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Modelling and electro-optical testing of suspended particle devices

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ABSTRACT

Some smart windows make use of suspended particle devices (SPDs) which are made of charged rod-shape particles that change their orientation in an applied electric field, thereby allowing transmittance control. In this work, the electro-optical behaviour of a commercial SPD is analyzed. Impedance analysis shows characteristics similar to those of a Randles circuit, and a modified equivalent circuit is proposed and experimentally validated. Intermediate levels of transmittance are obtained using a customized field programmable gate array (FPGA)-based electrical circuit. Finally, measurements are taken to check the applicability of the SPD device and control system in smart glazing or photonic applications.

1. Introduction

There are many products where controlled variable light transmission is desired: smart windows, skylights and sunshades for the architectural, aircraft, marine, automotive and appliance industries; sunglasses, goggles and other eyewear; self-dimmable automotive sunroofs, sun visors and rear-view mirrors; and flat panel information displays. Light transmission control can be obtained with chromogenic materials. The science and technology of these chromogenic materials has attracted growing interest during the recent years [1–3].

There are two main categories of chromogenic technologies, depending on the activation process: non-electrical and electrical. Within the first category the most relevant are photochromics, thermochromics and thermotropics. Three types of materials are mainly used in the second category: liquid crystals (LCs), electrochromic (EC) materials, and electrophoretic or suspended particle (SP) substances. Each type of material manages light transmittance control in its own way.

LCs dispersed in organic polymer matrices (polymer-dispersed liquid crystals (PDLCs)) may be prepared as flexible, wide-area thin films where LCs form microdroplets that strongly scatter visible light. When an AC field is applied perpendicularly to the film, its LC molecules change directions and its optical characteristics vary [4]. Electrochromism involves electroactive materials that present a reversible change in optical properties when electrochemically oxidized or reduced [5,6].

The development of suspended electrophoretic particle devices spans many years. The first device based on suspended particle device (SPD) technology (also called "light valve") was invented by Dr. Edwin Land in the 1930s. The active layer of the device has needle-shaped or spherical particles suspended in an organic fluid or gel, and is laminated or filled between two transparent electrodes. Particles are suspended randomly when no voltage is applied, blocking the passing of light (see Fig. 1(a)). If a signal of alternate voltage is applied, the particles move their internal charges to a minimum energy state, rotating them and aligning as a set, permitting light to pass through the film (Fig. 1(b)). Typical transmission ranges are 20–60%, with switching speeds of hundreds of milliseconds. The voltage required for the device to operate depends on its thickness, usually in a range between 20 and 150 V rms. In contrast to ECs, an electric field is required to keep the film transparent.

In this work, a commercial SPD has been analyzed in detail, both in electrical and optical response, based on a previous approach [7]. An improved electrical model is proposed and validated in order to permit understanding of the electro-optical switching of these devices. An electronic driver to control the device has been implemented and tested. Several conclusions about its operation are also presented.

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2. Devices and experimental set-up

The SPD test, with an active area of 28 cm × 22 cm and a thickness of 300 μm, used for this work is a Cri-Regulite device supplied by CRICURSA (Cristales Curvados SA, Barcelona, Spain). CRICURSA [8] is a Licensee of Research Frontiers [9] for the SPDs. The film was made as detailed in Ref. [10], by means of a cross-linked polymer matrix with droplets of polyhalide particles suspended in a liquid suspension distributed in it. The first step is the synthesis of a matrix resin with pendant phenyls. A photoinitiator was dissolved in 1 ml of tetrahydrofuran (THF) and added to 1 g of the matrix resin. The combination was mixed and left in a vacuum oven at 90 °C under reduced pressure for 1 h. A suspending polymer and a paste of pyrazine dicarboxylic acid polyiodide crystals were added to 0.182 g of a suspending polymer with a molecular weight that leads to the decreasing viscosity of the capsules containing the crystals and to the reduction of their response time to an externally applied electrical voltage [10].

The emulsion was spread over an indium tin oxide-coated glass plate using a glass rod and exposed to UV radiation for 30 s in order to cure it. Curing was carried out with a second indium tin-oxide-coated glass plate on top of the emulsion. Refractive indices of the droplets and the matrix components in the film matched to within 0.005, and the droplets were specified around 1 μm in size, both items leading to a low-scattering and blue-tone device, as can be seen in Fig. 2.

Fig. 3 shows a microscopic photograph of the main layer, in which the spherical particles are suspended. A mean diameter of 8.9 μm is obtained in the micro-droplets originating from the manufacturing process. The homogeneity in the droplet distribution, measured through photographs such as the one shown, resulted in a density of 1050 droplets/mm^2. By means of microscope focusing, a layer depth of around 30 μm is determined.

Impedance analysis was carried out using a Solartron 1260 analyzer, capable of scanning between 0.5 mHz and 32 MHz, with a voltage bias between ±40.95 V. It can measure impedances of up to 1014 Ω. The optical response of the device was measured during switching, using a lamp with an emission similar to the A illuminant, and an Acton Research monochromator with a Hamamatsu photomultiplier tube, a system with 5 nm resolution and 1% error in radiance measurement. Transmittance measurements are taken through an optical fibre bundle in close proximity to the SPD surface, with a numerical aperture of 0.22. The acceptance angle is 12.7°, which means that the main contribution to measured transmittance is by direct, not diffused (scattered) light.

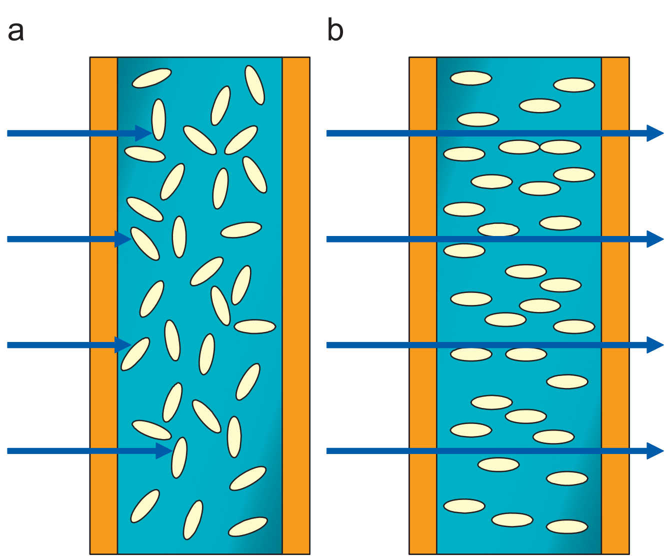

Fig. 1. Working principle of a suspended particle device: (a) operation with no applied voltage and (b) operation with applied voltage.

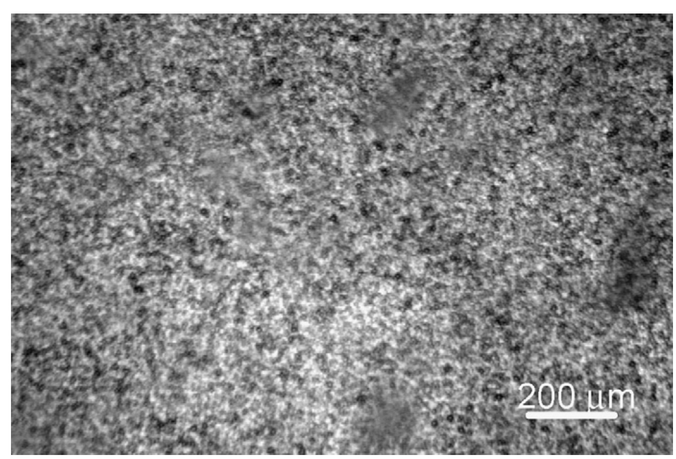

Fig. 3. Microscopic photograph of the SPD balls obtained focusing between the two contact layers.

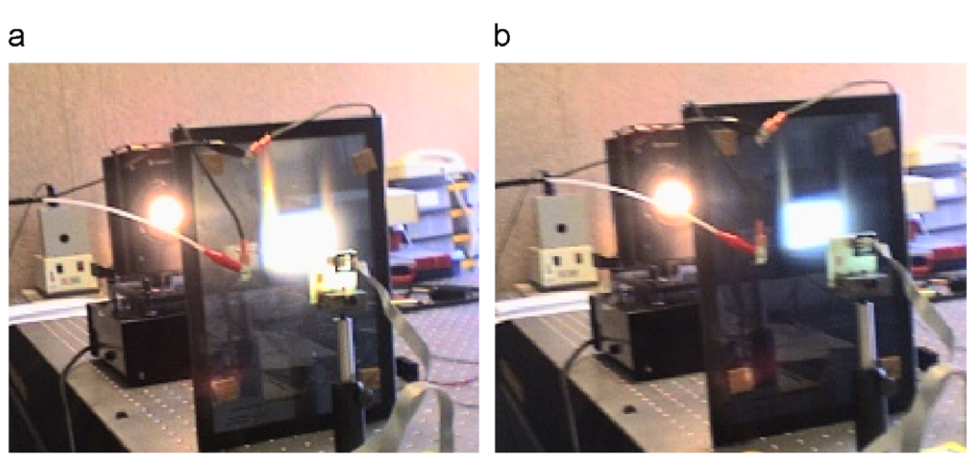

Fig. 2. Photograph of the SPD and the measurements setup: (a) with applied voltage and (b) without applied voltage.