Liquid Crystal Displays Compatible with Contact Lenses for Vision Correction Applications

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ABSTRACT

This paper presents the measurements of light transmission and spectral radiance of guest-host liquid crystal cells compatible with contact lenses for vision correction applications. From these measurements a contrast of 1:2 was calculated and its optical quality was qualitatively compared to ND filters (1:3 contrast).

1 INTRODUCTION

A smart contact lens is a device in direct contact with the eye, with integrated electronics which can provide sensing, actuation and wireless communication or energy transfer functionality [1, 2]. Figure 1 presents the smart contact lens concept with possible components such as: electro-optical module (i.e. guest-host liquid crystal GH-LCD) and driver chip fully embedded on a soft package. The displayed smart insert was developed by thin-film technology, lamination steps and thermoforming steps, as described in [3]. Since the range of possible applications is very wide, including active vision correction or enhancement [3–6], biomedical sensing [7, 4, 8, 9] and in the long term perhaps even augmented reality [6, 10], many groups are performing research on this topic worldwide. Following this relevant trend, it is already clear that the potential impact and the relevance for biomedical applications are very high [2]. The use of smart contact lenses to actively correct certain vision disorders has only been proposed [6] through the integration of liquid crystal (LC) cells particularly appealing for eye disorders (related to the iris and the crystalline lens).

The so-called White-Taylor Guest-Host liquid crystal (GH-LC) has proven to be a suitable configuration for an active artificial iris [5 ,6] due to the fact that it provides a bright OFF-state and an acceptable contrast in a polarizer-free and hence extremely thin stack, thus enabling the embedding within contact lenses, as shown in Figure 2. The GH-LC is a mix of colored dye, a chiral dopant and a negative dielectric liquid crystal which is homeotropically aligned. It is based on voltage dependent light absorption. The automatic switching is controlled by a custom-made silicon chip or specific power source.

Optical quality and contrast are two key parameters to express the performance of the GH-LC, especially for the artificial iris application. However, their characterization has not being investigated for a GH-LC display compatible with a contact lens [11].

In this work, we would like to present the experimental results of qualitative optical quality and quantitative contrast of a GH-LC compatible with smart contact lenses, and its benchmark to neutral-density ND filters.

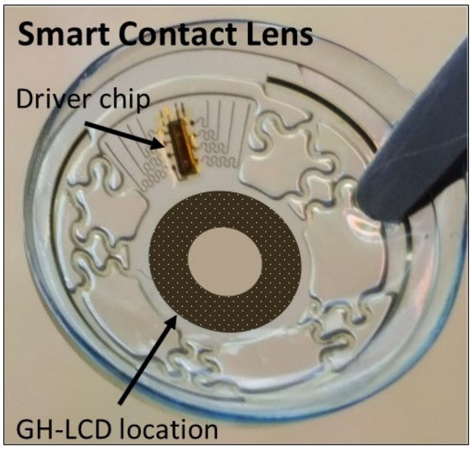

Fig. 1: Picture of the smart contact lens with a representation of a guest-host LCD display.

2 EXPERIMENTAL SETUP

2.1 CMOS digital camera

The experiment consisted on capturing white light passing through a glass/chrome visual target with a CMOS digital camera from Thorlabs®, while keeping all the camera settings constant. Image quality and contrast were extracted after comparing situations with and without the GH-LC and different ND filters.

2.2 Spectral radiance

Using the same optical setup the spectral radiance was measured with the spectrum analyzer SpectraScan® PR®-670 from PHOTO RESEARCH® between 380 nm and 780 nm when the cells were OFF and ON, in order to validate the contrast at different light wavelengths and its quantitative filtering effect.

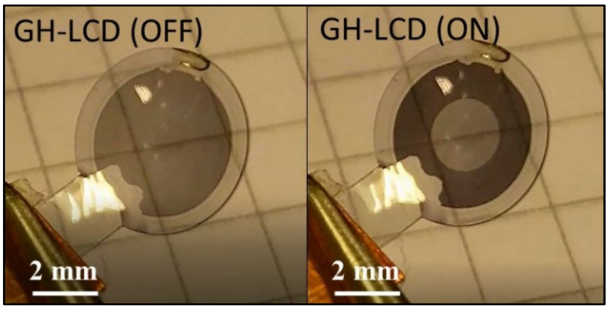

Fig. 2: Pictures of guest-host liquid crystal thermoformed cell with one patterned ring as active pixel (center is kept without actuation), without (left) and with (right) electric field.

3 RESULTS

3.1 CMOS digital camera

Figure 3 presents the results when imaging the light source with the CMOS digital camera. First, the reference background and glass/Cr target were measured to calibrate the set of following measurements, as shown in Figure 3a-b. It should be noted that all the measurements were taken in a dark room in order to reduce light interference. Next, a neutral density (ND) filter with a light transmission of 40% and 10% were interposed to the optical setup. The results are shown in Figure 3c-d with measured transmissions of 39.2% and 11.8% with respect to the glass/Cr target and measured for the dotted-line central square. These values were selected as benchmark for the electro-active element, as guidelines for a clear OFF state and relatively opaque ON state. The contrast calculated with the transmissions of the ND filters is $1{:}\frac{39.2\%}{11.8\%} = 1{:}3.3$.

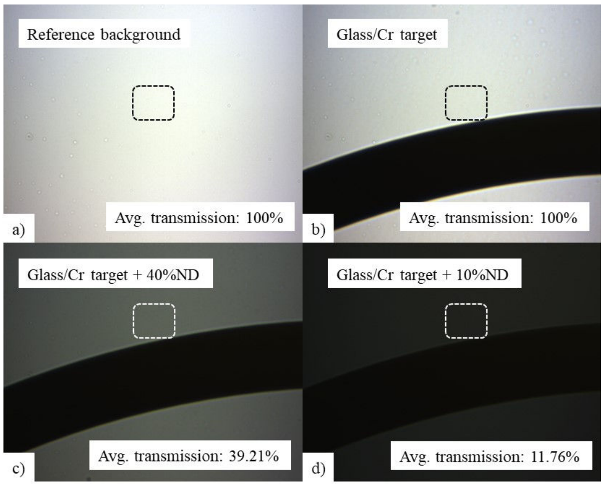

Fig. 3: a) Image of the reference white background imaging directly the light source; b) Image of the glass/Cr target with calibrated average transmission of 100% at the dotted-square; c) Image of the target with a 40%ND filter and d) Image of the target with a 10%ND filter.

Figure 4 presents the results when imaging the target through a GH-LCD cell (diameter: 6 mm, gap: 10 μm, thickness: 110 μm) previously fabricated as explained in [5]. Figure 4a-b shows the calibration measurement of the white reference background and glass/Cr target at 100% of transmission. Next, a GH-LCD with a 3%wt concentration of black dye was interposed to the optical setup when switched OFF and ON (using an electrical signal of 20 Vpp at 1k Hz). The results are shown in Figure 4c-d with measured transmissions of 65% and 32% with respect to the glass/Cr target and measured for the dotted-line central square. The contrast calculated with the transmissions is $1{:}\frac{65\%}{32\%} = 1{:}2$.

Qualitative optical quality can be assessed when comparing the ND filters with the GH-LCD transmissions images in Figures 3c-d and 4c-d, respectively. Besides providing an intrinsic higher contrast, ND filters ensures a clear image of the Cr traces on the target. The GH-LCD provides a blurrier image of the Cr traces. This can be due to the higher number of interfaces (air/PET/electrode/LCD) and the spacing technology used to separate the top and bottom electrodes. While contrast can be improved by optimizing the dye concentration, chiral dopant concentration, gap thickness and dichroic ratio, the optical quality could be improved by a different spacer's arrangement and less birefringent substrates.

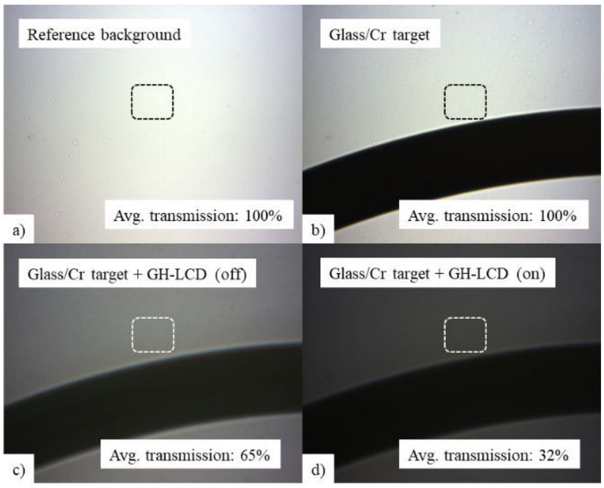

Fig. 4:) Image of the reference white background imaging directly the light source; b) Image of the glass/Cr target with average transmission of 100% at the square; c) Image of the target through the GH-LC when off (transmission of 65%) and d) Image of the target through the GH-LC when on (transmission of 32%).

3.2 Spectral radiance

Figure 5 shows the measured radiance (W.sr^{-1}.m^{2}) versus the wavelength (nm) from 380 to 780 nm, for the reference background signal (red solid line), the GH-LCD when OFF (blue dotted-line) and the GH-LCD when ON (blue solid line). The radiance peaks in the reference measurement are expected from the type of white light source used (Mercury-Xenon lamp, L10852 / L8251). The radiance levels at the green color spectrum (between 495 nm and 570 nm) for the reference, OFF and ON (using an electrical signal of 20 Vpp at 1k Hz) are 4.5, 2.7 and 1.4 $W.sr^{-1}.m^{2}$, respectively. With respect to the reference signal, the GH-LCD OFF, ON ratio is 1:1.7 and 1:3.2, respectively, while the contrast OFF/ON is 1:1.9. This result is within error measurement of the CMOS digital camera output, validating a current 1:2 contrast ratio.

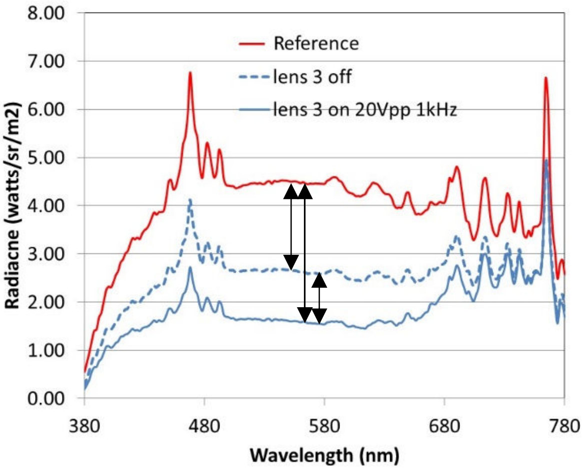

Fig. 5: Measured radiance ($W.sr^{-1}.m^{2}$) versus wavelength (nm) between 380 nm and 780 nm for the reference background signal (red solid line), GH-LCD when OFF (blue dotted-line) and GH-LCD when ON (blue solid line). The black arrows represent the calculated contrast ratio between the signals.

4 CONCLUSIONS

This paper presents the optical transmission measurements of a GH-LCD when imaged through a glass/Cr target illuminated with white light. From the optical transmission measurements a contrast of 1:2 was found for the GH-LCD, while the ND filters benchmark showed a contrast of 1:3.3. Contrast can be improved by optimizing the dye concentration and dichroic ratio as well as the geometry of the cell. Additionally, the paper shows the radiance versus wavelength, which allows to calculate the contrast at different light colors. For green color a contrast of 1:1.9 was found. Optical quality was quantitatively extracted when comparing the images between the ND filters and GH-LCD cells. Blurry images are thought to be caused by higher number of interfaces at the GH-LCD cells and the spacers within the cell. The latter ones will be optimized in order to reduce such effect.

ACKNOWLEDGEMENTS

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