

Fast birefringent mode stressed liquid crystal

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We report a stressed liquid crystal (SLC) that produce a large shift in phase retardation at submillisecond speeds. The SLC consists of uniformly aligned micro-domains of a liquid crystal dispersed in a polymer structure. Mechanical stress produces uniform alignment, essentially eliminates light scattering, and substantially improves the electro-optic performance. A 22- μm -thick SLC film switches more than 2 μm of phase retardation in less than 1 ms. The system has a linear voltage response with essentially no hysteresis. © 2005 American Institute of Physics. [DOI: 10.1063/1.1852720]

Liquid crystal polymer composites have been extensively studied over the last decade because of their intriguing physics and their potential application in novel, fast-switching liquid crystal devices. Polymer networks created by thermal- or UV-curing of a liquid crystal/monomer mixture strongly affect the electro-optic properties of liquid crystal devices. Depending on the concentration of the monomer in the liquid crystal matrix and the details of the phase separation process, a variety of network structures can be created. At low monomer weight concentration ($<6\% - 8\%$), a low density polymer network is formed. According to Fung *et al.*¹ low-density networks dispersed in a nematic host consist of nano-sized polymer fibrils that form bundles with lateral sizes of hundreds of nanometers. The polymer bundles orient along the liquid crystal director. The director may be controlled by a surface alignment or external fields. The network stabilizes the liquid crystal matrix by locking in the director orientation with the bundles, resulting in decreased response time and increased driving voltage. Escuti *et al.*² reported a decrease of the on-times of IPS mode from ~ 90 ms in pure liquid crystal to ~ 10 ms in 2% polymer stabilized liquid crystals. An even faster response of the polymer-stabilized liquid crystal composites can be achieved by increasing the polymer concentration. However, light scattered by the polymer network and the liquid crystal micro-domains drastically reduces light transmission through the cell.

Several approaches have been explored to increase the switching speed of liquid crystal-polymer composites while maintaining optimum optical properties. Holographic polymer dispersed liquid crystals (PDLCs), having submicron liquid crystal droplets dispersed in a polymer binder, are among the fastest known liquid crystal devices, providing submillisecond response.³ Fan *et al.*⁴ produced devices operating in the near IR wavelength range using relatively high concentrations of polymer ($c \approx 10\%$) dispersed in a liquid crystal. This system can modulate IR light with about 2 ms switching speeds. High transmission was achieved by uniform surface alignment of the liquid crystal domains, eliminating light scattering. We found that while good performance can be achieved with relatively thin cells, uniform

alignment is difficult to maintain using this surface alignment approach with the thicker films required to produce the large phase retardations reported in this paper.

Doane *et al.*⁵ and Aphonin⁶ oriented liquid crystal domains by mechanical shearing of a polymer dispersed liquid crystal. This approach produced a composite with a well-oriented, relatively dense polymer network without using any aligning layers.⁷ These materials scatter light with a clear polarization dependence. In this letter we report using stressed liquid crystals (SLCs) for ultrafast birefringence switching at relatively low driving voltage and with essentially no light scattering for any polarization of incident light.

The production of a SLC cell consists of two main steps. First, a continuous polymer network is formed. The concentration of the polymer is optimized to be high enough to maintain the mechanical stress induced by shearing (we assume by adhering to the substrate) while being as low as possible to maximize the electro-optic performance (maximum phase retardation and minimal light scattering). Before shearing the SLC cell scatters light because of the randomly aligned liquid crystal domains dispersed in the polymer network. In the second step the cell is sheared by moving one substrate relative to the other. Typically the substrates are moved distances on the order of several times the thickness of the cells. This essentially eliminates light scattering and produces uniform alignment of the liquid crystal domains as is seen from the birefringence produced by the cell. We assume that shearing orders the polymer network, which then orients the liquid crystal domains in the direction of shearing. This dramatically reduces the light scattering and decreases the switching time.

We prepared sets of 22- μm -thick SLC cells using a mixture of a cyanobiphenyl liquid crystal (either 5CB, E7, or E44) and the photocurable monomer NOA65 in a weight ratio of 9 to 1, respectively. Lower concentrations of polymer produced a polymer network that could not sustain the mechanical shear. The cell, made of two indium-tin-oxide covered glass substrates, was filled with the mixture and maintained at a constant temperature while irradiated with unpolarized UV light for about 30 min at ~ 30 mW/cm². After the irradiation, all the cells appear opaque. The amount of light scattering depended on the temperature of polymerization. We found that if a cell is polymerized at a tempera-

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