Nematic liquid crystal devices with sub-millisecond response time

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ABSTRACT

Conventional nematic liquid crystal devices exhibit switching times that are in the order of several milliseconds. In this work we focus on two types of nematic liquid crystals that can overcome the limitations of conventional nematic liquid crystals and allow sub-millisecond switching times for both switching on and off: nano-pore polymer-liquid crystals and dual-frequency liquid crystals.

1. INTRODUCTION

Liquid Crystal Displays (LCDs) nowadays are based on conventional nematic liquid crystals in different configurations: twisted nematic, in-plane switching or vertically aligned. The response time of these displays is limited mainly by the switching-off time of the liquid crystal. The liquid crystal relaxes back to the voltage-off state due to elastic forces and interface alignment. The switching-on time can be accelerated actively by applying higher voltages or using overdrive schemes. The switching time in most of the current LCDs is several milliseconds.

For certain non-display applications, such as optical shutters or fast polarization switches, such a switching time is too slow. For this reason, a number of clever methods have been invented to bring the switching times below one millisecond. Unfortunately these techniques are often difficult to implement in displays. One method consists of two liquid crystal cells (one planarly and one vertically aligned cell) in which the slow switching-off speed is compensated by the other cell [1]. In this way both switching-off and switching-on of the total device occurs within 1 millisecond. Such a method is applied in commercial optical shutters from LC-Tec. Another approach that offers faster switching with conventional nematic LCs is the pi-cell [2] in which the traditional anti-parallel alignment is replaced by parallel alignment with large pretilt angles.

Apart from the smectic LCs with inherent fast switching, in the past decade mainly the blue-phase LC has attracted a lot of attention. The blue phase is actually a chiral nematic LC organized in a lattice of double twist cylinders. Until the beginning of the current century the phase was believed to be unsuited for applications due to the limited temperature interval in which the phase exists. Thanks to the polymer stabilization of the blue phase, the temperature interval in which the blue phase can be used is now several tens of degrees C [3]. Blue phase LC offers a number of interesting properties, such as sub-millisecond switching, isotropic voltage-off state (for high contrast displays) and the fact that no alignment layer is necessary. For the commercial application in displays, still some issues need to be solved, such as the switching hysteresis and the relatively high switching voltages.

In this work we will discuss recent results on two other

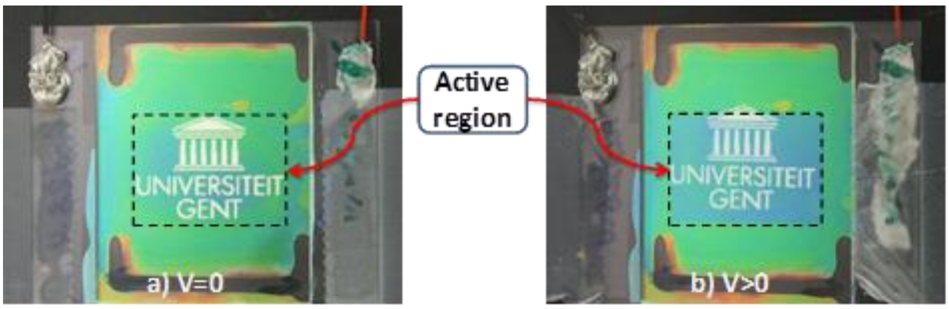

Fig. 1 Picture of a nano-pore polymer-CLC cell with the logo of Ghent University behind without voltage applied (left) and with voltage applied (right). The cell is perfectly transparent in both states but the reflection color is changed.

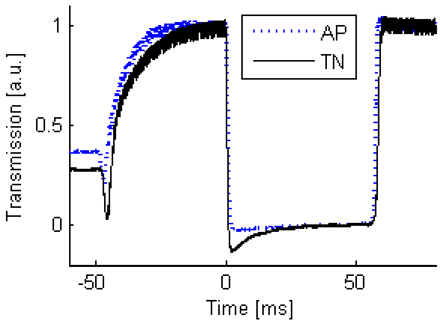

Fig. 2 Transmission of two dual-frequency nematic LC cells (AP: Anti-Parallel alignment, TN: Twisted Nematic alignment) when applying different voltages. Switching on (at 0 ms) and switching off (at 60 ms) occurs in about 1 ms.

types of materials which offer fast switching.

2. NANO-PORE POLYMER LIQUID CRYSTALS

Chiral nematic Liquid Crystals (CLCs) spontaneously align in a helical alignment with a pitch determined by the concentration of chiral dopant. When the periodicity is in the order of the wavelength of visible light, a reflection band appears which reflects one handedness of circularly polarized light. Tuning the wavelength of this reflection band in nematic chiral LC is only possible over a very limited range because the uniform CLC quickly turns into a scattering focal conic state which is unwanted for many applications.

By adding a large amount of reactive LC monomers to the non-reactive nematic LC, the uniform CLC structure can be fixed using UV photopolymerization. When the polymerization reaction is fast enough, the partially polymerized LC network exhibits nano-scale droplets of non-reactive LC [4]. Upon application of electric field, the LC inside the droplets reorient, causing a shift in the photonic band gap and due to the small droplet size, no scattering can be observed. Recently we have demonstrated that a large shift of the reflection band of 100 nm is feasible with a response time of less than 50 µs [5]. A picture of a cell with reflection band in the visible is shown in Figure 1.

3. DUAL-FREQUENCY NEMATIC LIQUID CRYSTALS

Dual-frequency nematic liquid crystals are characterized by a positive dielectric anisotropy for low frequencies and a negative one for higher frequencies. This enables the traditional switching-on by applying a low frequency voltage signal (typically around a few hundred Hz) and a fast switching-off by using a short pulse of a high frequency voltage signal (typically a few tens of kHz). Ideally the LC material should have a transition from positive to negative anisotropy around a few kHz. However, the switching-off voltage (and consequently also the speed) should be limited because for higher voltages backflow occurs and the switching-off time is drastically increased [6]. Recently we have demonstrated that the backflow effect can be used in a positive way, leading to switching-off times of about 1 millisecond [7] as demonstrated in Figure 2.

5. CONCLUSION

Thanks to some new developments, special types of nematic liquid crystal exhibit fast switching times, which is especially wanted for fast optical shutters. Using either polymerizable nematic LCs or dual-frequency nematic LCs, we have demonstrated respectively 50 µs and 1 ms switching times.

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