

Improved modeling of grid structures on optics: transmission, sheet resistance and diffraction effects

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Abstract: Metallic grid layers are used for EMI-shielding and heating on aerospace windows and domes. The authors demonstrate the capability to accurately model the optical transmission, EMI attenuation and diffraction effects of such sub-mm-scale grid structures.

OCIS codes: (310.7005) Transparent conductive coatings; (050.1940) Diffraction.

1. Introduction

Windows and domes often require an electrically conductive coating to shield the underlying sensors from electromagnetic interference (EMI). While a very thin layer of metal can be deposited on the substrate to provide excellent conductivity, the optical transparency would be dramatically reduced. An alternative conductive coating that has high transmission in the visible wavelength region is indium tin oxide (ITO). However, this material's transmission rapidly diminishes in the IR and the sheet resistance is typically limited to several ohms per square for sufficient transparency. A metalized grid has greater flexibility. The grid is composed of a single or multiple metal layers with thin line-widths and adjustable heights for modifying conductivity. This approach allows for transmission in both the visible and the IR, while still providing electromagnetic shielding; however, some limitations exist for the higher frequencies, where shielding is dependent on the grid aperture size. Metallic grids can also be used for heater applications, where the dissipated power density across the surface of the window is a function of resistance. While resistance is a governing factor for shielding or heating, little has been openly reported on how to analytically determine the sheet resistance of a given pattern based on its geometry and the inherent resistivity of the metal. Obscuration caused by the grid will diminish optical transmission. Numerical predictions of transmission have been published [1], but little has been reported on how to analytically determine the obscuration for more complex geometries, particularly over non-normal angles of incidence. Diffraction also occurs, but the visibility of the unwanted orders can be reduced by empirically developing randomized patterns. This presentation will describe the recent efforts of EEO to establish closed-form calculations for modeling the key performance characteristics of useful grid structures and demonstrate the validity of these models via comparison to actual gridded windows.

2. Optical transmission

EEO employed an open-area-squared formulation for calculating transmission through a given grid pattern, modified to accommodate varying degrees of structure randomization and the effect of non-normal angles of incidence (taking physical grid height into account). This approach was demonstrated to be accurate by comparing modeled results to actual measurements as shown in Figure 1. Transmission measurements of windows with grid patterns identical to modeled patterns demonstrated excellent agreement between model and window. For example, Figure 1 shows that for a random hub-and-spoke pattern, model and grid agreed to within 2.1% at all angles of incidence between 0° and 70°.

3. Sheet resistance / shielding effectiveness

A comprehensive sequence of analyses was performed to more clearly define the relationships between various grid patterns and effective sheet resistance, which ultimately governs shielding effectiveness (SE). EEO examined the viability of various modeling approaches for predicting SE, including the existing models developed by others, models developed by EEO using commercial software, and more fundamental mathematical models. Also included were models of system components that likely influence the effective SE, such as the size of the test aperture. Integrated into the basic modeling work, EEO conducted actual experimental measurements of SE for gridded windows identical to the modeled designs. Results indicated a good overall match between the EEO models and the observed performance of the window, as shown in Figure 2. Similar analyses and measurements were performed for non-gridded windows composed of a semiconductive material, such as germanium. As shown in Figure 2, a similar level of agreement for such monolithic configurations was observed.

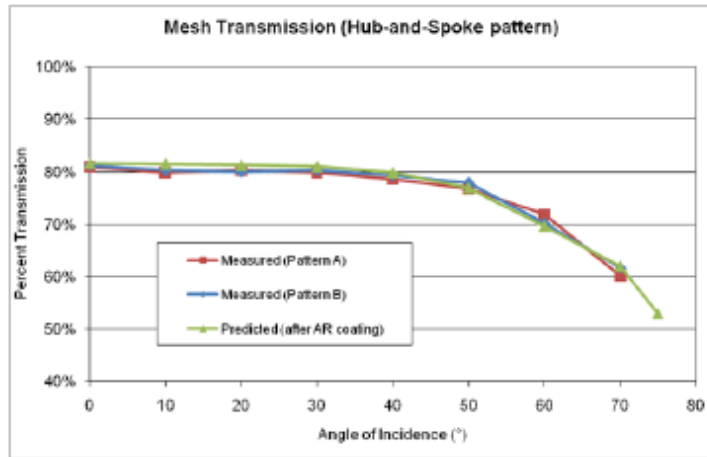


Fig. 1. Optical transmission data.

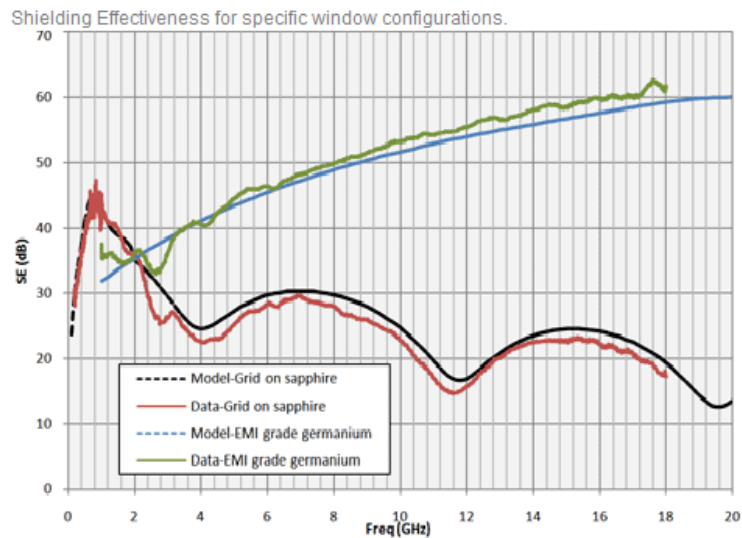


Fig. 2. Shielding effectiveness for specific window configurations – metal grid on a sapphire window and a bare germanium window.

4. Diffraction effects

In order to accurately model diffraction characteristics of grid patterns, existing diffraction propagation software was enhanced to add a novel approach for calculating diffraction from an arbitrary input. When operating on an appropriate computer system, the improved algorithm produces results hundreds of times faster than standard Fourier-based methods, and allows realistic cases to be modeled for the first time. The final algorithm has been tested against previously published results, which included analytically-derived as well as measured data. The modeled OptiScan results qualitatively and quantitatively match referenced literature within the assumptions and test errors of the references, and the algorithm is shown to be reliable for predicting both locations and energies of diffracted peaks. Measurements of samples demonstrated the accuracy of modeling repeating and randomized patterns of all types. Transmission of a set of samples was measured at normal incidence using a 4 mm diameter beam with a camera focused on the central diffraction pattern. A measurement of the un-attenuated (0,0) peak was first obtained, followed by a measurement with the peak removed to allow a comparison of the diffracted energy relative to the central peak. A wavelength of 533 nm was used to allow digital camera images of the large-scale diffraction pattern. The resulting patterns matched modeled patterns extremely well as seen in Figures 3 and 4.

Measured and modeled diffraction of a repeating square pattern.

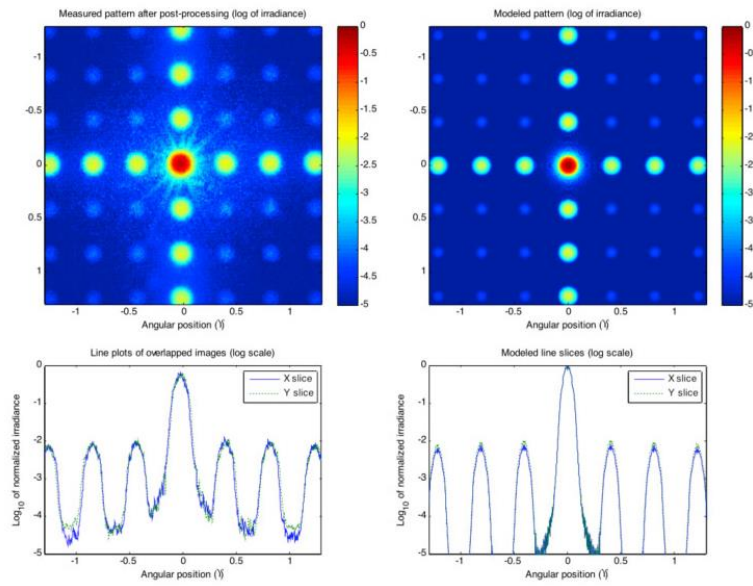


Fig. 3. Measured vs. modeled diffraction of a repeating square grid pattern.

Measured and modeled diffraction of a randomized overlapping circle pattern.

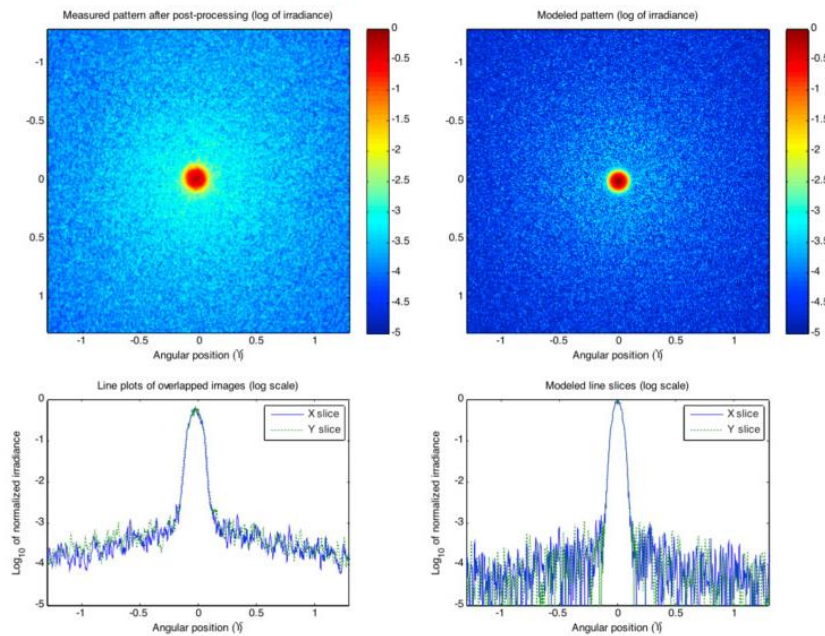


Fig. 4. Measured vs. modeled diffraction of a randomized overlapping circle pattern.

5. Conclusions

The authors have demonstrated the ability to accurately model optical transmission, EMI attenuation and diffraction effects of practical grid structures used to provide EMI-shielding and heating on optical windows and domes.

6. References

[1] Jennifer I. Halman, Keith A. Ramsey, Michael Thomas, and Andrew Griffin, "Predicted and measured transmission and diffraction by a metallic mesh coating," *Proc. SPIE* **7302**, (2009).

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