Regular non-coarsening surface patterns on evaporating heated films

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Purpose and scope. We study a thin liquid film with a free surface on a uniformly heated substrate. We show that if the fluid is initially in equilibrium with its own vapor in the gas phase, regular surface patterns in the form of long-wave hexagons or stripes having a well defined lateral length scale can be observed. This is in sharp contrast to the case without evaporation where rupture or coarsening to larger and larger patterns is seen in the long time limit. In this way, evaporation could be used for regular structuring of the film surface. We are able to estimate the finite wave length for the simplified case of an extended Cahn-Hilliard equation.

Previous work, contribution to the state of the art. Surface patterns of thin liquid films on a solid support were studied during the last decade in numerous experimental and theoretical contributions (see [1, 2, 3, 4] and references therein).

Self-organized pattern growth due to an instability mechanism of the initially flat film is often discussed in the long-wavelength or lubrication approximation [2]. There are several mechanisms that may destabilize a flat surface and allow to control the growth of surface patterns. Flat ultra-thin films may become unstable by van der Waals forces between surface and substrate. Thicker films can be destabilized by inhomogeneous tangential surface tensions, which in turn are often caused by lateral gradients of temperature and/or, in mixtures, of concentration [4, 5, 6].

Up to now, most of the theoretical work is based on an interface equation, often called thin film equation, describing the location $z = h(x, y, t)$ of the free surface of the liquid [2, 8]. Additional effects caused by (moderate) evaporation or condensation on the interface can be included easily in the formalism [9, 10]. Previous work shows that in the case of a surface-driven thermal instability, rupture of the film occurs after a relatively short time [2]. To avoid rupture, a repelling short range interaction can be introduced. Then patterns in the long time limit may be studied and show coarsening, a slow increase of the lateral dimensions of the structures (drops or holes) until one big hole (or drop) eventually remains [6].

Essential results already obtained. In a recent paper [11], we concentrated on the Rayleigh-Taylor instability (RTI) as destabilizing mechanism of the flat surface (fig. 1). If the fluid is heated from below, this usually would stabilize the flat film. As was shown in [7], RTI may occur if the temperature gradient is not too large and film rupture is avoided by the stabilizing Marangoni effect.

In previous works, evaporation was considered as a destabilizing mechanism. Here we shall concentrate on the opposite case. Assume that the fluid is heated from below (or cooled

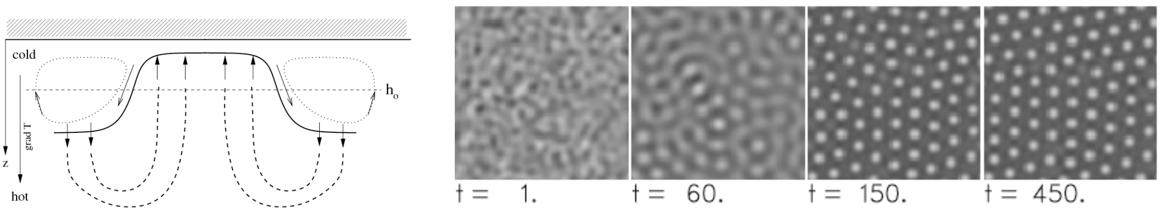

Figure 1: Left: Sketch of the system studied in ref [11]. Right: Time series found by numerical integration of the thin film equation with.

from above). If the partial pressure of the vapor in the gas layer under the fluid is equal to the saturation pressure belonging to the surface temperature of the initial flat film, then a small elevation of the surface into colder regions leads to local condensation, a small depression into hotter regions causes evaporation (fig. 1, left frame). In [11] we showed that this mechanism may avoid rupture for large enough evaporation rates even without the Marangoni effect. Moreover, due to the modified character of the instability, coarsening does no longer occur in the long time limit. Instead we find very regular cell structures in the form of hexagons, known from their morphology from small scale convection in thicker fluid layers (fig.1, right frame).

Results to be included in the final version . In the contribution, we show how other stability mechanisms may be included. The Marangoni effect may be considered as another (stabilizing) mechanism. In this way, a richer pattern dynamics is expected, showing also squares, stripes and hexagons and transitions among them. A stability diagram in parameter space will be computed.

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