Multiple Light Scattering in Polymer Dispersed Liquid Crystals: A Monte Carlo Simulation

Serafin Delica[1] **and Carlo Mar Blanca**[2]
[1]Liquid Crystal Laboratory, [2]Instrumentation Physics Laboratory
National Institute of Physics
University of the Philippines Diliman, 1101 Quezon City, Philippines

Polymer dispersed liquid crystals (PDLC's) are non-homogeneous materials consisting of liquid crystal (LC) droplets randomly distributed in a polymer matrix. Light incident on the PDLC undergoes multiple scattering along the boundaries of the matrix and the LC droplets making the PDLC viable for window shutter and light modulator applications (Commander et al., 2000; Kelly et al., 2000). Because light scattering is the main mechanism that governs the optical behavior of PDLC films, it is essential that a model describing the scattering behavior of the film be formulated.

Diffusion theory and random walk simulations have been utilized to describe light propagation through PDLC layers (Neijzen et al., 1997). However, their validity is limited to highly scattering and isotropic cases (Uvera & Durian, 1996). The treatment has been extended to include large droplet sizes but is limited to single scattering. Most PDLC systems consist mainly of nematic LC droplets, each having a random director configuration, making the sample highly anisotropic. In this paper, we utilize a Monte Carlo (MC) model (Blanca & Saloma, 1999) to trace the photon trajectories inside the layer. The model possesses several advantages: (1) it can incorporate droplet concentration and size; (2) it can accommodate complex optical configurations without the need to satisfy complex boundary conditions; and (3) it can incorporate particle anisotropy. In particular, the MC model is utilized to investigate the angular dependence of transmitted light for varying LC concentration and droplet size, in the presence of sample refractive index mismatch.

A collimated laser source is incident normal to the PVP:E7 LC sample of thickness h=30 mm as shown in Fig. 1. Each of the $N=10^6$ incident photons is propagated through the LC scattering layer with a free path l_i following Beer-Lambert's distribution $l_i=-l^*\ln(s)$, where l^* is the sample mean free path and s is a uniform random number within [0,1]. The direction of scatter is controlled by a Henyey-Greenstein probability distribution (Blanca & Saloma, 2000).

$$\cos\theta_i = \frac{1+g^2}{2g} - \frac{(1-g^2)^2}{2g(1-g+2g\sigma)^2} \tag{1}$$

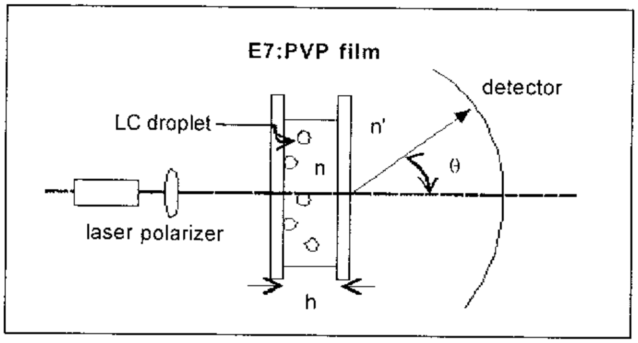

Fig. 1. The optical set-up for angular distribution measurement

Reflection and refraction on the film-air interface are considered using the laws of Snell and Fresnel for parallel and perpendicular incident polarization (Reitz et al., 2000). Since the index of refraction of the matrix approximates that of the glass (Neijzen et al., 1997), we neglect reflection between polymer and glass interface. Angular distribution of the N_D detected photons is determined for varying size parameters and E7 concentration.

Fig. 2 shows the dependence of forward and back scattered intensities with varying number of scattering events (h/l^*) achieved by increasing the LC concentration. Forward scattering dominates for large anisotropy g=0.9 but decreases in magnitude as the LC concentration is increased. With increasing number of scattering events, the backscattered component grows in extent and dominates the signal for the isotropic case. In cases, however, the unscattered fraction follow Beer-Lambert's equation with decay length defined by the ratio of thickness ***h*** over the mean-free-path ***l****.

The index mismatch between the sample-air interface is considered, and as shown in Fig. 3, there is considerable attenuation in the transmitted signal and broadening of angular distribution for both parallel and perpendicular polarization of incident light. This is mainly due to backscattering and total internal reflection.

The angular distribution of transmitted light through the PDLC is considered with varying droplet size represented by g. Fig. 4 shows that for large particles, light is concentrated at a smaller range of angles about the normal to the surface. The angular distribution also broadens with decreasing droplet size. The relation between actual size of droplet and anisotropy parameter, g, could be further investigated by experimental fitting.

Fig. 5 shows the dependence of angular distribution with E7 concentration. The broadening of profile for increasing LC concentration is due to the increase in the number of scatterers within the film. This also increases back scattering and leads to attenuation of forward scattered light.

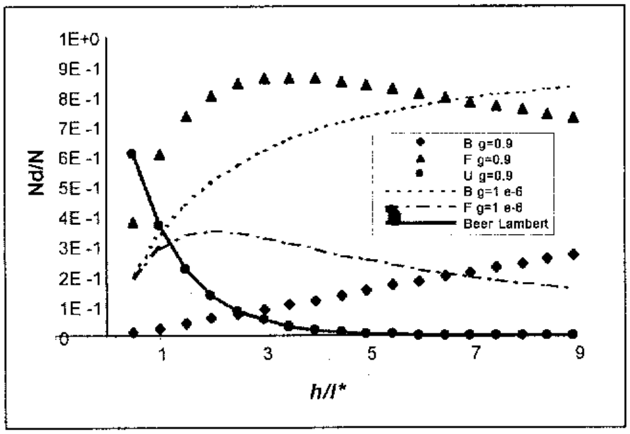

Fig. 2. Light intensity for unscattered (U), backscattered (B) and forward scattered (F) light with varying LC concentration

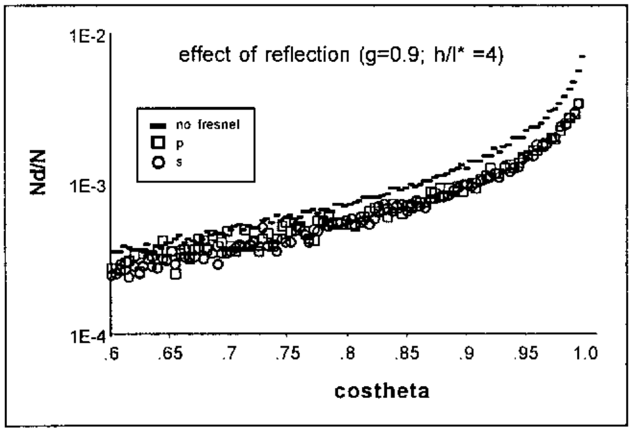

Fig. 3. Effect of film-air index mismatch. n=1.53, n'=1.0. The vertical axis is on a logarithmic scale

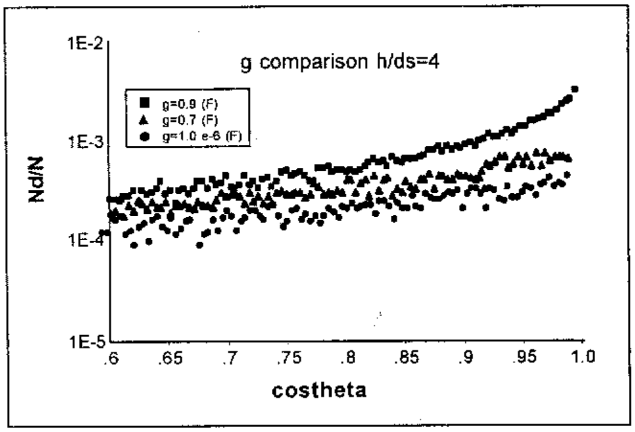

Fig. 4. Effect of anisotropy on detected intensity. The distribution broadens with decreasing droplet size h/l* = 2, N=10^6 (the vertical axis is on logarithmic scale)

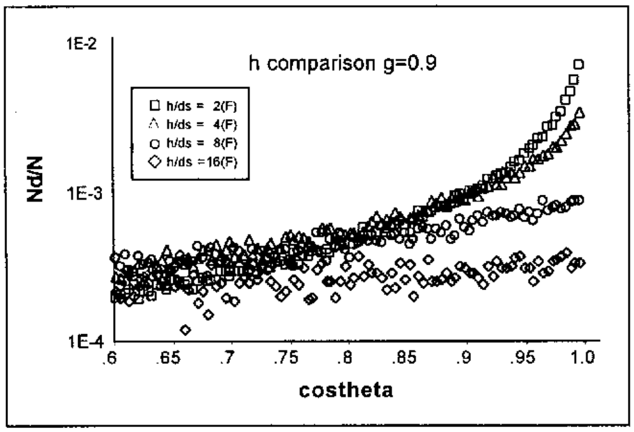

Fig. 5. Effect of E7 LC concentration. Angular distribution broadens with increasing number of scattering events (g=0.9) (vertical axis is on logarithmic scale)

Applications in optical switches require that the PDLC be highly scattering. This could be attained by setting the droplet size to be small while taking the concentration at the optimal value such that light is maximized in the backward direction. For applications that utilize backscattering, high LC concentration is recommended.

REFERENCES

Blanca, C.M. & C. Saloma, 1999. Efficient analysis of temporal broadening of pulsed focused Gaussian beam in scattering media. *Appl. Opt.* 38:5433-5437.

Blanca, C.M. & C. Saloma, 2000. Third harmonic generation microscopy in highly-scattering media. *Appl. Opt.* 39:5187-5193.

Bloisi, F., C. Ruocchio, & L. Vicari, 1996. Angular dependence of light transmittance in polymer dispersed liquid crystal. *Phys. Rev. E.* 54(5):5242-5248.

Commander, L., S. Day, & D. Selviah, 2000. Variable focal length microlens. *Opt. Commun.* 177:157-170.

Kelly, T., A. Naumov, M. Loktev, M. Rakhmatulin, & O. Zayakin, 2000. Focusing of astigmatic laser diode beam by combination of adaptive liquid crystal lenses. *Opt. Commun.* 181:295-301.

Neijzen, J., H. Boots, P. Paulissen, M. van der Mark, & H. Cornelissen, 1997. Multiple scattering of light from polymer dispersed liquid crystal. *Liq. Crys.* 22(3):255-264.

Reitz, J., F. Milford, & R. Christy, 2000. Foundations of electromagnetic theory. 4th ed. New York, Addison-Wesley Publishing Co.: 630 p.

Uvera, M. & D. Durian, 1996. Angular distribution of diffusely transmitted light. *Phys. Rev. E.* 53(4):3215-3224.