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Superhydrophobic films obtained from a spraying technique: Electrowetting dependence on the drying condition and ultraviolet irradiation

Hérica Dias da Rocha, Marcos da Silva Sousa, Kevin Figueiredo dos Santos,
Nara C. de Souza, Josmary R. Silva*

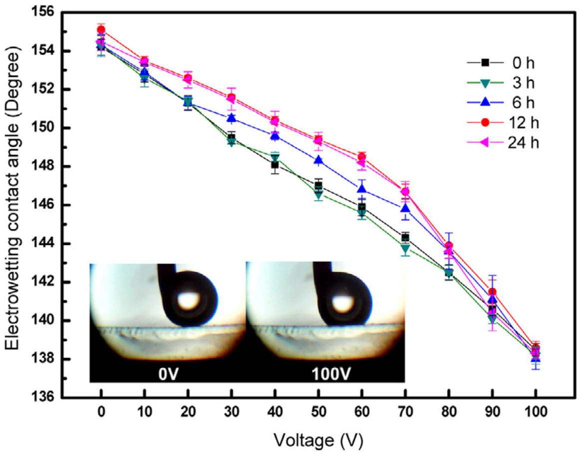
Grupo de Materiais Nanoestruturados, Universidade Federal de Mato Grosso, Barra do Garças, Mato Grosso, Brazil

HIGHLIGHTS

- Superhydrophobic films were successfully prepared using a spray technique.
- Electrowetting on dielectric (EWDO) effect was demonstrated in sprayed superhydrophobic films.
- Electrowetting on dielectric effect in superhydrophobic films depended on the ultraviolet irradiation time.
- The Young–Lippmann theory was applied to the electrowetting of irradiated films.
- This work showed the importance of experimental factors in controlling the EWDO effect.

GRAPHICAL ABSTRACT

Electrowetting contact angle as a function of applied voltage for superhydrophobic films (dried under vacuum) at different irradiation times (0, 3, 6, 12 and 24 h). The inset shows illustrative images of droplets on films without irradiation (0 h) and at two different applied voltages. Error bars represent sample standard deviations. The solid curves are drawn to guide the eyes.



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ABSTRACT

Superhydrophobic films were prepared using a spray technique. For these systems, the influence of the drying condition (atmospheric and vacuum) on their surface morphologies was investigated. Films obtained under vacuum exhibited a higher uniformity of surface morphology than those obtained under atmospheric pressure. For films dried under vacuum, electrowetting on dielectric (EWOD) effect was demonstrated. In the applied voltages from 0 to 100 V, the variation range of the electrowetting contact angles was found be $\Delta\theta \sim 17^0$. Before electrowetting saturation was achieved, the films displayed an electric breakdown. The influence of UV-C (254 nm) irradiation times on the EWOD effect was also examined. The electrowetting experimental curves were observed be either nearly linear (0 h and 3 h) or nonlinear (12 h and 24 h). Young–Lippmann equation

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* Corresponding author.
E-mail address: josmarysilva@cpd.ufmt.br (J.R. Silva).

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was able to describe the electrowetting behavior of irradiated films for 12 h and 24 h. The roughness of the films – obtained by atomic force microscopy – was observed to be nearly 14 nm for films without irradiation and 80 nm for those irradiated for 24 h. The increase in the roughness was associated with the change of the electrowetting behavior after irradiation. These results pave the way for further studies on experimental factors that may control the EWOD effect.

1. Introduction

Electrowetting phenomenon is a heavily researched topic to date because of its potential applications in such areas as displays [1], microfluidics systems [2], nanofluidic pumper [3], electrical actuation [4], and optical switch [5]. Electrowetting on dielectric (EWOD) occurs by changing the wetting of a dielectric surface when applying a certain voltage [3]. EWOD can be realized by using DC or AC voltage [6]. It can be monitored by measuring the wetting contact angle as a function of the voltage [7,8]. To find a system with the best electrowetting response, films made from various types of compounds have been studied, including Teflon AF 1600, Teflon (PTFE), Cytop, polyimide, and polydimethylsiloxane (PDMS) [3]. Because of their simplicity, planar electrodes are the most commonly used for the EWOD. Regarding the electrode nature, a number of EWOD works have employed indium tin oxide (ITO) [2,9]. These days, EWOD has been the subject of both theoretical [10,11] and experimental investigations, which have employed methods such as high-speed imaging [12], zeta potential [9], and dielectric spectroscopy [6], as well as atomic force microscopy [13] in combination with wetting contact angle analysis. Many of the works have focused on both steady-state [6] and transient responses [12] of droplets to DC voltage. Apart from the several works on EWOD, no reports on the dependence of this effect on experimental factors during the preparation of the dielectric films, such as the drying condition, and UV-C irradiation on the electrowetting exist. A better knowledge of the electrowetting behavior as a function of these two factors is important for the fabrication control of electrowetting-based devices.

In this study, we prepared and characterized superhydrophobic films by using a spray technique. In this type of system, the influence of the drying condition on their surface morphologies was examined by using optical microscopy. The influence of UV-C irradiation on EWOD, exhibited by the films deposited onto ITO, was examined using electrowetting contact angle analysis. The results were discussed using both Wenzel and Cassie-Baxter models, which describe superhydrophobic surfaces. Finally, the Young-Lippmann model was applied to describe the EWOD from our films.

2. Materials and methods

2.1. Compound

The NeverWet system (Rust-Oleum Co., IL, USA) was acquired commercially. This is a product that consists of two spray vessels called step 1 and step 2. The latter consists of siloxanes and silicones, di-Me, reaction products with silica (CAS Reg. No. 67762-90-7). An advantage of using the NeverWet system is that the spray technique can be applied easily for preparing the films.

2.2. Preparation of films and thickness estimation

Superhydrophobic films were obtained by spraying (for 2 s) the content of step 2 onto the electrode surfaces formed by indium tin oxide (ITO) layer on glass slides (10 mm × 10 mm × 1 mm). The outlet of the step 2 vessel was placed at 10 cm from the film surfaces. To ensure a high-quality spray, the vessel was tilted approximately 30^0 from the horizontal. All films were prepared at room temperature (23 °C). Film thickness, which was found be ~50 μm, was measured by inscribing a furrow on the film surfaces with an AFM tip, and then measuring the height profile across it [14].

2.3. Electrowetting experiments

The experimental setup to perform the EWOD experiment was assembled using an in-house wetting contact angle analyzer [15]. The setup is described in the literature [16]. Briefly, applied voltages in the range of 0–100 V were applied between a needle and the ITO electrode, which were electrically grounded. The electrowetting contact angles were measured using the in-house instrument in ambient conditions. Purified water droplets (volume of 3 μL) were gently placed onto the film surfaces. A sample of six measurements at different locations on each film was taken and the uncertainty is represented by the sample standard deviation.

2.4. Influence of drying condition on surface morphology

Films were submitted to atmospheric pressure or vacuum. Under atmospheric pressure, the films were dried in a chapel. Under vacuum condition, the films were dried in a desiccator, in which a pressure of approximately 270 mmHg was established using the vacuum pump.

2.5. Influence of UV-C irradiation

A BT107 080410 chamber (Biothec®, São Paulo, Brazil) equipped with a low-pressure mercury vapor lamp TUV30 (Philips, Holland) emitting UV-C radiation at ~254 nm was employed for the irradiation of the films. Immediately after the drying procedure, the films were submitted to different times of UV-C irradiation at a distance of ~16 cm from the UV-C lamp. The irradiation times were 0, 6 and 24 h. Other intermediate times did not lead to regular results.

2.6. Microscopy

Optical images of the films were examined by using an LCD digital microscope 44340 (Celestron, USA). Atomic force microscopy (AFM) images were acquired using an atomic force microscope EasyScan II (NanoSurf Instruments, Switzerland) in tapping mode (512 × 512 pixels) with a scan area of 5 μm × 5 μm under ambient conditions.

3. Results and discussion

3.1. Influence of drying conditions on surface morphology

One way to control the surface morphology is to change the drying condition of the films [14]. Here, we have studied the influence of the drying condition (atmospheric or vacuum) on the surface morphologies of the films. Fig. 1 shows optical microscopy images