Electrified viscous film flow over inclined substrates

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In coating applications such as the manufacture of photographic plates or magnetic memory devices, a liquid film is delivered onto a moving substrate to form an even coated layer. If applied, an electric field affects the flow through an additional Maxwell stress at the film surface and can be used to control the non-uniformities of the free surface. In particular, we investigate the gravity-driven flow of a liquid film down an inclined wall in the presence of a normal electric field. We consider both the flow over a flat substrate and the flow over a substrate with periodic indentations. For our models, the film is assumed to be a perfect conductor and the air above the film is assumed to be a perfect dielectric. We use a systematic asymptotic expansion to derive a long-wave nonlinear evolution equation for the thickness of the liquid film. At smaller amplitudes the weakly nonlinear evolution is governed by a modified Kuramoto–Sivashinsky (KS) equation. For the case of the flow over a flat substrate, through a combination of analysis and extensive numerical experiments for the modified KS equation, we find parameter ranges that support non-uniform travelling waves, time-periodic travelling waves and complex nonlinear dynamics including chaotic interfacial oscillations. For the case of the flow over a corrugated substrate, we examine the effect of the electric field on the shape of the film surface under steady conditions. We compute steady solutions of the long-wave model equation for flow into a rectangular trench and over a rectangular mound. In the absence of an electric field the film develops a capillary ridge above a downward step and a slight depression in front of an upward step. We demonstrate how an electric field may be used to completely eliminate the capillary ridge at a downward step. In contrast, imposing an electric field leads to the creation of a free surface ridge at an upward step. The effect of the electric field on film flow into relatively thin trenches and over relatively thin mounds is also considered. The long-wave results are corroborated by fully nonlinear boundary integral calculations for Stokes flow.