Simulation Standard

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Third Generation Solar Cell Technologies: Localized Surface Plasmons

Solar cells are experiencing a surge in activity due to concerns about sustainability of non-renewable resources and the negative impacts of global warming due to human activity.

In order to be competitive with other energy sources, developers of solar cells see an impetus to both increase efficiencies and reduce costs. Much work has recently gone into the development of the so called second generation technologies. These technologies focus on reduced production costs mainly by relying on thin film materials such as amorphous silicon and CIGS.

Emerging third generation technologies are targeting improving the efficiencies of first and second generation cells while maintaining relatively low cost.

In this article we discuss how the ATLAS simulation framework can be used to model one important third generation technology. We will demonstrate the modeling and optimization of localized surface plasmons which are used to improve the coupling of light into the solar cell.

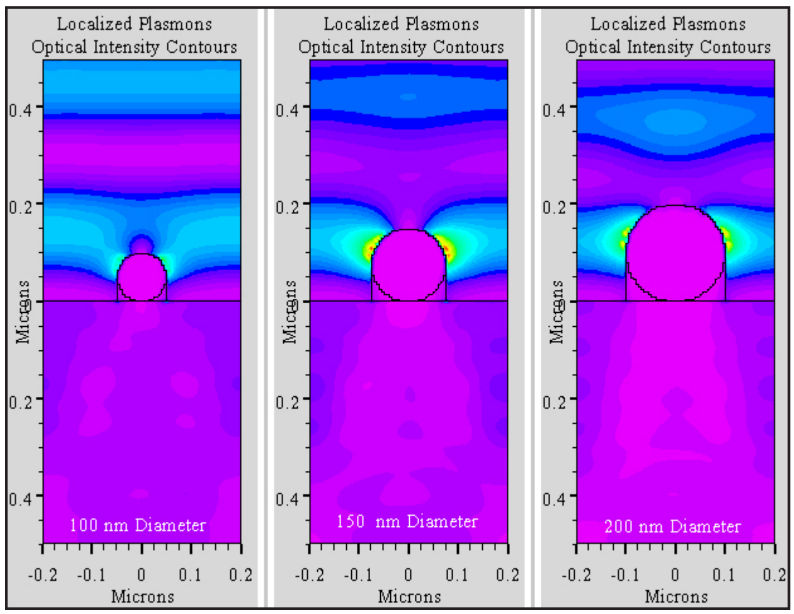

Figure 1: Optical Intensity Contours for Three Sizes of Nano-particle.

Localized surface plasmon resonance is produced by metal nano-particles on the top surface of the solar cell. Such particles can be introduced easily and cheaply onto existing structures and can greatly reduce the surface reflectivity of the otherwise untreated devices.

Due to the electromagnetic nature of the localized plasmon coupling, the Finite Difference Time Domain (FDTD) models included in the Luminous2D and Luminous3D optoelectronic simulators in the ATLAS framework are ideally suited for analysis of this phenomenon in two and three dimensions.

For demonstration purposes we will look at the reflection coefficient of a plane silicon surface as a function of wavelength with various sizes, densities and materials composition of surface nano-particles. These particles are easily introduced into the FDTD simulation domain using the built-in lenslet capability already supported by the simulators. By placing a positive and negative spherical lenslets on top of each other with the proper characteristics one can easily define a spherical metal nano-particle.

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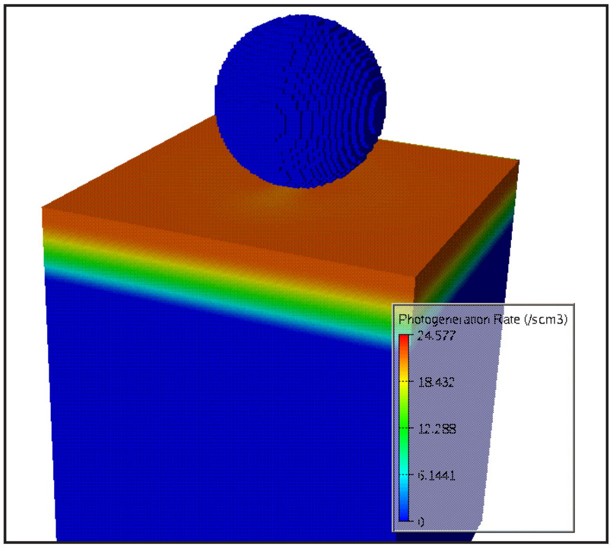

Figure 2: Three Dimensional Photogeneration Rate Under an Example Nano-particle.

By taking advantage of periodic boundary conditions you can model a periodic array of such particles. By varying the diameter and spacing you can easily analyze the effects of size and density of such particles.

Figure 1 shows a light intensity contour plots for three particle sizes. These contour plots were produced by 2D FDTD simulation of a normal incident monochromatic source. By summing the incident intensity in the top and bottom perfectly matched boundaries we calculate the reflection coefficient.

As shown in Figure 2 we can do similar analysis in 3 dimensions. Here we show the photogeneration rate contours under an example nano-particle.

In Figure 3, we show a comparison of various spectral reflectivities of surfaces with various particle sizes. These are compared to the reflectivity of a bare surface. Here we see an improvement with nano-particle surface plasmons over the bare surface response. Further, we see that for this example we can optimize the particle diameter for the best collection of the solar spectrum.

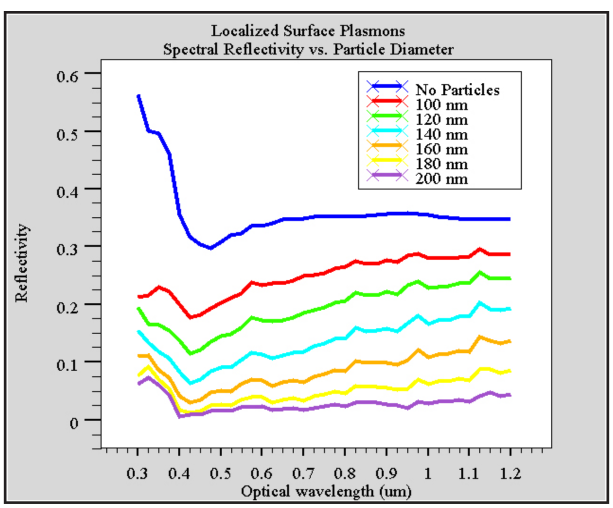

Figure 3: Comparison of Spectral Reflectivity vs. Nano-particle Diameter.

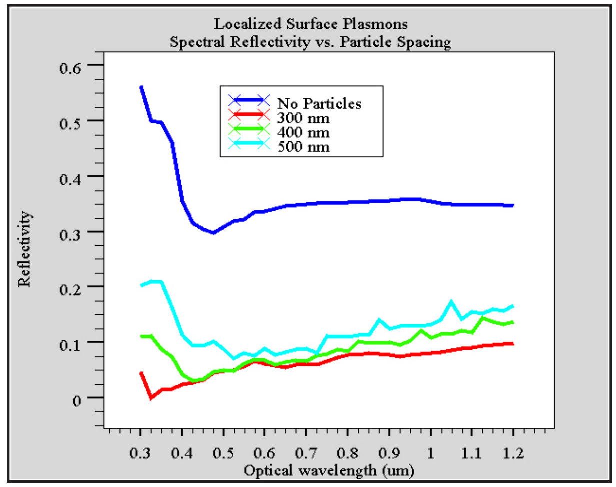

Figure 4: Comparison of Spectral Reflectivity vs. Nano-particle Spacing.

In Figure 4, we compare spectral reflectivity for three different particle spacings against the reflectivity of a bare surface. The spacings are given by the width of the simulation domain. The periodic boundary conditions allow simplified analysis.

Finally, in Figure 5 we show the simulated results for four examples materials. The materials are characterized by a complex index of refraction as a function of wavelength.

Conclusion

We have shown that analysis of localized surface plasmons is supported by the ATLAS, Luminous2D and Luminous3D simulators. This capability supports analysis of particle size and density effects. Analysis of particle shape and composition is also supported.

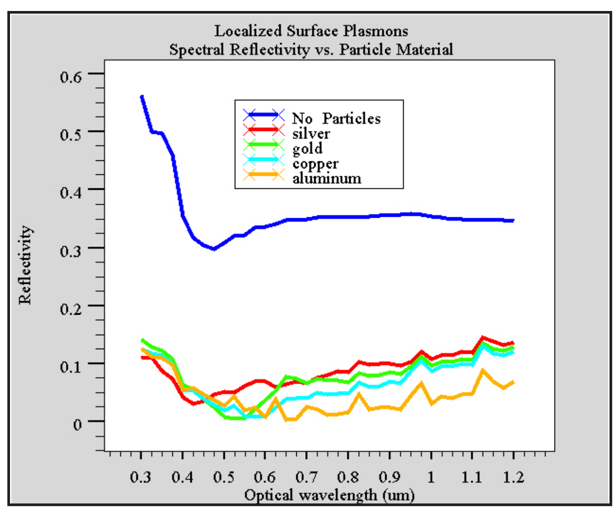

Figure 5: Comparison of spectral Reflectivity vs. Particle Composition.