Microfluid Nanofluid (2013) 15:587–597
DOI 10.1007/s10404-013-1184-y

RESEARCH PAPER

Flow rate analysis of an EWOD-based device: how important are wetting-line pinning and velocity effects?

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Received: 11 January 2013 / Accepted: 3 April 2013 / Published online: 21 April 2013

Abstract An electrowetting on dielectric (EWOD)-based micropump was used as a platform to study the contribution of the pinning and wetting-line velocity effects on its flow rate. In this micropump, a droplet is driven into a microchannel using EWOD to manipulate a meniscus in the channel. An interesting observation was that the shrinking input droplet changes its shape in two modes: (1) in the first mode, droplet contact angle decreases while its wetting area remains constant (pinning) and (2) in the second mode, droplet wetting line recedes while its contact angle changes as a function of its velocity (dynamic contact angle). Unexpectedly, the micropump flow rate was found to be constant in spite of the changes in the droplet radius. The pump performance was studied to unravel the physical concept behind its constant flow rate. A detailed characterization of variation in contact angle due to pinning, wetting-line velocity, and EWOD was carried out. Dynamic contact angles were used to accurately calculate the pressure gradient between the droplet and the meniscus for flow rate estimation. It was shown that neglecting either the wetting-line energy or the velocity effect results in not only a considerable gap between the predicted and the measured flow rates but also an unphysical instability in flow rate analysis. However, when these effects were fully taken into account, an excellent agreement between the predicted and the measured flow rates was obtained.

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Keywords Droplet · Electrowetting on dielectric · Hysteresis · Dynamic contact angle · Wetting-line velocity · Pinning · Advancing and receding wetting-lines

Abbreviations

EW	Electrowetting
EWOD	Electrowetting on dielectric
PDMS	Polydimethylsiloxane
SOG	Spin-on glass
WL	Wetting-line
WLE	Wetting-line energy
WLV	Wetting-line velocity

1 Introduction

In devices that are designed based on electrowetting on dielectric (EWOD), a liquid meniscus is manipulated by an applied voltage which reduces the contact angle of the wetting line (WL) formed at the boundary between the liquid, air, and the solid surface. The behavior of the moving WL has a complex nature due to the WL pinning and wetting-line velocity (WLV) effects, which alter the liquid contact angle on the solid surface from its equilibrium value obtained from Young's equation (Young 1805; Baviere et al. 2008). The wetting-line energy (WLE) effect or pinning effect is a result of the local microscopic defects on the solid surface (Tadmor 2004), by which liquid is pinned to the surface. Therefore, different values for contact angle are expected depending on whether the WL is in advancing or receding modes. The contact angle is also changed when the WL is moving, depending on the magnitude and direction of the WLV (Dussan 1979; Nelson et al. 2011). Theoretical and numerical models have been