Mueller Matrices for like and Cross Polarized Scattering from Irregular Layered Structures Based on a Full Wave Approach – Theory

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The Mueller matrix elements are evaluated for a three-media stratified structure with a two dimensionally random rough uppermost interface. Intermediate medium 1 is assumed to be optically thin and, therefore, multiple reflections in medium 1 are accounted for in the analysis. The solutions are based on the full-wave approach. Thus Maxwell's equations are converted into generalized telegraphists' equations. Exact boundary conditions are imposed at rough interfaces. Iterative solutions for the generalized telegraphists' equations are first obtained for the deterministic case, before random rough surfaces are considered. These solutions are compared with controlled laboratory experiments taken with an optical polarimetric scatterometer and atomic force (or scanning tunneling) microscope in order to validate the full-wave analytical solution.

We obtain a database for the Mueller matrix elements over a broad range of rough-surface parameters. A family of non-Gaussian probability density functions PDF's is assumed for the random rough surface heights in order to avoid convergence problems that arise when standard Gaussian PDF's are assumed (resulting in a finite probability for a coating material with a negative thickness). This database can be used to determine the optimum angle of incidence and frequency that should be used to identify (ie., remotely sense) the coating material. It can also be used to identify the Mueller matrix elements that provide the most reliable data for optical detection of the coating material.

The solutions have been shown to account for scattering upon reflection from above and below the rough surface and scattering upon transmission across the rough surface from above and below. The solutions are expressed as single and double infinite sums that account for waves that undergo multiple reflections in the coating material. An optimum truncating scheme is used. They retain the reciprocal properties of the full-wave solution and result in rapid convergence of the results.

Illustrative examples are presented for the diffuse, specularly scattered modified Mueller matrix elements (as a function of incident angles). The modified Mueller matrix elements M_{ij} (i,j = 1,2) are proportional to the like-polarized $(i = j)$ and cross polarized $(i \neq j)$ cross sections. They are linearly related to the original Mueller matrix elements. A wide range of rough surface parameters (rms height 0.01-14 wavelengths) is assumed and individual contributions to the modified Mueller matrix elements are presented. It is shown that the elements of the modified Mueller matrix M_{ij} (i,j =3, 4) that contain relative phase data are most sensitive to parameters of the layered media. The data taken at the Brewster angle are also very sensitive to the parameters of the coating material. A database, generated from the full-wave solution, could be applied to electromagnetic remote sensing of rough coating materials over a wide range of frequencies.