ENVIRONMENTAL AND WASTE MANAGEMENT: ADVANCEMENTS THROUGH THE ENVIRONMENTAL MANAGEMENT SCIENCE PROGRAM

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ADVANCEMENTS IN THE MONITORING OF HIGHLY CONCENTRATED SLURRY SYSTEMS WITH OPTICAL LOW COHERENCE REFLECTOMETRY

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INTRODUCTION

Optical Low Coherence Reflectometry (OLCR) is a non-destructive optical technique that can be used to measure 180° coherent backscatter of light incident on a heterogeneous medium. Changes in particle size and concentration may be extracted from the OLCR decay profiles of highly concentrated slurries and emulsions, such as high-level waste. We have shown OLCR to be a valuable tool for monitoring changes in particle size over several orders of magnitude at high concentration.

OLCR is a white-light interference technique originally developed for applications in the optoelectronics test and measurement arena[1,2]. The instrumental design is an autocorrelator to detect interference fringe position and intensity, using a broadband LED source[3]. The detection of only coherent light allows us to extract characteristic information about the sample, such as particle size and concentration.

Tailing decay profiles, in the form of reflectance vs. photon dwell distance (time spent within the matrix), are generated with OLCR from highly scattering samples as shown in Figure 1a. As described in Equation 1, reflectance is related to the proportion of incident light which is returned in phase to the optical fiber.

$$\text{Reflectance (dB)} = 10 * \log_{10} (\text{Reflected Light / Incident Light}). \quad (1)$$

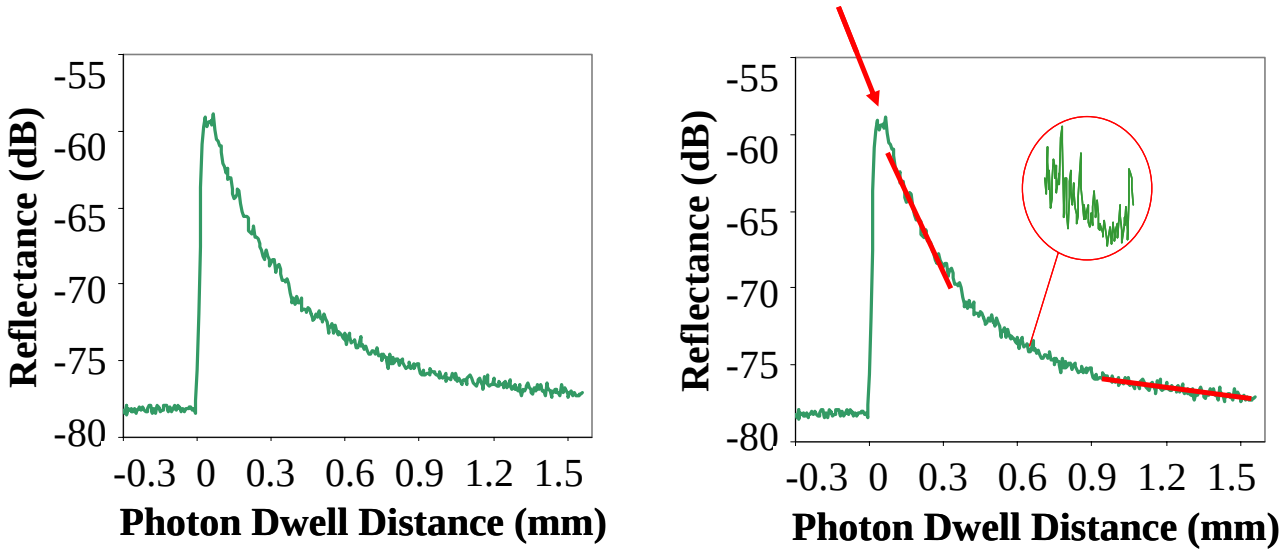

Figure 1. a) Tailing decay profiles are produced by highly scattering samples. b) The four methods of signal analysis are signal intensity, slopes of the two exponentials and fluctuation analysis of the individual scans from the mean.

During any scattering event, wave packets of light may change their direction of propagation as well as the phase relations they have with the wave packets of the incident light. OLCR is a unique light scattering technique in that it is sensitive to the very small portion of light that retains its coherence despite multiple scattering events. Thus, information regarding the phase properties of scattered light and the morphology of the matrix is contained, albeit in a convoluted way, in the OLCR scattering signal. Three regions of interest for signal analysis are shown in relation to the decay profile in Figure 1b. These include signal intensity and slopes of the two exponentials, as well as fluctuation analysis of the individual scans from the mean. Recent work has focused on the relationship of particle size to signal intensity. An overview of analysis methods and previous applications of OLCR is shown[4].

EXPERIMENTAL

The Optiphase Inc., AIF-INST-02 Optical Coherence Domain Interferometer was used to perform the refractive index measurements. This instrument has been detailed[3] and is shown schematically as Figure 2.

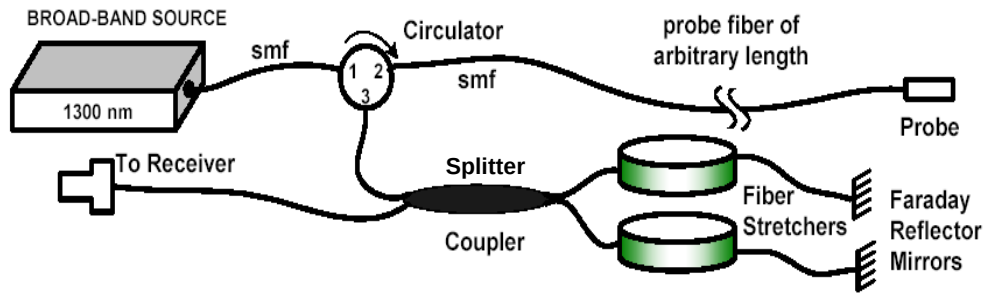

Figure 2. The Optiphase, Inc. Optical Coherence Domain Interferometer.

The model is composed of monodispersed, nanosphere standards purchased from Duke Scientific. The standards are 1% polystyrene spheres in water with diameters ranging from 20 nm to 1800 nm. Each standard also contains less than 0.2% of a Duke proprietary surfactant, with the exception of the 20 nm standard which has a surfactant concentration of 0.86%.

RESULTS AND DISCUSSION

One of the most interesting features of light scattering from spherical particles is the appearance of so-called Mie resonances when the particle radii of a randomly distributed system are comparable with the wavelength of light. This non-monotonic oscillation of backscattered intensity is dependent upon optical parameters, such as dielectric contrast between the medium and the particles[5]. We describe the experiments of light coherently backscattered by such media and compare the experimental signal intensities shown as Figure 3a with the theoretical estimations shown as Figure 3b and described in the following equation:

$$\text{Log } S = \text{Log}(1 + C\rho_0[([\cos(y)]/y - ([\sin(y)]/y^2)^2 + (\tfrac{1}{2} - [\sin(y)]/y + [1-(\cos(y)]/(y^2))^2] \quad (2)$$

where S is the coherent backscattering signal, C is an instrumentally-based constant, ρ_0 is the volume fraction of particles in the studied media and y is equivalent to $4\pi R\Delta / \lambda$ with R as the particle radius, Δ as the optical contrast between the particles and media and λ as the effective wavelength of light in the media in the same units as particle radius. The described results are interesting as a step toward advancement in the understanding of the theoretically and practically important problem of wave propagation in multiscattering random media. This work will help to describe the effects of light scattering by particle sizes which transition from the Rayleigh scattering regime, where particles are much smaller than the wavelength of light, to the Fraunhofer scattering regime, where particles are much larger than the wavelength of light.

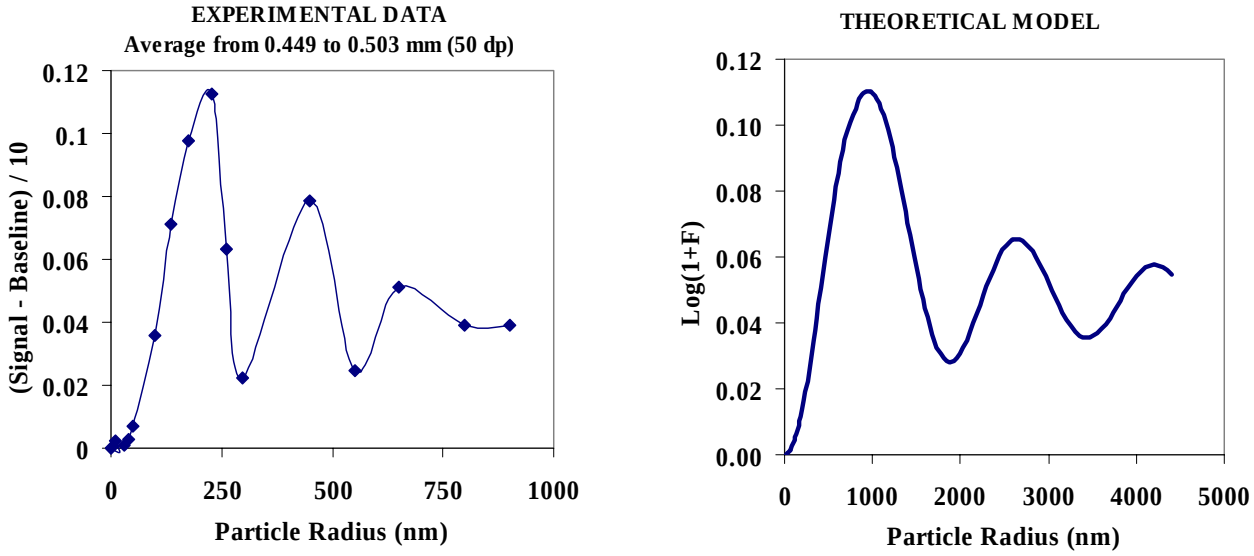

Figure 3. a) Experimental intensity values over a window of the OLCR decay profiles. b) Theoretical model of Mie resonances in a multiple scattering system.

CONCLUSIONS

We have made significant progress in the analysis of signals obtained from multiple scattering events. We have observed the appearance of Mie resonances, a non-monotonic oscillation of backscattered intensity dependent on optical parameters, over the interval where radii are comparable to the wavelength. We have modeled the slopes of the OLCR tailing decay in relation to particle radius. Analysis of the individual profile fluctuations from the mean values is promising to show composition differences in bimodal or polydispersed systems. Fundamental science development performed on model systems is essential for the analysis of polydispersity and the complex effects of clustering, sedimentation, gelation and other dynamic changes which may occur in an environmental waste system.

ACKNOWLEDGEMENTS

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