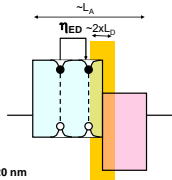


## Introduction

Overall Quantum Efficiency  
 Fundamental problem:  $L_D \ll 1/\alpha$

- (1)  $\eta_A > 50\%$
- (2)  $\eta_{ED} \sim 10\%$
- (3)  $\eta_{CT} \sim 100\%$
- (4)  $\eta_{CC} \sim 100\%$



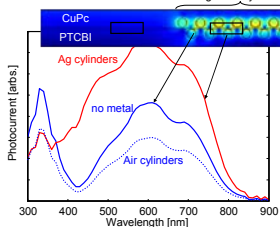
Exciton diffusion length ~ 5-20 nm

$$\eta_{EQE} = \eta_A \cdot \eta_{ED} \cdot \eta_{CT} \cdot \eta_{CC} \sim 10\%$$

## Plasmonic Solar Cell

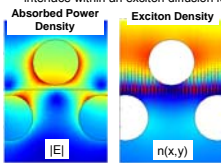
- Simple model system: Ag cylinders in DA solar cell
- Model: optical absorption + exciton diffusion
- Exciton quenching at Ag interface not modeled

Ag nano-cylinders



## Mechanisms

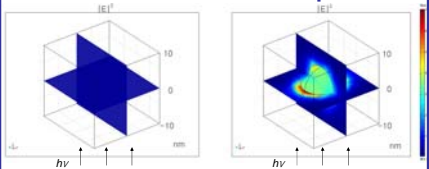
Localized photon absorption near the DA interface:  
 • Increase optical electric field near the DA interface within an exciton diffusion length



• Increased exciton diffusion length

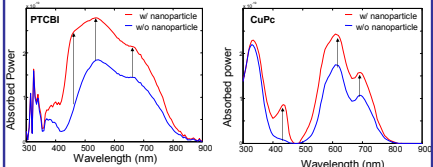
## Localized Fields

### Localized Photon Absorption



Finite Element Method  
 Nanoparticle: Ag (radius = 5nm)  
 Organic: copper phthalocyanine (CuPc)  
 Wavelength: 450nm  
 Maximum exciton generation rate  $\propto |E|^2$ : ~70 times enhancement  
 Calculated absorbed power enhancement:  $\frac{3.54 \times 10^{-20}}{7.0 \times 10^{-21}} = 5$  times

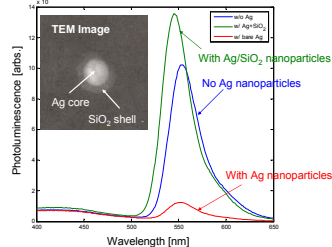
### Broadband Resonance: Increased Absorption Near and Off Resonance



- Substantial increase in optical absorption near plasmon resonance of the Ag nanoparticles
- Even off-resonance: scattered field enhance absorption

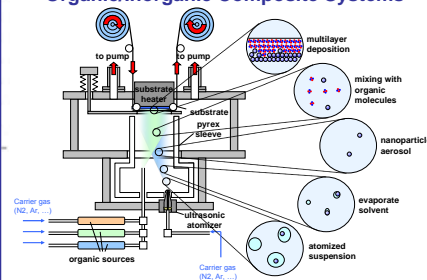
### Reduced PL Quenching

- Ag/SiO<sub>2</sub> particles embedded in organic thin films enhance absorption
- SiO<sub>2</sub> shell is essential (bare Ag particles leads to PL quenching)



## Deposition Technology

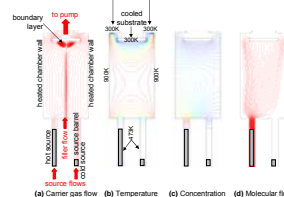
### Deposition Technology for Organic/Inorganic Composite Systems



### Why Use Vapor Phase?

- Materials use efficiency >50%
- Multilayers
- Additional degrees of freedom in controlling nanostructure (pressure, temperature, gas flow)
- Rates as high as 1  $\mu\text{m/s}$

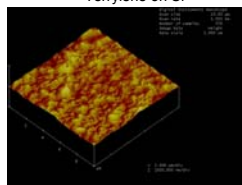
Shtein, Peumans, Benziger and Forrest, Adv. Mater. 16, p.1615 (2004).



### Thin Film by Aerosol Deposition

- Can deposit films at very low solubility (e.g. 0.0001wt%)
- 10nm roughness for 100nm films

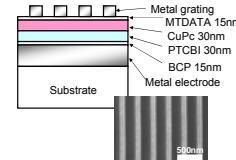
Terylene on Si



## Metal Gratings and Nanowires Electrodes

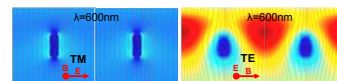
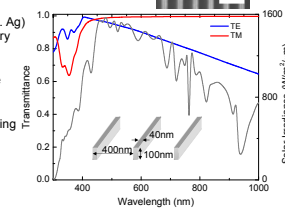
### Metal Gratings in Solar Cells

- Conventional transparent electrodes such as Indium-Tin-Oxide (ITO) are problematic:
  - Expensive
  - Brittle (crack when bent)
  - Resistive OR transparent
  - Cannot be deposited on top of organic



- Metals are cheap (e.g. Ag) in thin film form and very conductive but opaque

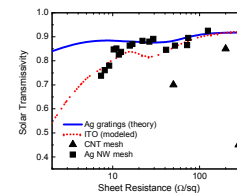
- Can we nanostructure metals such that they become optically transparent without losing conductivity?



• Calculation of:

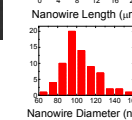
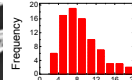
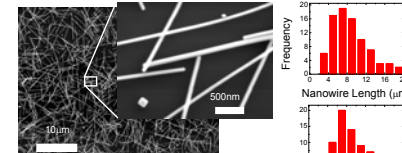
- optical energy flow (streamline)
- optical electric field (colormap)
- Metal gratings are excellent transparent contacts to solar cells

### Metal Gratings and Nanowires mesh are Very Good Transparent Contacts

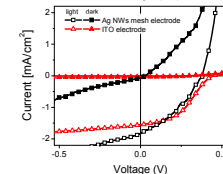
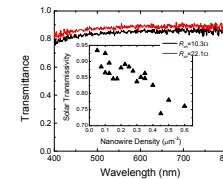


- Transmittance depends on geometrical factors, such as grating period, aperture ratio, thickness, etc.
- For both TM and TE polarizations, transmittance is better than that of ITO for comparable sheet resistance

### Silver Nanowires Film



### Organic Photovoltaic Cell with Ag NWs



## Conclusions

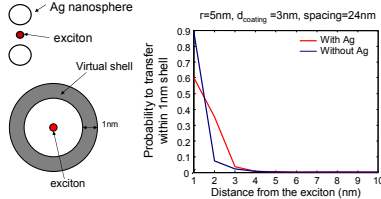
- More excitons can be created by plasmonic effects using metal nanoparticles
- Insulator shell prevents exciton quenching
- Metal nanoparticles may accelerate exciton diffusion
- Metal core/insulator shell particles are interesting additives to organic solar cells
- Metal gratings with appropriate period and duty rate, etc. can be more transparent than conventional transparent electrodes.
- New device performance can be as good as conventional organic PV cells.
- Metal nanowires are candidates for the replacement of ITO.
- Organic Photovoltaic cells with Ag NWs mesh are demonstrated and shows comparable performance to the conventional cells.

The authors gratefully acknowledge financial support from GCEP and NSF.

## Enhanced Exciton Diffusion

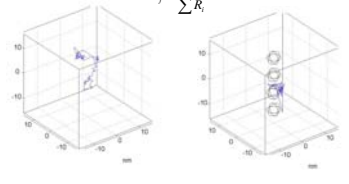
### Enhanced exciton diffusion

- Exciton = oscillating dipole.
- Power absorption at point R:  $R_j = \frac{dQ}{dt} = \frac{1}{2} \omega \epsilon'' |E_j|^2$
- Transfer probability:  $P_j = \frac{R_j}{\sum R_i}$  (i = lattice number)



### Monte Carlo Simulations

1. Start at (0, 0, 0).
2. Calculate the magnitude of electric field, |E| at each 1 nm lattice grid.
3. Rate to transfer to grid j is,  $R_j \propto |E_j|^2$
4. The probability to transfer to the grid j is,  $P_j = \frac{R_j}{\sum R_i}$



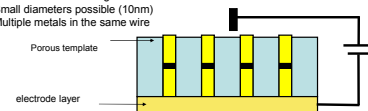
Average step size: 1.3 nm      Average step size: 2.8 nm

## Growth of Metal Nanowires

### 1. Template-Assisted Electroplating

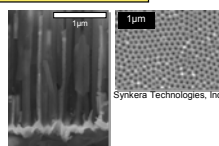
Template Assisted Electroplating provides required fine control

- Fine control of wire length
- Small diameters possible (10nm)
- Multiple metals in the same wire



Anodized Alumina Templates

Available Pore Diameters: 10 nm - 1  $\mu\text{m}$



M. Barbic & A. Scherer, Nano Lett. 2005

### 2. Shape-Controlled Synthesis of Metal Nanoparticles

3mL 0.1M AgNO<sub>3</sub> injected into 5mL 0.3M PVP in ethylene glycol at 170°C in 20 aliquots.

