Design and Fabrication of an In-Plane Nano structured Solar Concentrator

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The need for space and cost-efficient solar energy is growing as the challenges of mass deployment photovoltaic (PV) cells become apparent. They are costly in assembly and require a large amount of surface area to obtain sufficient power output. As a result, there is a need for a solar concentrator that can take advantage of pre-existing space as well as reduce the amount of PV cells used. The concept of a solar concentrator, an optical device that channels sunlight from a large area to be gathered by a small area, is broad and can be implemented in multiple approaches. One common approach involves reflecting sunlight from parabolic mirrors onto a central tower. This energy received is in the form of heat and is used to operate a steam turbine [1]. Another approach uses transmission Fresnel lenses [2] or holographic elements [3] to concentrate sunlight. Luminescent solar concentrator (LSC) is also an effective approach and uses total internal reflection (TIR) in combination with an organic dye to channel fluorescent light to the edge of glass where a PV cell receives it [4]. While these innovative methods are promising, they cannot be readily integrated into existing infrastructures.

Here we propose the use of a nanostructured surface to diffract out-of-plane sunlight and channel light in-plane to the edge of a glass window. On the glass edge, a thin PV cell is placed to harness and convert this energy into electric current (Figure 1), resulting in a solar energy harvester. The nanostructure itself also has antireflection effects to increase efficiency, and ismade from pillars of a polymer (NOA) with an index of refraction of 1.56, which was selected due to its similarity to glass. This is important so as to allow the glass to remain transparent while also diffracting a small portion of the light that passes through. The fabrication is illustrated in Figure 2, where interference lithography is used to pattern a 2D structure array in photo-resist on silicon. This pattern is then transferred to holes in the Polydimethylsiloxane (PDMS) using soft lithography. These holes are then transferred back to NOA nanopillars directly on a glass window. The NOA is then cured and the PDMS is removed, leaving NOA nano-pillars and a thin layer of NOA residing on top of the glass window. The geometry of the height and period of the pillars can be designed to be efficient for different wavelengths.

The initial optical trapping efficiency as a function of angle is shown in Figure 3(b), where the overall is found experimentally to peak around 0.4%. This is supported by optical simulation using rigorous coupled-wave analysis, which shows that the device efficiency can be controlled by modifying the structure geometry. Initial simulations show that taller pillars result in a more intense diffracted order, but that shorter pillars result in more trapping efficiency. This means that for different window sizes, different structure patterns might be the most effective, and will be analyzed in detail. To test electrical performance, a thin solar cell is adhered to the glass edge and copper wires with conductive silver epoxy are cured to each terminal as shown in figure 3(a). Initial measurements show current in the 10 µA range when looking at a small surface area. We will present the optical design, structure fabrication, and the device characterization of this in-plane solar concentrator. When completely optimized, this concentrator could be put to use on office windows without taking away the transparency properties needed. The glass would be able to harvest some energy from the sunlight, while still allowing enough light to use as a typical window.

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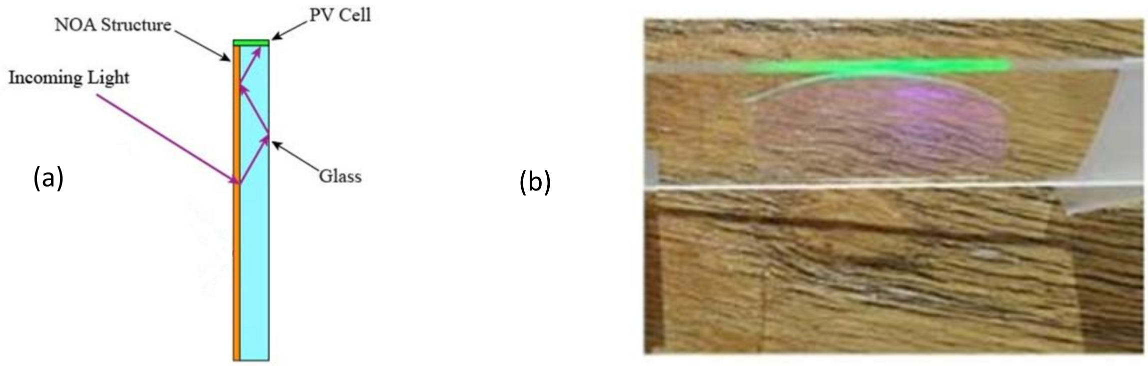

Figure 1. (a) Glass with NOA structure showing trapping of green light (b) Packaged sample with PV cell on edge of light trapping

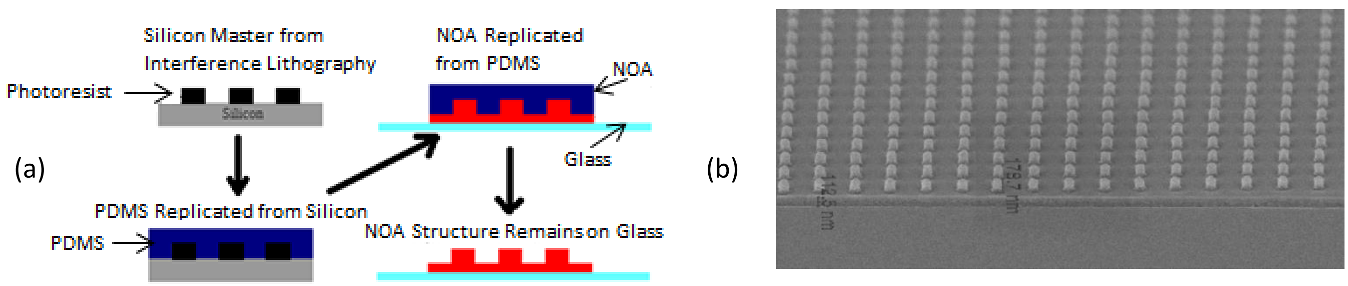

Figure 2. (a) Replication Process from Silicon Master to NOA pillars (b) Silicon Master from Interference Lithography 324nm period

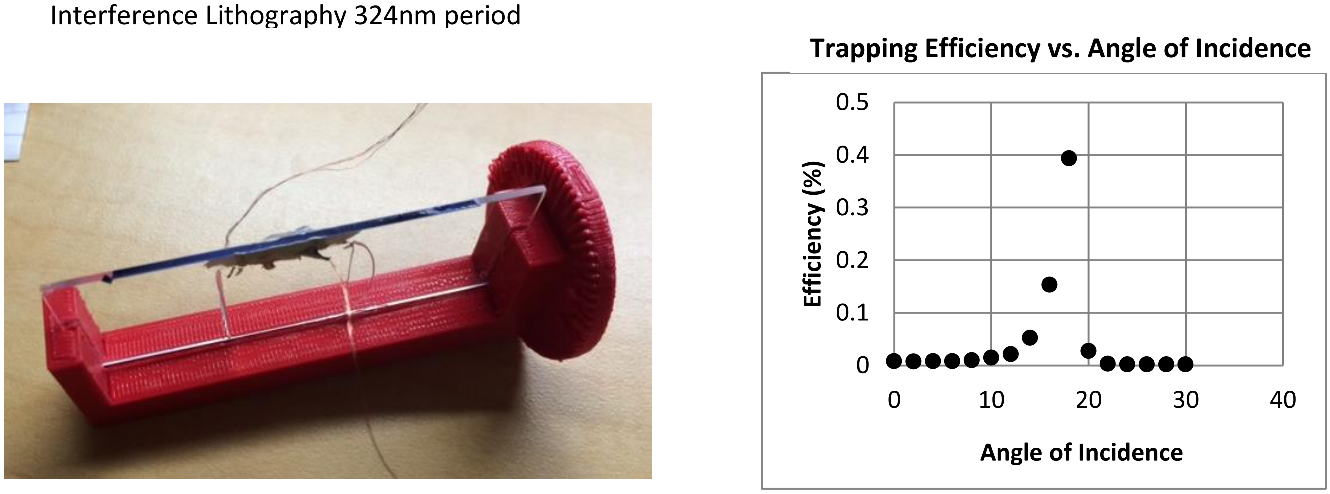

Figure 3. (a) Completely Packaged Sample ready for electrical testing. A thin PV cell resides with silver epoxy cured to the terminals on each side. Copper wires extend from the epoxy to output this current. (b) Experimental graph showing trapping efficiency as a function of incidence angle.

REFERENCES

[1] Buck R. Brauning, *et al., Journal of Solar Energy Engineering* **124**, 2-9 (2001).

[2] Xie, W. T., *et al., Renewable and Sustainable Energy Reviews* **15**, 2588-2606 (2011).

[3] Mohammad, *Nabil, et al., Optics Express* **22**, A1519-A1525 (2014)

[4] Peter S. Friedman, *Optical Engineering*, **20**, 887-892 (1981).