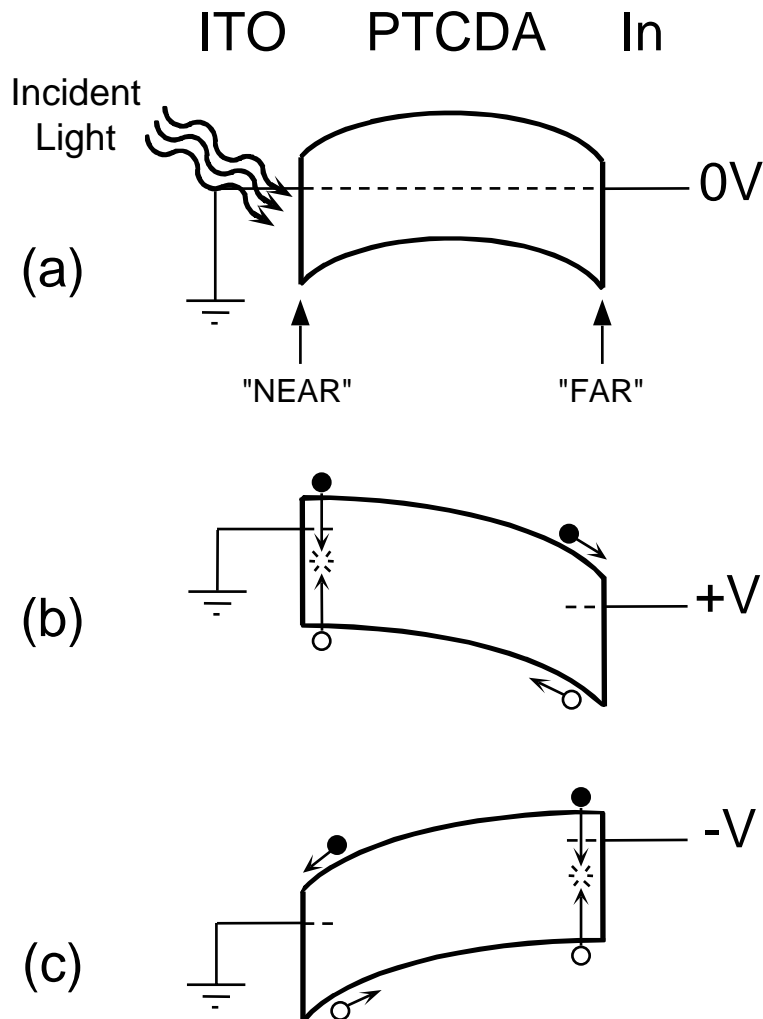


Photocurrent Dependence on Electric Field

Different photocurrent response for positive and negative applied bias



Electric Field inside the Organic Film



PTCDA is assumed to be a depleted hole-transporting organic semiconductor

PTCDA carrier density is
 $n = 5 \times 10^{14} \text{ cm}^{-3}$

→ band bending of 0.1 V at each interface would be sufficient to completely deplete 500 nm thick sample

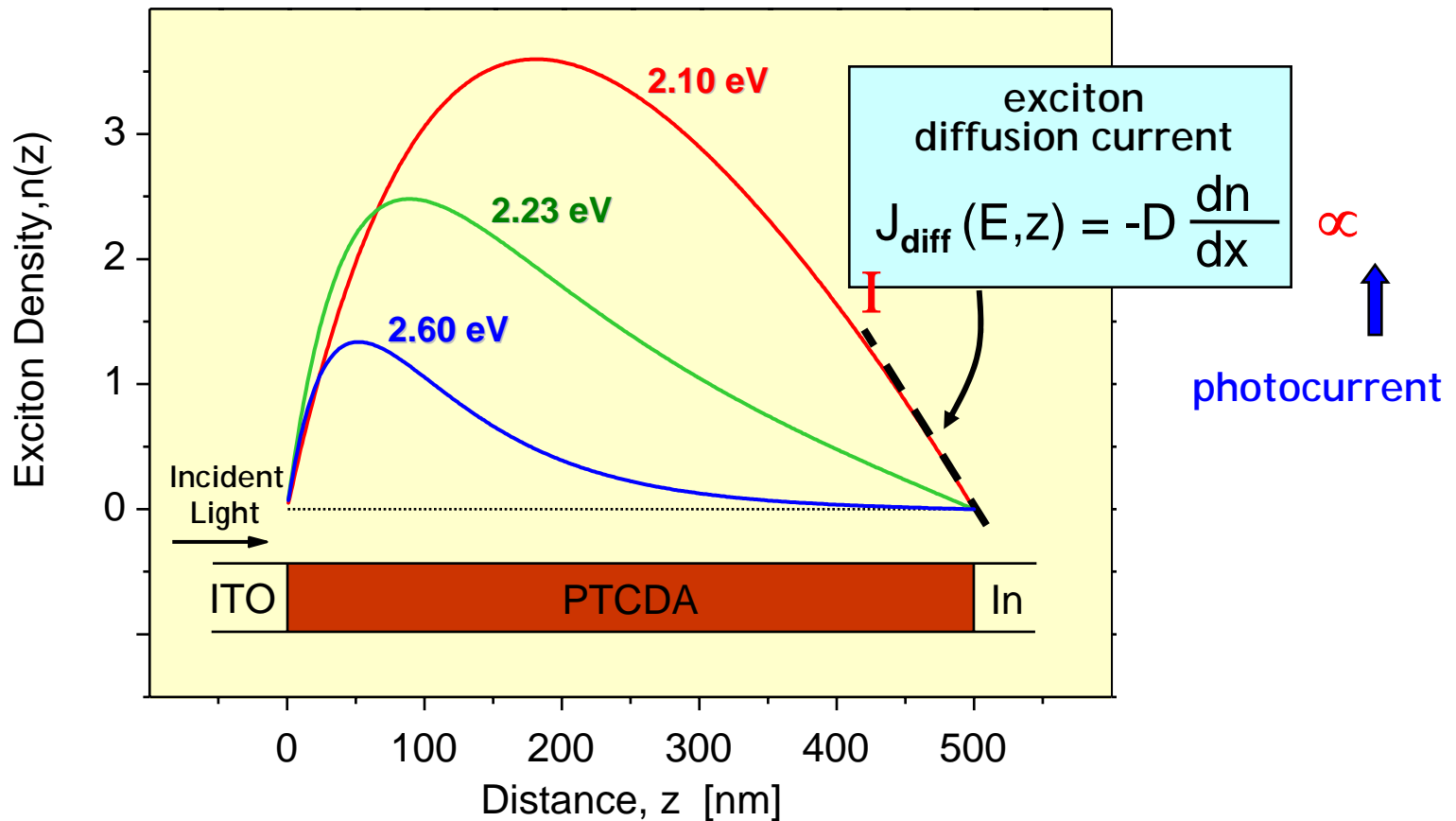
Exciton Distribution

DIFFUSION EQUATION

$$0 = D \frac{d^2 n}{dz^2} - \frac{n}{\tau} + \alpha \phi N \exp(-\alpha z)$$

$$n = \frac{\alpha J_0}{D} \frac{1}{\beta^2 - \alpha^2} \left[\frac{\exp(\beta L) - \exp(-\alpha L)}{\exp(-\beta L) - \exp(\beta L)} \exp(-\beta z) - \frac{\exp(\beta L) - \exp(-\alpha L)}{\exp(-\beta L) - \exp(\beta L)} \exp(\beta z) + \exp(-\alpha z) \right]$$

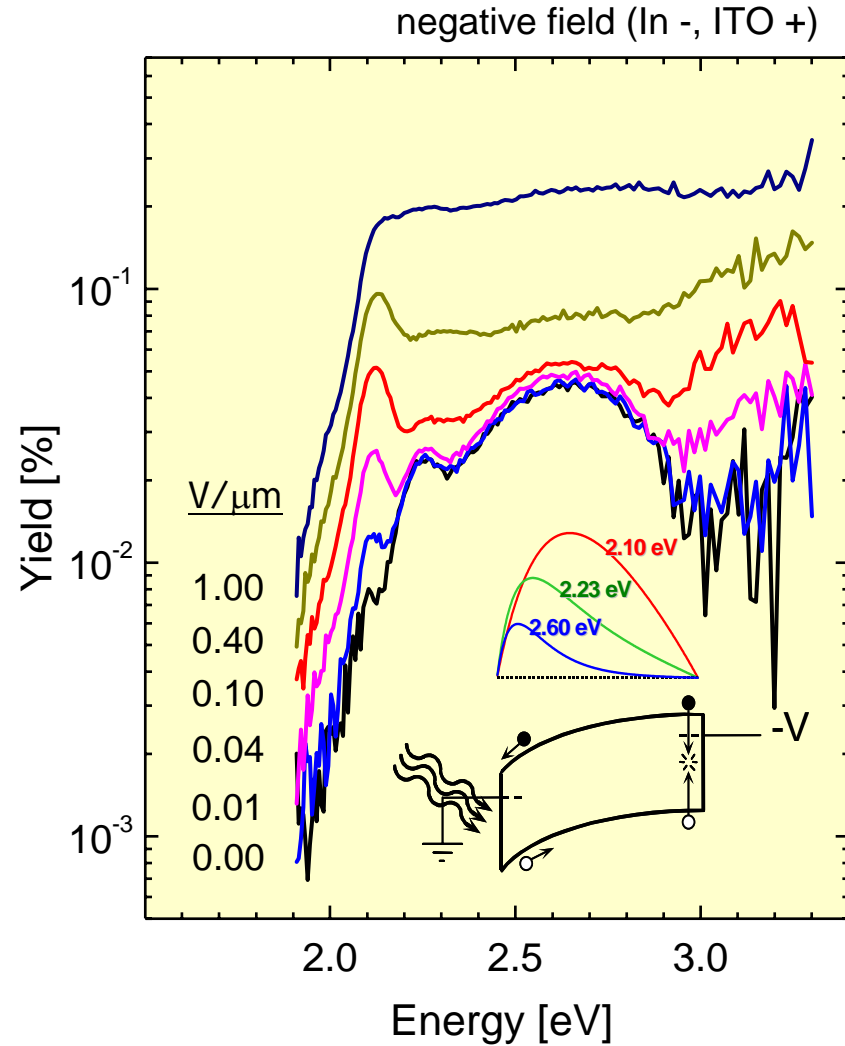
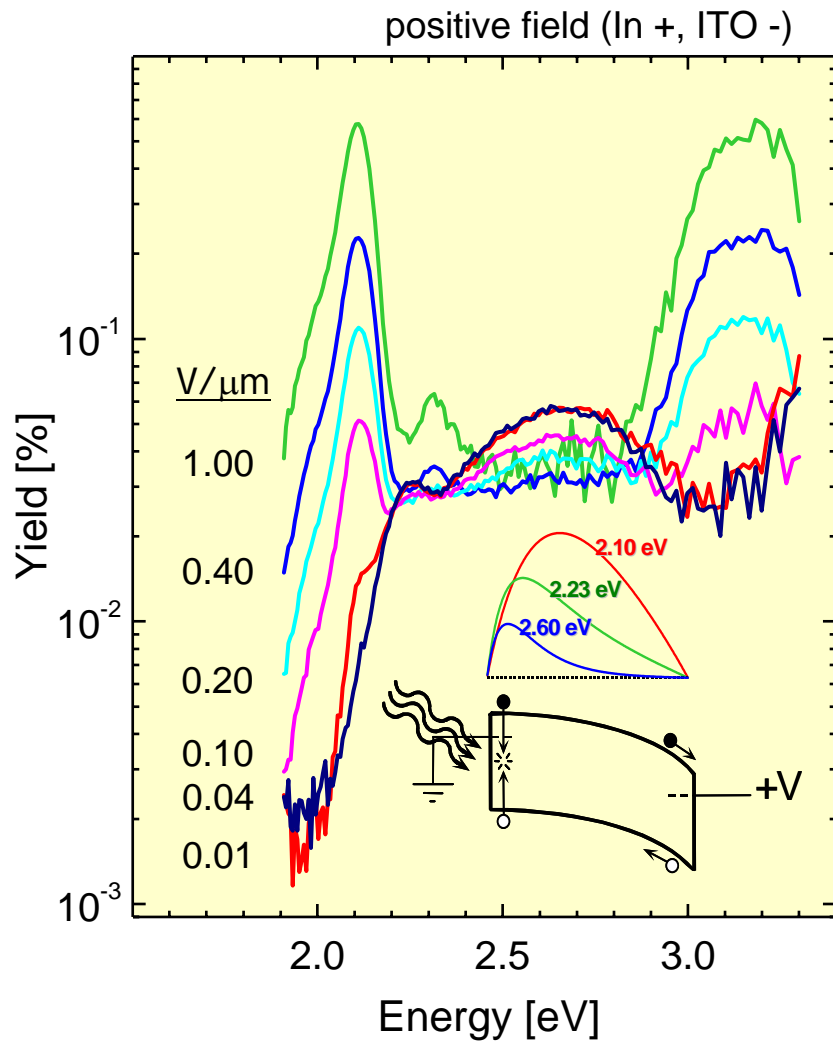
where, $\beta = 1/L_D$

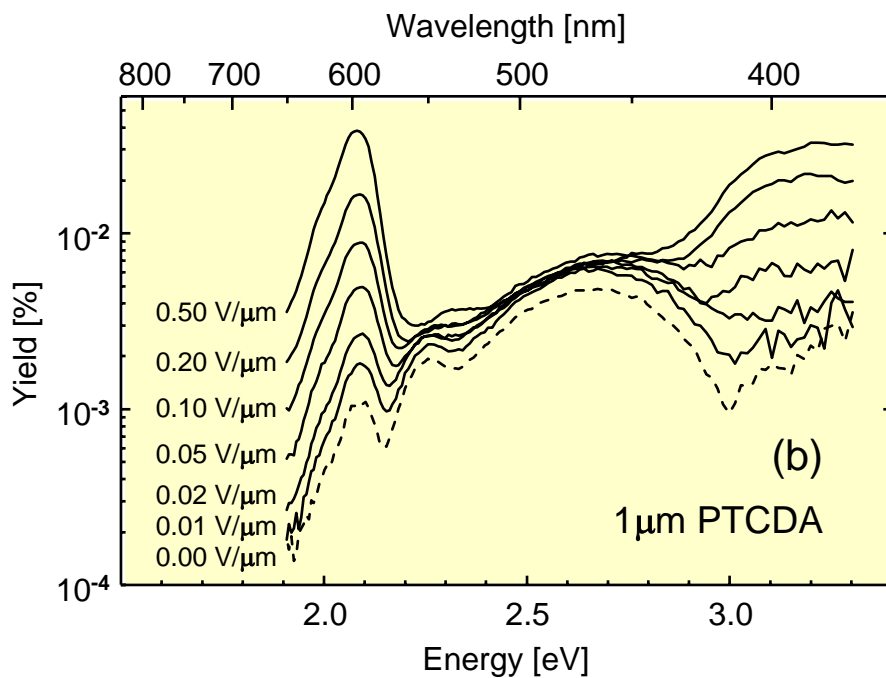
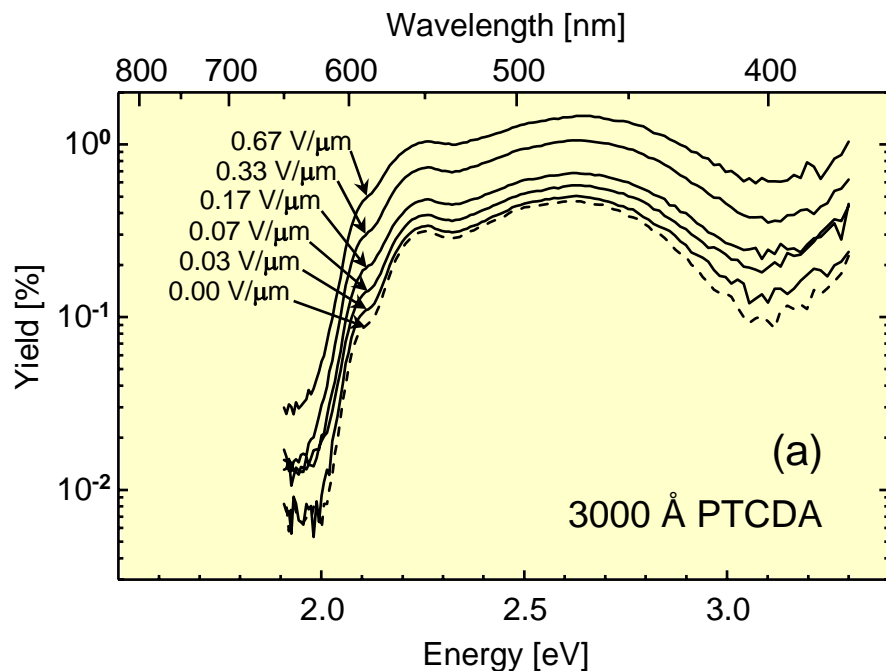


$L_D =$ exciton diffusion length

Photocurrent Dependence on Electric Field

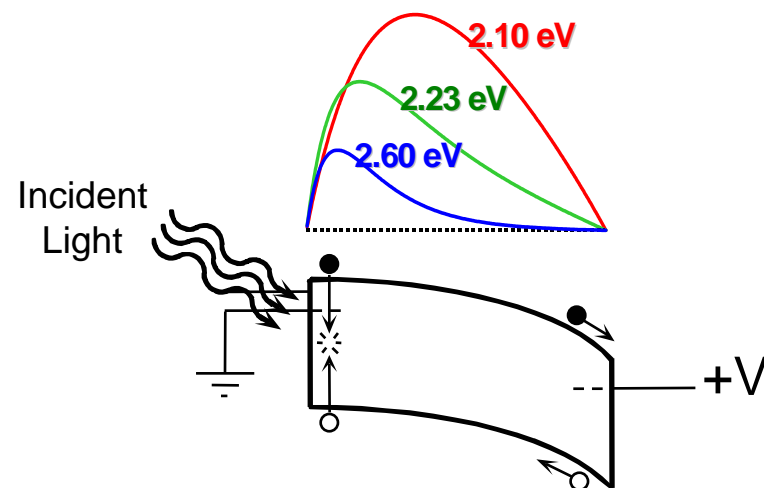
Different photocurrent response for positive and negative applied bias



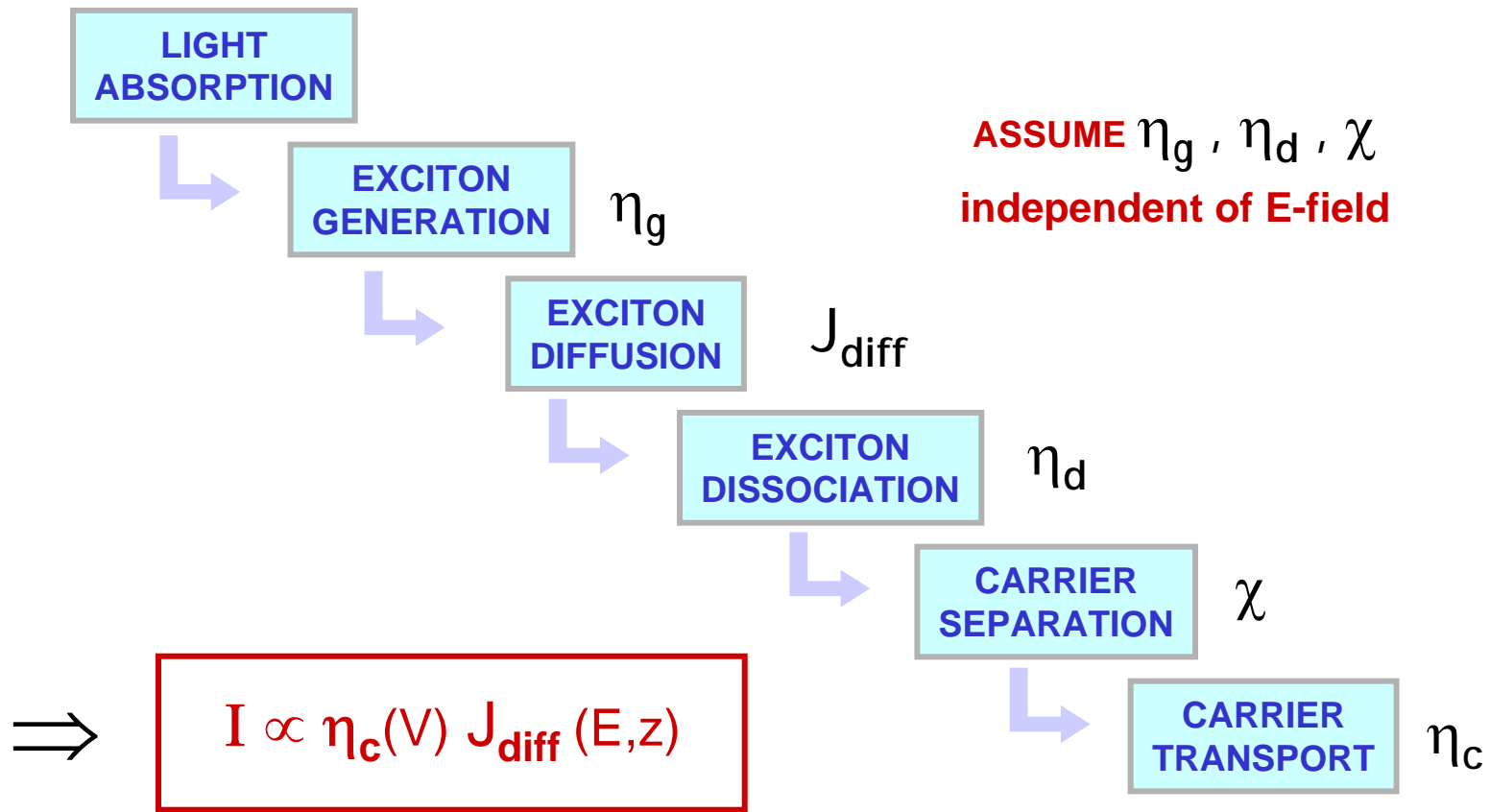


Photocurrent response changes
with device thickness

(positive bias = far interface, In, active)



For the 1 μm PTCDA device red
light (2.1) eV has the lowest
absorption constant hence 2.1
eV excitons can be generated
next to the far, In interface



at ITO interface ($z = 0$):

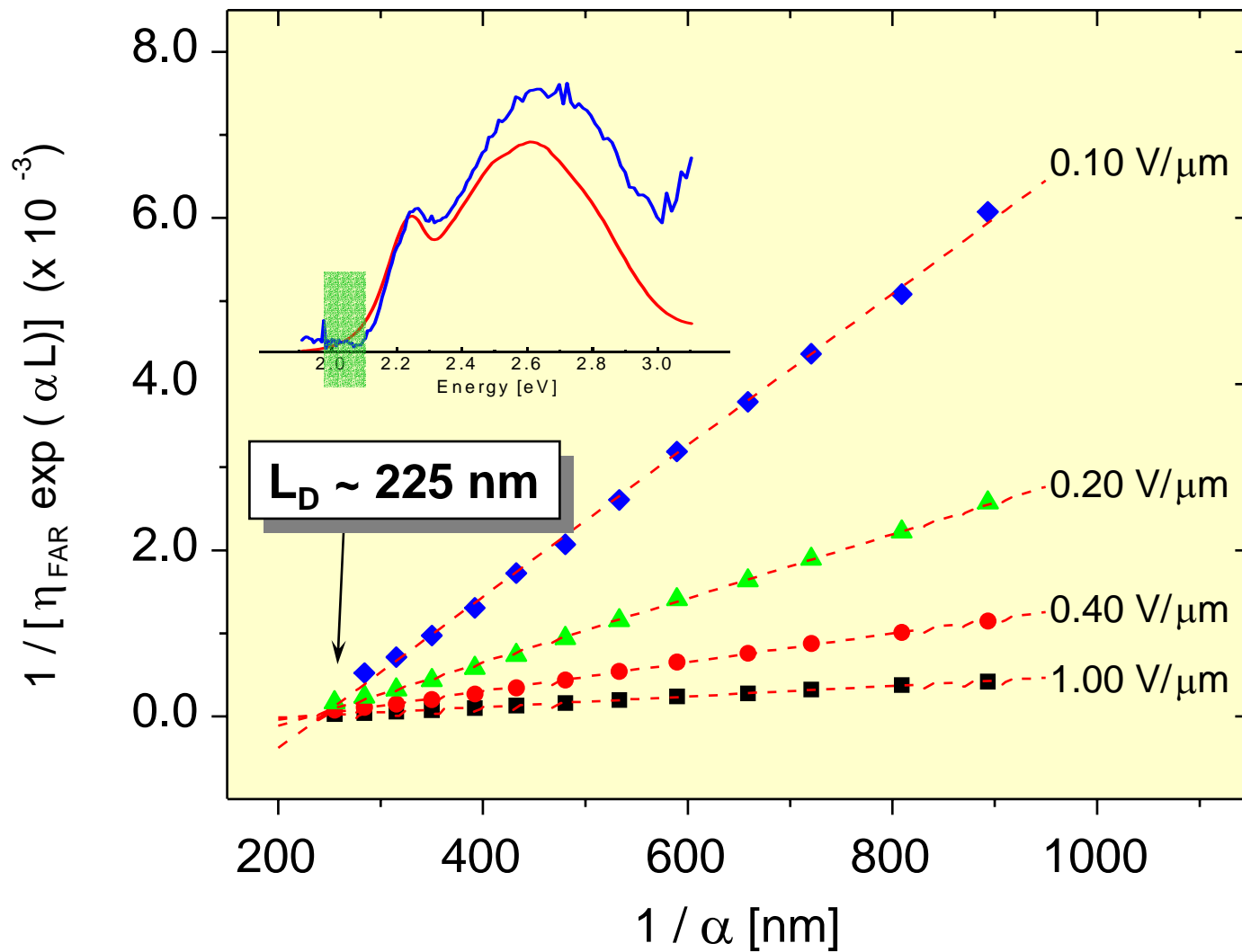
$$I_{ITO} \propto \eta_c(V) [\alpha / (\alpha + 1/L_D)]$$

at In interface ($z = L$):

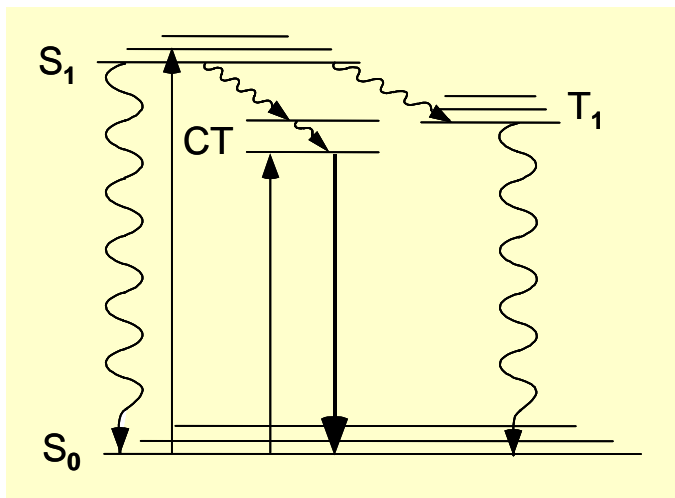
$$I_{In} \propto \eta_c(V) \alpha \exp(-\alpha L) / (1/L_D - \alpha)$$

$$I = I_{ITO} + I_{In}$$

Exciton Diffusion Length (for $E = 1.99 - 2.10$ eV exciton)

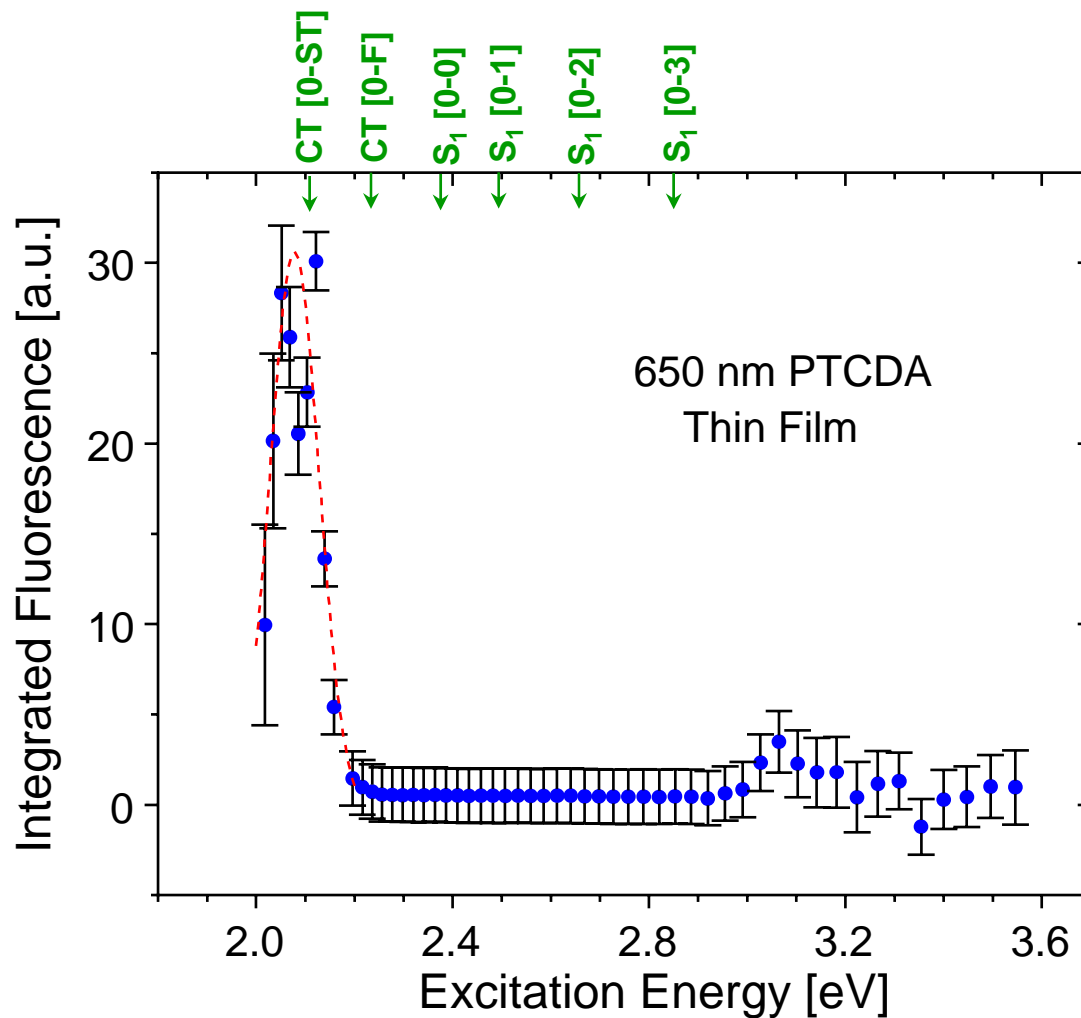


Thin Film Excitation Fluorescence

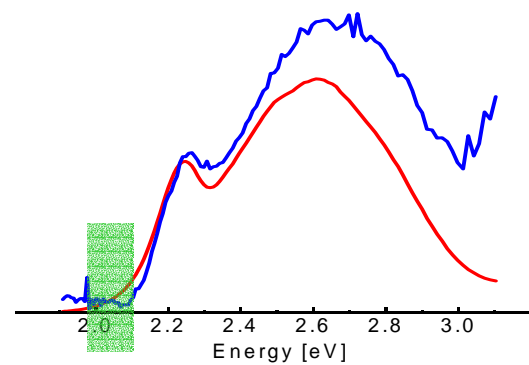
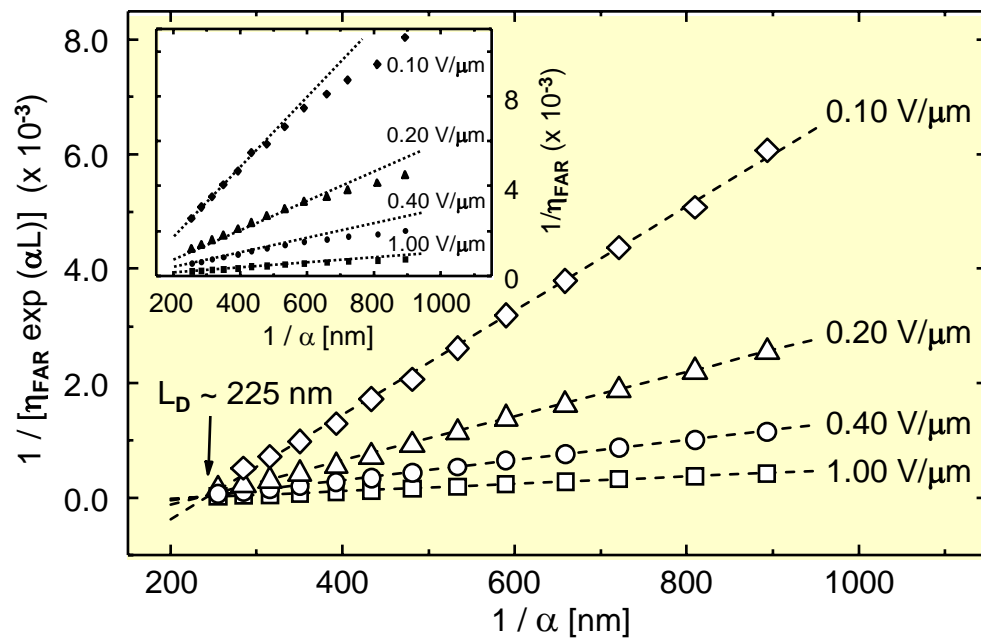


* Fluorescence energy and shape is not affected by the change in excitation energy

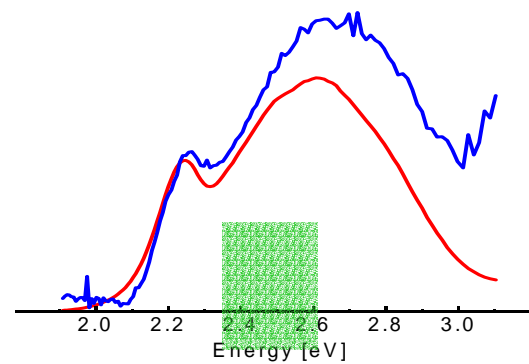
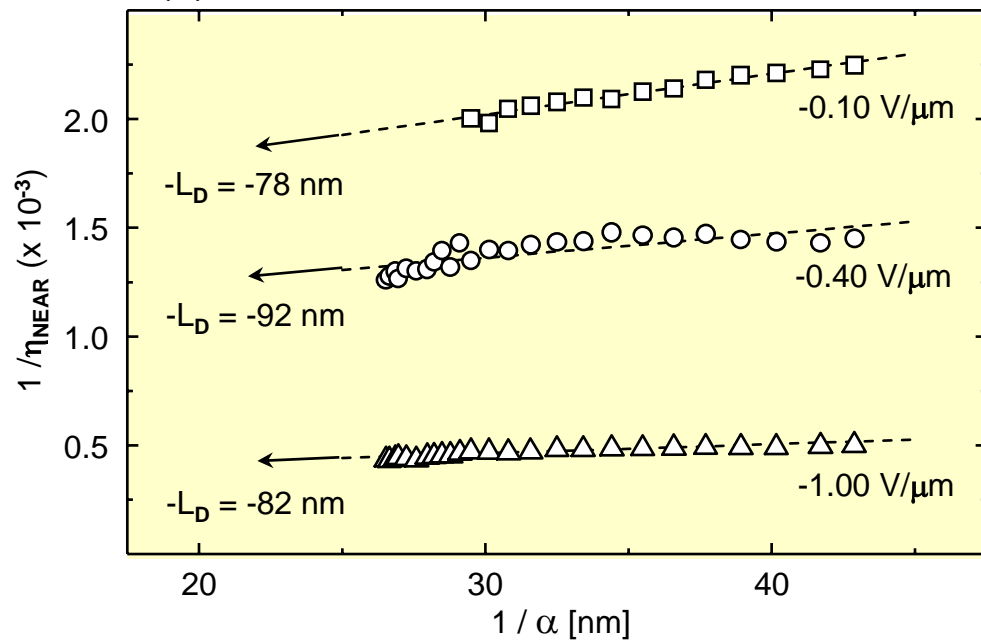
* Fluorescence efficiency increases when exciting directly into CT state



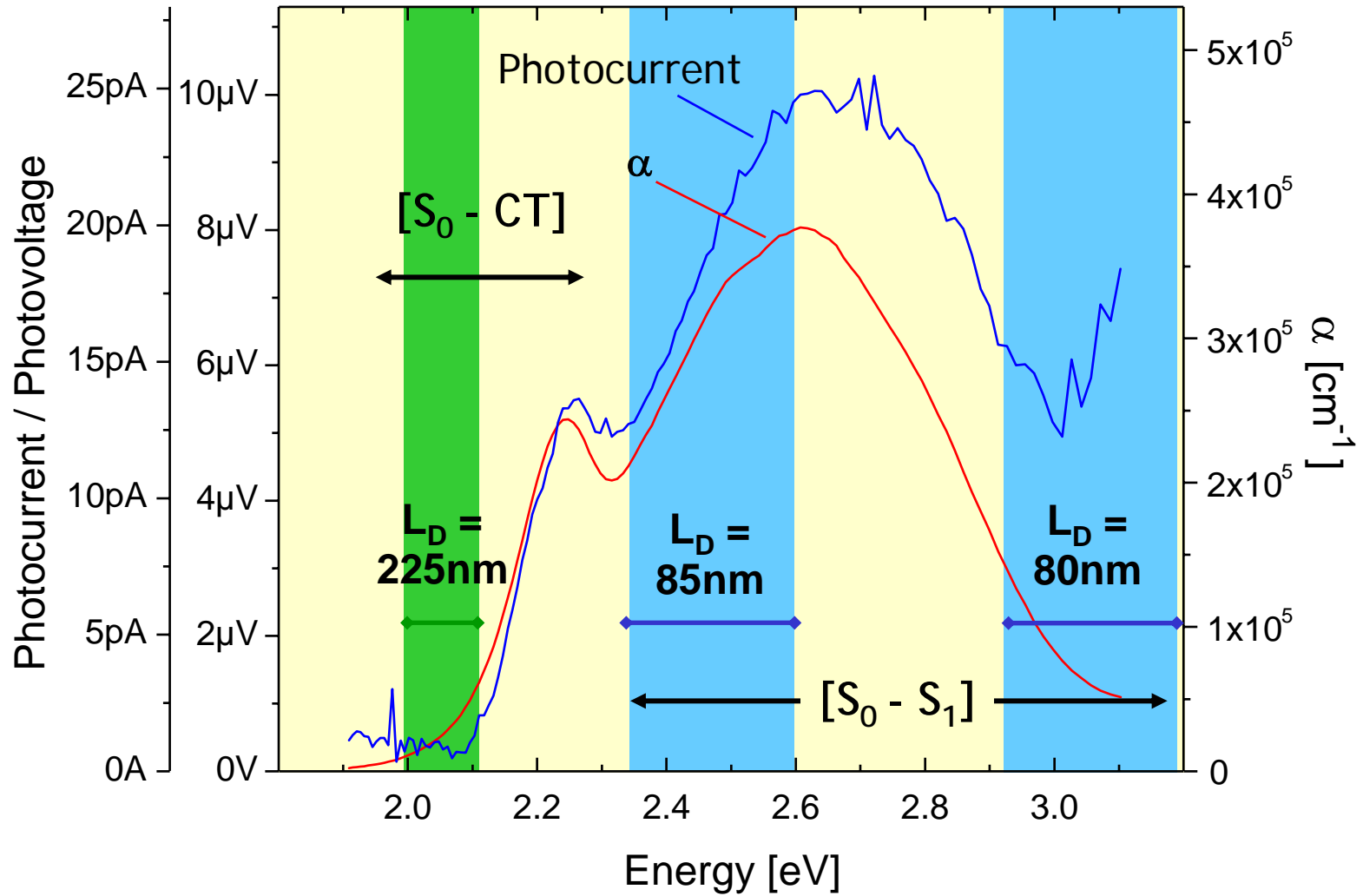
(a) 1.99 - 2.10 eV



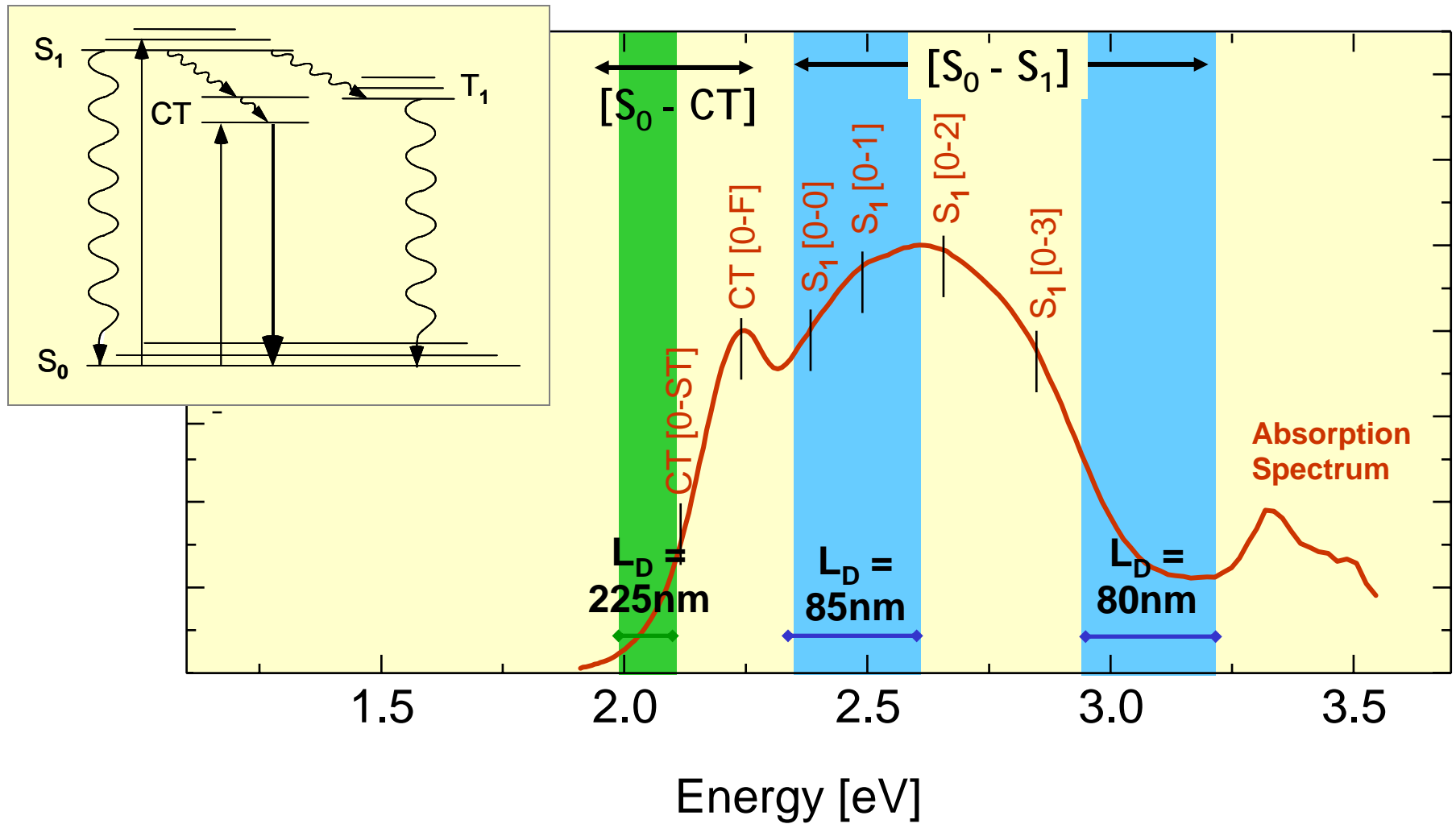
(b) 2.36 - 2.60 eV



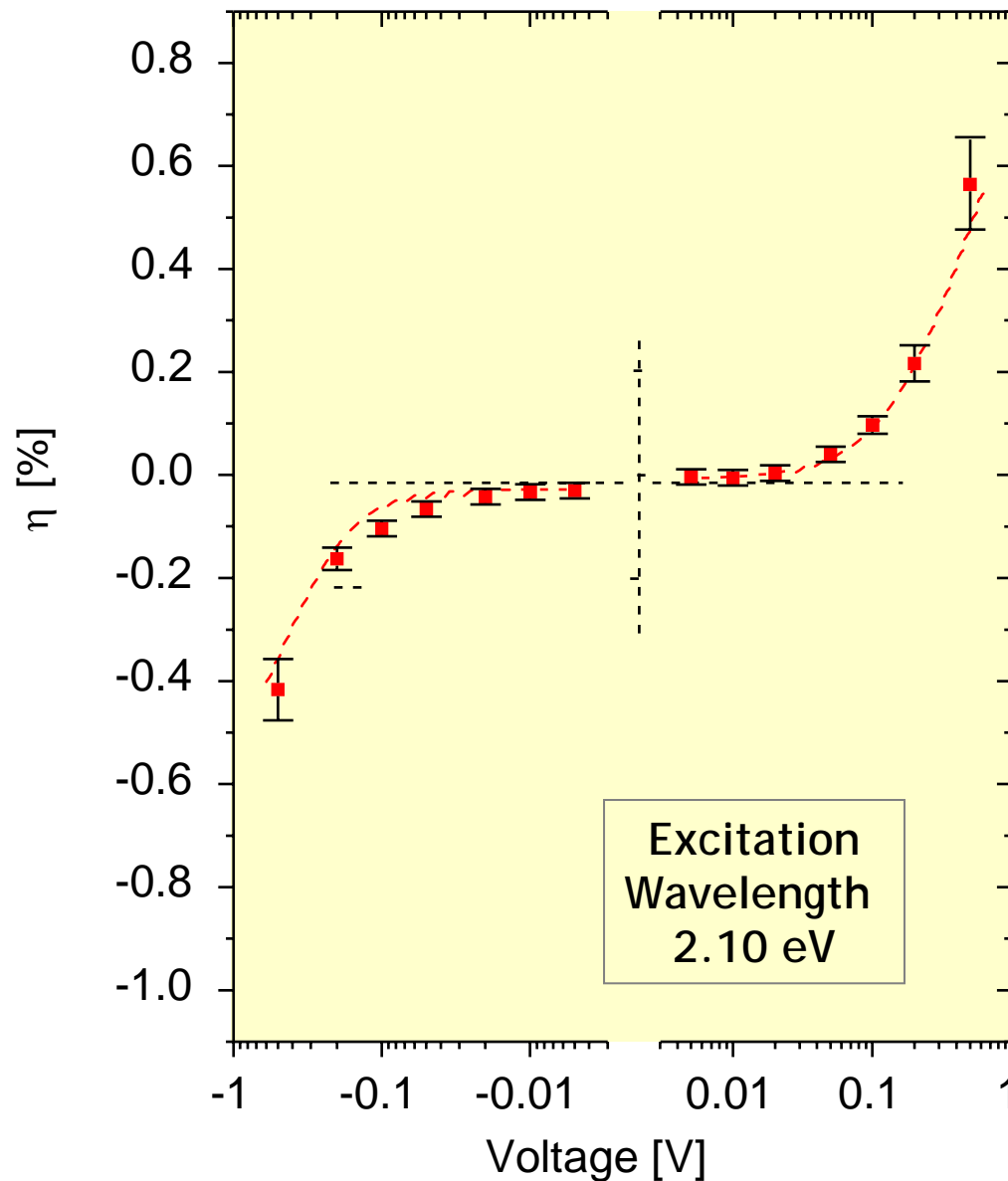
Exciton Diffusion Lengths



Exciton Diffusion Lengths

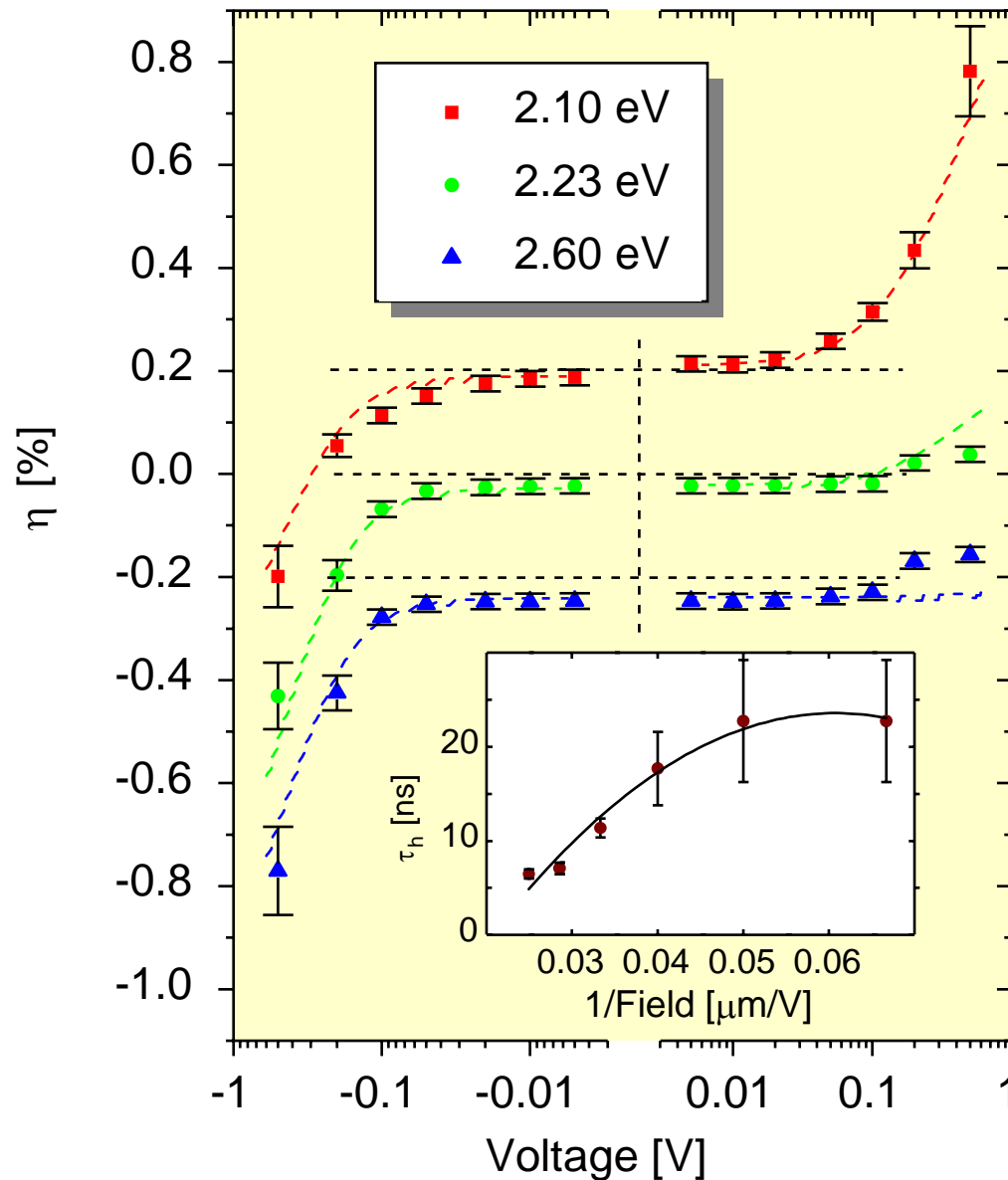


E-Field Dependent Photocurrent Response



$$\begin{aligned} I &\propto J_{\text{diff}} \eta_c \\ &= J_{\text{diff}} \exp(-t/\tau_{\text{rec}}) \\ &= J_{\text{diff}} \exp(-L^2/V\mu\tau_{\text{rec}}) \\ &\quad \text{one parameter fit !} \end{aligned}$$

E-Field Dependent Photocurrent Response



$$\begin{aligned} \eta &\propto J_{\text{diff}} \eta_c \\ &= J_{\text{diff}} \exp(-t/\tau_{\text{rec}}) \\ &= J_{\text{diff}} \exp(-L^2/V\mu\tau_{\text{rec}}) \end{aligned}$$

one parameter fit !

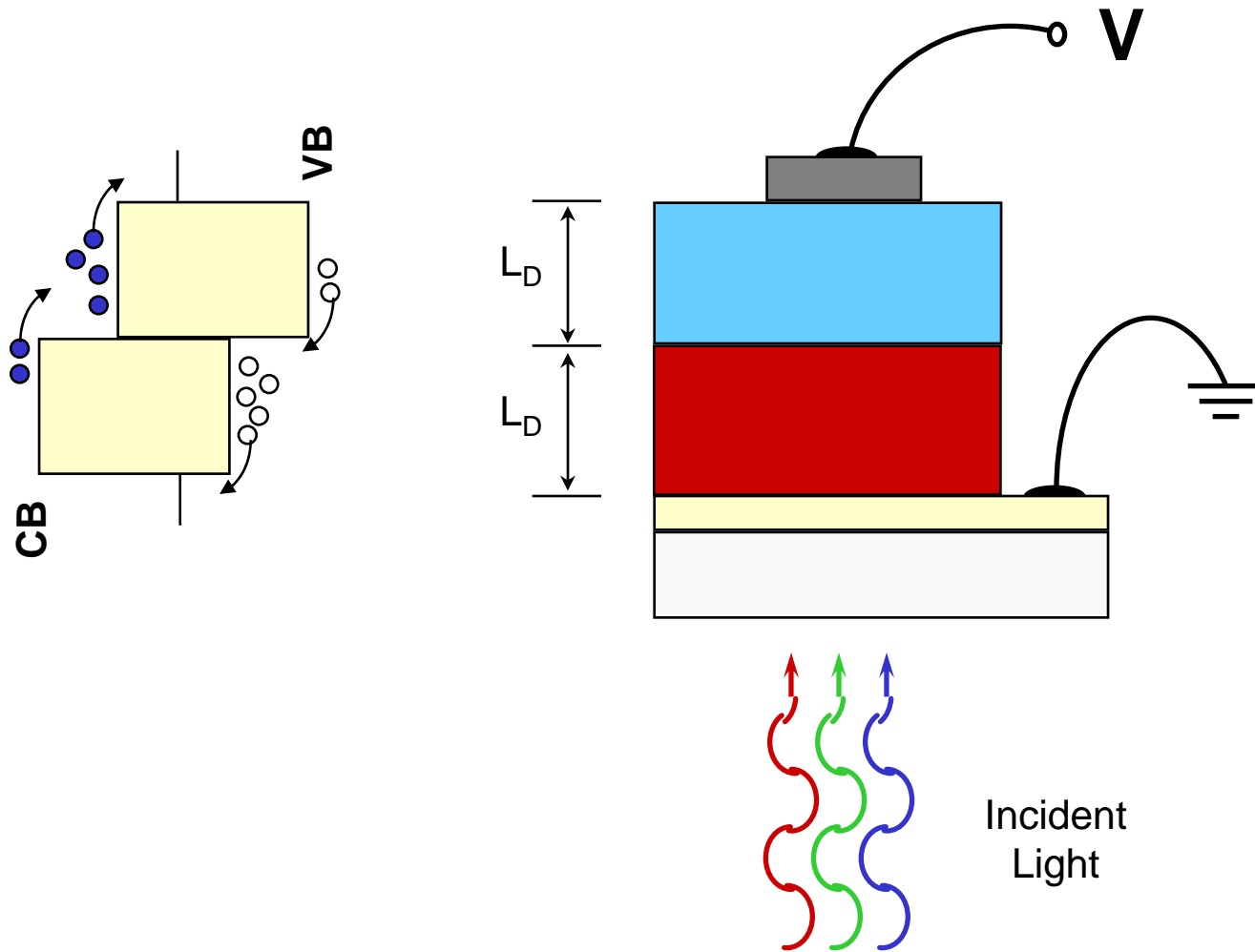
from the FIT to
PHOTOCURRENT
RESPONSE

$$\mu\tau_{\text{rec}} = 10^{-8} \text{ cm}^2/\text{V}$$

from the TOF
measurements

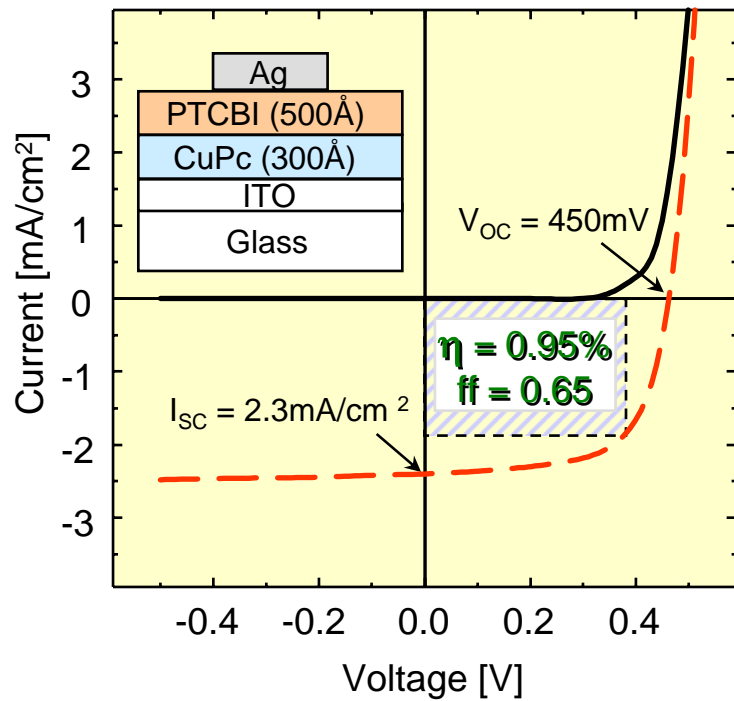
$$\mu = 0.03 \text{ cm}^2/\text{Vs}$$

Organic Heterojunction PVs



Organic Heterojunction PVs

Tang, *Appl Phys Lett.* **48**, 183 (1986).



Forrest, et al., *J. Appl. Phys.* **66**, 5908 (1989).

