Optical switching behaviour of electrochromic devices

Matthias Marescaux
Supervisor: Kristiaan Neyts

I. INTRODUCTION

The electric switching behaviour of electrochromic materials has been widely studied for many years. Recent applications in flexible electronic displays have only fueled the interest in enhancing switching speeds, up to video applications. In this paper, the focus is on the optical properties of the switching behaviour. With the use of a CCD camera, the diffusion constant of the molecules can be calculated.

In 1966, S.K. Deb and J.A. Chopoorian discovered the electrochromic effect [1]. Electrochromic molecules can reversibly change their colour by absorbing or ejecting an electron. Because the reversible colour change can be controlled by applying a voltage, electrochromic materials quickly found their way in some interesting applications: dimming of rear mirrors, electronically driven attenuators and sunglasses and ambient lighting. The first efforts to integrate this technology in electronic displays were unsuccessful due to the slow colour change of the technology (order of a few seconds). It lasted until the late nineties before a solution for this problem was found. By attaching the electrochromic molecules on a TiO$_2$ nanostructured electrode, the switching speed can be reduced to the order of 100 milliseconds (Fig. 1 & 2) [2-4], resulting in one of the fastest electronic papers.

II. EXPERIMENTAL

The investigated solutions are mixtures of 2 electrochromic molecules, solved in propylene carbonate. The concentration of both molecules is about 25 millimolar ($\approx 10^{-5}$ m$^{-3}$). One of the two molecules is a viologen, which is a popular electrochromic molecule (the base group of this molecule is shown in Fig. 2).

In this paper, I will focus on the optical switching behaviour of electrochromic mixtures and the calculation of the diffusion constant.
100 µm away from each other. A CCD camera is mounted on a microscope which measures the change of light intensity as a voltage step of $V_L - V_R$ is applied (Fig. 3).

![Experimental setup](image)

**Fig. 3: Experimental setup**

**III. RESULTS AND DISCUSSION**

Due to the applied voltage, an electric field will force the charges in the solution to move towards the electrodes (drift and diffusion). The charge content of the solution, originating from the viologen molecules ($z = +2$) and their counterions ($z = -1$), is so high that the electric field in the bulk is screened. The only significant voltage drop is situated near the electrodes, while the voltage in the bulk is homogeneous. Because the voltage drop near the electrodes is now of the order of the redox potential, the electrochromic molecules can exchange electrons with the electrodes, giving them a colour (fig. 4).

![Time dependent light intensity measured by CCD camera](image)

**Fig. 4: Time dependent light intensity measured by CCD camera**

The beginning of the electrochemical reaction is fast but as time progresses, the diffusion barrier near the electrode will saturate. To overcome this saturation, molecules from the bulk that have not exchanged electrons will diffuse towards the electrodes while molecules that already exchanged electrons will diffuse away from the electrodes. This means that all charges move by diffusion:

\[
\frac{\partial c(x,t)}{\partial t} = D \frac{\partial^2 c(x,t)}{\partial x^2},
\]

with $c(x,t)$ (m$^{-3}$) the concentration of charges and $D$ (m$^2$/s) the diffusion constant. Because of the relation between the concentration of coloured molecules and light intensity (law of Lambert-Beer), the diffusion constant of the molecules can easily be deduced from Fig. 4. In this case, the diffusion constant of the molecule on the left is $8.5 \times 10^{-11}$ m$^2$/s and of the one on the right is $1.2 \times 10^{-11}$ m$^2$/s.

**IV. CONCLUSIONS**

Optical analysis is a fast and accurate method to study the switching of electrochromic displays and to calculate the diffusion constant of electrochromic molecules.

**ACKNOWLEDGEMENTS**

The author would like to thank F. Strubbe for the help with the experimental setup.

**REFERENCES**