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#4.2 Karakterisasi dan Pemodelan DSSC (Dye-Sensitized Solar Cell)

# Elektronika Organik

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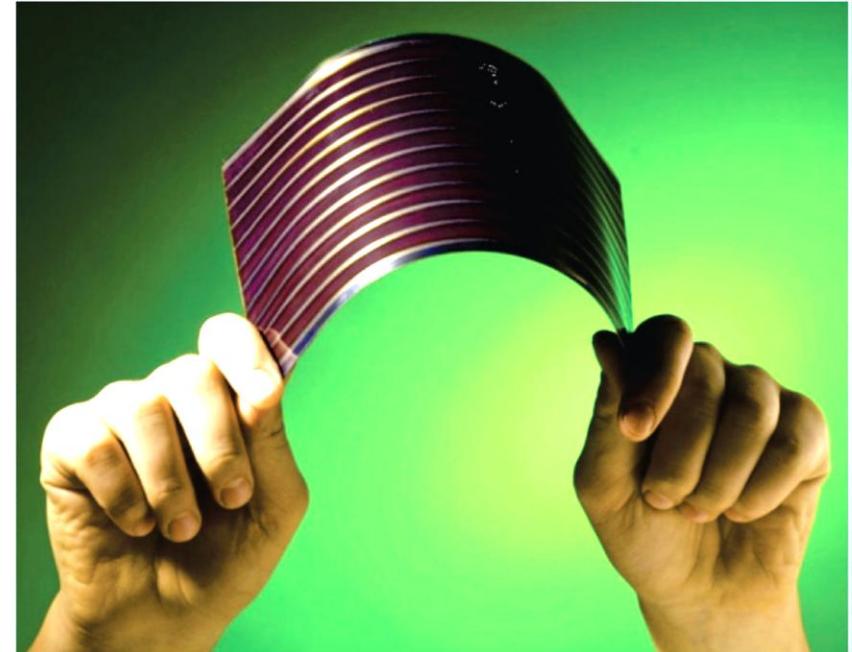
Teknik Elektro  
Universitas Brawijaya

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# Outline

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1. Pengantar Solar Cell
2. Prinsip Kerja DSSC
3. Pemodelan DSSC
4. Karakterisasi DSSC
5. Performansi DSSC
6. Optimasi dan Peluang



# Solar Sel

- Unit yang memiliki kemampuan mengkonversi cahaya matahari menjadi listrik
- Dibuat dari bahan semikonduktor
- Dapat digunakan untuk berbagai tujuan  
ex. *power resource*, light houses, power to the electrical grids, dan smart vehicle



# Efisiensi Konversi

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- How do they work?
  - Light is absorbed by semiconductor
  - Energy of the electrons increases
  - Electrons move in the material
  - Charge carriers have to be present
- Limitations
  - Band gap of the semi-conducting material
  - Maximum efficiency of a solar cell (single material) is about 30 %

# Perkembangan Solar Sel

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Three Generations of solar cell technology:

## 1. Single-crystal silicon based photovoltaic devices

- Good efficiency
- High Cost
  - Higher than traditionally-produced electricity

## 2. $\text{CuInGaSe}_2$ (CIGS) polycrystalline semiconductor thin films

- Low Cost
- Less Efficiency

## 3. Nanotechnology-enhanced solar cells

- Low Cost
- Medium Efficiency

# Sejarah Perkembangan DSSC

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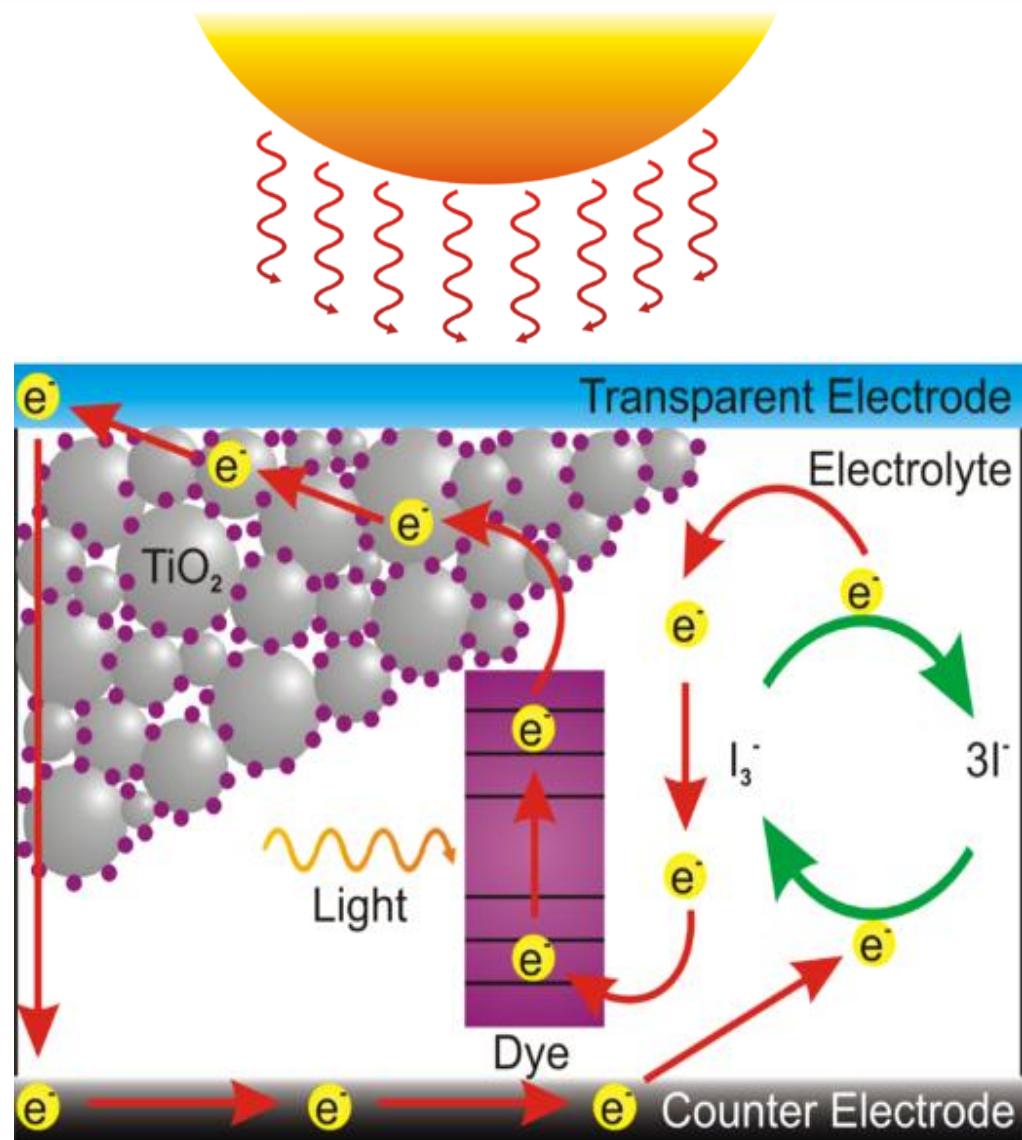
## *(Dye-Sensitized Solar Cell)*

- 1991
  - *Nature* paper by O'Regan and Grätzel
  - First suggestion of workable DSSC
- 2006
  - Use of nanowires and nanoparticles
  - Demonstrated good chemical and thermal resistance
- 2007, 2008
  - Use of low-cost organic dyes and solvent-free electrolyte solution investigated

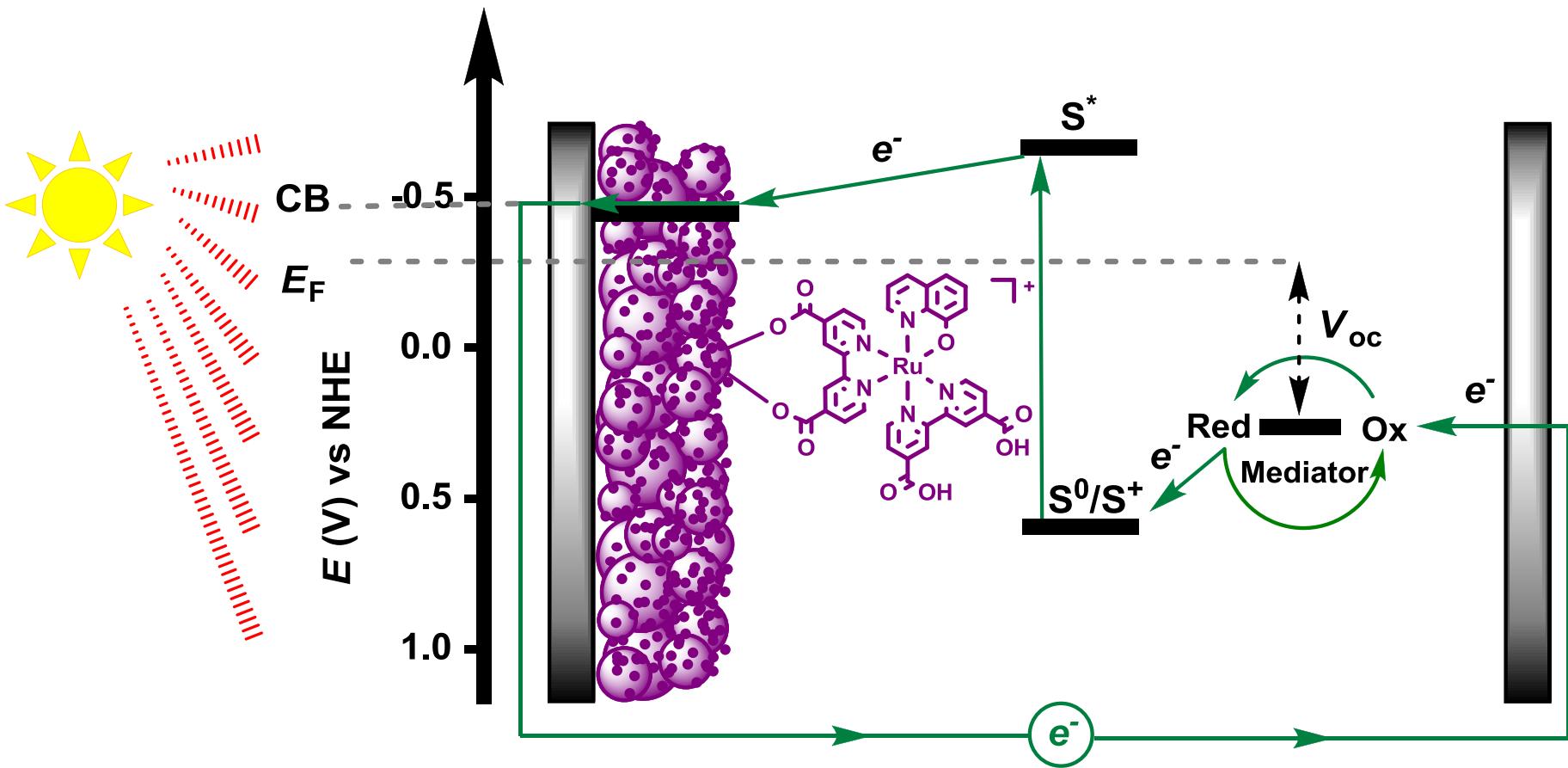
# Prinsip Kerja DSSC

## Lapisan DSSC:

1. Glass coated with fluorine-doped tin oxide
2. Titanium dioxide layer (n-type semiconductor)
3. Ruthenium dye
4. Electrolyte solution
5. Glass coated with platinum/C



# Mekanisme



# Efisiensi Konversi DSSC

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- High chance of photon absorption and high chance of electron movement
  - 90% Quantum Efficiency for green light
    - Quantum Efficiency-chance that one photon will convert one electron
- Overall efficiency is 11% or less, depending on materials of construction
- Medium efficiency and Low cost
- Problems to be addressed:
  - Liquid electrolyte (freezing, expanding, volatility)
  - Poor performance in red region of light

# Faktor-faktor pengaruh Efisiensi

❑  $I_{sc}$  ( $J_{sc}$ ) – Short Circuit Current (density)

❑  $V_{oc}$  – Open Circuit Voltage

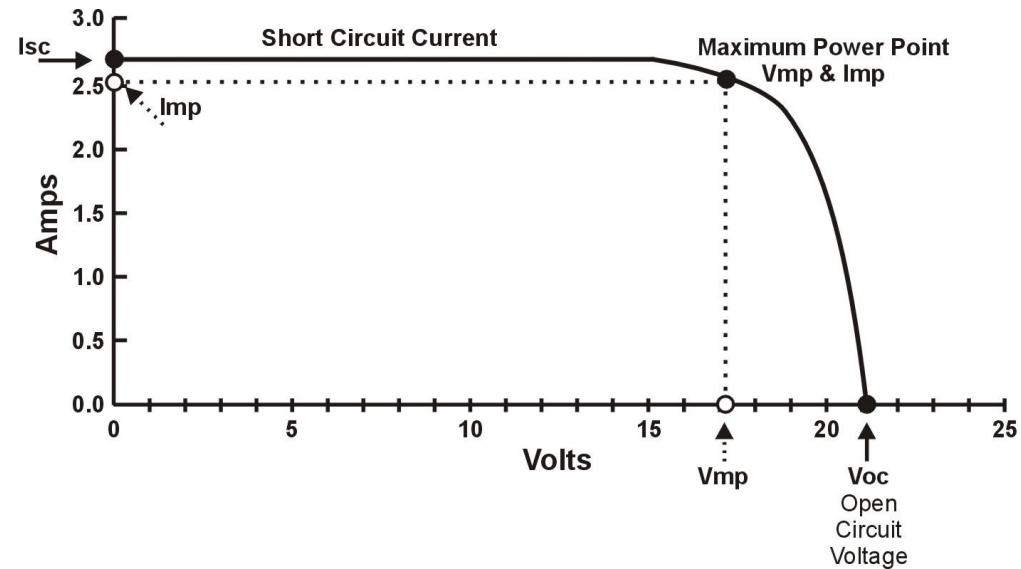
❑ FF – Fill Factor

❑ Maximum Power Output

$$P_{max} = V_{oc} \times I_{sc} \times FF$$

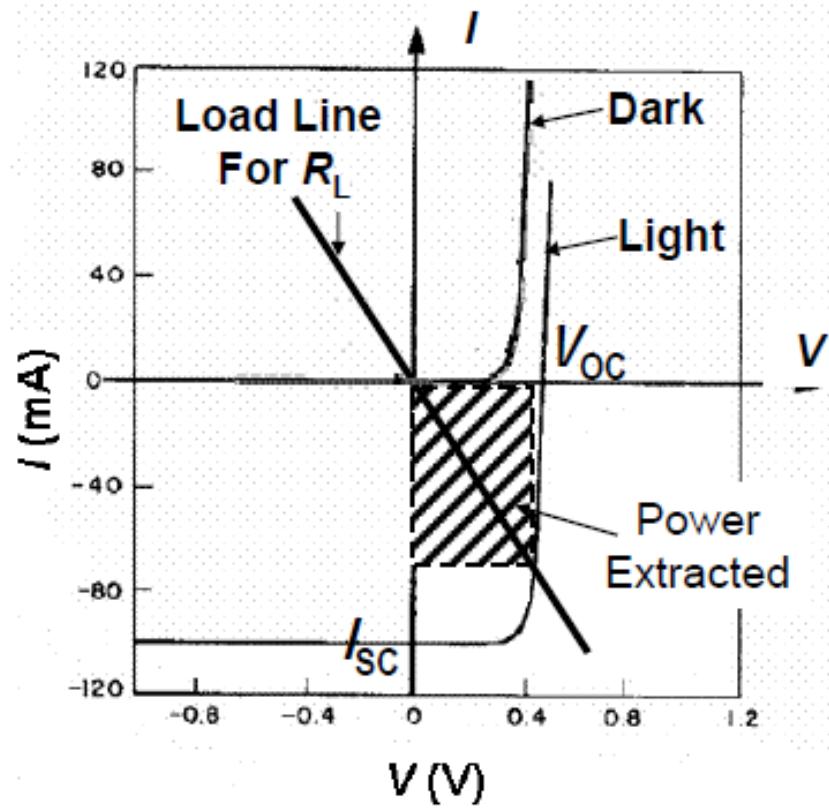
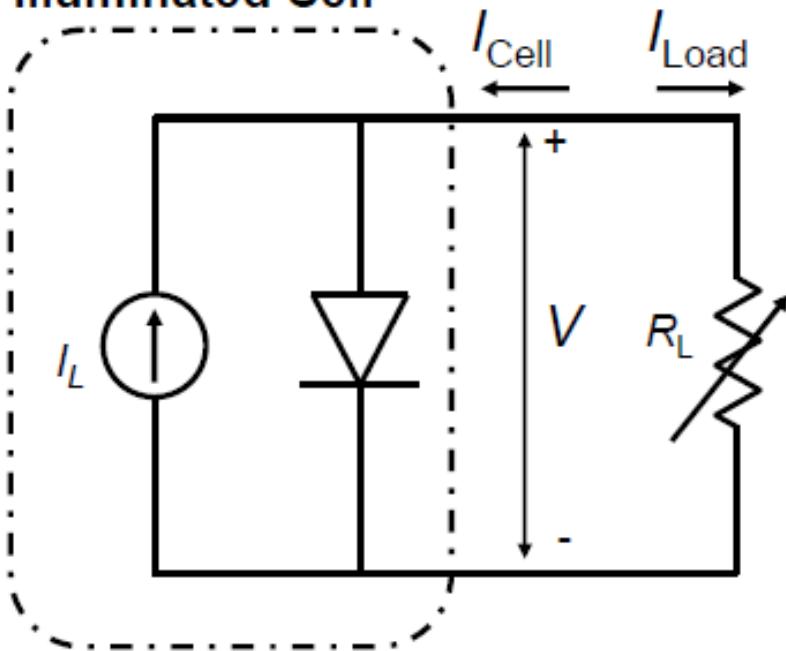
❑ Efficiency

$$\eta = P_{max} \div \text{Incident Light Power}$$



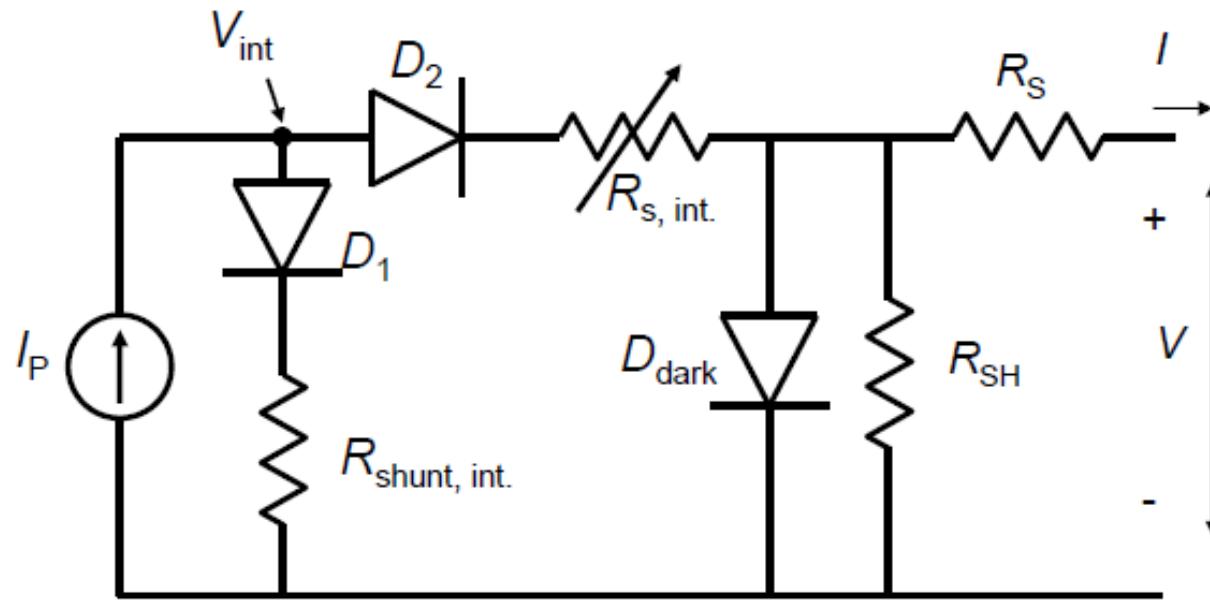
# Model Solar Sel (basic)

Illuminated Cell



- ❑  $I_{Cell} = I_s [\exp(qV / nkT) - 1] - I_L$ ; and  $I_{Load} = V / R_L$
- ❑ Choose  $R_L$  to get maximum power
- ❑ Series resistance causes ohmic loss
- ❑ Shunt resistance cases charge separated to recombine

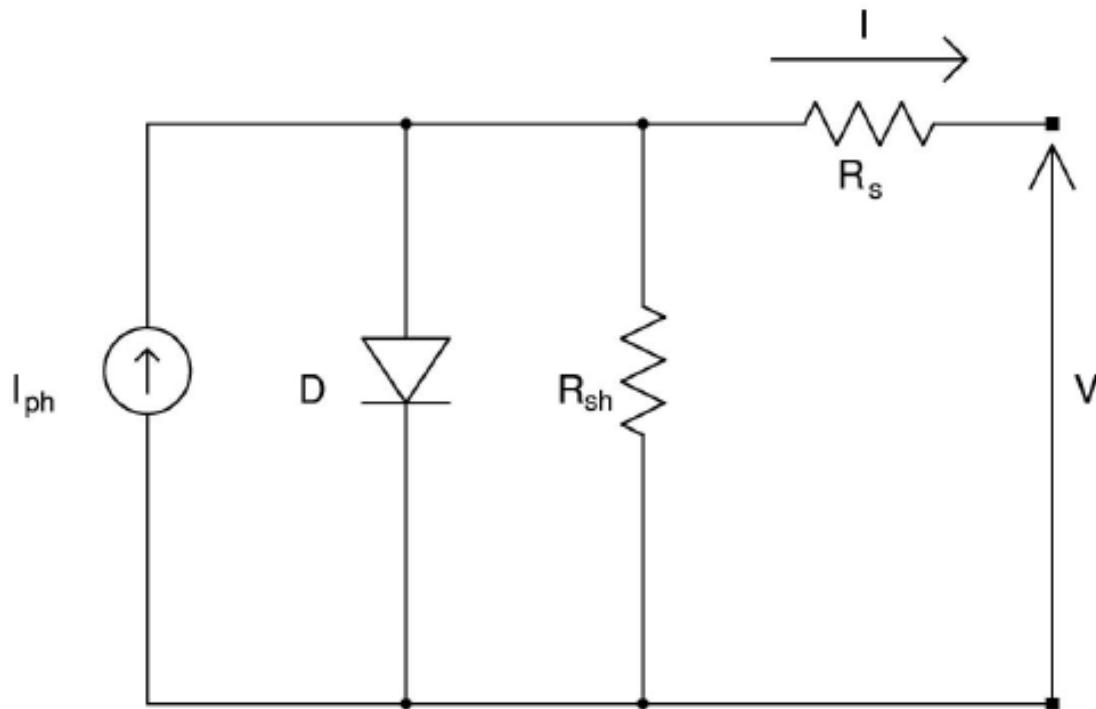
# Model Solar Sel Organik



- $I_L$  is a function of voltage
- Exciton generation  $I_P$  is a constant
- $R_{\text{shunt, int.}}$  will account for exciton recombination
- $R_{s,\text{int}}$  will account for extraction of  $e^-$  and  $h^+$  to electrodes

B. Mazhari 2006

# Model Rangkaian Equivalen DSSC (Ideal)



$I_{ph}$  represents photocurrent  
 $I_0$  Initial current  
 $R_s$  series resistance  
 $R_{sh}$  shunt resistance  
 $n$  ideality factor  
 $k$  Boltzmann constant  
 $K=kT/q$

$$i = I_{ph} - I_0 \left( e^{\frac{V + i R_s}{n K}} - 1 \right) - \frac{V + i R_s}{R_{sh}}$$

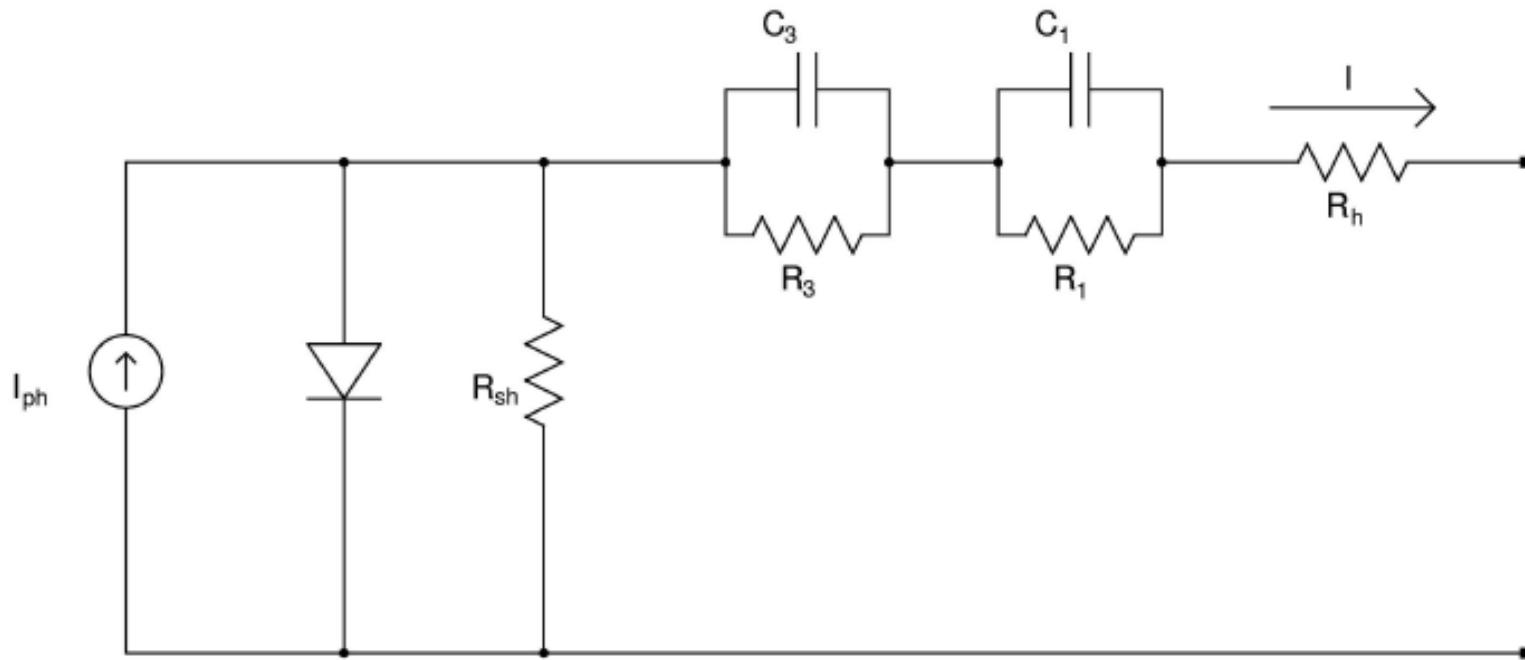
*The Open Renewable Energy Journal, 2012, 5, 49-60*

# Model Tegangan dan Arus dalam DSSC

$$V = -i R_s - i R_{sh} + I_{ph} R_{sh} - n K \text{LambertW} \left( \frac{\frac{I_0 R_{sh} e^{-\frac{R_{sh}(i - I_{ph} - I_0)}{n K}}}{n K}}{n K} \right) + I_0 R_{sh}$$

$$i = -\frac{1}{R_s} \left( V - \left( -\text{LambertW} \left( -\frac{\frac{R_{sh}(R_s I_{ph} + R_s I_0 + V)}{n K (R_{sh} + R_s)}}{-R_s n K - R_{sh} n K} \right) + \frac{R_{sh}(R_s I_{ph} + R_s I_0 + V)}{n K (R_{sh} + R_s)} \right) n K \right)$$

# Model Rangkaian Ekuivalen DSSC (Aktual)



$$R_s = R_h + R_1 + R_3$$

$$R_{s0} = -(\partial V / \partial i)_{V=V_{oc}}$$

$$R_{sh0} = -(\partial V / \partial i)_{i=I_{sc}}$$

# Model Resistansi Dinamik

$$R_{s0} = R_{sh} + \frac{\text{LambertW} \left( \frac{I_0 R_{sh} e^{-\frac{R_{sh}(i - I_{ph} - I_0)}{nK}}}{nK} \right) R_{sh}}{1 + \text{LambertW} \left( \frac{I_0 R_{sh} e^{-\frac{R_{sh}(i - I_{ph} - I_0)}{nK}}}{nK} \right)}$$

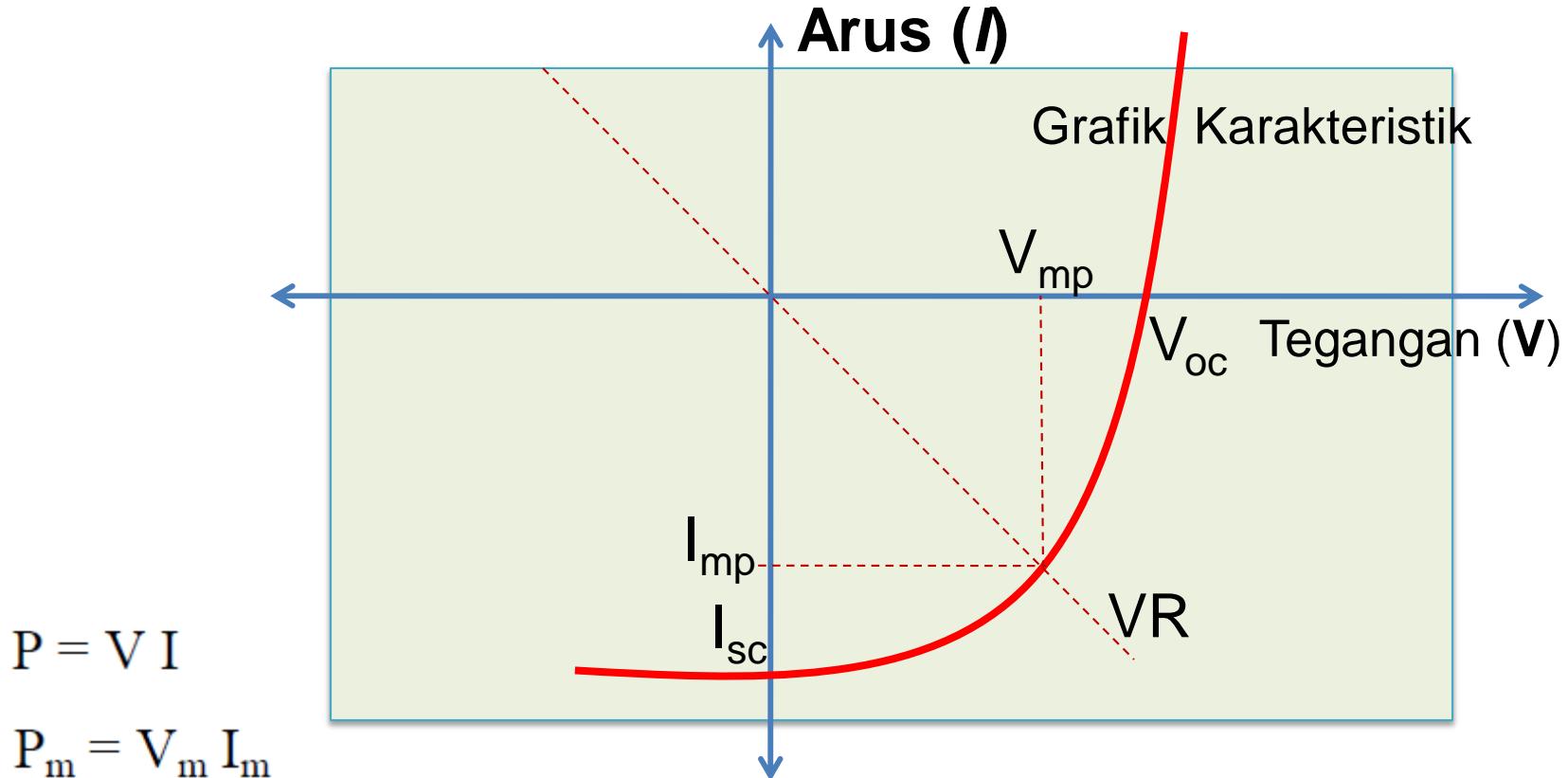
$$R_{sh0} = -R_s - R_{sh} + \frac{\text{LambertW} \left( \frac{I_0 R_{sh} e^{-\frac{R_{sh}(i - I_{ph} - I_0)}{nK}}}{nK} \right) R_{sh}}{1 + \text{LambertW} \left( \frac{I_0 R_{sh} e^{-\frac{R_{sh}(i - I_{ph} - I_0)}{nK}}}{nK} \right)}$$

## Tegangan Hubung Buka ( $V_{oc}$ ) dan Arus Hubung Singkat ( $I_{sc}$ )

$$V_{oc} = I_{ph} R_{sh} - n K \text{LambertW} \left( \frac{\frac{R_{sh} (-I_{ph} - I_0)}{n K}}{I_0 R_{sh} e^{\frac{R_{sh} (-I_{ph} - I_0)}{n K}}} \right) + I_0 R_{sh}$$

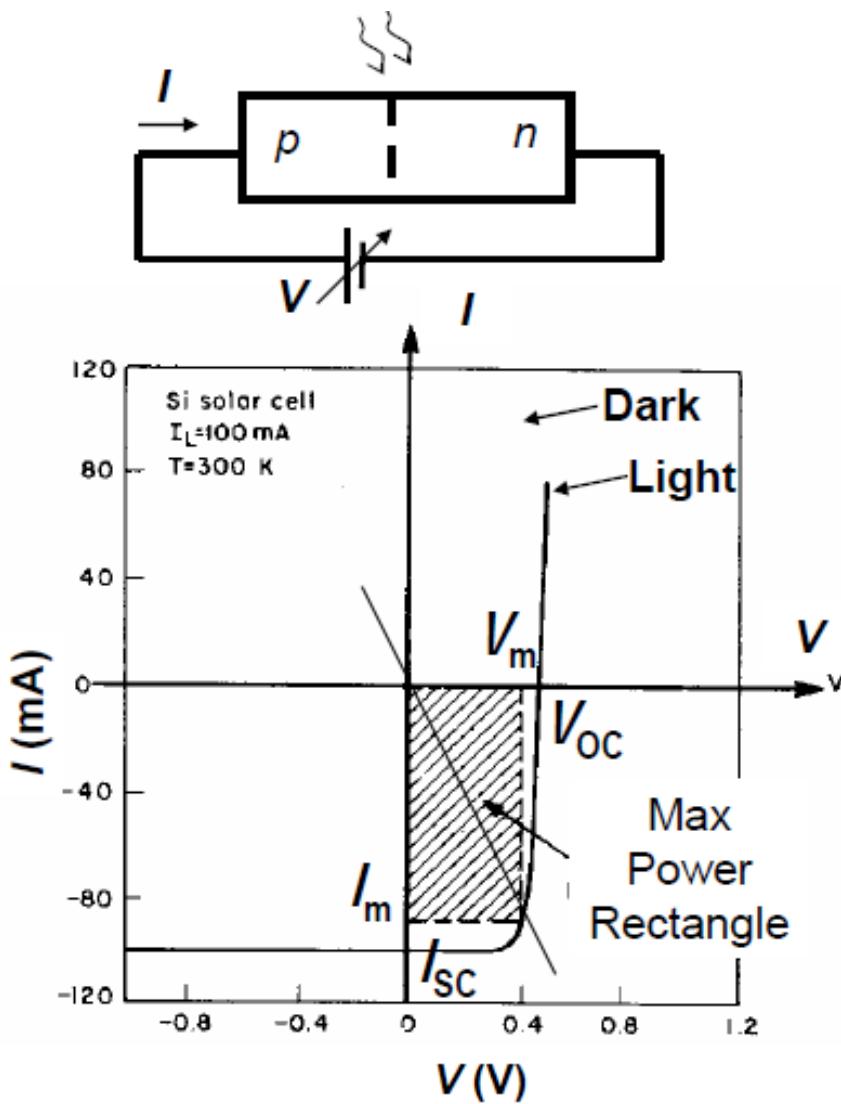
$$I_{sc} = \frac{1}{R_s} \left( -\text{LambertW} \left( -\frac{\frac{R_{sh} (R_s I_{ph} + R_s I_0)}{n K (R_{sh} + R_s)}}{-R_s n K - R_{sh} n K} \right) + \frac{R_{sh} (R_s I_{ph} + R_s I_0)}{n K (R_{sh} + R_s)} \right) n K$$

# Titik Daya Maksimum (MPP)



$$P := i \left( -i R_s - i R_{sh} + I_{ph} R_{sh} - n K \text{LambertW} \left( \frac{I_0 R_{sh} e^{-\frac{R_{sh}(i - I_{ph} - I_0)}{n K}}}{n K} \right) + I_0 R_{sh} \right)$$

# Definisi *Fill Factor*



- ❑ Fill Factor FF is the ratio of area of maximum rectangle fitted in the 4<sup>th</sup> quadrant  $I\text{-}V$  and the product of  $V_{oc}$  and  $I_{sc}$
- ❑ 
$$FF = (V_m \cdot I_m) / (V_{oc} \cdot I_{sc})$$

# Fill Factor

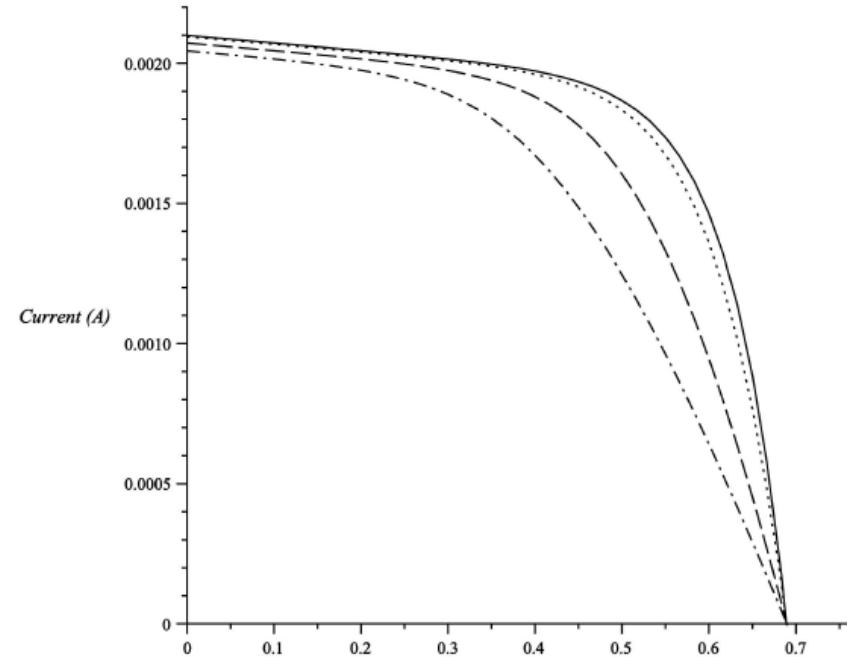
$$FF_1 = \frac{(V_m I_m)}{(V_{0c} I_{sc})}$$

$$FF_0 = \frac{v_{0c} - \ln(v_{0c} + 0.72)}{v_{0c} + 1}$$

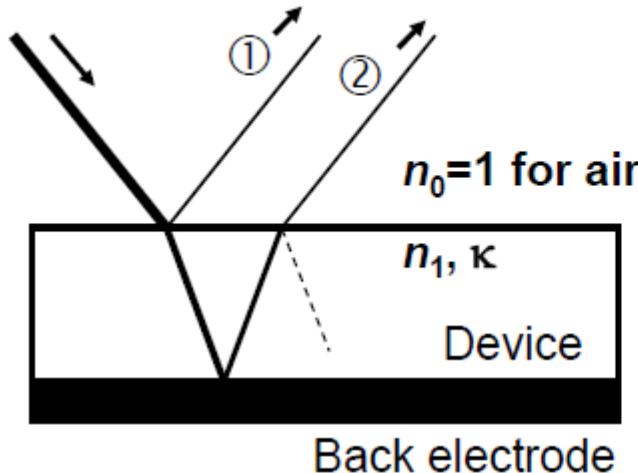
$$FF_s = FF_0 (1 - 1.1 r_s) + \frac{r_s^2}{5.4}$$

$$FF_2 = FF_s \left( 1 - \frac{(v_{0c} + 0.7) FF_s}{v_{0c} r_{sh}} \right)$$

$$v_{0c} = \frac{q}{nkt} V_{0c}; r_{sh} = \frac{R_{sh} I_{sc}}{V_{0c}}; r_s = \frac{R_s I_{sc}}{V_{0c}}$$



# Efisiensi Optik ( $\eta_O$ )



$$\eta_O = 1 - R \text{ where}$$

$$R = \frac{(n_1 - n_0)^2 + \kappa^2}{(n_1 + n_0) + \kappa^2}$$

□ Optical losses maybe due to

- Reflection at the surface ①
- Unabsorbed light leaking out ②

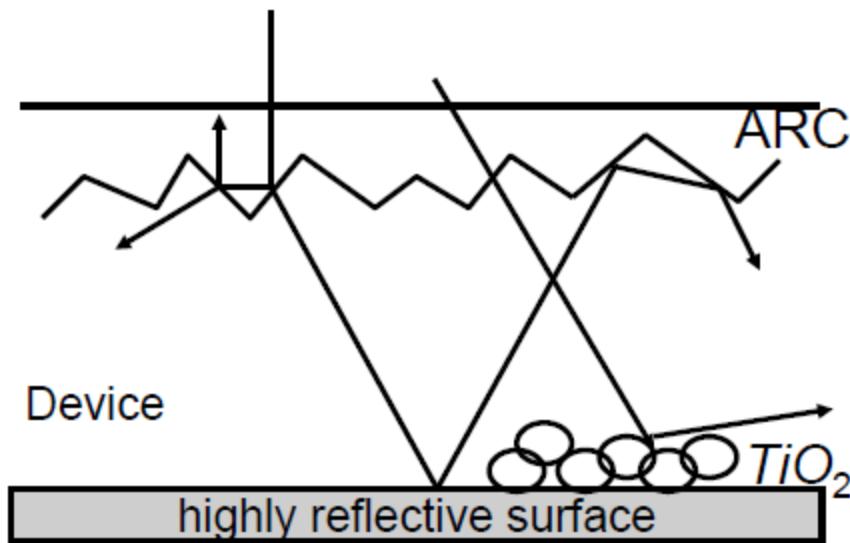
□ Solutions

- Anti Reflection Coating (ARC)
- Texturing the top surface
- Concentrators

$n_i$  : refractive index of medium i

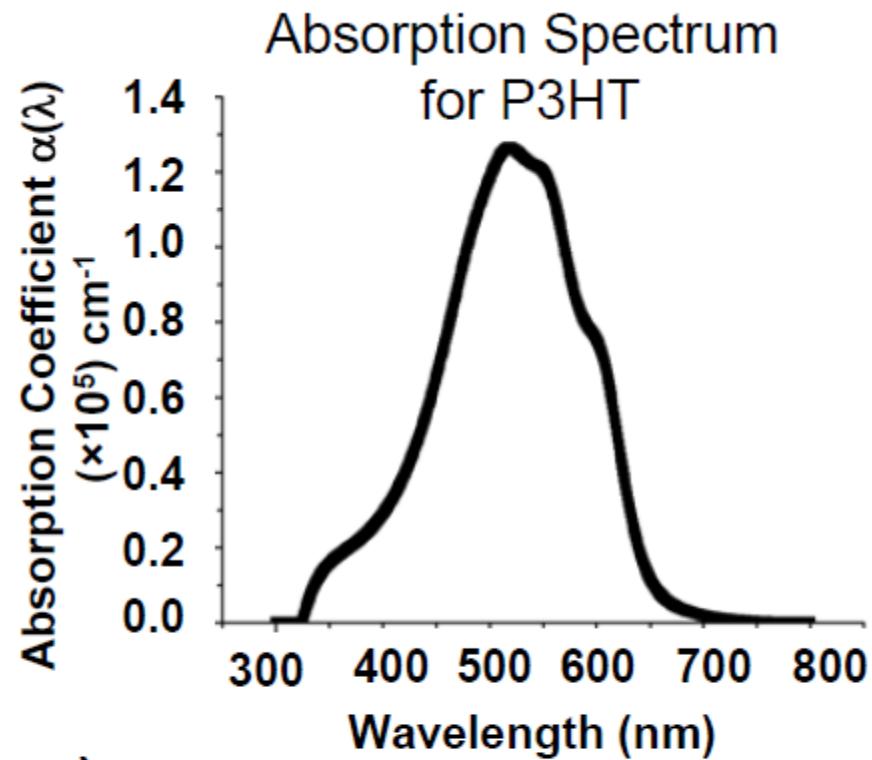
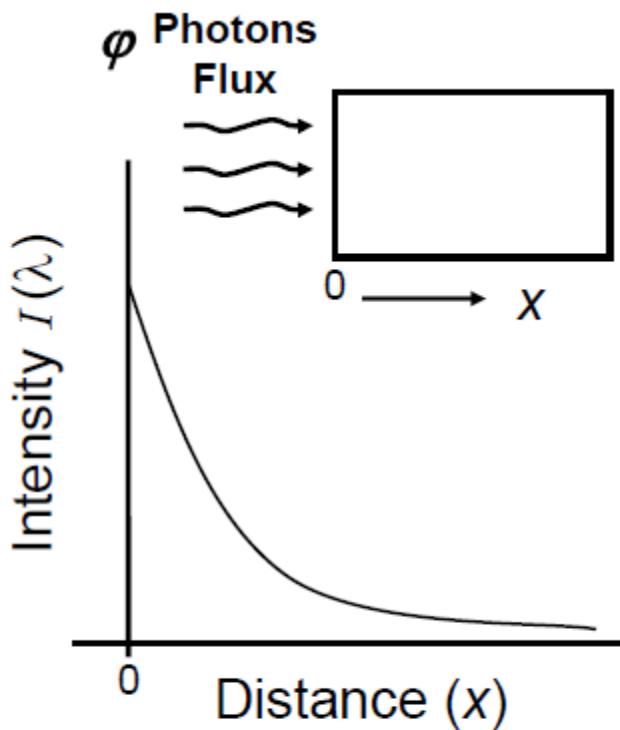
$\kappa$ : attenuation coefficient in device

# Traping cahaya



- ❑ Surface modification
- ❑ Anti-reflection coating
- ❑ Nanoparticles such as  $TiO_2$

# Penyerapan cahaya



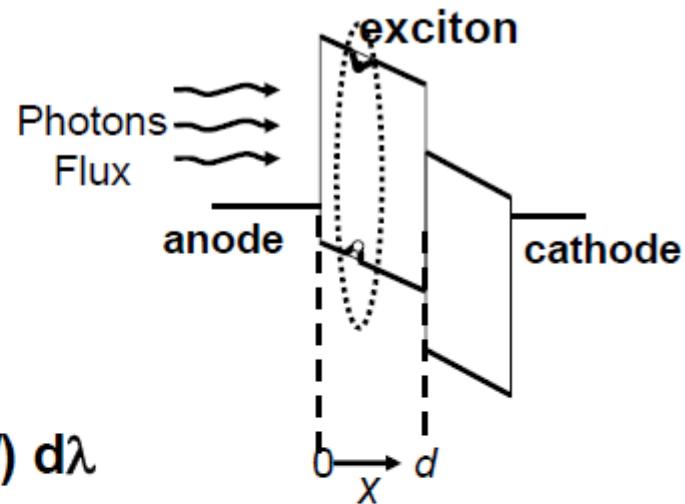
$$I(\lambda, x) = I(\lambda, x = 0) \exp(-\alpha x)$$

$$\varphi = I(\lambda, x) / (h\nu/\lambda)$$

$h$  : Plank's constant  
 $c$  : Speed of light

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# Efisiensi Absorbsi ( $\eta_A$ )



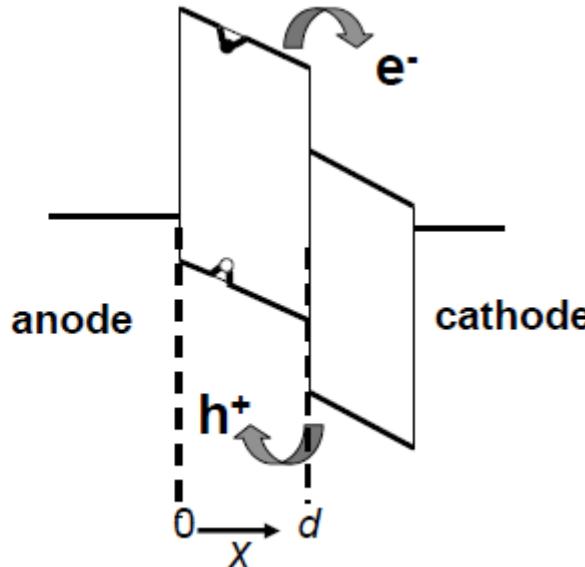
$$\eta_A = 1 - \frac{\int_{\text{Full spectrum}} (h\nu/\lambda)^{-1} I(\lambda) \exp(-\alpha(\lambda)d) d\lambda}{\int_{\text{Full spectrum}} (h\nu/\lambda)^{-1} I(\lambda) d\lambda}$$

=  $\frac{\text{Number of photons absorbed}}{\text{Number of photons incident}}$

# Efisiensi Disosiasi Eksiton ( $\eta_{ED}$ )

- Excitons are neutral
- Concentration of surviving excitons at  $x'$  is

$$\xi(x+x') = \frac{1}{2} \xi(x) \exp(-x'/L_D)$$



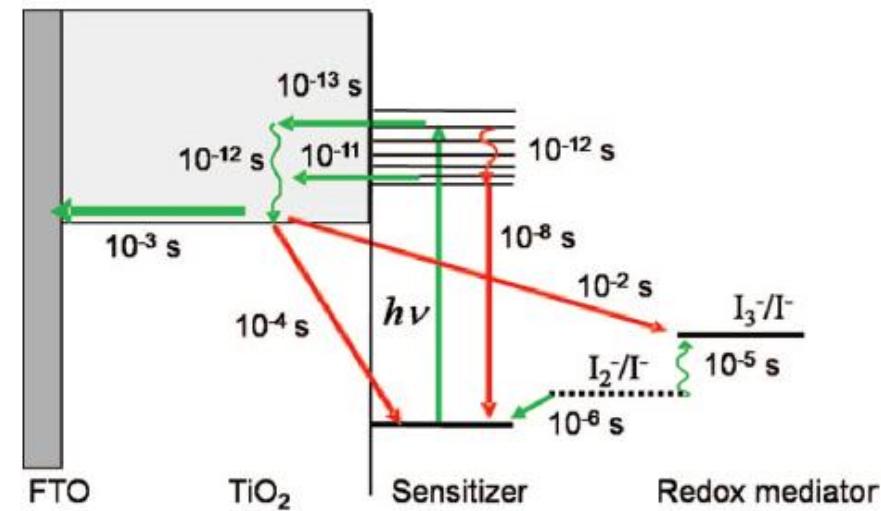
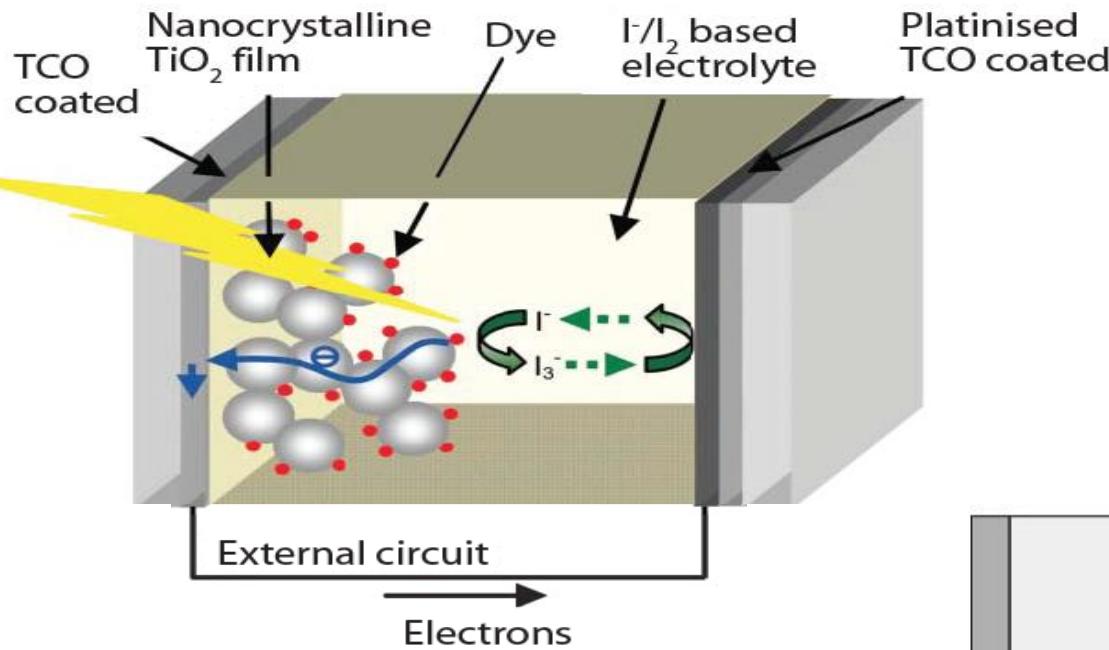
- $L_D$  is the average exciton diffusion length
- Likely location of dissociation is the interface

$$\eta_{ED} = \frac{\int_0^d \frac{1}{2} \xi(x) \exp(-(d-x)/L_D) dx}{\int_0^d \xi(x) dx} = \frac{\text{Excitons reaching interface}}{\text{Number of excitons created}}$$

## Factors Affecting $\eta_{ED}$

- Choice of Electrodes
- Thickness of active layer(s)
- Morphology and Phase in active layer

# Mekanisme untuk optimalisasi



# Development of DSSC

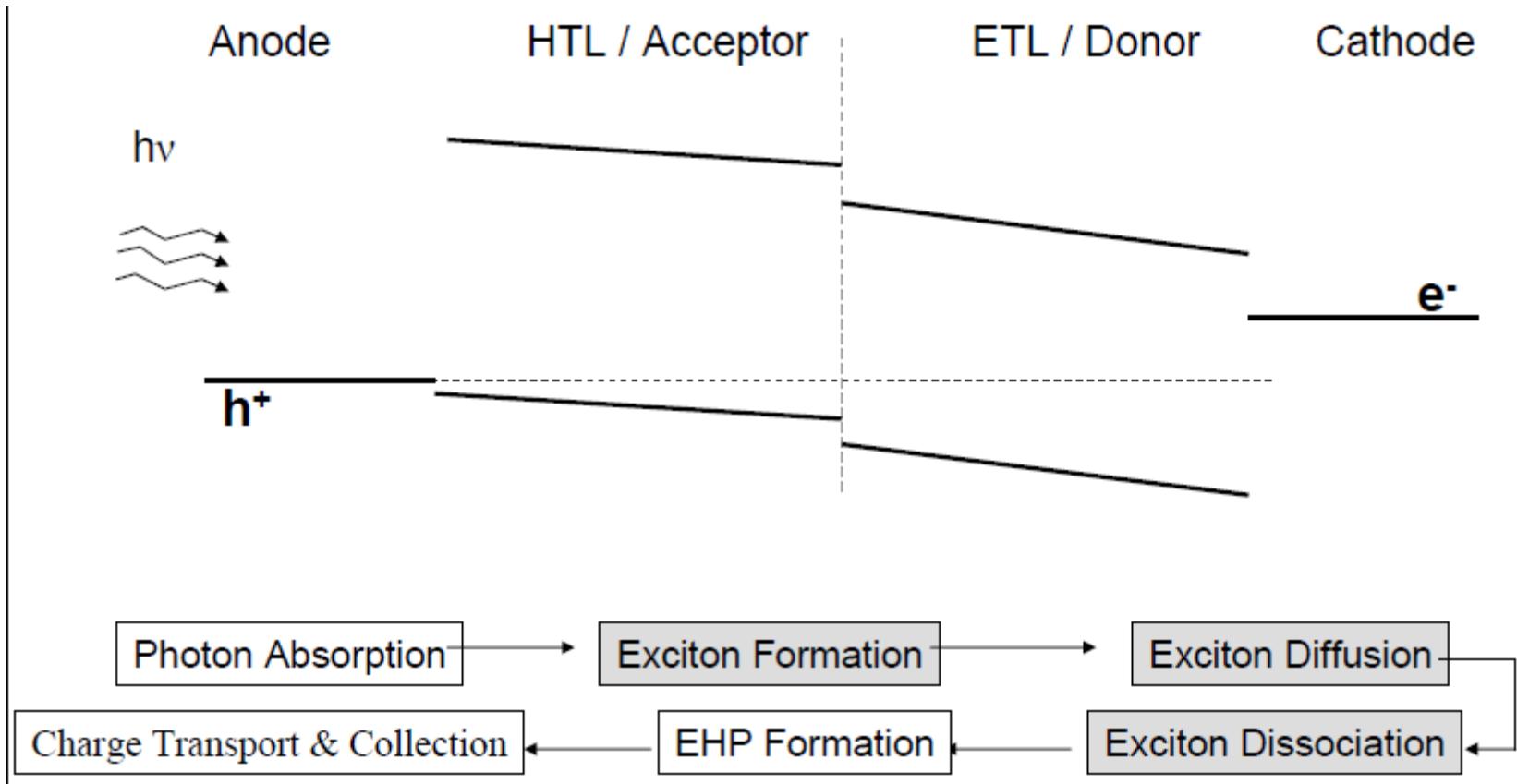
## Green Principle

1. Waste Prevention
2. Atom Economy
3. Less Hazardous Chemical Process
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. Energy Efficiency
7. Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time Analysis for Pollution Prevention
12. Safer Chemistry for Accident Prevention

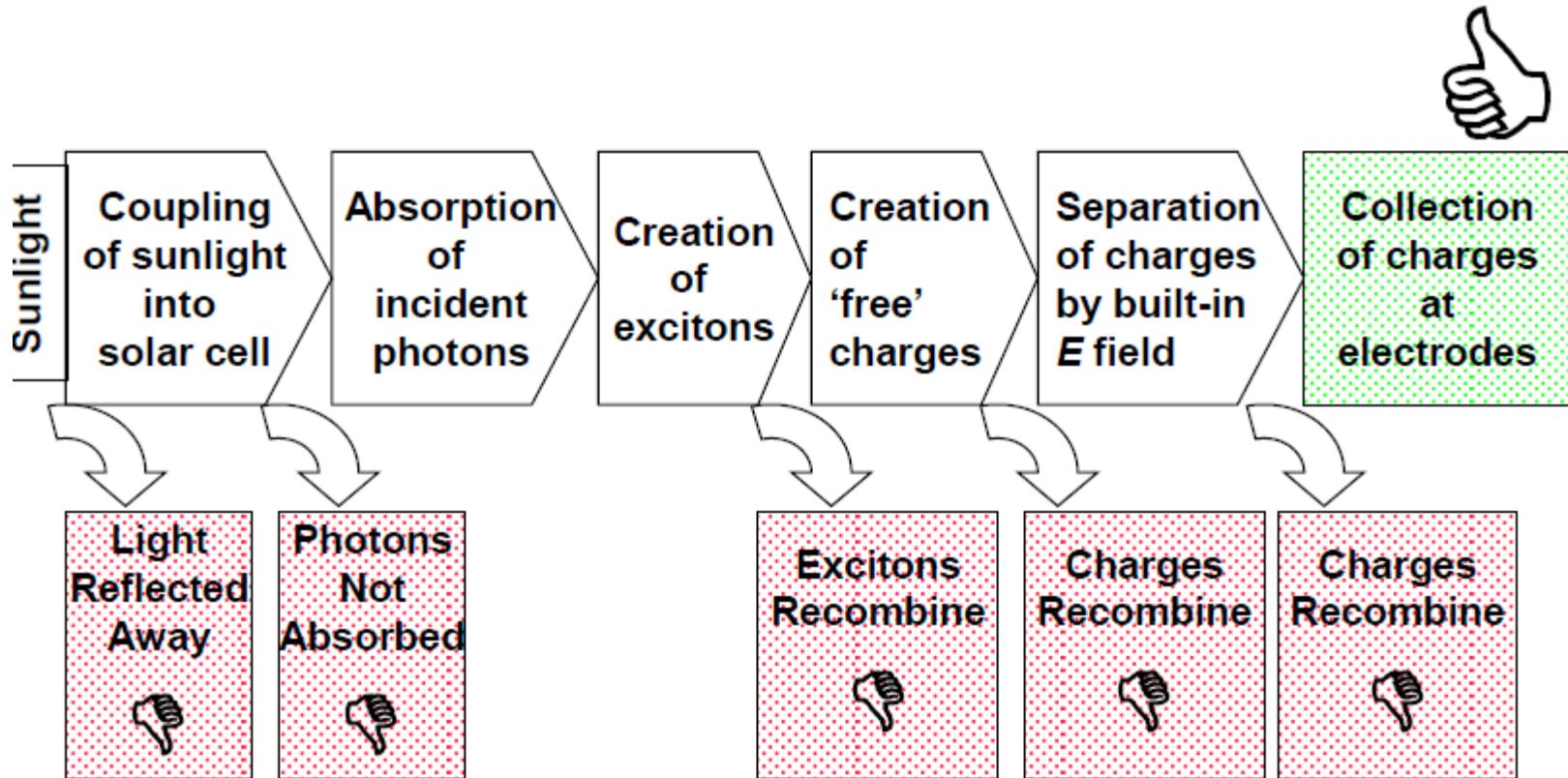
Glass-based DSSC Module



# Proses mekanisme konversi



# Proses dalam fotovoltaik

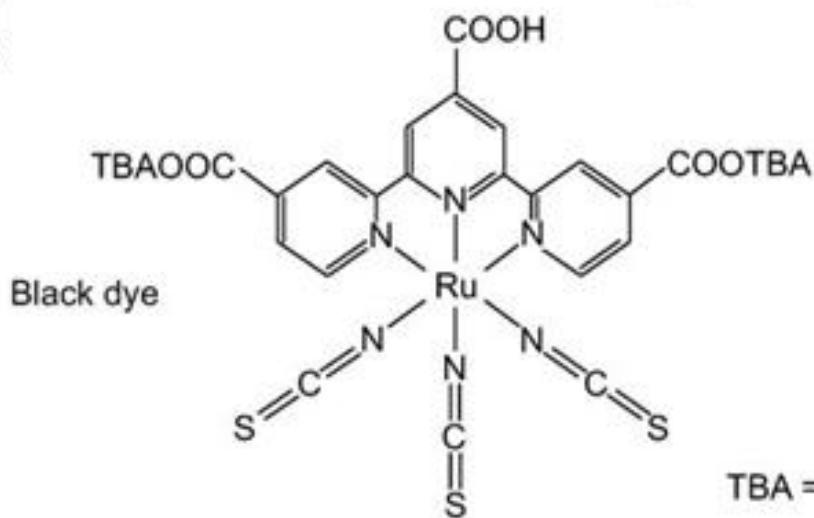
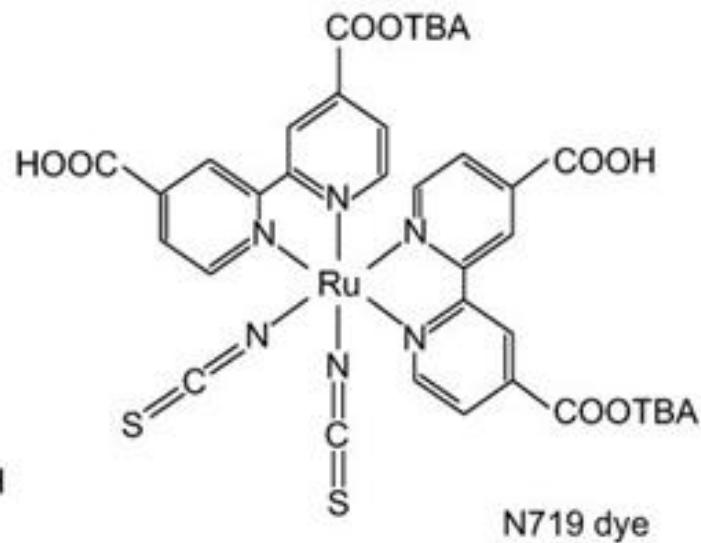
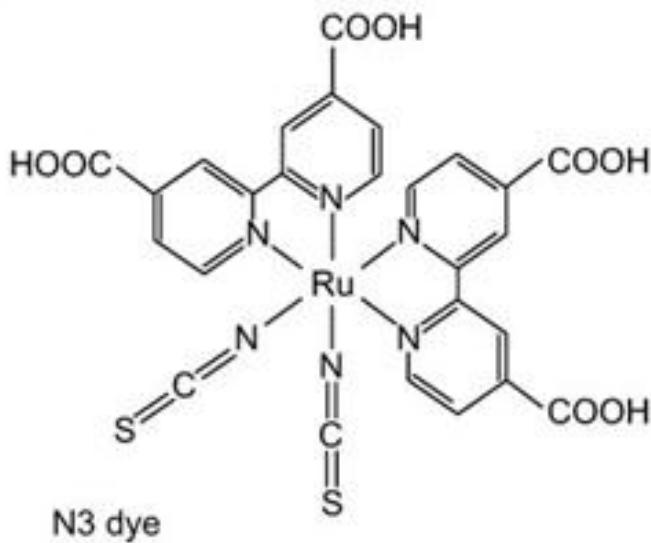


# Komponen DSSC

The DSSC device consists of 4 components:

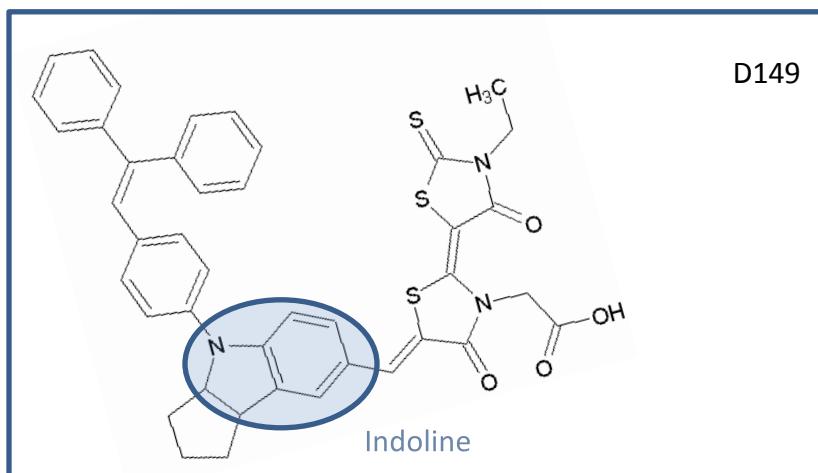
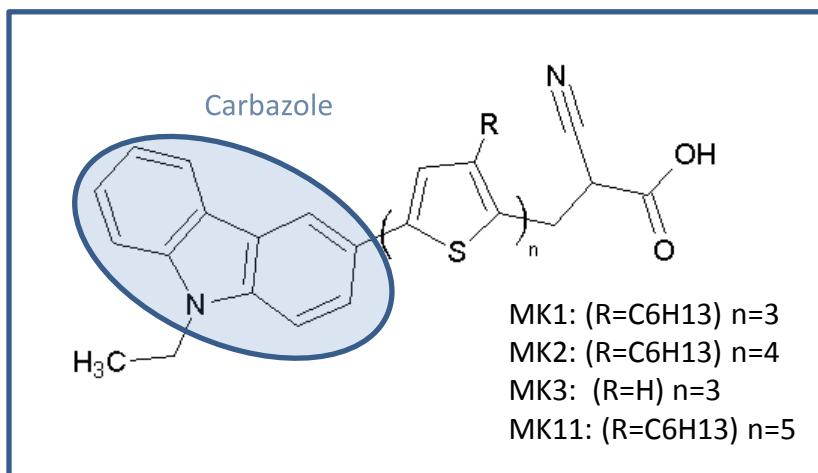
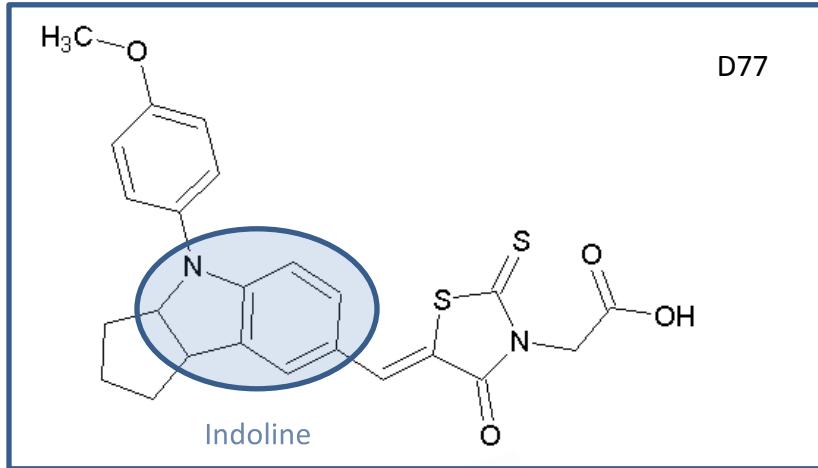
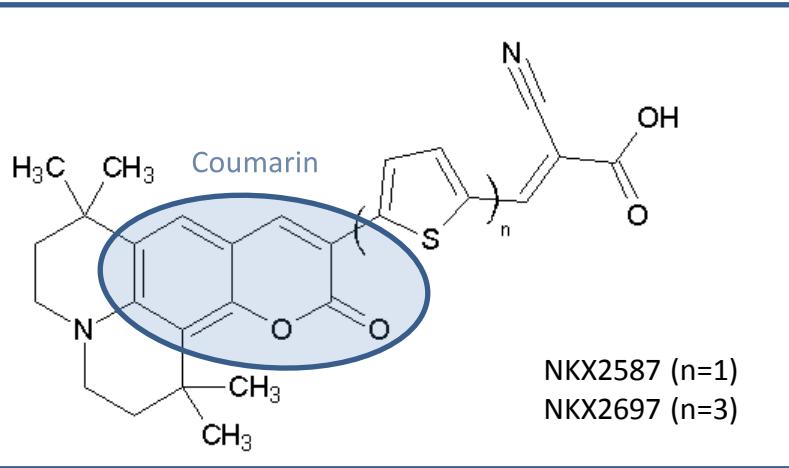
- semiconducting electrode
  - $\text{TiO}_2$
- Dye-sensitizer
  - Light harvesting and electronic transition
- Redox mediator
  - $\text{I}^- / \text{I}_3^-$  or  $\text{Co}^{\text{II}} / \text{Co}^{\text{III}}$  complexes
- Counter electrode
  - Carbon or Pt

# Sensitasi Dye



TBA = tetrabutylammonium cation

# Tested Organic Dyes



# Review

- Tentukan topik kajian/ review/ ide tentang pengembangan solar cell organik dan DSSC (dapat berupa hasil resume jurnal)

# Review

Baca Paper tentang DSSC berikut dan pelajari tentang: metode, karakteristik, dan performansinya

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- **The effect of photoelectrode TiO<sub>2</sub> layer thickness to the output power of chlorophyll-based Dye-Sensitized Solar Cell (DSSC).** Pramono, S.H.; Maulana, E.; Sembiring, M., in Intelligent Technology and Its Applications (ISITIA), 2015 International Seminar on, vol., no., pp.107-112, 20-21 May 2015. [IEEE Link](#)
- **Effect of Chlorophyll Concentration Variations from Extract of Papaya Leaves on Dye-Sensitized Solar Cell'**, Maulana, E. ; Pramono, S. ; Fanditya, D. ; Julius, M. (2015), World Academy of Science, Engineering and Technology, International Science Index 97, International Journal of Electrical, Computer, Electronics and Communication Engineering, vol. 9, no. 1, 49 – 52. [link jurnal](#)
- **Characterization of Dye-Sensitized Solar Cell (DSSC) Based on Chlorophyll Dye.** SH Pramono, Eka Maulana, AF Prayogo and Rosalina Djatmika. International Journal of Applied Engineering Research. Volume 10, Number 1 (2015) pp. 193-205. [link jurnal](#)
- **Organic Solar Cell based on extraction of Papaya (*Carica papaya*) and Jatropha (*Ricinus communis*) leaves in DSSC (Dye Sensitized Solar Cell)**  
[Sholeh Hadi Pramono, Eka Maulana, M. Julius St., and Teguh Utomo], 2013 [abstract](#)

<http://maulana.lecture.ub.ac.id/research/penelitian-publikasi/>

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