Enhanced optical absorption in ultrathin PV absorbers via embedded metal nanopatterns

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Introduction

Compared to conventional crystalline solar cells, thin film cells use less material and can be made on flexible substrates, allowing for potential cost savings, among other benefits. However, they typically suffer from poorer performance than crystalline cells. A key limiting factor of conventional thin films is that the optical absorption length is typically much greater than the minority carrier diffusion lengths — the **thick-thin compromise**:

Conventional thin films

- High absorption of light
- Reduced charge extraction

Ultrathin films

- Poor absorption
- High charge carrier extraction
- Lower material use
- Potential for hot carrier enhanced solar cells[1-3]

Aim

The goal of this work is to **solve the thick-thin compromise** by using a light management scheme[4-6] of embedded metal nanopatterns (EMN) into ultrathin films of cadmium telluride (CdTe) and amorphous silicon (a-Si).

For each case, the absorption enhancement can be attributed to plasmonic, waveguide, cavity, scattering, etc. effects. Calculation and simulation help elucidate the contributions of each effect.

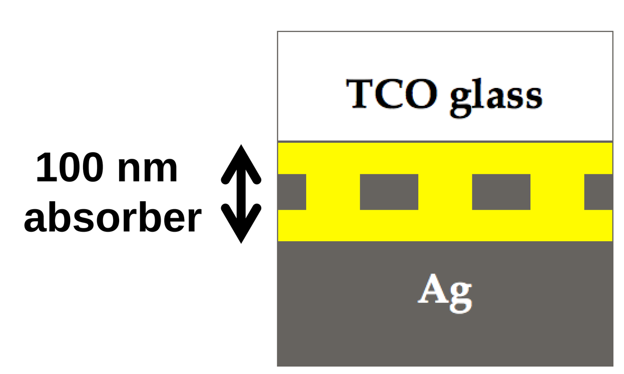
Further, we use a scalable production technique — nanosphere lithography (NSL) — to produce the nanopatterns.

Fan Ye showed that the maximum absorption enhancement was obtained when the position of a cross metamaterial in a-Si was embedded[7] and that this concept should be generalizable[8].

Methods

Fabrication: CdTe device

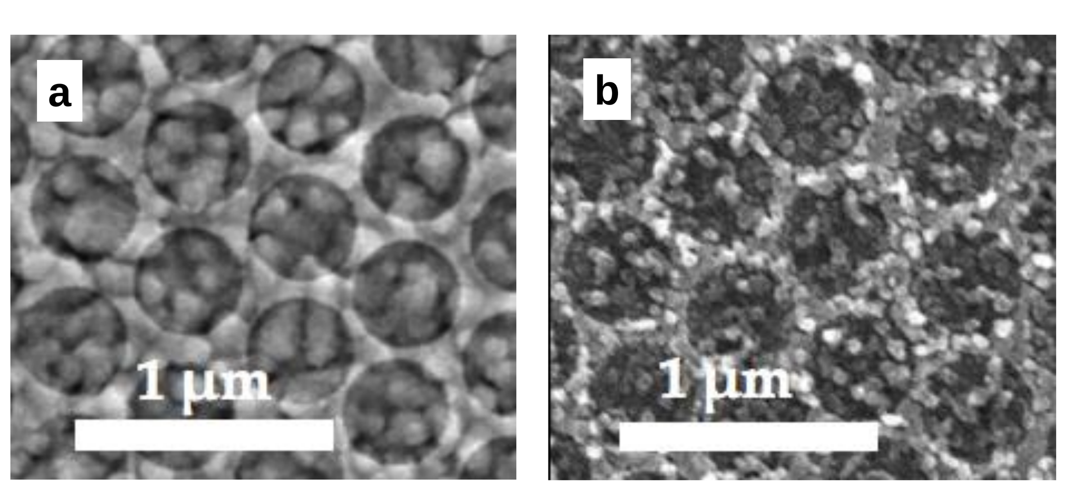
- 50 nm x 2 CdTe depositions by RF magnetron sputtering (U. Toledo)
- 30 nm thick Ag hole pattern (500 nm pitch) via nanosphere lithography w/ e-beam evaporation
- 200 nm Ag back reflector via e-beam evaporation



Cross section of proposed device. CdTe: TCO is fluorine doped tin oxide (FTO) on glass (TEC-15). a-Si: TCO is commercial indium doped tin oxide (ITO) coated glass.

Fabrication: a-Si device

- 20 nm + 80 nm a-Si by PECVD
- 20 nm Ag hole pattern
- 250 nm Ag back reflector



SEMS of devices after 1st absorber depostion and NSL Ag pattern. (a) CdTe, (b) a-Si.

Other Techniques

- Integrating sphere for reflection measurements
- AFM to characterize surface morphology of films
- Ellipsometry to calculate dielectric functions and thicknesses of a-Si device films

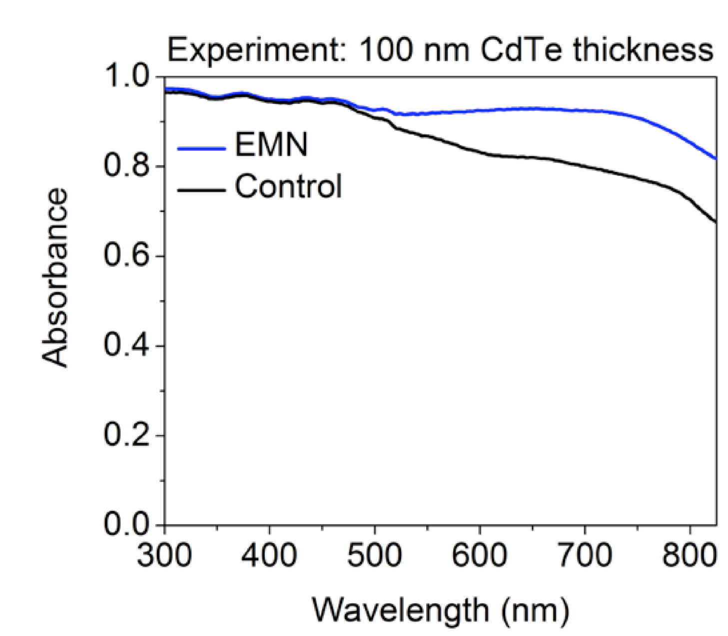
Results

CdTe

Experiment

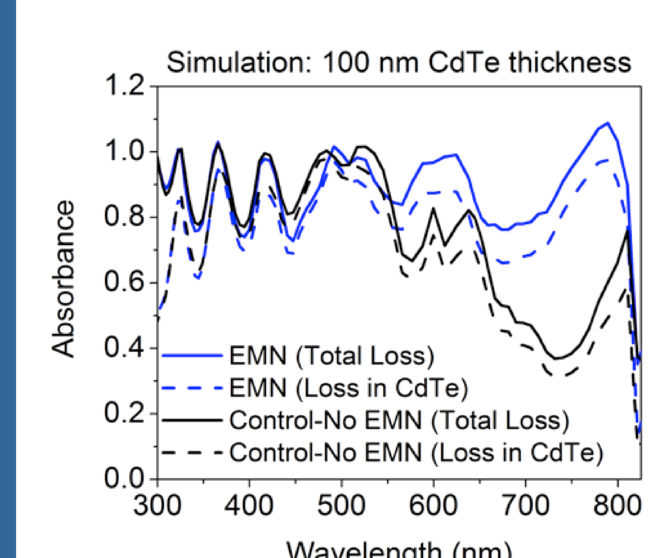
- 8% enhancement (300-825 nm)
- 16% enhancement at band edge
- **93% average absorbance** vs. 86% for control
- **20x less material** than conventional cell

Large enhancement in absorbance at the band edge. Similar absorbance to conventional 2-8µm thick CdTe solar cells. Enhancement decreases to 2% for 150 nm thick devices.



Simulation

- Performed with COMSOL
- Literature values of complex dielectric functions[9,10]
- **Most loss occurs in CdTe, not Ag**
- Rough agreement w/ exp. due to textured FTO and defects



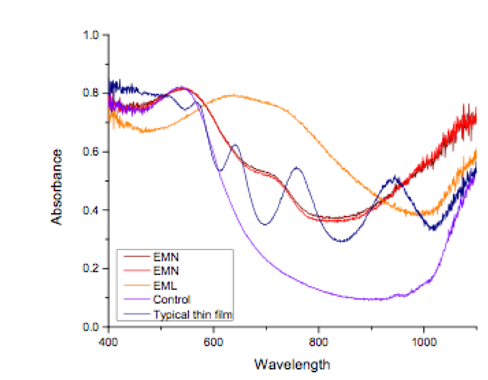
Simulation is used to show that the absorbance enhancement seen in experimental samples likely occurs in the semiconductor, not the metal, and thus should lead to an increase in EQE in an active solar cell.

a-Si

Experiment

- **11% enhancement** (300-689 nm), assuming band gap of 1.8 eV
- 3% enhancement over conventional control (500 nm)

Absorbance of 2 EMN ultrathin films samples, control ultrathin film, conventional thin film, and a sample with an embedded metal thin film without nanopatterning. There is high enhancement at longer wavelengths, suggesting that tuning the bandgap to lower values by switching to nc-Si or µc-Si may be beneficial.



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