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Polarization characteristics of diffraction scattering from metal rough surface

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ABSTRACT

For macroscopically rough surface with roughness much greater than wavelength of probe light, scatter from the surface can be explained to some extent as the specular reflection by the local facet. When surfaces possess gratinglike one dimensional patterns diffraction is also the reason of scatter. In this paper, we have characterized the polarization signature of the diffraction scattering by measuring Stokes parameters and polarization degree of scattered light by four samples with different surface patterns and roughness. Through comparison of polarization signatures of scattering from arbitrary and gratinglike one dimensional surface, it was found that the diffraction does not significantly affect the change of polarization state of scattering. The facet model is still available to some extent for polarization behavior of diffraction scatter by macroscopic rough surface.

1. Introduction

Rough surfaces scatter light. Intensity distribution pattern and polarization status of scattering depends on sample surface roughness and materials, as well as the incident angle, wavelength, polarization of probe light and so on. Roughness is characterized by a mean height of irregularities with respect to an average plane, and a correlation length between irregularities [1]. When mean height and correlation length of the irregularities are both much less than the wavelength of light, the surface is microscopically rough and considered as one or more layers of effective medium. The effective medium specularly reflects light and affects polarization state of incident light as any single film. The complex index of refraction of the effective medium can be estimated with Bruggeman effective medium approximation model [1,2]. When the length scale of irregularities is near the wavelength of light, the roughness contributes to scattering distribution pattern as well as the change of polarization states. Scatter from this type of surface is treated as diffraction in many cases, and explained by using Kirchhoff diffraction theory, the Rayleigh approach [3]. When irregularities are much greater than the wavelength of light, the scattering is explained by using facet model, also called the specular point theory [4–7]. Several facet-based models have been developed empirically and/or physically [8–13] to describe scattering distribution patterns, and some included polarization behavior of scattering [10–13]. Polarization measurement of samples with different roughness, materials, and surfaces is therefore important to obtain a further general scattering model to cope with different cases. In previous work [14,15], we have measured polarization behaviors of scattering from isotropic dielectric and metal surfaces with macroscopic roughness (RMS roughness was less than 105 μm), and found that polarization of scattering changes with the roughness. Polarization behaviors of both in-plane and out-of plane scattering of metal surface showed the validity of facet theory to great extent [15]. Surface possessing patterned one-dimensional roughness diffract light in continuous scatter pattern. In this paper, we have characterized the polarization signature of the diffraction scattering by measuring Stokes parameters and polarization degree of scattered light by four samples made of Nickel with different patterns, roughness. It was found that the diffraction does not significantly affect polarization, the facet model is still available to some extent for polarization behavior of diffraction scatter from macroscopically rough surface.

2. Scattering coordinate system and experimental setup

In this work, we use scattering coordinate employed in Refs. [14–16]. Fig. 1 depicts scattering coordinate and geometry illustrating directions of the incident and scattered light. Sample with one-dimensional surface roughness possess grating or gratinglike lines on the surface. Here, the grating lines are oriented parallel

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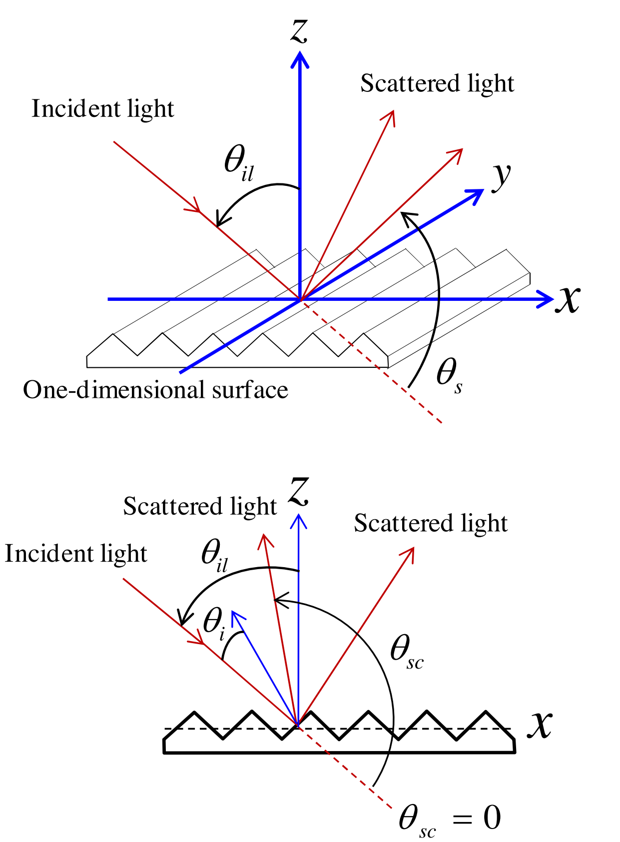

Fig. 1. (Upper) Geometry of the light scattering on one-dimensional surface, and (lower) angles used in this work.

to the y axis. The z axis coincides with the mean sample surface normal, and light traveling in the x-z plane is incident at the illumination angle θ_{il} with respect to the z axis. Gratinglike one-dimensional surface scatters/diffracts a band of light onto the x-z plane, and the direction of the light is determined by the scattering angle θ_{sc}. The electric-far-field amplitude of scattered light in the direction θ_{sc} is considered to be the sum of the contributions of the facets reflecting light in this direction on the x-z plane. The incident angle θ_i for the facet is given by [14–17],

$$\theta_i = \frac{180^\circ - \theta_{sc}}{2} \quad (1)$$

The s and p polarization of the incident and scattered light are defined in the x-z plane, and are perpendicular to the propagation direction and to each other. The p polarization is parallel to the x-z plane, while the s polarization is perpendicular to this plane. Incident light employed here is circularly polarized light. The polarization state of the light is often expressed with the Stokes vector containing four parameters S_0, S_1, S_2, and S_3. The Stokes S_0 is the total intensity of the light. The Stokes S_1 is the amount of linear horizontal or vertical polarization, S_2 is the amount of linear +45° or −45° polarization and, S_3 is the amount the right or left circular polarization contained within the light. The mathematical expressions of each parameter and the degree of polarization *DOP* are described in Appendix A.

Fig. 2 shows a schematic diagram of the Stokes parameter measurement system. A quarter-wave plate (**QWP**1) is placed after the linearly polarized light source (He-Ne gas laser, λ=632.8 nm) to produce the right circularly polarized light. Consequently, the light scattered or diffracted by sample surface passes through the quarter-wave plate (**QWP**2), a photoelastic phase modulator (**PEM**), an analyzer (**A**), and finally is received by a detector. A slit with width of 2 mm was installed before the detector. The distance between the center of sample surface and the detector is 530 mm. The azimuth axes of the modulator and analyzer are fixed at 0° and 45°, respectively. The detected intensity signal will be processed through a low pass filter and two lock-in-amplifiers to obtain full Stokes parameters. The measurement principle was described in ref. [18] in detail. The analyzing optics including **QWP**2, **PEM**, the analyzer, and the detector were mounted on a 530 mm-long arm that rotated vertically around the sample surface. The full Stokes of scattered light were measured in respect to x-z plane. The polarization measurements were carried out at 1° increments of scattering angle θ_{sc} over a range from 40 to 110°.

For measurement samples with one-dimensional rough surface, a commercial surface roughness standard plate made of solid nickel (thickness of nickel is approximately 400 µm) electroformed on the copper plate was employed. The samples are distinguished by symbols #95, #130, #260, and #265. The proposed RMS roughness of these sample surfaces are about 3.7, 5.1, 10.2, and 10.4 µm, respectively. The sample surface possesses different morphology in accordance with finished process. Fig. 3 illustrates practical profiles of sample surfaces with different roughness and patterns, which were measured by the stylus profiler (Dektak, Bruker Co.). The surfaces for samples #95 and #265 (group I) were finished by a grinding machine and possess arbitrary one-dimensional roughness, while surfaces for #130 and #260 (group II) were finished by a shaper and manifest gratinglike one-dimensional roughness. The distances between two gratinglike lines of samples #130 and #260 are about 130 and 260 µm, respectively. Fig. 3(b) shows that the surfaces of group II are of blazed variety, and the blaze angle γ is about 11°. All Samples were illuminated at the angle θ_{il} of 55°. Fig. 4(a) and (b) shows bands of light scattered and/or diffracted by samples #260 and #265. The Stokes of light bands were measured in terms of scattering angle θ_{sc}.

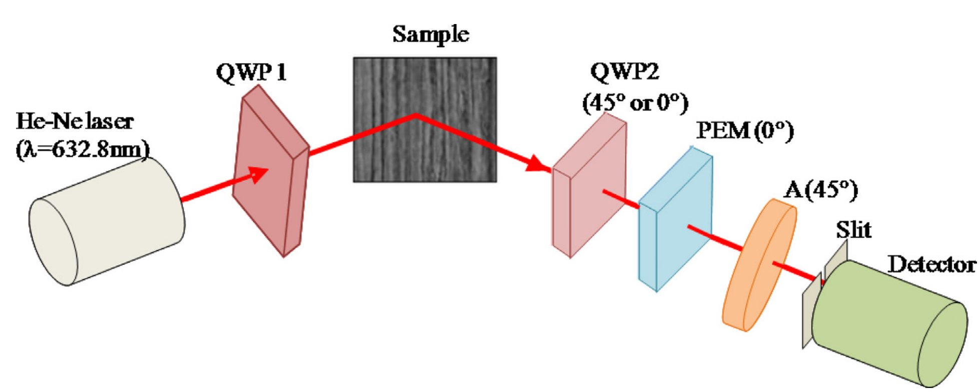

Fig. 2. Schematic diagram of experimental setup to measure the Stokes parameters. **QWP** is a quarter-wave plate, **PEM** is a photo-elastic modulator, and **A** is an analyzer.