PLASMONIC ENHANCEMENT OF Ag NANOFLOWERS IN ACTIVE LAYER ORGANIC SOLAR CELLS

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Outlines

- Introduction
- Objectives
- Experimental method and Results
- Conclusions
Introduction

Plasmonic

Surface plasmon resonance (SPR)

- Depends on: shape, size, distributions of nanoparticles, dielectric function of metal and dielectric surrounding environment.
- Among the metals that support SPR modes, noble metals (Au, Ag and Cu) exhibit resonances in the visible or near infrared region of EM spectrum.
Objectives

- To fabricate silver nano-flower using electron-beam deposition, alumina template and electrochemically deposition techniques.
- To compare the morphology performance of Ag NFs in organic solar cells for plasmonic enhancement.
- To improve efficiency of organic solar cell devices by plasmonic enhancement.
- Motivation: to produce different morphology without expensive equipment!
Plasmon resonance frequency strongly depends on geometry
The shape of the nanoparticle extinction and scattering spectra, and in particular the peak wavelength $\lambda_{\text{max}}$, depends on nanoparticle composition, size, shape, orientation and local dielectric environment.

Effect of size and shape on LS PR extinction spectrum for silver nanoprisms and nanodiscs formed by nanosphere lithography. The high-frequency signal on the spectra is an interference pattern from the reflection at the front and back surfaces of the mica.

Anker et al., Nature Mat. 2008
Light Scattering by a Sphere Particle Using Mie Theory

- Used Mie theory software to manipulate light interaction with particles at different environment

![Figure 3 Schematic diagram of the three general cases: normal incidence, p- and s-polarized incident irradiation at different angles $\theta$ with particle on substrate.]

![Figure 4. (a) Comparison of the intensity distribution in the different medium refractive index ($n$) using an input illumination of 248nm (b) Light intensity $IE^2$ distribution inside and outside 1.24µm sapphire particles in water ($n = 1.3$), $n_{\text{app}} = 1.84$.]
Experimental procedures

Fabrications was divided into two parts~

☐ Fabrications of Silver Nanoparticles/Nanoflowers
  ☐ E-beam evaporation technique
  ☐ Electrochemical deposition technique of Ag NFs

☐ Preparation of AgNFs using alumina template

☐ Fabrication of solar cell devices
Morphology of AgNFs using e-beam

TOP: FESEM images of several clusters Au NF's at the selected area with sizes and spacing stated at low-magnification shows smaller cross-section NF's as ~6 µm and

BOTTOM: FESEM images of several clusters Ag NF's at the selected area with sizes and spacing stated with smallest formation measured about 60 µm
UV-Vis

Absorption spectra in comparison (a) Au NF’s and Au NP’s and (b) Ag NF’s and Ag NP’s (inset graph is Ag NP’s in bigger view) where band for (a) is at 545 nm and (b) is at 440 nm are referred as the transverse plasmon resonance.
Absorption spectra of PEDOT: PSS/VOPcPhO: P3HT arrangement layer (black line) without Ag NFs; (red line) Ag NFs prepared at 10 mVs$^{-1}$ scan rates and (blue line) Ag NFs prepared at 1 mVs$^{-1}$ scan rate.
Photoluminescence analysis

<table>
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<tr>
<th></th>
<th>Au µF</th>
<th>Au NP</th>
<th>Ag µF</th>
<th>Ag NP</th>
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<tbody>
<tr>
<td>Peak I</td>
<td>600</td>
<td>716</td>
<td>591</td>
<td>591</td>
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<tr>
<td>Peak II</td>
<td>1159</td>
<td>16676</td>
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<td>780</td>
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<td>Wavelength (nm)</td>
<td></td>
<td></td>
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<tr>
<td>PL (max)</td>
<td>38026</td>
<td>47402</td>
<td>5341</td>
<td>7692</td>
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Photoluminescence spectrum analysis comparing Au/Ag micro-flowers and NPs
Morphology of AgNFs using electrochemical deposition

**Figure 1** FESEM images of Ag NFs (a) prepared at 1 mV\text{s}^{-1} scan rates and (b) higher magnification from (a), (c) morphology of Ag NFs at scan rate of 10 mV\text{s}^{-1} and d) higher magnification of Ag NFs of (c) 1 \text{\mu m}.
Morphology of AgNFs using electrochemical deposition

Low- and high-magnification FESEM images of the Ag NDs coated on the N-graphene modified ITO electrode after electrochemical deposition.
Organic solar cells

- Can potentially become a promising technology for harvesting of solar energy.

- Devices can be fabricated using low cost solution based processes and scalable printing techniques with low environmental impact

Efforts for achieving higher efficiencies are focused in optimizing the morphology of the active photovoltaic layer and the charge transport properties of the absorber through:

- Thermal annealing treatment
- Use of various solvents
- Use of additives
- Optimize process conditions
- Introduction of metallic nanoparticles for plasmonic enhancement of light absorption
Fabrication of Solar Cells Device

- ITO-coated glass substrate
- Spinning
- VOPc-PhO : P3HT
- PEDOT:PSS
- Anneal at 120 °C for 30 min
- Aluminium Deposition (in vacuum)
- Ag nanoparticles
- I-V Characterization
- Anneal at 120 °C for 30 min
Electrical properties of devices

- Initial results: improvement observed on $V_{oc}$, $I_{sc}$, and $P_{max}$

Without Ag nanoparticles: $V_{oc} = 0.8V$, $I_{sc} = 3.725 \times 10^{-7} A$

With Ag nanoparticles: $V_{oc} = 0.9V$, $I_{sc} = 1.625 \times 10^{-6} A$

$V_{max} = 0.25$, $J_{max} = 1.718 \times 10^{-7} mA/cm^2$

$V_{max} = 0.30$, $J_{max} = 7.035 \times 10^{-7} mA/cm^2$

Efficiency

<table>
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<tr>
<th></th>
<th>$J_{sc}$ (mA/cm$^2$)</th>
<th>$V_{oc}$ (V)</th>
<th>Fill factor</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Ag NPs</td>
<td>2.98</td>
<td>0.71</td>
<td>0.51</td>
<td>1.09</td>
</tr>
<tr>
<td>With Ag NPs</td>
<td>5.03</td>
<td>0.72</td>
<td>0.51</td>
<td>1.86</td>
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</table>
Mobility

- $\varepsilon$ is the relative permittivity of organic material with value $3$
- $\varepsilon_0$ is the permittivity of free space
- $\Theta$ is the trap factor that can be obtained from the experiment ($\Theta=J_1/J_2$)
- $\mu$ is the value charge carrier mobility across the junction device
- $d$ is the thickness of effective material between two electrodes

\[
J = \varepsilon \varepsilon_0 \Theta \mu V^2 d^3 = 0.39 \times 10^{-5} \text{cm}^2/\text{Vs}
\]

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Slope = 2.0 (SCLC)

Slope = 1.1 (Ohmic)
Scope of research

Nano particles

Increase the absorption and enhance the efficiency of organic solar cells
Results obtained by all characterization have exposed that silver nanoparticles prepared by e-beam evaporation technique have uniformity of nano-scale size distribution.

The Ag nanoparticles has been deposited and was introduced to the high potential material blend VOPcPhO:P3HT.

The presence of silver nanoparticles in the VOPcPhO:P3HT film has given very significant impacts towards its optical and electrical properties.

The size distribution and homogeneity of silver nanoparticles film produce a good trend of surface plasmon resonance behaviour of the particles.

This behaviour leads towards the improve performance of charge carrying activity of the VOPcPhO: P3HT blend system.
Thank You!!