Observation of Coherent Backscattering for Detection of Physical State Changes

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Observation of light scattering is an innovative tool in studying quantum optics, optical materials, and photon localization. Coherent backscattering (CBS) of light is an interference phenomenon that is observed when light rays propagate through random media where the particle size is comparable to the wavelength of the incident light. Light incident on such media can be scattered multiple times by its constituent particles. When two light rays follow time-reversed scattering paths, they interfere constructively only in the backscatter direction, causing an enhanced intensity cone with twice the magnitude as the incident light (Fig. 1; CBS signal). Coherent backscattering is considered "weak localization", a precursor to the strong localization predicted by Anderson localization, and is reliant on the relationship between the transport mean free path and the scattering mean free path within the medium, key characteristics of the physical state of a scattered media. Thus, CBS has been used recently to detect the denaturation of milk caused by protein aggregation[2]. CBS then has application in detection of physical state changes, where the size of and distance between the scattering centers of the medium change.

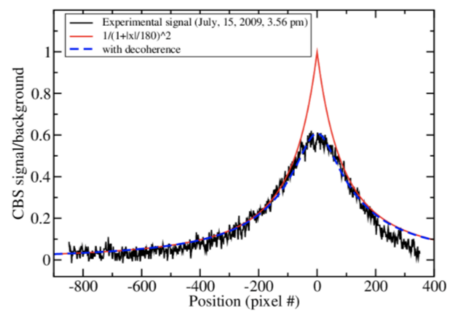

Figure 1. A typical CBS signal with the characteristic twice enhanced intensity peak. Experimentally detected signals are typically less acute due to residual scattered light[1].

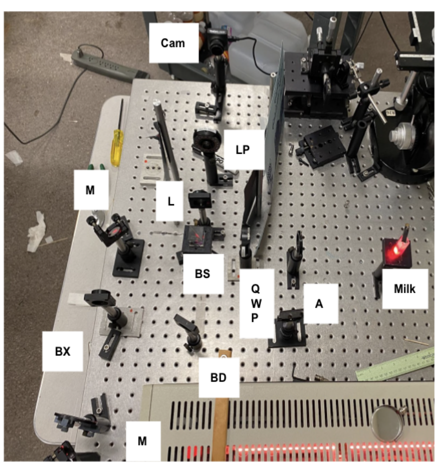

Figure 2. Optical alignment used. M-Mirror; BX- Beam expander (4x); BS- Beam splitter; L- Lens (f = 40cm); LP- Linear Polarizer; QWP- Quarter Wave Plate; BD- Beam Dump; A- Aperture

The experimental setup utilized to detect the CBS signal is displayed in Figure 2. Here, a sample of milk is used for initial detection, as milk's scattering and suspension properties make it an ideal candidate for detecting the backscatter signal. Once the optical alignment is perfected, the sample can be easily swapped or manipulated. To improve the angular resolution of the apparatus, the laser beam diameter is quadrupled using a beam expander. The CBS signal will follow back along the incident laser path, which is then split at the beam splitter so that a portion of the light can be imaged by the CMOS camera. Detection of the signal is complicated by the presence of stray light, which can be eliminated by blocking any possible back reflections or diffuse light through careful stacking and placement of neutral density (ND) filters. Due to the faint nature of the CBS signal, detection with the CMOS camera requires subtraction of the background signal through image post-processing.

Coherent backscattering remains a promising method to detect physical state changes of random, scattered media. Future studies can further investigate the CBS signal's response to physical state changes by adjusting the density, concentration, and content of the scattered media, and the detection apparatus can be further applied to assess protein denaturation in vaccines or reflectivity in materials, providing an innovative way to detect physical state changes and characterize physical properties.

[1] Müller, Cord, Delande, Dominique. (2010). Disorder and interference: localization phenomena. 10.1093/acprof:oso/9780199603657.003.0009.
[2] Verma, M., Singh, D. K., Senthilkumaran, P., Joseph, J., & Kandpal, H. C. (2014). Ultrasensitive and fast detection of denaturation of milk by Coherent backscattering of light. Scientific Reports, 4(1). doi:10.1038/srep07257.