DDA SIMULATIONS OF LIGHT REFLECTION FROM ROUGH METALLIC AND DIELECTRIC SURFACES. Ye. Grynko, BASF AG, GVC/S, B009, Carl-Bosch-Strasse 38, 48165, Münster, Germany, Yegen.Grynko@basf.com

Introduction: Natural and artificial light scattering objects often have irregular shapes and rough surfaces. The natural examples are planetary regolith, ocean surface, deserts and terrains. The industrial light scattering applications deal with rough surfaces of metals and dielectrics of various structures and composition. The interaction of electromagnetic waves with such objects is strongly influenced by degree of surface roughness, i.e. the amplitude of heights and the slope statistics. For different scientific and industrial applications the knowledge of the optics of rough interfaces is required [e.g., 1-3]. In this paper we use numerical experiments to study light reflection from thin metallic and dielectric films with the surface roughness scale comparable to or smaller than the wavelength of light.

Numerical method: We use discrete-dipole approximation (DDA) [4, 5]method as it provides full flexibility for the geometry of the scatterer [e.g., 6]. In the DDA continuous object is approximated with an array of dipoles. The dipoles and spaces between them are much smaller than the wavelength of incident light. A system of equations is required to describe basic interaction of each dipole with the total field. The solution of the problem is the sum of the incident wave and the contribution from all the dipoles in the array [4]. The disadvantage of this method is that computer memory requirements quickly increase with the size of the scatterer as large objects must be approximated with large enough number of dipoles. Among the publicly available computer codes we chose ADDA code [7] which provides parallel multi-processor calculations of light scattering by single particles.

The scattering object in our simulations is a thin square slab consisting of a substrate of constant thickness and a layer representing random rough surface. Fractal statistics of hights is used to model the surface. In this case the standard deviation σ in all points follows the power law [8]

$$\sigma(\vec{r}) = \sqrt{\left\langle [h(\vec{r}) - h(0)]^2 \right\rangle} = \sigma_0 \left(\frac{|\vec{r}|}{r_0} \right)^{3-D},$$

where D is fractal dimension ($2 < D < 3$) and r_0 is thopothesy which influences to certain extent the horizontal scale of roughness [8]. Fig. 1 shows an example of a 2-D fractal random field with $D = 2.5$ and $r_0 = 0.5$.

Horizontal size of the slab is 512x512 dipoles and the substrate layer thickness is 10 dipoles. The thickness of the rough layer τ varies between 0 and 30 dipoles and is expressed in the fractions of the wavelength λ.

The slab is illuminated at certain angle of

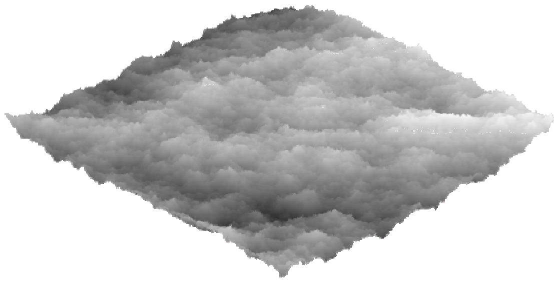

Fig. 1. Sample of 2-D random fractal field with $D = 2.5$ and $r_0 = 0.5$.

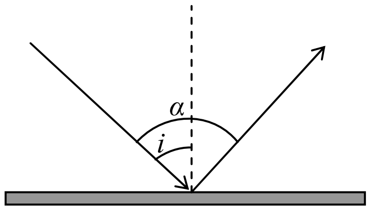

Fig. 2. Geometry of incidence and reflection.

incidence i relative to the normal to the slab (Fig. 2.). The result of the calculation is a full scattering matrix $F_{ik}(\alpha, \varphi)$ obtained in the entire range of phase and azimuthal angles.

Results: Here we present two examples of DDA calculations of phase dependencies of intensity. The results are obtained for $i = 45^o$ and scattered intensity is detected in the principal scattering plane. We consider two materials: aluminum in a resin with relative refractive index $m = 0.8 + 4.8i$ and an arbitrary absorbing dielectric $m = 1.5 + 1.0i$. The simulation of an infinite surface is impossible in the frame of DDA therefore we simulate as large particles as possible. For both cases we took maximal size parameters ($X = \pi d / \lambda$) for the horizontal dimensions of the slabs allowed by the DDA condition of discretization [4, 5], $X = 52$ for the metal and $X = 94$ for the dielectric.

Fig. 3 shows phase curves for three types of metallic slabs: flat surface with $D = 2.0$ (solid curve) and two fractal surfaces with moderate $D = 2.5$, $r_0 = 0.2$ and extreme roughness $D = 2.9$, $r_0 = 0.1$ (dashed curves). The thickness of the transition layer, i.e. the amplitude of heights equals $\tau = 0.5\lambda$. The most of the reflected energy is concentrated in the peak of specular reflectance. Its width is equal to that of the forward scattering peak as they both are caused by diffraction and depend on the dimensions of the projection of the slab in the direction of incidence. In the presence of roughness on the reflecting surface the intensity is distributed over wider range of phase angles due to scattering by the roughness elements.

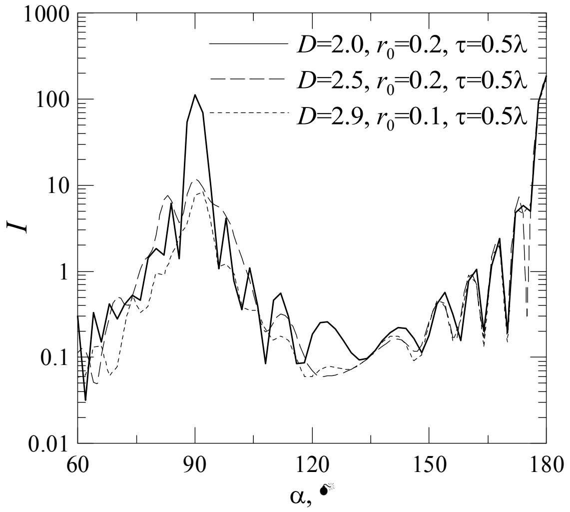

Fig. 3. Phase curves of intensity of scatterring by aluminum slabs in a resin, $m = 0.8 + 4.8i$, $i = 45°$.

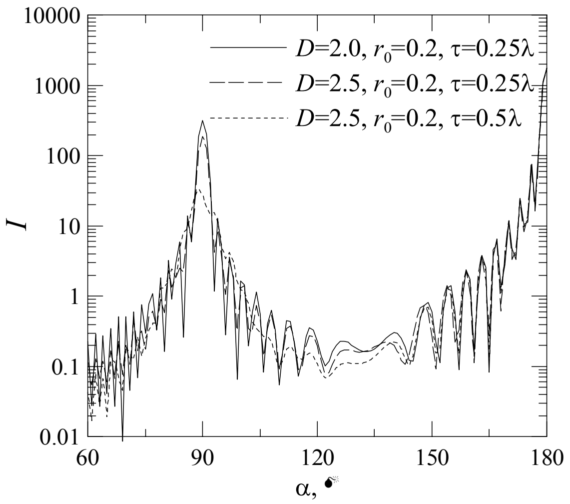

Fig. 4. Phase curves of intensity of scatterring by absorbing dielectric slabs, $m = 1.5 + 1.0i$, $i = 45°$.

Obviously, the extent of this distribution is determined by the height statistics and the horizontal scale of roughness. The peak becomes lower and wider. However, even extreme roughness at $\tau = 0.5\lambda$ does not kill it. It may disappear only if one increases further the amplitude of heights τ.

In Fig. 4 we consider flat and rough dielectric slabs of larger size ($X = 94$) with constant fractal dimension and different parameter $\tau = 0.25\lambda$ and $\tau = 0.5\lambda$. We see that introduction of moderate roughness with $\tau = 0.25\lambda$ leads to insignificant decrease of intensity of specular reflection. At the same time double increase of the roughness layer thickness results in the intensity drop of one order of magnitude.

Conclusions: The presence of roughness on the reflecting surface leads to the decrease and widening of the specular reflection peak. This depends on the surface fractal dimension and the amplitude of heights relative to the wavelength of incident light. However, the specular peak does not disappear for a metal even at large fractal dimension if vertical roughness amplitude is smaller than the wavelength.

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