Pinch in the vicinity of a meniscus in a thin liquid film

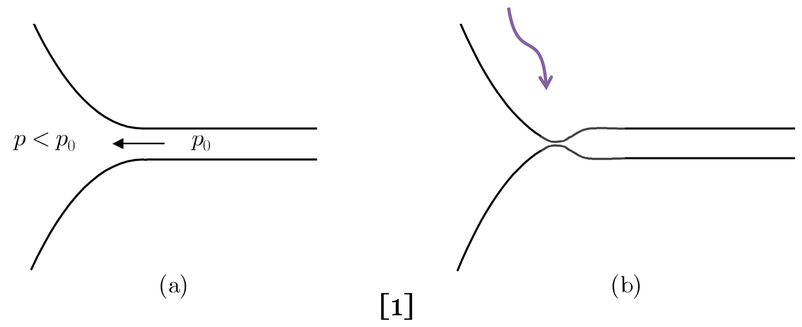
Alice Etienne-Simonetti [1], Isabelle Cantat [2], Frédéric Restagno [1], Emmanuelle Rio [1]

[1] Laboratoire de Physique des Solides, Université Paris-Saclay, Orsay, France ; [2] Institut de Physique de Rennes, Université Rennes 1, Rennes, France

In a thin liquid film connected to a meniscus, Aradian et al. [1] predict a zone of small thickness, called the pinch, between the meniscus and the film.
This pinch is the origin of the marginal regeneration phenomenon observed in the 60s by Mysels in soap films [2] and which is of major importance in describing thin film drainage [3] and therefore their stability.
Thanks to a model experiment, we measure thickness profiles in the pinch zone and highlight the pinch.

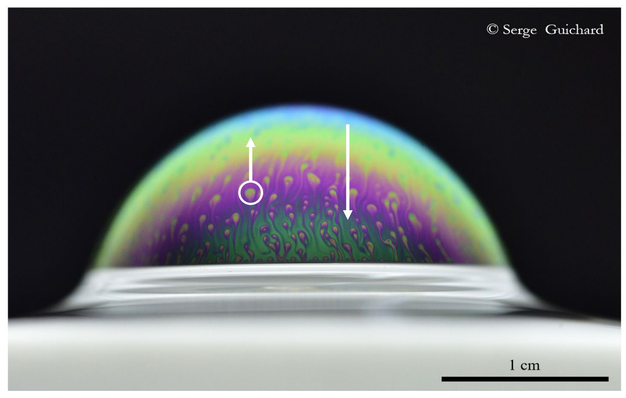
Pinch and marginal regeneration

- The meniscus is sucking the liquid of the film due to the Laplace pressure -> zone of small thickness = pinch



[1]

- The pinch (at the bottom of the bubble) destabilizes into thin patches
- The thin patches go up and replace thicker film portions that go down (= drainage): the thick film regenerates in the meniscus as thin film

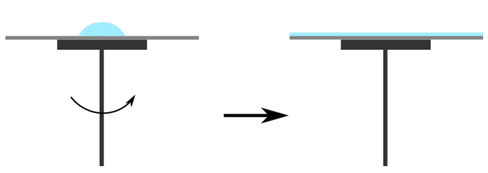


[3]

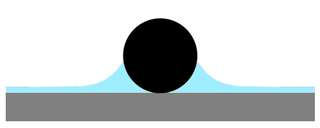
Experiment

We deposit a thin film of silicone oil on a silicon wafer by spin-coating. The pinch destabilizing should be prevented by the solid surface. We deposit a glass capillary tube on the film to create a meniscus. We observe the reflection of a white light on the film thanks to a hyperspectral camera.

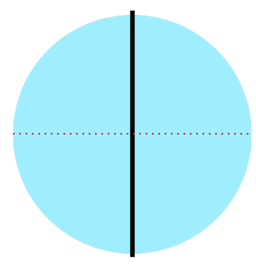
Creation of thin liquid films
Spin-coating

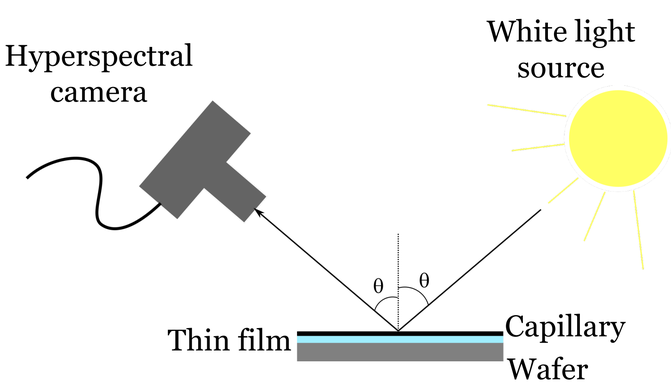


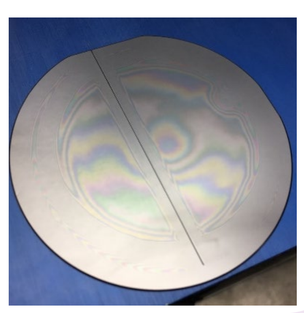
Creation of a meniscus
Depositing a capillary horizontally



Measurement of the film thickness
Interferometric method using a hyperspectral camera (= a line of spectrometers)
The camera is looking at a line that is perpendicular to the capillary

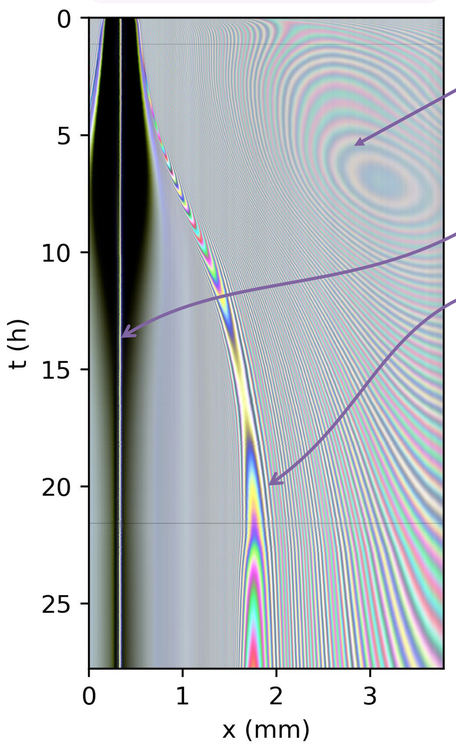




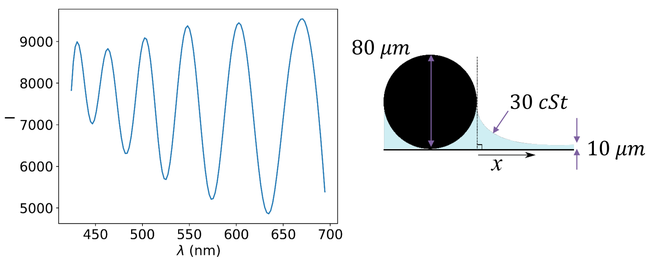


Thickness profiles

Diagram of the film colors



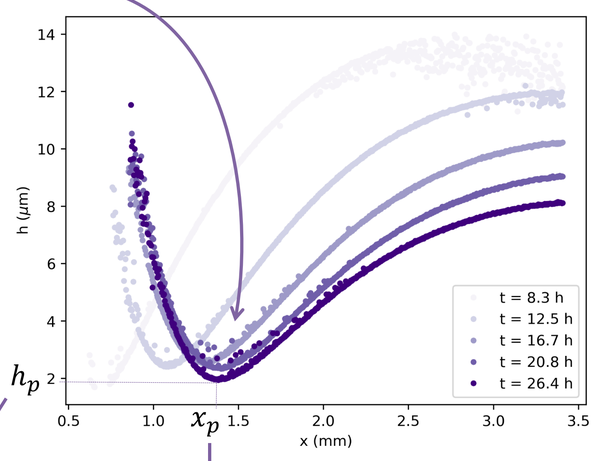
Spectrum

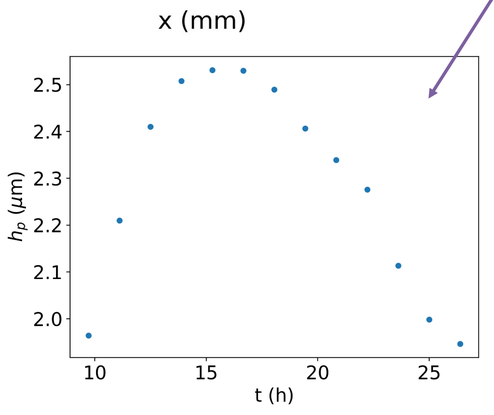


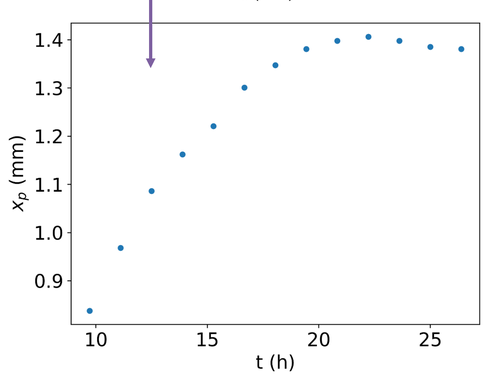
capillary tube

pinch

Thickness profiles

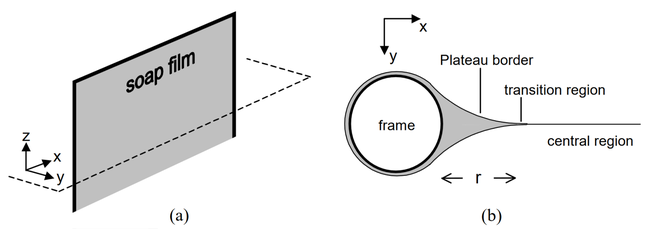






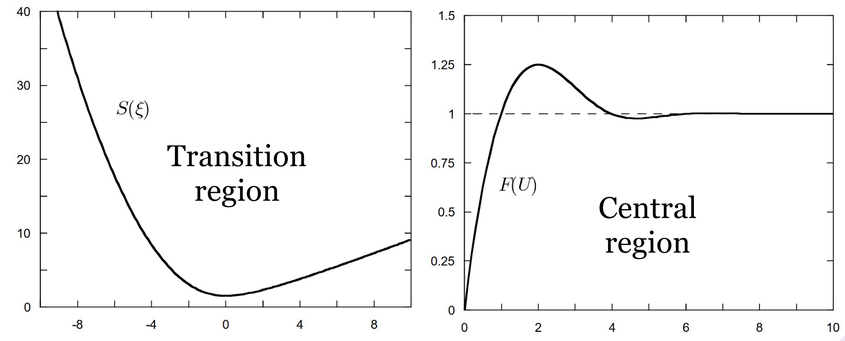
The pinch dynamics are not yet reproducible, and we believe this is partly due to the films getting less and less homogeneous with time, away from the pinch.

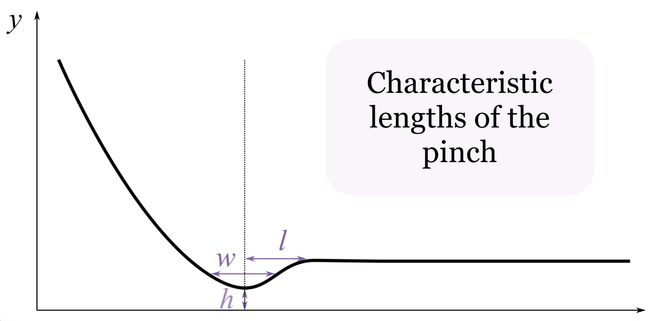
Model [1]



- Solving the lubrication equation in the transition region and in the central region, self-similar solution
- Imposing asymptotic matching between the solutions and the Plateau border

Dimensionless thickness profiles





Characteristic lengths of the pinch

Scaling laws for the characteristic lengths

$$l \sim \eta^{-1/4} e_0^{3/4} t^{1/4}$$
$$h \sim \eta^{1/2} e_0^{1/2} t^{-1/2}$$
$$w \sim \eta^{1/4} e_0^{1/4} t^{-1/4}$$

η film viscosity
e_0 initial film thickness

Discussion and outlooks

Results:

- We observe the pinch predicted by Aradian et al. [1] in a thin film of silicone oil,
- But its dynamics are not reproducible partly because when the pinch appears, the film has become inhomogeneous.

Ways to improve:

New geometries:

- Ring deposited on a wafer to get rid of the edge effects causing inhomogeneities
- Vertical rod deposited on a wafer to make the pinch appear faster and to be less subject to the inhomogeneities [4]

[1] A. Aradian, E. Raphaël, P.-G. de Gennes, Europhys. Lett., (2001)
[2] K.J. Mysels, S. Frankel, K. Shinoda, Pergamon press, (1959)
[3] J. Miguet, M. Pasquet, F. Rouyer, Y. Fang, E. Rio, Phys. Rev. Fluids, (2021)
[4] M. L'Estimé, thesis, (2021)