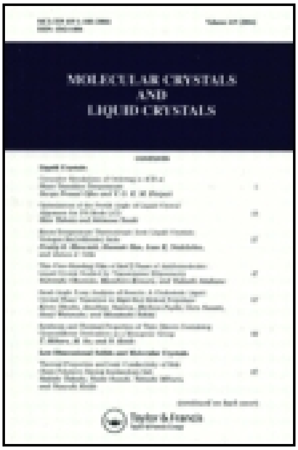

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Spatial Light Modulation with a Bacteriorhodopsin-Driven Liquid Crystal-Cell

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Dried oriented Purple-Membrane (PM)-films were fabricated by electrosedimentation of aqueous PM-suspensions on ITO-covered slides. The photoelectric signals of illuminated films were used to switch twisted-nematic (TN)- and ferroelectric (FE) liquid-crystal (LC) cells. Due to the quasi differential behaviour of the photocurrent with respect to illumination intensity, a PM/TN system represents an inherent novelty filter. The use of FE-LC cells for permanent data display is demonstrated and a prototype of a pixelated BR-LC-OASLM is presented.

<u>Keywords:</u> bacteriorhodopsin; purple membrane; oriented films; spatial light modulators

INTRODUCTION

Optically-addressed spatial light modulators (OASLM) are important devices for real-time incoherent-coherent-light conversion, optical correlation, phase conjugation, real-time holography, and in the field of opto-electronic implementations of neural networks[1]. SLM's based on the photochromic properties of Bacteriorhodopsin (BR) have been used[2,3] successfully. However, these devices have a limited write- and readout wavelength range.

BR is a retinal protein found in the purple membrane of the archaebacterium *Halobacterium salinarum*[4] and acts as light-driven proton pump. By absorption of light, it undergoes a photocycle of various intermediate states differing in conformations, absorption spectra and refractive indices. Due to it's remarkable stability and interesting photochromic properties, BR has attracted attention for technical applications[5,6,7].

PM-fragments (patches) can be purified and deposited as oriented films by different methods[8,9]. Here the electrosedimentation method[10] is used, which takes advantage of the negative net charge and the permanent dipole moment of a PM-patch due to different negative surface-charge densities of cytoplasmic and extracellular side. When applying an electric field to a PM-suspension, the PM-patches partly orient, migrate and finally deposit as a soft layer on the anode. These films can be dried, thereby fixing the PM-patches, so that the orientation is preserved. After appropriate contacting, dried films show photoelectric activity due to a charge displacement with a vectorial component in direction of the device normal[9].

EXPERIMENTAL

All PM-films were prepared on ITO-covered slides (25 Ω/□). Aqueous PM-suspensions were sonified prior to use and placed between the ITO- and a planar counterelectrode made of Au or Pt (Fig. 1). The parallel alignment of both electrodes was checked with a microscope. A constant voltage was applied and the resulting current was monitored.

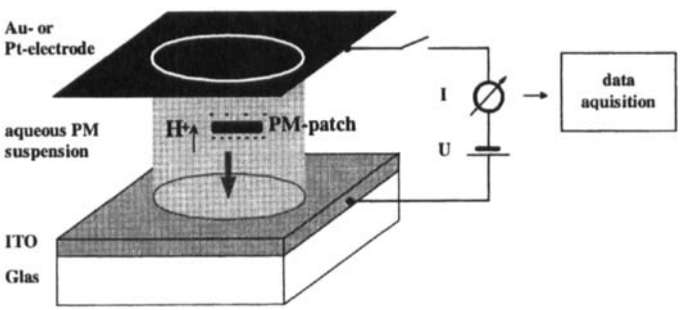

FIGURE 1: Schematic of PM-film deposition on ITO-slides

To avoid film-cracking, the PM-films were slowly dried for at least 24 h in an atmosphere of ≈ 95% relative humidity. Film thickness and surface roughness were measured with a surface profiler (Dektak). All PM-films were contacted with a 250 nm thick aluminium counterelectrode vacuum deposited directly on the PM-material, forming a planar capacitive system. Pixelated films were prepared by mechanically dividing the PM-films and Al-electrodes into smaller sections.

Because of the high impedance of PM-films an electrometer (Keithly 6512, input impedance >200 TΩ) was used to measure the photovoltages. All photoelectric experiments were performed with the focused and heat filtered light of a 150 W halogen lamp, resulting in up to 0.7 W/cm^2 white-light intensity.

Pixelated LC-cells with 4 x 4 individually contacted pixels of 1 mm^2 size were fabricated from ITO-slides with photolithography techniques. For alignment (AL), two crossed layers of SiO were vapour deposited onto the ITO. Two matching slides were glued together with epoxy resin and the cell gap was adjusted by 7 μm spacers. The cells were filled with a twisted nematic LC (Merck MLC 6204-000) and finally sealed. For experiments with ferroelectric LC's commercial available single pixel LC-cells with polyimid-AL and gaps of 2 μm and 4 μm were used. These cells were filled with Merck ZLI 3654 and Merck ZLI 4237-000 respectively.

A BR-LC-OASLM prototype consisting of a 4x4 pixelated PM-film with a pixel size of 5 mm x 5 mm size connected to a correspondingly pixelated TN-LC cell was build (Figs. 2 and 3). After illumination of a PM-pixel, the TN-cell is temporary switched and the resulting transmission changes are monitored with a photodiode.

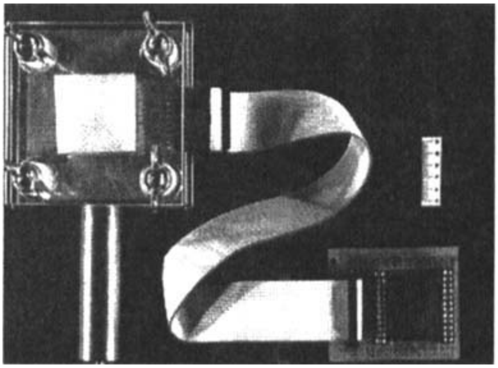

FIGURE 2: BR-LC-OASLM setup, consisting of pixelated PM-film connected to LC-cell

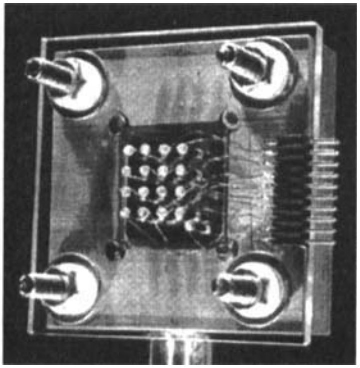

FIGURE 3: Detailed view to the contacted PM-film

RESULTS AND DISCUSSION

Dried oriented PM-films with 0.5 μm to 10 μm thickness and an average roughness of 0.3 μm were produced. For a fixed gap-size of 0.49 mm the deposition-voltage and -time was varied for optimized photoelectric power and surface quality. The latter is strongly influenced by the applied voltage because of water electrolysis, leading to the formation of gas bubbles and local pH changes in the suspension.

With oriented PM-films of 1.3 cm^2 size, peak photovoltages of up to 13 V have been observed. The measured (transient) photocurrents showed a quasi-differential behaviour with respect to the incident light intensity (Fig. 4).

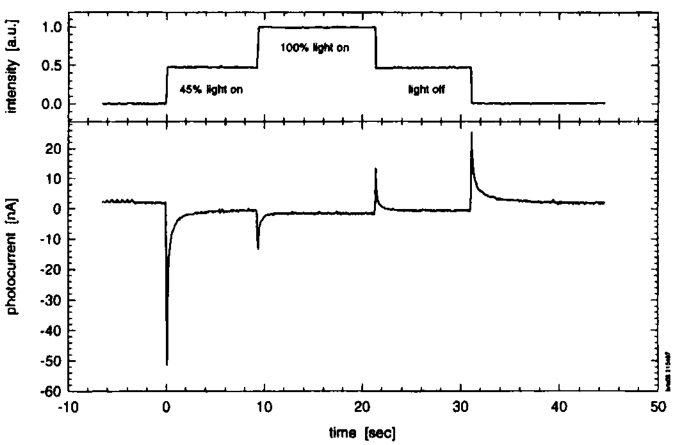

FIGURE 4: Photocurrent of an illuminated dried PM-film

When connected to an TN-LC-cell, this leads to transient absorption changes whenever the differential change of the illumination intensity is large enough. The system thereby represents a novelty filter (Fig. 5). When connected to a bistable FE-LÇ-cell, the LC remains switched during PM-film illumination so that a permanent display of the incident optical data is possible (Fig. 6). In addition, this system has the advantage of a faster response.

As can be seen from Fig. 5, the response time of the pixelated PM/TN-device was unsatisfyingly slow, also limiting the novelty filtering option. Nevertheless, single pixels could be optically addressed and the display of simple patterns was possible. The sensitivity of the device is still poor compared to commercially available OASLMS, but may be improved by PM-films with enhanced orientation.

To overcome the limited optical resolution of pixelated devices, we propose a BR-LC-OASLM consisting of an oriented PM-film in direct contact with an AL-LC-AL stack. The ITO-layers enclosing the whole stack are in galvanic contact, so that, if light hits the PM-film, a voltage should appear across the LC-layer within the illuminated area and switch the crystal. An additional dielectric mirror between PM-film and the alignment-layer may seperate write- and readout light. The proposed configuration resembles commercially available α:SiH-OASLM's[11], but it offers the advantage of stand-alone operation without any driver electronics.

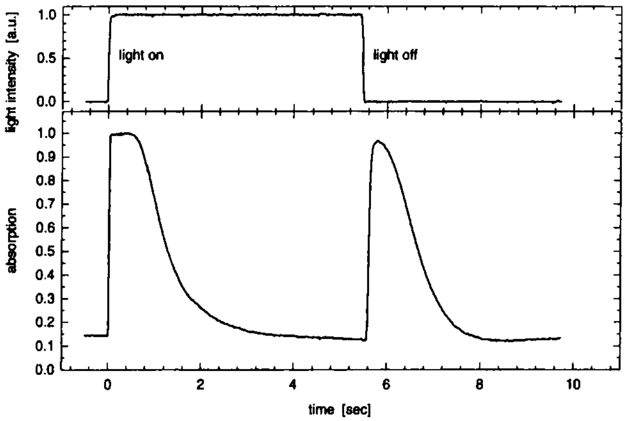

FIGURE 5: Transient absorption change of a TN-LC-cell driven by an illuminated PM-film. The absorption of polarizers is neglected.

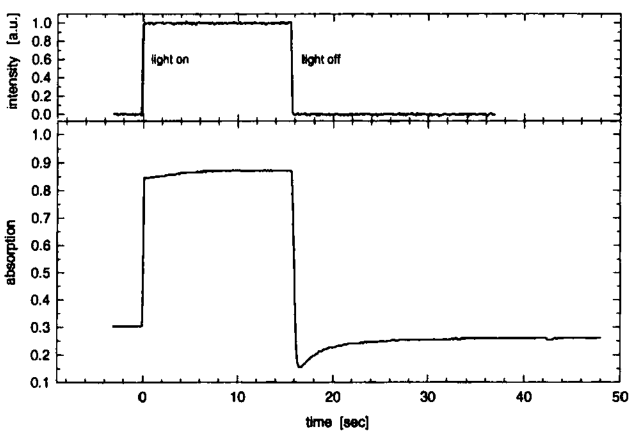

FIGURE 6: Transient absorption change of a FE-LC-cell driven by an illuminated PM-film. As in Fig. 5, the absorption of polarizers is neglected.

Up to now, no direct switching of TN-cells has been observed. Experiments with single-pixel TN- and FE-LC cells externally connected to PM-films showed that the photoelectric power of PM-films is still too low to drive a LC-cell of the same size. Intensity modulated experiments suggest that the photoelectric output of the films is not so much limited by the used light intensity, but by the low degree of PM-orientation. In addition, an improved PM-film surface quality is needed for precise gap size adjustment.

CONCLUSION

Together with LC-cells, the photoelectric properties of dried oriented PM-films can be used to perform optically-addressed spatial light modulation. The limited resolution of pixelated devices may be overcome with the proposed direct contact BR-LC-OASLM, for which a higher degree of orientation and an improved surface quality of the used PM-films is necessary.

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