Charge transport in electronic paper

Filip Beunis, Filip Strubbe, Matthias Marescaux

Supervisors: Kristiaan Neyts, Alwin Verschueren

Abstract: **Electrophoretic ink is an important candidate for the realization of electronic paper. This ink contains pigments which are charged by surfactants. The surfactant also creates excess charges in the form of micelles. The total charge in the micelles is usually orders of magnitude larger than the total charge in the pigments, so it is very important to understand the behavior of these charged micelles. Transient current measurements of a low dielectric fluid containing charged inverse micelles between planar electrodes can be used to determine properties of the charges. It is not always easy to interpret these currents, because different physical mechanisms are involved. Which of these is dominant depends on the device parameters and on the operating conditions. In this work, different operation regimes are explained and the parameter regions where they apply are discussed.**

Keywords: **electronic paper, electrophoresis, charge transport**

I. INTRODUCTION

Electronic paper is a new display concept which combines the advantages of printed paper (readability, flexibility, little or no power consumption) with the advantage of electronic displays: the ability to change the information content. It is only starting to be commercialized (Figure 1) and there are a lot of competing technologies to implement this concept. Among the most important ones are reflective liquid crystal displays, electrochromic displays, electrowetting displays and electrophoretic ink displays.

Figure 1: The newspaper ‘De Tijd’ experiments with a display from I-Rex based on electrophoretic ink, a technology developed by Philips and E-Ink.

The ELIS department of UGent is active in many fields related to electronic paper. Research is carried out, in cooperation with industrial partners, on flexible electronics, driving schemes, liquid crystals, electrochromism and electrophoresis. This work deals with the latter technology.

II. ELECTROPHORETIC INK DISPLAYS

The working principle of electrophoretic ink displays is very simple: electrically charged colored pigment particles move in a fluid under the influence of an electric field. In the most straightforward implementation, this results in a display as illustrated in Figure 2.

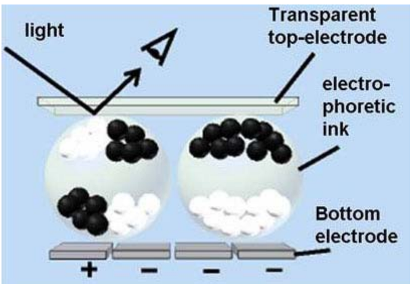

Figure 2: Implementation of an electrophoretic ink display: by changing the polarity of the voltage over the pixel electrodes, either positively charged white pigments or negatively charged black pigments become visible to the viewer.

For the fluid, an oil with a very low dielectric constant is used. In this environment, as a result of very strong electrostatic attractions, charges which would interfere with the movement of the pigments can hardly exist. However, the pigments themselves have to be charged. In order to obtain a stable charge on the pigment, a surfactant is added, which encapsulates the pigment particles (Figure 3a). Unfortunately, the surfactant molecules also self-aggregate into inverse micelles, in which stable charges can exist (Figure 3b). The amount of these extra charges is much smaller than in the case of a polar solvent, but still much larger than the charge represented by the pigments themselves.

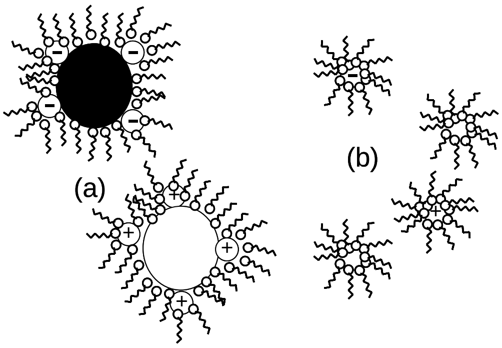

Figure 3: Surfactant molecules encapsulate the pigments and stabilize their charges (a) but also self-aggregate into inverse micelles, of which some are also charged (b).

F. Beunis, F. Strubbe, M. Marescaux and K. Neyts are with the Electronics and Information Systems Department, Ghent University (UGent), Gent, Belgium.

A. Verschueren is with Philips Research Laboratories, Eindhoven, The Netherlands.

E-mail of corresponding author: Filip.Beunis@ELIS.UGent.be .

Therefore the invisible charged inverse micelles determine the electric behavior of the electrophoretic display. Their movement causes the most important contribution to the electric current and to the power dissipation. They also influence the electric field felt by the pigments, resulting in a slower operation. Therefore, it is important to model their behavior.

III. TRANSIENT CURRENT MEASUREMENTS

We work with a very simple structure (Figure 4): two plain electrodes are fixed at a known distance between each other, and in the gap between them is a mixture of solvent and surfactant, without pigments. A simple initial condition, a homogeneous distribution of all the inverse micelles, is obtained by short-circuiting the electrodes for a few minutes. Then a dc-voltage is applied over the electrodes and the resulting electric current is measured.

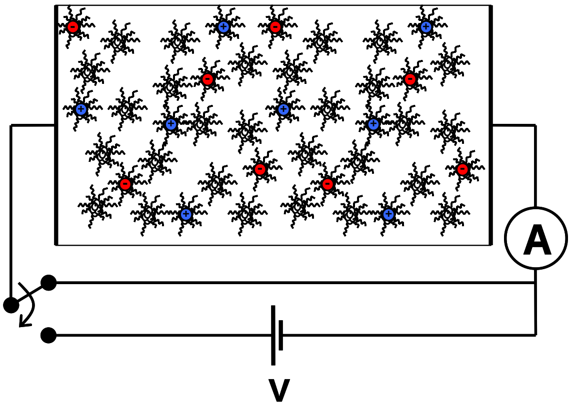

Figure 4: Representation of a transient current measurement.

IV. MODELING CHARGE TRANSPORT

Analyzing the transient current measurements shows that different mechanisms play a role. Usually one of them is dominant, resulting in a typical regime. Measurements (Figure 5) in different situations show a good correspondence with the results predicted by simulations and analytical approximations.

A. Drift of charged inverse micelles

When charges are subjected to an electric field, they feel a force which accelerates them. When they move in a liquid, they feel an opposite force due to friction. These two forces become quickly balanced, resulting in a speed of the charge which is proportional with the electric field.

If the average concentration of charges is relatively low and the applied voltage high, this mechanism dominates the transient current measurement. An analytical approximation shows that in this situation the current decreases linearly over time [1], which is observed in the measurements (Figure 5a).

B. Screening of the electric field

For higher average charge concentrations, the field induced by the charges which are moved becomes important. As a result the movement of the charges slows down and analytically the current should decrease according to a power law [2]. In Figure 5b we can see that this is indeed the case, at least in some time interval.

C. Diffusion of inverse micelles

When the applied voltage is very low, the thermal movement of the charges is dominant over the movement in the electric field. This should result in an exponential decrease of the current, which is confirmed by the measurement in Figure 5c.

D. Reactions between inverse micelles and at the electrodes

Two neutral inverse micelles can interact to generate two charged ones, and two charged inverse micelles can recombine into two neutral ones [3]. In addition, new charges can be injected at the electrodes. All these mechanisms result in new charges which can move through the device and cause a steady state current. In some cases this steady state current becomes of the same order of magnitude as the transient current. In this case the measurements (Figure 5d) show a current which is almost constant over time.

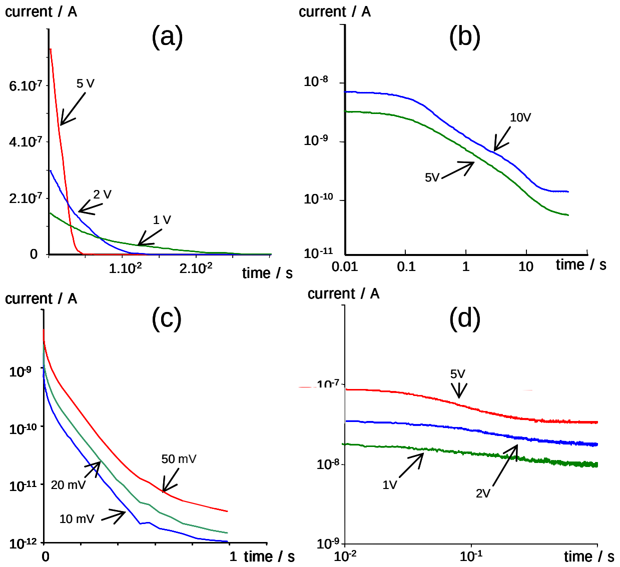

Figure 5: Transient current measurements in different regimes: (a) in a cell with few charges, when drift is dominant (linear scale), (b) in a cell with many charges, when field-screening is dominant (double-logarithmical scale), (c) for low voltages, when diffusion is dominant (logarithmical scale), and (d) in a thick cell, where reactions are dominant (double-logarithmical scale).

V. CONCLUSIONS

The electrical operation characteristics of electrophoretic ink displays are strongly depending on charges in invisible, inverse micelles. The mechanisms governing their behavior have been identified and modeled. Measurements, theory and simulations show a good agreement.

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