Transient Flow of Gravity-Driven Viscous Films Used for Coating Substrates with Variable Topography

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We study the two- and three-dimensional flow over square substrates which have practical applications in microelectronics and microfluidics. The problem we address is the liquid advancing over a substrate with variable topography. The entrainment of air between the trenches of the substrate and the coating liquid must be avoided in coating of microelectronic devices, but is desirable in producing super-hydrophobic surfaces for microfluidic applications.

The flow of a viscous liquid in atmospheric environment is simulated by making use of the OpenFOAM open source CFD software package. The full unsteady in time Navier-Stokes equations are discretized on structured or unstructured computational grids, while they are solved in time through an Euler implicit time marching method by which the time step is adjusted automatically in order to guarantee numerical stability. The computational cost is reduced by the application of parallel execution on a cluster of interconnected CPUs using Message Passing Interface (MPI).

The physical phenomenon studied herein is the gravity-driven flow of a liquid film down a plane, as it encounters the rectangular trench to be coated. Due to the bulge formed at the front of the film the complete coating is not always guaranteed. For example, if the bulge in the film front encounters the far wall while the contact point of the interface is still on the upstream wall, the film leaves entrapped air in the trench (the so-called capping failure)[1]. Poor coating can also happen in deep enough trenches if the contact point has not yet moved around the bottom surface of the trench by the time the bulge hits the downstream wall resulting in air entrapment within the trench (the so called bulge failure)[1]. If the trench is wide and deep enough the bulge on the film front may also be cut-off from the rest of the liquid before it reaches the far wall of the trench. Finally, there is a so-called runout length[1] which is the maximum depth of the trench to be coated before the film collapses due to gravitational force.

Our aim is to investigate the dimensions of a rectangular trench (depth and width) as well as the range of the capillary numbers and contact angles, which guarantee full coating of the trench. The trench topography and a full map of successful or poor coating with respect to trench dimensions are presented in figures 1 and 2 respectively. In figure 2 the capillary number (Ca) and the contact angle (φ) are set as following $Ca = 0.1$, $\varphi = 30^{o}$.

In terms of three-dimensional flows we study the thin viscous liquid film over an inclined planar surface containing topographical features [2]. The free surface profiles over this topography are first compared with published results [2]. Here the conditions for air entrapment are met more easily and the shapes and locations of entrapped air inside the trench are more complicated.

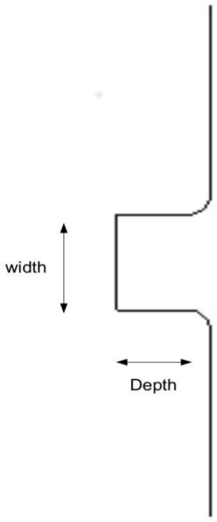

Fig. 1 Trench Topography

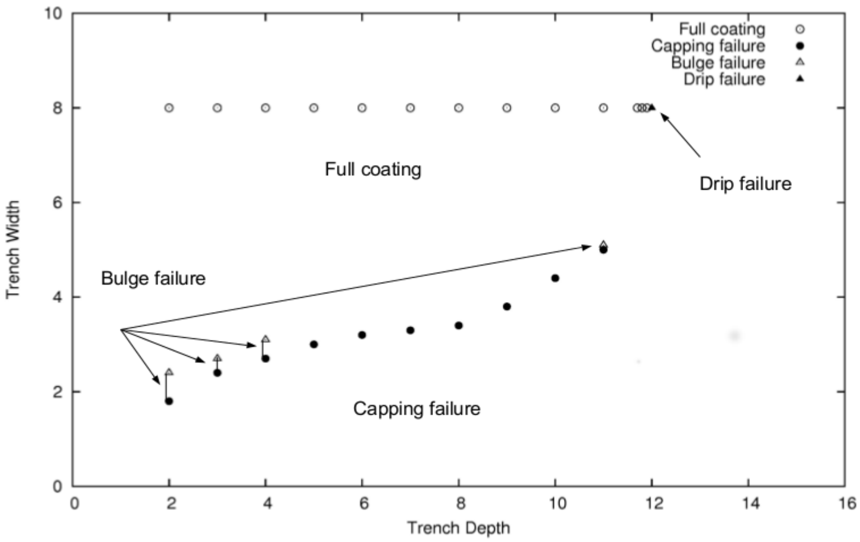

Fig. 2 Coating map (Ca=0.1, $\varphi=30^0$)

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Keywords: Thin film, Coating,Volume of Fluid, OpenFOAM

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