Application of Electromagnetic Full-wave Modeling for Porous Silicon Photovoltaic Devices

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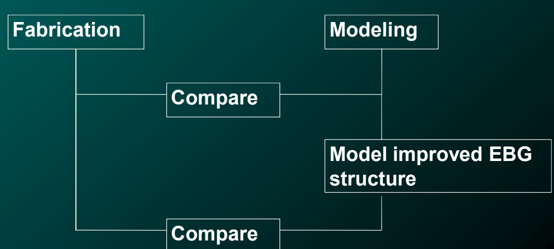
Introduction

- The purpose of this work is to model and fabricate nano-structured porous silicon for efficient solar cell devices. Full-wave electro magnetic modeling is being used to advise and direct the fabrication of the silicon nanostructures through photo-chemical etch processing. The modeling allows us to evaluate the power that is collected or re-reflected from the porous Si and use this information to design more efficient devices.

Methodology

- The porous silicon takes the form of an electronic band-gap (EBG) structure. The etched Si structure is modeled in Ansoft HFSS. The same structure is fabricated in the laboratory and measured. The results are compared.
- The modeling goal is to develop a robust, frequency-scalable model that will be used to compare different pore size, period, and Si geometry for etched porous silicon.
- The effects of surface topography and material dielectric properties are evaluated in an effort to tune the material bandgap and, thus, improve the efficiency of the solar cell.



- The figure to the right is a porous silicon etching from reference [1] that the modeling aims to replicate in order to validate the model.

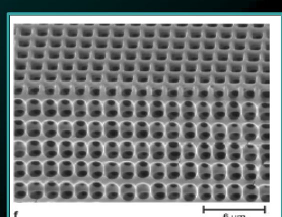


Fig 1. Etched porous Si [1]

Modeling Porous Si

- Porous silicon was modeled following [1] using 1 μm circular pores spaced 1.5 μm apart in silicon with a relative dielectric constant of 11.9. Unpolarized light was incident from 700 – 5600 GHz. With frequency scaling, this models a free-space wavelength of about 3 – 13 μm.

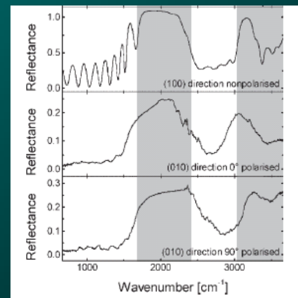


Fig 2. Reflectance of etched Si from [1]

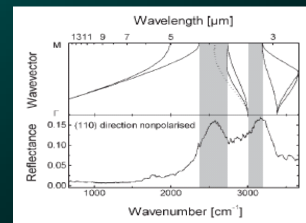
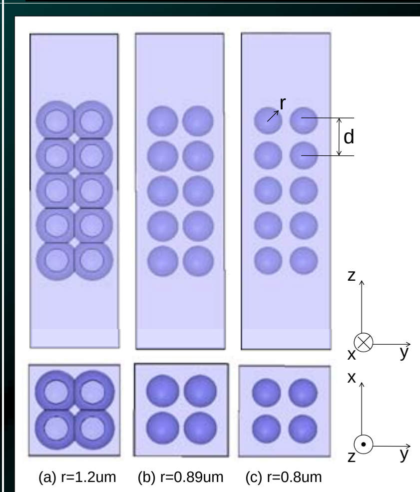


Fig 3. Reflectance of etched Si from [1]

Validation &Tunable band gap



- The porous silicon is modeled as silicon dielectric with air spheres, as shown in Fig 4, which is infinitely periodic along the x and y axes. Five periods along z axis are simulated in the models. The energy excites along z axis. d=2um.

Fig 4. The models in the HFSS for different r

- The simulation results indicates, as shown in Fig 5, that the resonance shifts to higher frequency with decreasing air sphere radius.

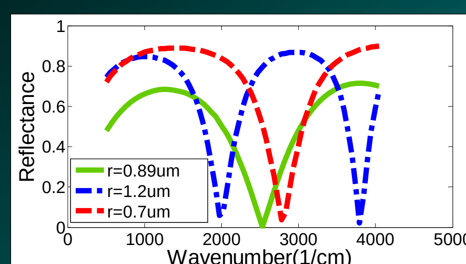


Fig 5. The simulation results for different r

Photochemical Materials Processing

- Modeled structures are fabricated by photoassisted micropourous silicon etching [3].
- Process utilizes a combination of applied anodic bias potential and backside illumination during chemical etching.
- Modulation of illumination parameters enables manipulation of pore size and structure.

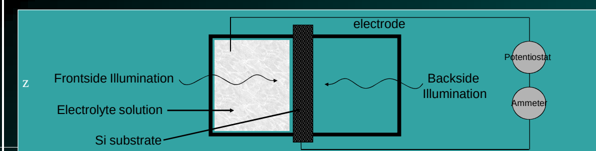


Fig 6. Fabrication process schematic

Device Performance Testing

- Optical, electrical and microstructural analysis of films and devices.
- Surface microscopy of fabricated structures provide feedback to modeling variables.
- I-V characterization of fabricated nanostructured Si devices.

Fig 7. I-V characterization

Conclusions

- Model yields strong agreement with experimental results from ref. 1, supporting validation of the model approach.
- Modeling shows the potential for the fabrication of tunable bandgap structure through engineered control of Si nanostructure (pore size, diameter, loss, etc.).
- Laboratory completed for fabrication and characterization of porous silicon nanostructures.

References:

[1] Matthias, S., Muller, F., Jamios, C., Wehrspohn, Ralf, and Gosele, U. "Large-area three-dimensional structuring by electrochemical etching and lithography." Advanced Materials ,Volume 16 No. 23- 24, Page(s):2166-2170, Dec. 2004.
[2] Weily, A.R.; Horvath, L.; Esselle, K.P.; Sanders, B.C.; Bird, T.S., "A planar resonator antenna based on a woodpile EBG material" IEEE Transactions on Antennas and Propagation, Volume 53, Issue 1, Part 1,, Page(s):216 – 223, Jan. 2005.
[3] Lehmann, V. and Foll, H., "Formation mechanism and properties of electrochemically etched trenches in n-type silicon." J. Electrochem Soc. , Volume 137, No. 2, Page(s):653-659, Feb. 1990.
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