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

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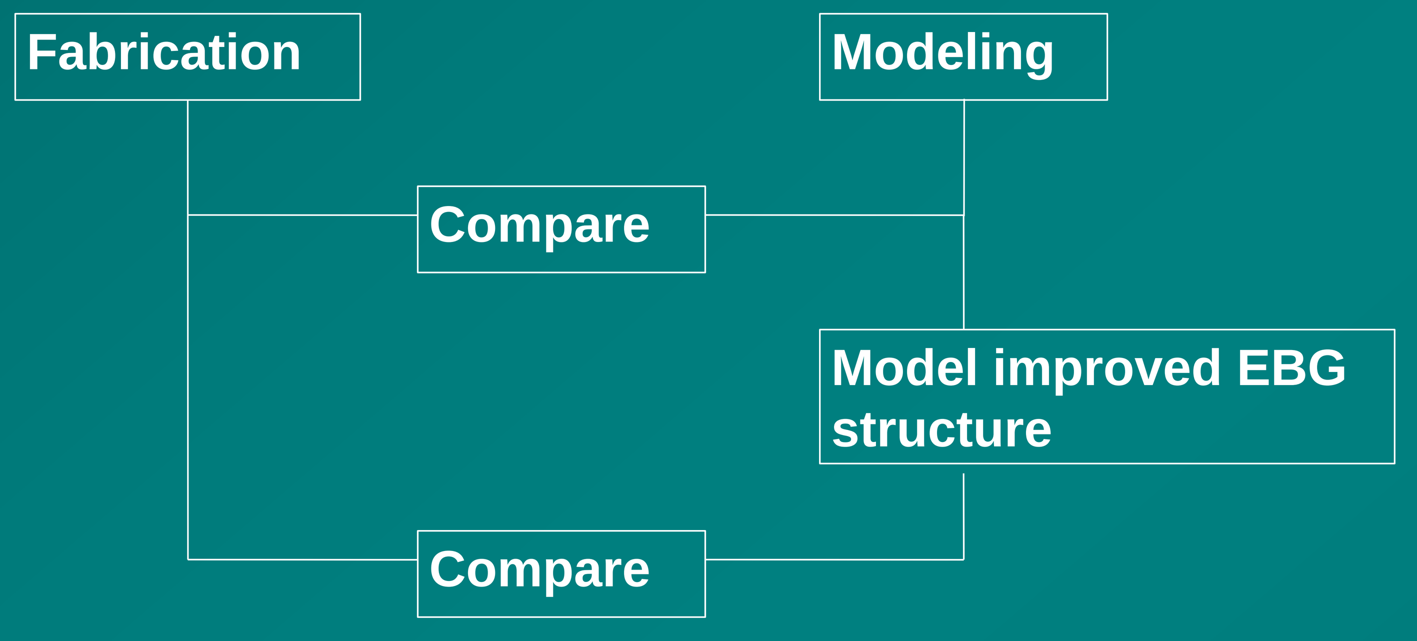
Introduction

- The purpose of this work is to model and measure the absorption and bandgap characteristics of porous Si in a single-junction solar cell, where the porous Si provides the p-type component of the p-n junction. Single-junction Si-based photovoltaic devices have the potential to achieve 30% efficiency, but the best commercially available devices only operate at ~ 17 – 19% efficiency. This is caused by poor absorption of light and photogeneration of electrons away from the junction.
- Full-wave electromagnetic modeling will be used to characterize the performance of the porous Si with regularly spaced antennae. The modeling will allow us to evaluate the power that is collected or re-reflected from the porous Si and use this information to design a more efficient substrate.

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 taper size for etched porous silicon.
- Use model to change pore size, period, and taper.
- Widen bandgap and thus improve efficiency of solar cell.



- This is the porous silicon etching from reference [1] that this project aims to replicate.

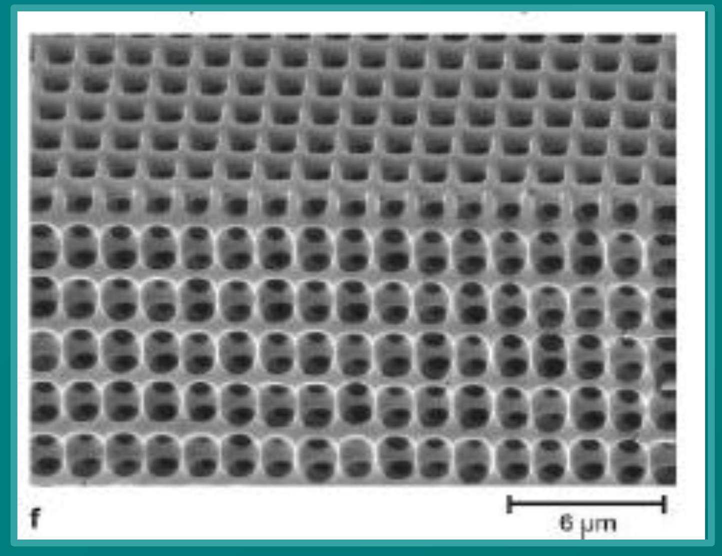


Fig 1. Etched porous Si [1]

Modeling Test Case

- To ensure the most accurate EBG model possible, first a test case is chosen and simulated. Here we use the woodpile planar antenna structure from Weily et al. [2]. The woodpile is a 3-D EBG structure consisting of alternating lengthwise and crosswise alumina rods. The periodic nature of this structure makes it a reasonable stand-in for the porous silicon.

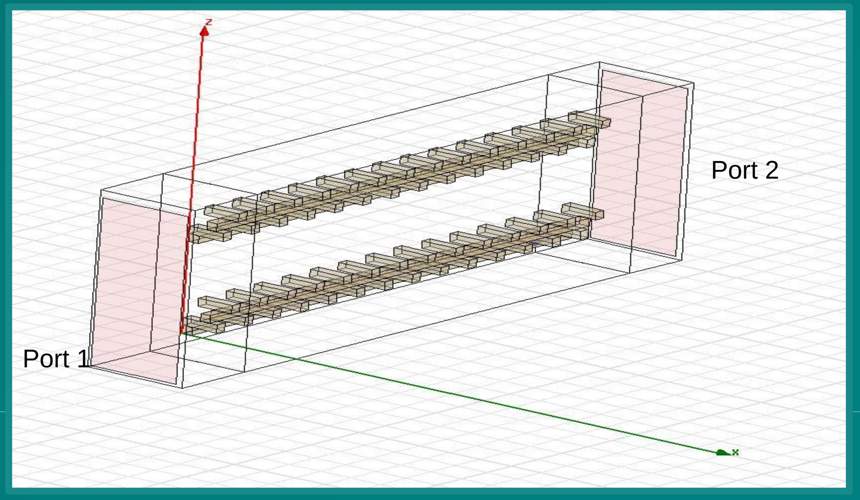


Fig 2. Woodpile 3-D view

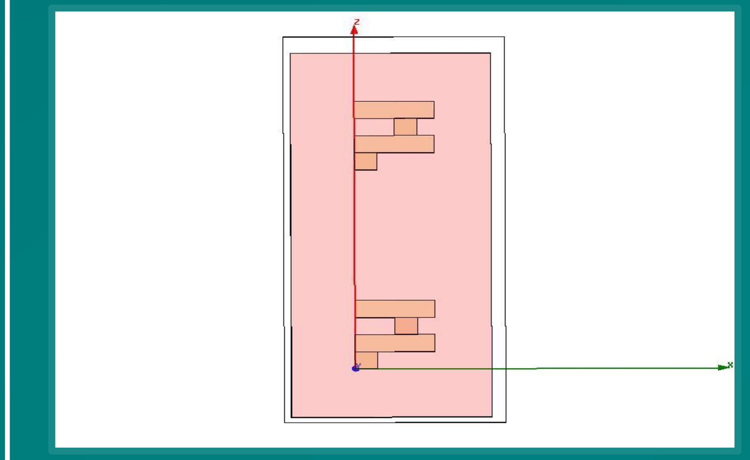


Fig 3. Woodpile end view

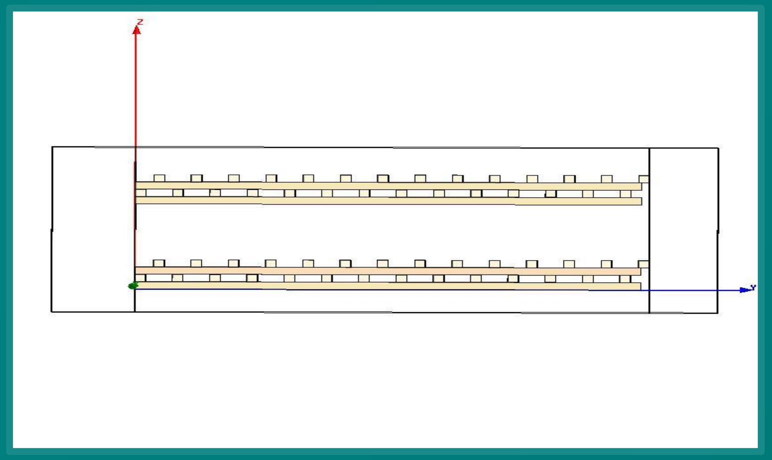


Fig 4. Woodpile side view

- The modeling goal is to develop a *robust, frequency-scalable model* that will be used to compare different pore size, period, and taper size for etched porous silicon.

Modeling Results

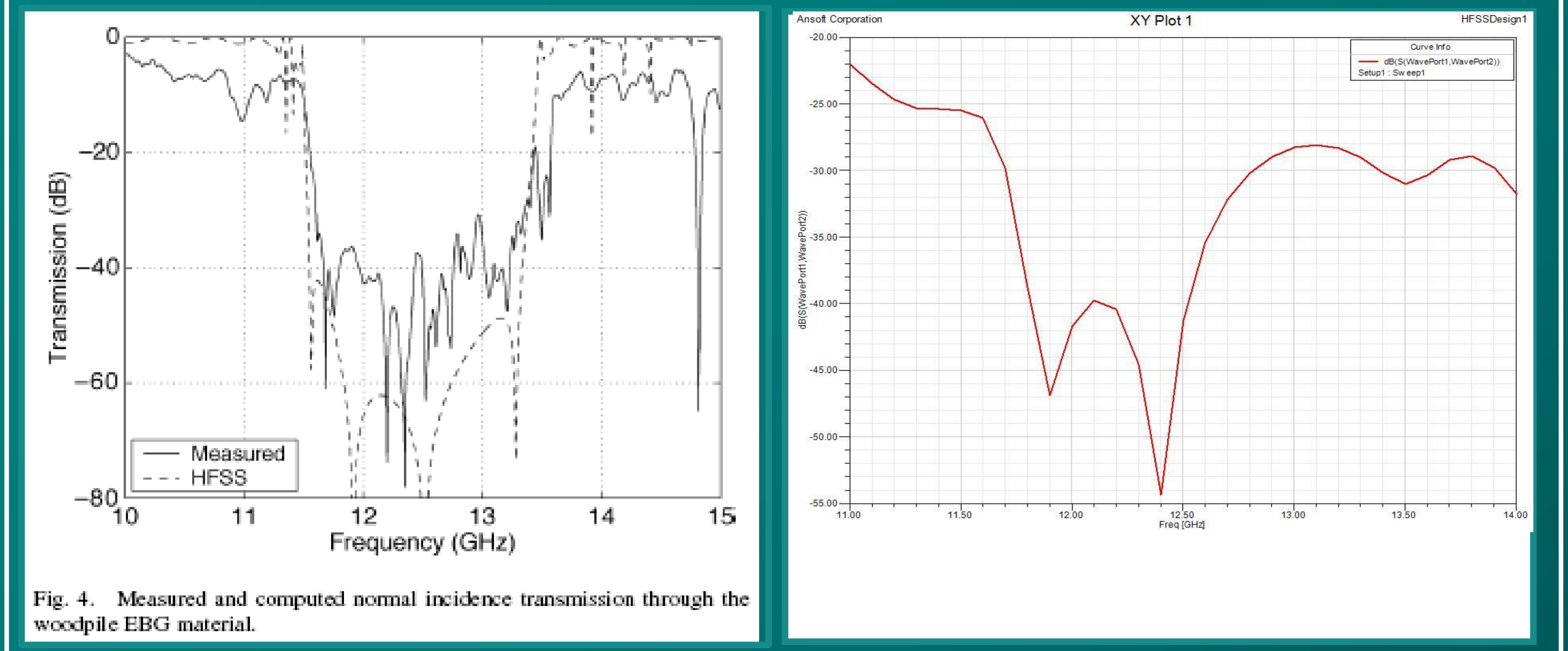


Fig 5. Measured results for woodpile resonator (left) [2]; result of HFSS model of same structure (right).

- The model closely follows the original results, particularly in the critical aspect of determining the edges of the band-gap!!

- One advantage of the HFSS software tool is the ability to plot the electromagnetic modes. Figure 6 shows the propagation mode at 11 GHz (outside the stopband) and at 12 GHz (within the stopband). Inside the stopband, the EBG structure refracts the energy out of the resonator cavity.

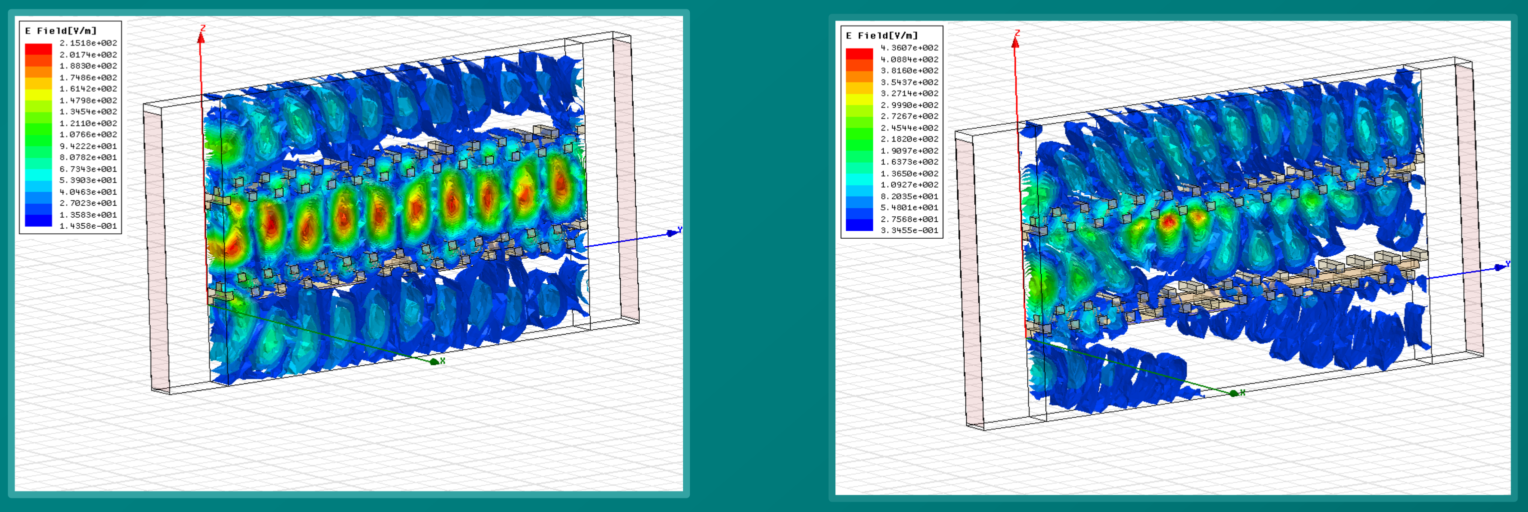


Fig 6. Electric field distribution at 11 GHz (left) and 12.5 GHz (right)

Photochemical Materials Processing

- Modeled structures 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.

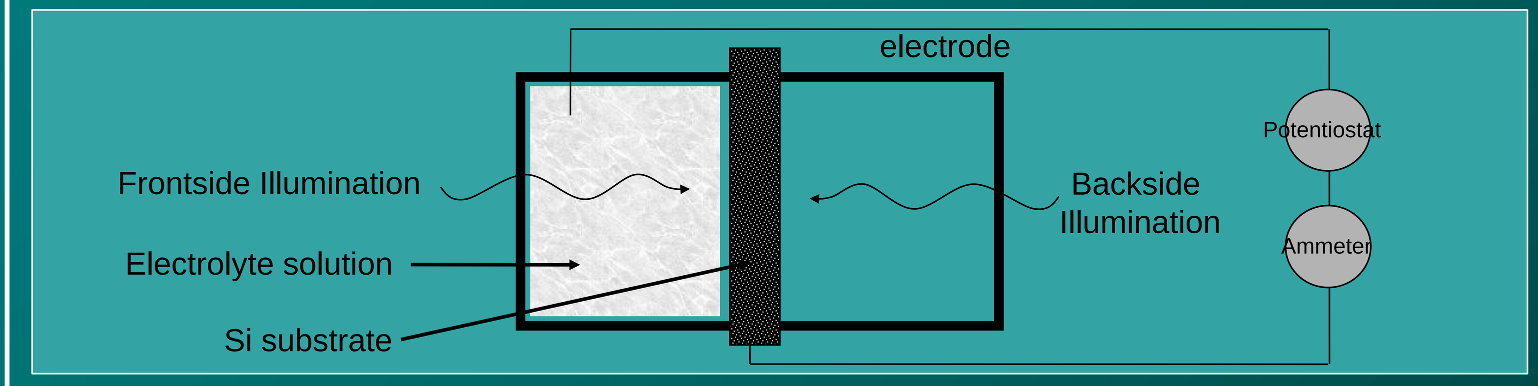


Fig 7. Fabrication process schematic

Conclusions

- Full-wave electromagnetic modeling has the potential to be a useful tool for efficient solar cell design. Altering the design of porous Si can save time and cost in fabrication.

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 onAntennas 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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