# Au@SiO$_2$ Core-Shell Nanocubes for Plasmon-Enhancement of Dye-Sensitized Solar Cells

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## Introduction

Dye-sensitized solar cells (DSSCs) have recently been developed as an alternative to conventional silicon solar cells. DSSCs offer significant cost reductions over silicon cells, but suffer from decreased photo-conversion efficiencies that make them unviable.

However, it has been observed that efficiencies can be increased through the use of metal nanoparticles. These particles exhibit an enhanced electromagnetic field due to plasmons, which in turn enhances the absorption of dye and increases efficiencies.

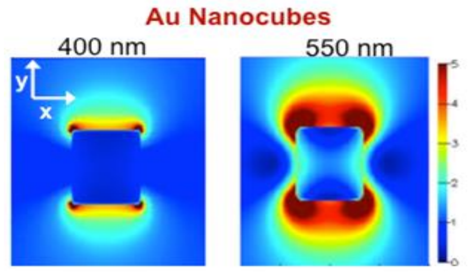



**Figure 1:** FDTD simulation of the near-field enhancement at the surface of a Au nanocube due to plasmons.

Plasmon-enhancement can be achieved through the incorporation of metal nanoparticles, such as Au@SiO$_2$ nanocubes which were used in this study.

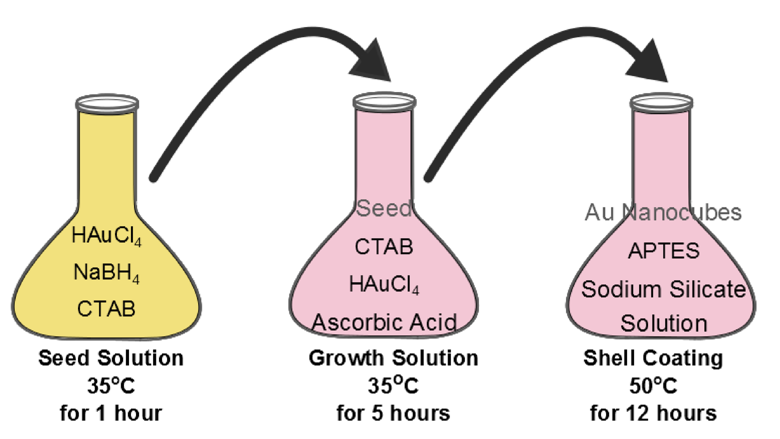
## Objectives

- Refine method for fabricating DSSCs.
- Fabricate plasmon-enhanced DSSCs using two different incorporation geometries, imbedded and top layer.
- Compare the photo conversion efficiencies of these cells with unenhanced DSSCs.

## Methods

### Synthesis of Au@SiO$_2$ Nanocubes

A three-step process with a seed-mediated growth method



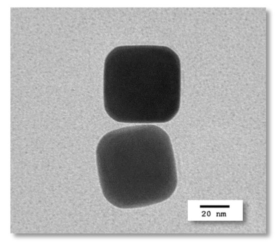



**Figure 2:** Transmission Electron Microscope (TEM) image of 50 nm gold nanocubes made from above method.

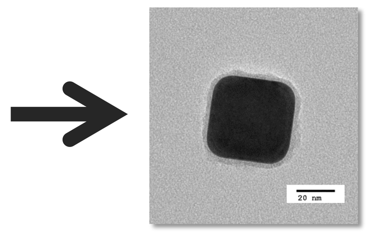
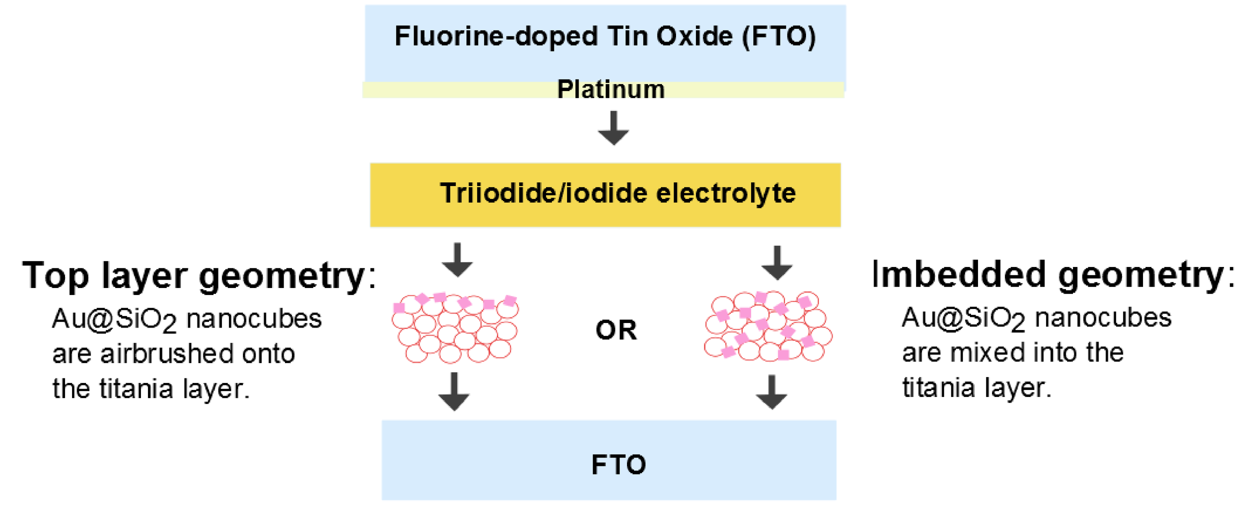


**Figure 3:** TEM image of a core-shell Au@SiO$_2$ nanocube made from above method.

In this process HAuCl$_4$ is the gold source. CTAB acts as the surfactant and shape-directing agent. NaBH$_4$ and ascorbic acid are both reducing agents.

## Methods

### Fabrication of Plasmon-Enhanced DSSCs




## Results

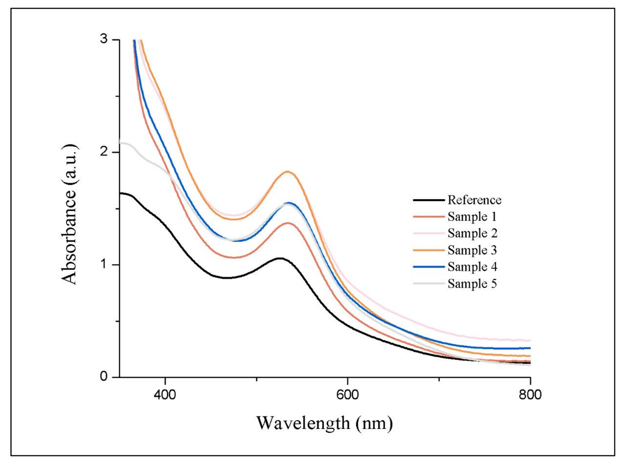



**Figure 4:** Absorbance spectra of fluorine-doped tin oxide conductive glass with the 12µm layer of TiO$_2$ after it has been soaked in dye. Compares the intensities of reference DSSCs with those of cells with imbedded and top layer geometries.

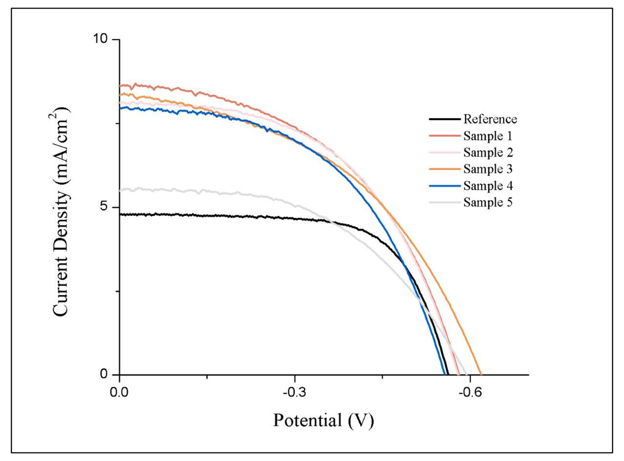



**Figure 5:** IV curves comparing imbedded geometries and top layer geometries of nanocubes with reference DSSCs

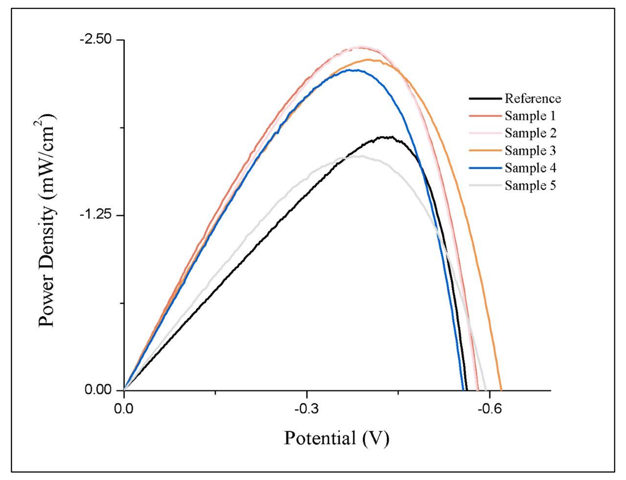



**Figure 6:** PV curves comparing imbedded geometries and top layer geometries of nanocubes with reference DSSCs

Sample 1: **Imbedded geometry** (109.9 µL nanoparticles in solution / g TiO$_2$ paste)
Sample 2: **Imbedded geometry** (164.8 µL/g)
Sample 3: **Imbedded geometry** (274.7 µL/g)
Sample 4: **Imbedded geometry** (384.6 µL/g)
Sample 5: **Top layer geometry**

Optical density of nanoparticles in solution was 58.4.

| | Short circuit current (mA/cm$^2$) | Open circuit voltage (V) | Current at max power (mA/cm$^2$) | Voltage at max power(V) | Fill Factor | Efficiency (%) |
|---|---|---|---|---|---|---|
| **Reference** | 4.781 | 0.562 | 4.288 | 0.421 | 0.671 | 1.804 |
| **Sample 1** | 8.264 | 0.580 | 6.277 | 0.389 | 0.510 | 2.441 |
| **Sample 2** | 8.345 | 0.619 | 5.792 | 0.406 | 0.456 | 2.352 |
| **Sample 3** | 7.981 | 0.556 | 5.931 | 0.382 | 0.511 | 2.264 |
| **Sample 4** | 8.492 | 0.579 | 6.222 | 0.390 | 0.494 | 2.426 |
| **Sample 5** | 5.694 | 0.604 | 4.735 | 0.394 | 0.543 | 1.866 |

### Efficiency Enhancements

| | |
|---|---|
| Sample 1 (**Imbedded geometry**) | 35.31% |
| Sample 2 (**Imbedded geometry**) | 30.38% |
| Sample 3 (**Imbedded geometry**) | 25.50% |
| Sample 4 (**Imbedded geometry**) | 34.48% |
| Sample 5 (**Top layer geometry**) | 3.44% |

## Conclusion

- Au@SiO$_2$ nanoparticles were successfully incorporated into the DSSCs.
- Photo-conversion **efficiency enhancement was seen in both geometries** of Au@SiO$_2$ nanocube incorporation.
- The largest enhancement (more than 35%) was seen in an imbedded geometry cell with the lowest concentration of incorporated nanocubes.

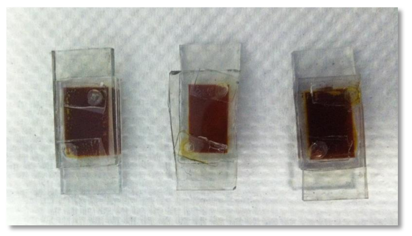


**Figure 7**: Sealed dye-sensitized solar cells ready for solar simulation testing.

- Other cells with imbedded geometries could have too many metal nanoparticles which might be causing the cell to convert energy from incident light into heat rather than the carriers that produce current.

## Future Directions

- The fabrication method has been revised to include TiCl$_4$ treatment which has improved efficiencies in reference cells and will be implemented in future work.
- When cells are treated with TiCl$_4$ before the TiO$_2$ layer is added, TiO$_2$ binds more easily to the FTO, meaning the layer is less likely to crack, which keeps the pathway open for photon-generated carriers to produce current.

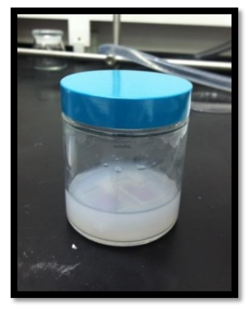


**Figure 8:** TiCl$_4$ treatment of FTO with TiO$_2$ layers before cells have been sealed.

### Preliminary results for modified method

| | Short circuit current (mA/cm$^2$) | Open circuit voltage (V) | Current at max power (mA/cm$^2$) | Voltage at max power(V) | Fill Factor | Efficiency (%) |
|---|---|---|---|---|---|---|
| TiCl$_4$ Treated | 10.109 | 0.549 | 7.754 | 0.374 | 0.524 | 2.903 |
| Not TiCl$_4$ Treated | 4.777 | 0.561 | 4.264 | 0.422 | 0.671 | 1.799 |

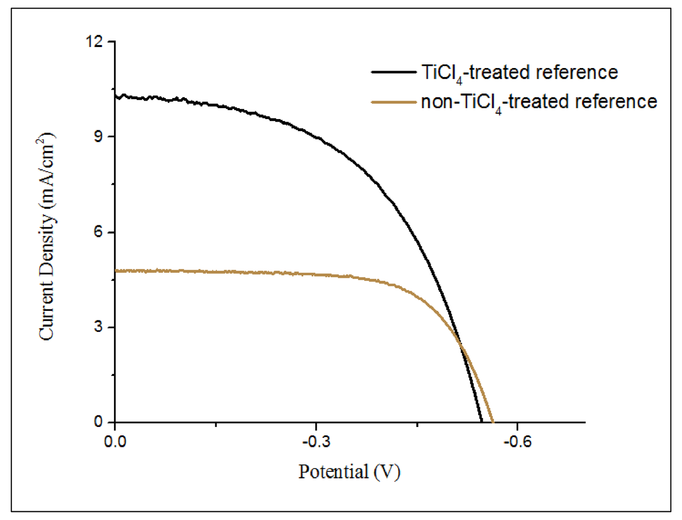



**Figure 9**: IV curves comparing TiCl$_4$ reference cells to those that have not undergone the same treatment.

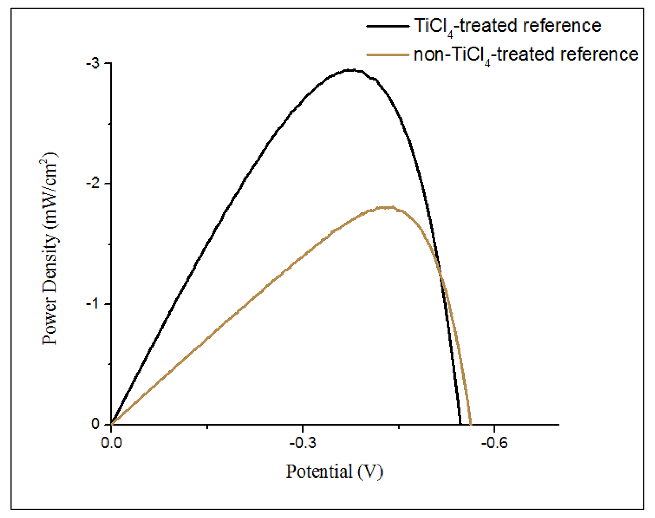



**Figure 10**: PV curves comparing TiCl$_4$ reference cells to those that have not undergone the same treatment.

## Acknowledgements/References

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