Quantum Dot Enhanced Rugate Filtering and Light Trapping

S. Shepard[*] and J. Copeland[**]

[*]Louisiana Tech University, Department of Electrical Engineering,
Ruston, LA, USA, sshepard@latech.edu
[**]CenturyLink, Monroe, LA, USA, josh.copeland@centurylink.com

ABSTRACT

Resonances of electromagnetically coupled nanoparticles can emulate the interferences of standard filter technologies and result in superior light-trapping capabilities. We also incorporate the nonlinear behavior that coupled-mode systems can exhibit, even at low intensities, and exploit this to enhance light-trapping and increase photovoltaic efficiency.

Keywords: optical filtering, light-trapping, solar energy

1 INTRODUCTION

All interference notch filters "blue-shift" to shorter wavelengths with increasing angles of incidence (since the distance between Bragg planes becomes less). Rugate filters [1] use an exponential sinusoidal index profile, which is also multiplied by a window function to further reduce side lobes. These have negligible harmonics and typically utilize low index materials resulting in greater angle sensitivity. In light-trapping for concentrated photovoltaic applications [2] the blue-shift can be utilized to our advantage as follows. Since the incident sunlight has already been focused by the collection optics our filter need not have a broad angular field of view. After any light not absorbed in the photovoltaic (PV) is scattered by the back surface (or elsewhere in the PV) most of it will attempt to exit the filter from a larger angle of incidence. Thus, a notch that blocks any below bandgap (hence useless) radiation incident on the PV; becomes a notch that has been blue-shifted to trap the desired frequencies and prevent them from exiting the PV. A limitation of the standard implementations however is that they all require thicker structures to provide more complex filters and this can diminish the transmission of the desired wavelengths.

2 A NOVEL LIGHT TRAPPING FILTER

We explore the possibility of circumventing these limitations by utilizing a transverse array (instead of several layers) of nanoparticles of various size and shape – deposited on (and/or etched into) a glass cover on top of a PV in just a few very thin (down to 100nm) layers. Although discrete (conducting or non-conducting) circles or squares etc., these quantum dots are small with respect to the incident wavelength – thus they produce a continuous (rather than discrete) variation of the effective index of refraction. This continuous variation; in conjunction with their ease of controlled deposition and their small size; make them ideal candidates for the fabrication of next generation Rugate filters. As depicted in figures 1 and 2 (where the top layer is air, the second layer is glass and the bottom layer is silicon) we observe useful light trapping. In figure 1: we launch a plane wave from the left into the glass slab and we observe the plasmonic resonant effect of routing the energy into the absorbing silicon.

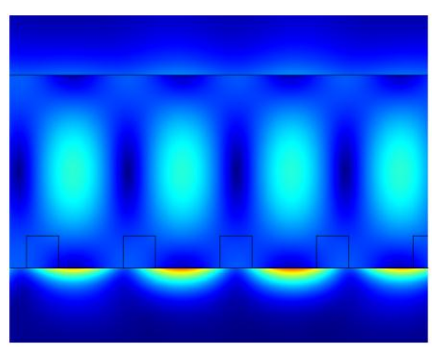

Figure 1. Conductive Nanoparticle Trap

In figure 2: we launch a plane wave from the top and dipoles induced within the dielectric circles routes the energy between them to better penetrate into the silicon. The fact that this can happen with non-conductive dots is important since it eliminates the ohmic losses incurred in conventional plasmonics.

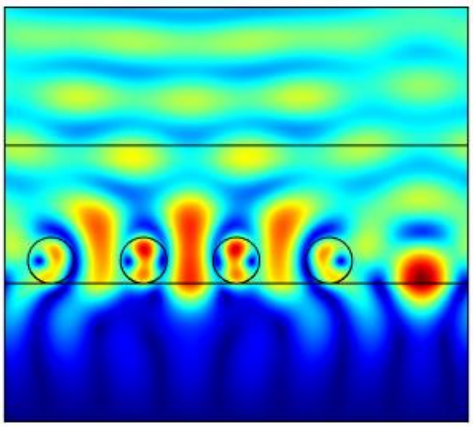

Figure 2. Non-Conductive Nanoparticle Trap

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[2] S. Fahr, et al., “Rugate Filter for Light-Trapping in Solar Cells,” Optics Express, Vol. 16, No. 13 (2008).