Simulating Specular Reflectance in Solar Cleaning Films using the Particle Tracing Module of the COMSOL Multiphysics® Software and LiveLink™ for MATLAB®

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INTRODUCTION: One of the obstacles facing the growth of solar power is the energy loss caused by natural dust accumulation on the surfaces of solar collection systems. [1] The electrodynamic screen film (EDS) is a dust removal technology which cleans these solar collector devices through the electrostatic charging of dust particles using electrodes printed onto the optical surface.[2] The device design is an optimization problem between dust removal efficiency and optical efficiency. Therefore, a model was developed to evaluate EDS optical efficiency before the manufacturing stage, decreasing both the time and money spent on design optimization, and eliminating variance in the data that arises due to manufacturing errors. To evaluate optical efficiency, the model computes specular reflectance (SR) measurements. SR is simply the percentage of light intensity that reaches a photodetector after interacting with the EDS/mirror system.

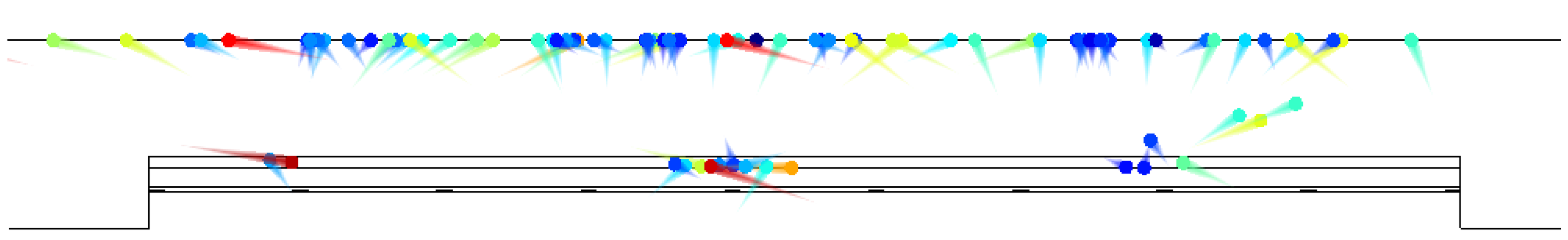

Figure 1. Particle Trajectories 0.2s after EDS activation. Electric fields charge the dust and generate a repulsion force, which propels the dust from the surface.

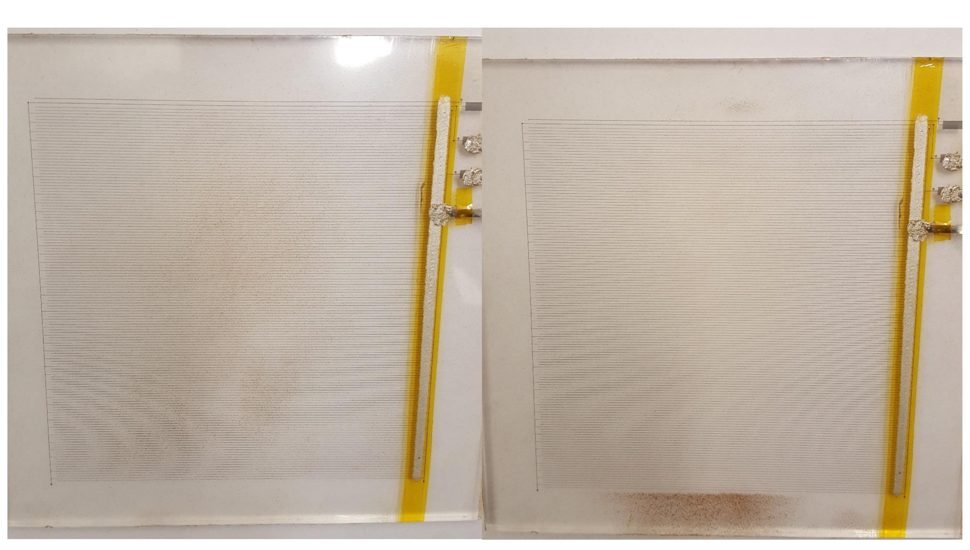

Figure 2. An EDS before (left) and after activation (right)

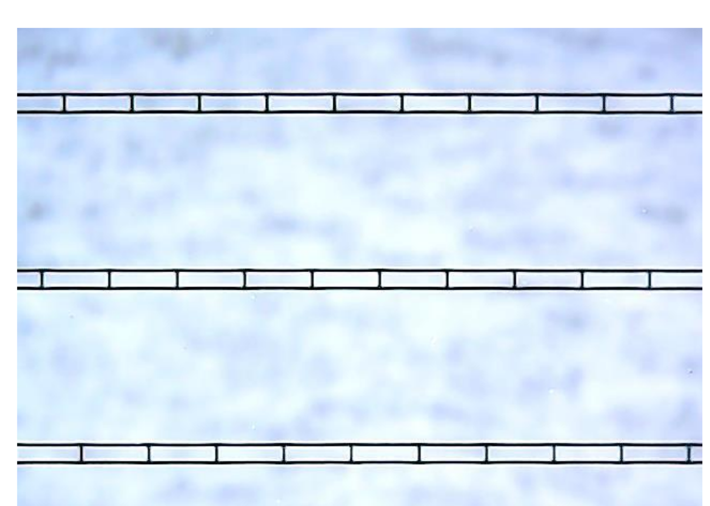

Figure 3. A microscope image of 120µm width "ladder" electrodes

COMPUTATIONAL METHODS: SR was computed for four different designs by tracing rays through the EDS using the Optometrika Ray Tracing Library. The model accounts for partial reflection, refraction, and the transmission efficiency of different film layers. We also use the model to evaluate SR restoration (SRR) according to the following formula:

$$\mathrm{SRR} = \frac{\mathrm{SR}_{\mathrm{restored}}}{\mathrm{SR}_{\mathrm{original}}} * 100\%$$

To measure SRR, dust particles were traced in COMSOL, and the positions of these particles were imported into the MATLAB environment using LiveLink.

Fresnel Equations (transmitted and reflected intensities for s and p-polarized light)

$$r_s = \frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t}$$

$$r_p = \frac{n_2 \cos\theta_i - n_1 \cos\theta_t}{n_2 \cos\theta_i + n_1 \cos\theta_t}$$

$$t_s = \frac{2 n_1 \cos\theta_i}{n_1 \cos\theta_i + n_2 \cos\theta_t}$$

$$t_p = \frac{2 n_1 \cos\theta_i}{n_2 \cos\theta_i + n_1 \cos\theta_t}$$

Ray directions according to Snell's Law

$$v_{reflect} = 1 + 2\cos\theta_i\, n$$

$$v_{refract} = \left(\frac{n_1}{n_2}\right)\boldsymbol{l} + \left(\frac{n_1}{n_2}\cos\theta_i + \cos\theta_t\right)\boldsymbol{n}$$

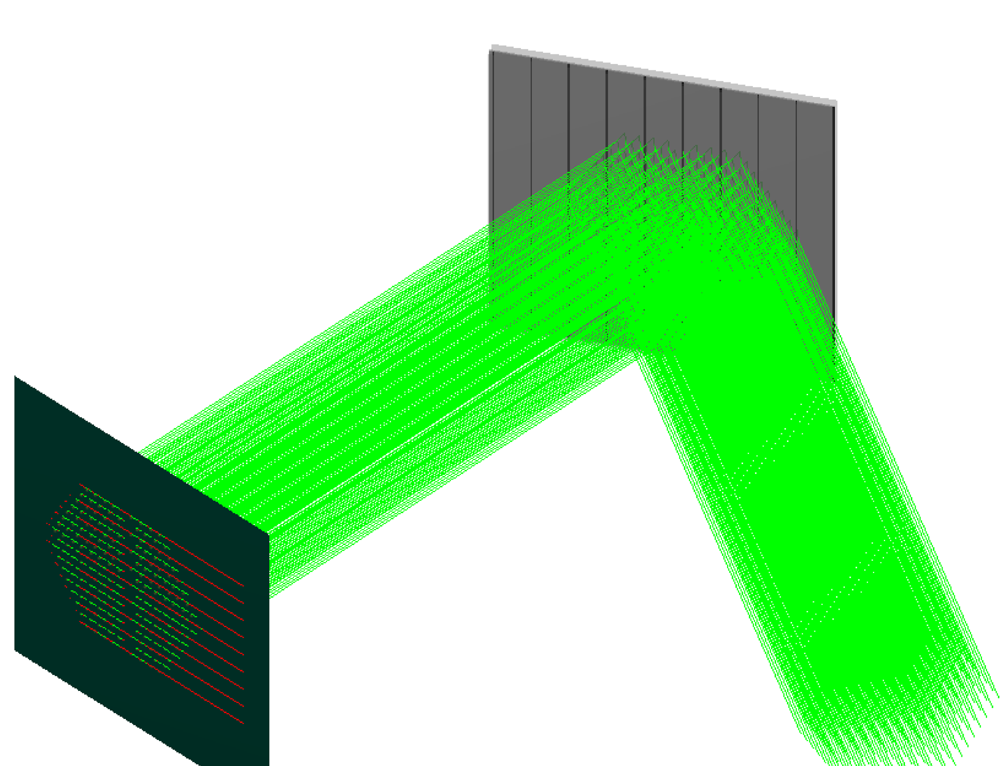

Figure 4. A visualization of the ray tracing model

RESULTS:

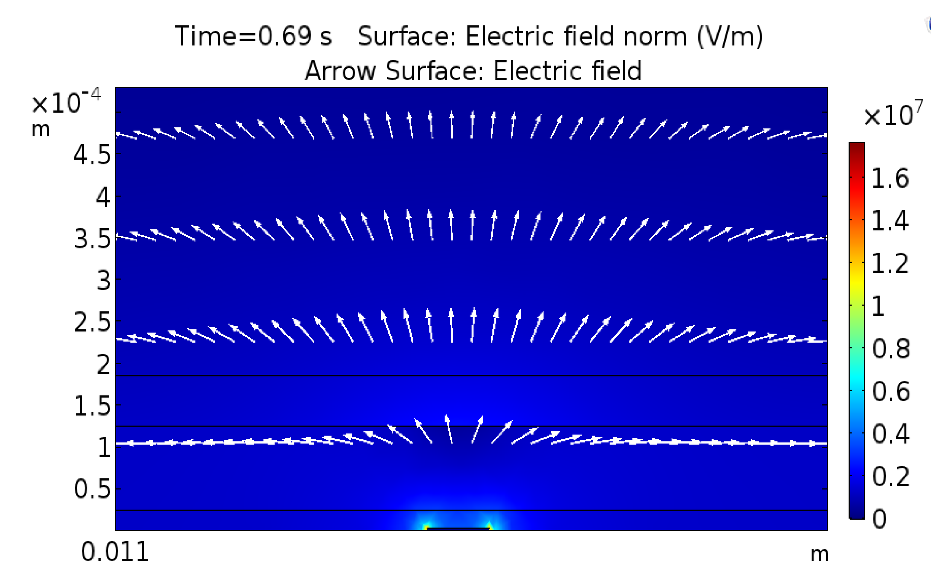

Figure 5. The electric field and potential over one electrode during activation

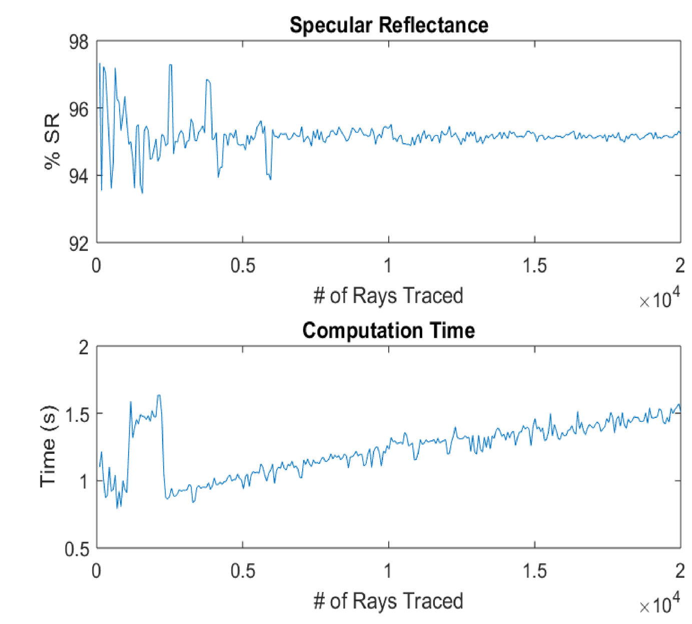

Figure 6. Determination of optimal # of rays traced in the model (10,000 was chosen). An increased # of rays increases both precision of results and computation time.

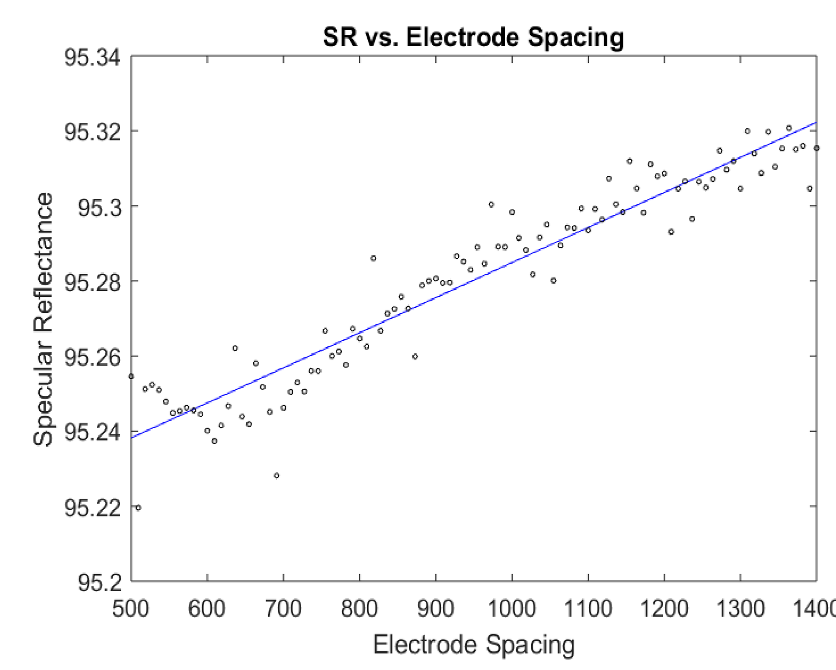

Figure 7. Single Rail, 10µm wide Electrode Design. For every 100 micron increase in spacing, SR improves by approximately 0.01%

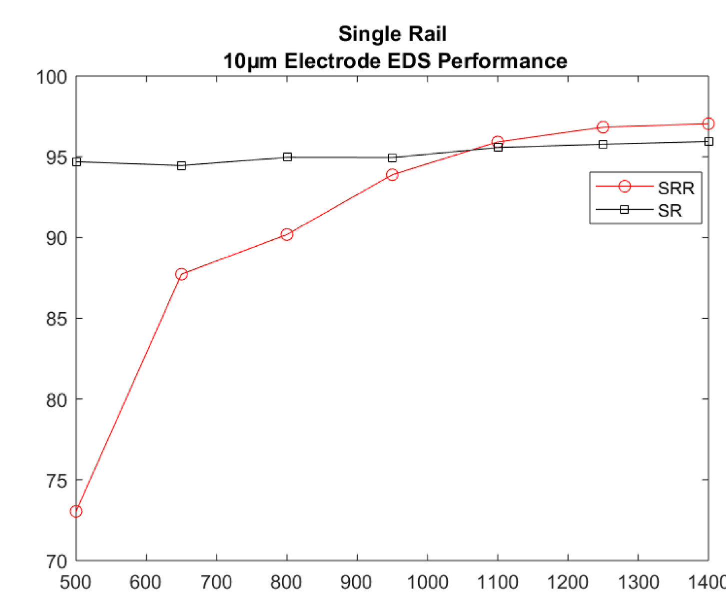

Figure 8. SRR and SR measurements of one EDS with varied electrode spacing

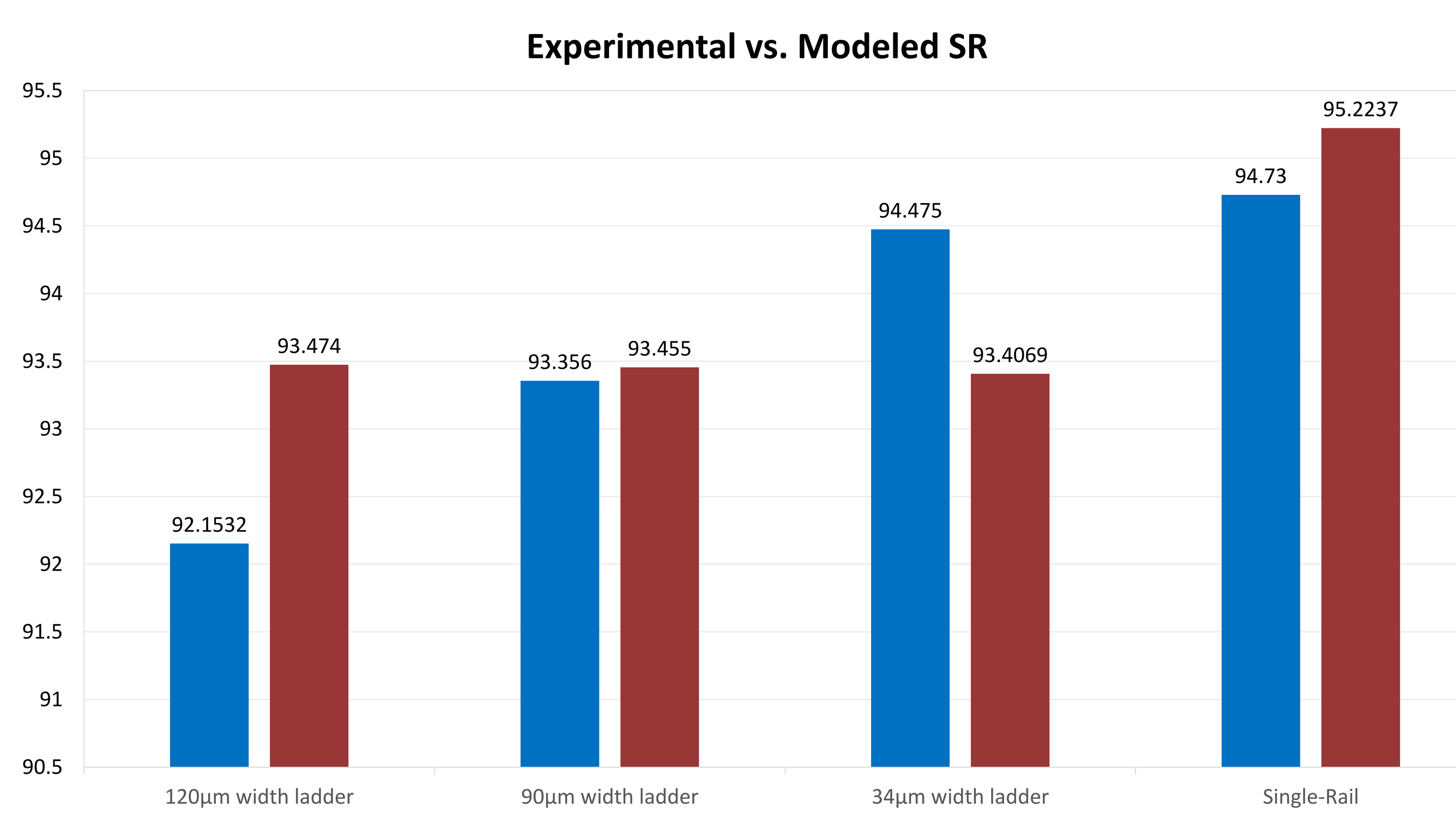

Figure 9. Modeled and Experimental SR of Medium-Scale Kodak EDS. Design 4 utilizes single rail electrodes, while designs 1-3 are ladder designs with decreasing inter-rail spacing.

CONCLUSIONS: It was found that while electrode spacing has a minimal impact on Specular Reflectance, it has a significant impact on dust movement. Single rail electrode designs were found to yield much higher SR measurements than "ladder" designs. But among these ladder designs, there was a trivial difference in SR.

REFERENCES:

1. Sayyah, Arash, et al. "Energy yield loss caused by dust deposition on photovoltaic panels", Solar Energy, Vol.107, Pages 576-604 (September 2014)
2. Mazumder, Malay K., et al. "Mitigation of Dust Impact on Solar Collectors by Water-Free Cleaning", IEEE Journal of Photovoltaics, Vol. 7, No. 5, Pages 1342-1353 (September 2017)

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