Influence of Micro-particle Surface Roughness on TAOS Patterns: Experimental and Theoretical Studies

Jean-Claude Auger[1], **Gustavo E. Fernandes**[1], **Yong-Le Pan**[1]
Kevin B. Aptowicz[2], **and Richard K. Chang**[1]

[1]Center for Laser Diagnostics and Department of Applied Physics, Yale University
New Haven, CT 06520, USA
[2]Department of Physics, West Chester University, West Chester, PA 19383, USA

Abstract— The relation between surface roughness of aerosol particles and the appearance of islands in their large-angle elastic-light scattering (TAOS) patterns is studied by means of an image processing routine. Measured TAOS patterns of aggregates of polystyrene spheres as well as numerically calculated TAOS patterns based on Chebyshev particles are analyzed and qualitative agreement is obtained.

DOI: 10.2529/PIERS061006055418

In recent years, large-angle elastic-light scattering has been investigated as a potential tool for use in the detection and characterization of aerosols in the micrometer range [1–5]. The aim of this work is to study the relation between surface roughness of microparticles and the appearance of islands in their two-dimensional angular optical scattering (TAOS) patterns. We first investigate a series of experimental TAOS patterns collected in the backward hemisphere [1] ($15^\circ < \theta < 95^\circ$) for various polystyrene latex spheres aggregates, which have similar volume but are composed of primary spheres of different sizes. An image analysis routine [2, 6] was applied to each pattern to calculate the mean island size and the mean density of islands appearing in the TAOS patterns. The image processing routine was designed to approximate the way the eye sees the islands by using the gradient of the TAOS patterns in determining the island boundaries, instead of absolute intensities. While the illuminating wavelength of the laser used was 0.532 μm, the primary PSL sphere diameters chosen for comparison were 0.202 μm, 0.988 μm and 2.9 μm (Fig. 1). The density of islands in the TAOS pattern is observed to increase as the size of the primary particles in the aggregate decreases.

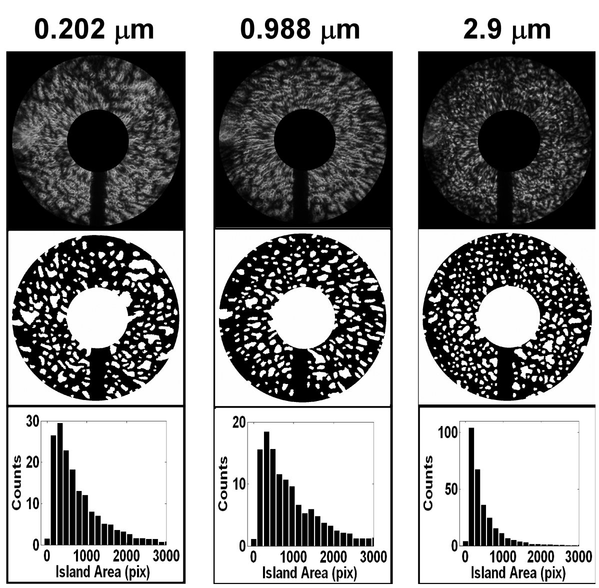

Figure 1: TAOS patterns of aggregates (≈ 5 μm in diameter) of primary PSL spheres (row 1), black-and-white island profile obtained from image processing (row 2), and island area histograms of each image in the top row (row 3). The primary PSL sphere diameter is shown on top of each column.

The same tendency was observed on theoretical TAOS patterns calculated from Chebyshev [7] particles with different surface roughness. Let us recall that a Chebyshev particle is an axisymmetric given by $r(\theta) = r_0(1 + \xi \cos n\theta)$, where r_0 is the radius of the unperturbed sphere, ξ is the deformation parameter and n is the polynomial order. Fixing r_0 to 3.0 µm, the surface roughness was changed by varying n from 10 to 30 and ξ from 0.01 to 0.06. Calculations of TAOS patterns were performed using the T-matrix formalism [8] in the backward hemisphere ($120° < \theta < 180°$), for various orientations and polarization of the incident wave with respect to the particle's axis of symmetry. The surrounding medium was supposed to be vacuum, the particle's complex index of refraction was set to $1.52 + i0.0182$ and the incident wavelength to 0.532 µm. Qualitative systematic studies showed that an increase in the number of ridges (n) and the deformation parameter caused the numerically calculated TAOS patterns to exhibit a greater number of islands. We give two examples of this general study.

Figure 3 illustrate TAOS patterns corresponding to $n = 30$, $\xi = 0.0$, 0.02, 0.04 and 0.06 whereas the corresponding surface morphologies are given in Fig. 2. The incident wave vector is parallel to the Oz axis of the laboratory reference frame and polarized in the Oy direction while the particle's axis of symmetry is rotated parallel to the Ox axis. Inspection of Fig. 3 clearly shows variations in the shape, number and density of the islands, starting from the well known rings related to spherical objects ($\xi = 0.0$) to a large number of islands corresponding to particles with rougher surface.

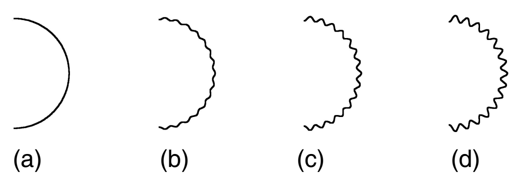

Figure 2: Surface of different Chebyshev particles, $r_0 = 3.0$ micrometers, $n = 30$, as function of increasing surface roughness. (a) $\xi = 0$ (sphere), (b) $\xi = 0.02$, (c) $\xi = 0.04$, (d) $\xi = 0.06$.

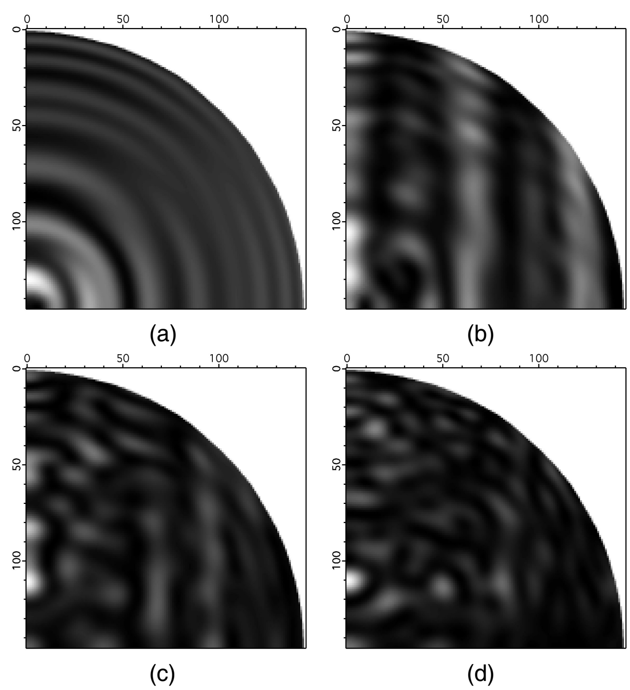

Figure 3: Theoretical backscattering patterns from Chebyshev particles, $r_0 = 3.0$ micrometers, $n = 30$, as function of increasing surface roughness. (a) $\xi = 0$ (sphere), (b) $\xi = 0.02$, (c) $\xi = 0.04$, (d) $\xi = 0.06$.

Figure 4 shows theoretical TAOS patterns calculated from the previous Chebyshev particles but considering a non-polarized incident beam. As expected, the image analysis routine shows that the density of islands in the TAOS pattern increases as the deformation parameter of the particle surface roughness also increases.

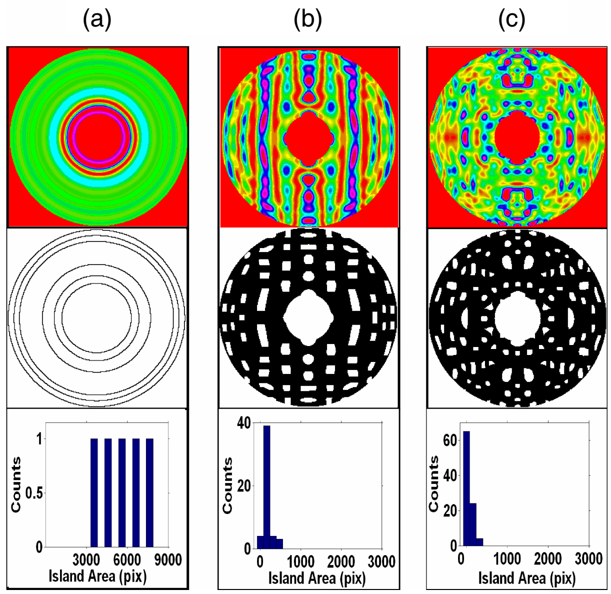

Figure 4: Theoretical backscattering patterns from a Chebyshev particle, $r_0 = 3.0$ micrometers, $n = 30$, as function of increasing surface roughness. (a) $\xi = 0$ (sphere), (b) $\xi = 0.02$, (c) $\xi = 0.06$.

Our results suggest that the island structure appearing in the TAOS patterns of certain aerosol aggregates is related to the surface roughness of the aggregates. We hope to be able to use this knowledge to obtain insight into the structure of aggregates of aerosol particles from their TAOS patterns.

REFERENCES

1. Pan, Y. L., K. B. Aptowicz, and R. K. Chang, *Opt. Lett.*, Vol. 28, 589, 2003.
2. Aptowicz, K. B., R. G. Pinnick, S. C. Hill, Y. L. Pan, and R. K. Chang, *J. Geophys. Res., C: Oceans Atmos.*, Vol. 111, D12212, 2006.
3. Holler, S., Y. L. Pan, J. R. Bottiger, S. C. Hill, D. B. Hillis, and R. K. Chang, *Opt. Lett.*, Vol. 23, 1489, 1998.
4. Hirst, E., P. H. Kaye, and J. R. Guppy, *Appl. Opt.*, Vol. 33, 7180, 1994.
5. Fernandes, G. E., Y. L. Pan, K. B. Aptowicz, R. G. Pinnick, and R. K. Chang, *Opt. Lett.*, Vol. 31, 20, 2006.
6. Gonzalez, R. C., R. E. Woods, and S. L. Eddins, *Digital Image Processing Using Matlab*, Pearson Prentice Hall, 2004.
7. Mishchenko, M. I., J. W. Hovenier, and L. D. Travis, *Light Scattering by Nonspherical Particles*, Academic Press, 2000.
8. Waterman, P. C., *Phys. Rev. D*, Vol. 3, 825, 1971.