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TREATMENT OF ELECTRIC FIELD SINGULARITIES AT SOLID-LIQUID-AIR JUNCTIONS IN ELECTROWETTING-ON-DIELECTRIC COMPUTATIONS

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ABSTRACT

Microfluidics applications that utilize electrostatic stresses, such as electrowetting-on-dielectric (EWOD), combine fast transport of liquid microdroplets with voltage-based control. A typical EWOD system consists of a conducting liquid drop sitting on a flat metal electrode coated by thin dielectric film. When a voltage is applied between the coated electrode and an electrode submerged into the drop, the drop spreads along the dielectric surface due to wetting enhancement, resulting in contact angle, θ_c, decrease.

The efficient manipulation of liquids in EWOD applications requires wide range of achievable values of θ_c. However, θ_c is limited to a lowest value, depending on the system configuration – a phenomenon known as contact angle saturation. This phenomenon is mostly attributed to the high electric field strength in the vicinity of the three-phase (solid-liquid-air) contact line (TPL) [1], where a wedge-like geometry is formed by the conductive liquid. The liquid geometry at the TPL induces a singularity where the corresponding electric field strength theoretically gets an infinite value [2]. Its accurate computation is important in any EWOD computational analysis aiming to account for material failure, like dielectric breakdown or air ionization, which presumably limit the electrowetting phenomenon.

The governing equations of electrohydrostatics form a nonlinear and free boundary problem where the droplet shape is coupled with the electric field distribution. Standard numerical schemes, such as finite or boundary elements, fail to capture the variation of the field strength near the TPL, due to its approximation by low-order polynomial functions. Local mesh refinement near the TPL is a common treatment that improves the accuracy at the expense of increasing the computational cost.

The local dependence of the field strength on the distance from the TPL, is theoretically derived and is incorporated in the numerical scheme. The singular expression is integrated in a finite or boundary element method by replacing the standard polynomial approximants with their singular counterparts. This replacement is applied seamlessly to

the above methods and the coupled problem is treated at the same fashion as before. The combined method improves considerably the accuracy of the computed field strength at the TPL and thus, only a modest number of elements is required, which in turn results to a significant reduction of the overall computational cost. The efficiency of the proposed method is illustrated through a benchmark case: A 2-d electrostatic problem corresponding to an EWOD system is tessellated in 35000 biquadratic elements selectively refined near the TPL. Equivalent results, in terms of accuracy of the field strength near the TPL, is achieved with the use of 2000 standard elements and only a few elements located at the TPL region that exploit the field's singular expression.

REFERENCES

[1] A.G. Papathanasiou and A.G. Boudouvis, "Manifestation of the connection between dielectric breakdown strength and contact angle saturation in electrowetting", *Applied Physics Letters*, Vol. **86**, pp. art. no.-164102, (2005).

[2] J. Van Bladel , "Field singularities at metal-dielectric wedges", *IEEE Transactions on Antennas and Propagation*, Vol. **33**, pp. 450-455, (1985).