Ultra-thin supported liquid films: effects of van der Waals interactions

Cécile Clavaud, Christian Frétigny, Laurence Talini
SIMM lab, ESPCI (France)

ESPCI PARIS | PSL

Ultra-thin supported liquid films

Supported liquid films of thickness $h \leqslant 50\,\mathrm{nm}$:

- modification of the dynamics?
- van der Waals air-solid interactions through the liquid: $\mathcal{E}_{\mathrm{vdW}} \propto A_H/h^2$?

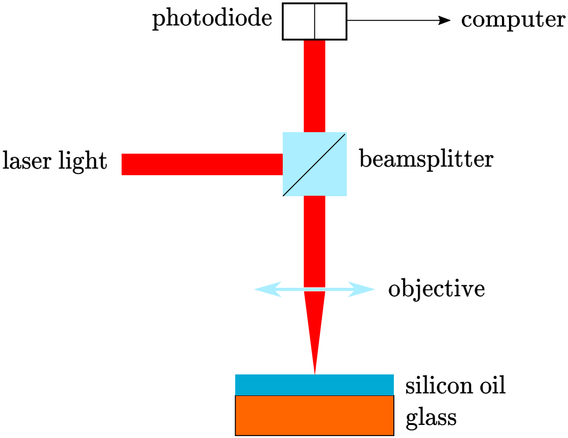
Ultra-thin supported liquid films

Supported liquid films of thickness $h \leqslant 50\,\text{nm}$:

- modification of the dynamics?
- van der Waals air-solid interactions through the liquid: $\mathcal{E}_{\text{vdW}} \propto A_H/h^2$?

Goal: form these films and measure their physical properties.

Experimental setup



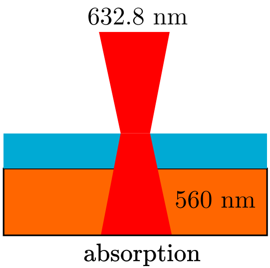
Low power laser (30 mW max).
Completely wetting liquid on a smooth surface.

Experimental setup

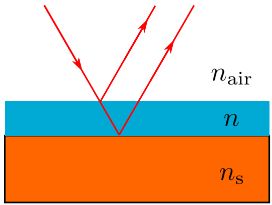
Forming a nanometric film:
thermally induced Marangoni flow.

$\lambda_\ell = 632.8\,\text{nm}$, $\lambda_g = 560\,\text{nm}$: absorption.

- $R_\ell = 1.5\,\mu\text{m} \ll l_T \sim 1\,\text{mm}$,
- $\Delta\theta < 1\,°\text{C}$,
- $\text{Pe} \ll 1$.

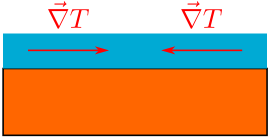


Measuring the film thickness: interferences.



Experimental setup

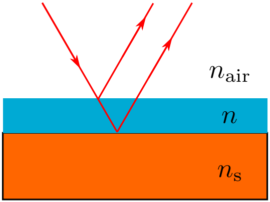
Forming a nanometric film:
thermally induced Marangoni flow.



$\lambda_\ell = 632.8\,\mathrm{nm}$, $\lambda_g = 560\,\mathrm{nm}$: absorption.

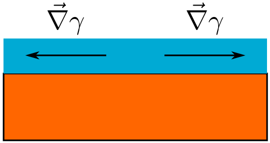
- $R_\ell = 1.5\,\mu\mathrm{m} \ll l_T \sim 1\,\mathrm{mm}$,
- $\Delta\theta < 1\,^\circ\mathrm{C}$,
- $\mathrm{Pe} \ll 1$.

Measuring the film thickness: interferences.



Experimental setup

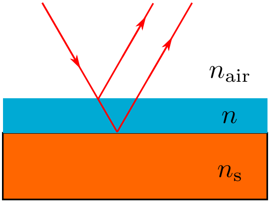
Forming a nanometric film:
thermally induced Marangoni flow.



$\lambda_\ell = 632.8\,\text{nm}$, $\lambda_g = 560\,\text{nm}$: absorption.

- $R_\ell = 1.5\,\mu\text{m} \ll l_T \sim 1\,\text{mm}$,
- $\Delta\theta < 1\,^\circ\text{C}$,
- $\text{Pe} \ll 1$.

Measuring the film thickness: interferences.

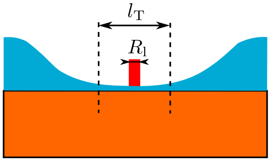


Experimental setup

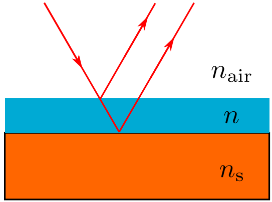
Forming a nanometric film:
thermally induced Marangoni flow.

$\lambda_\ell = 632.8\,\text{nm}$, $\lambda_g = 560\,\text{nm}$: absorption.

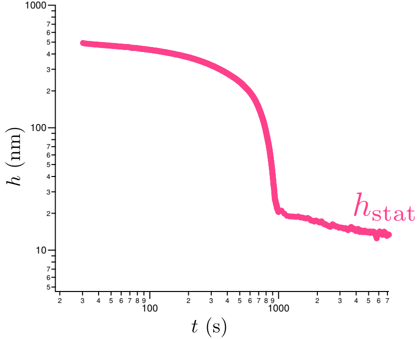
- $R_\ell = 1.5\,\mu\text{m} \ll l_T \sim 1\,\text{mm}$,
- $\Delta\theta < 1\,^\circ\text{C}$,
- $\text{Pe} \ll 1$.



Measuring the film thickness: interferences.

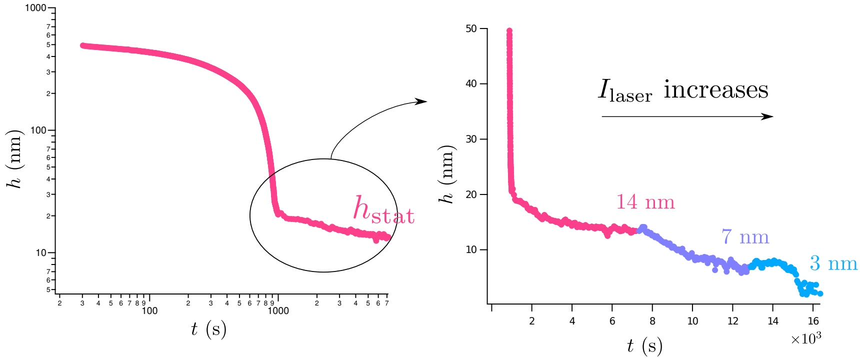


Thinning dynamics



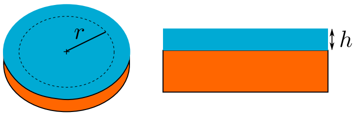
Non-zero stationary thickness h_{stat}

Thinning dynamics



Non-zero stationary thickness h_{stat} depends on the Marangoni forcing.

Thinning dynamics

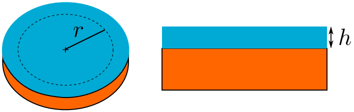


Dimensionless variables:
$R = \frac{r}{l_T}$, $H = \frac{h}{h_0}$, Θ, T.

Dimensionless parameters:

$$\kappa_c = \frac{\text{thermal length}}{\text{capillary length}}, \quad E = \frac{\text{van der Waals term}}{\text{capillary term}}, \quad A = \frac{\text{Marangoni forcing}}{\text{capillary term}}.$$

Thinning dynamics



Dimensionless variables:
$R = \frac{r}{l_T}$, $H = \frac{h}{h_0}$, Θ, T.

Dimensionless parameters:

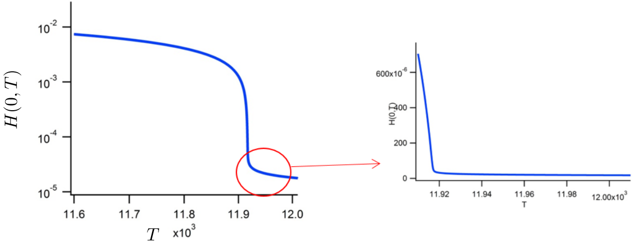
$$\kappa_c = \frac{\text{thermal length}}{\text{capillary length}}, \quad E = \frac{\text{van der Waals term}}{\text{capillary term}}, \quad A = \frac{\text{Marangoni forcing}}{\text{capillary term}}.$$

$$\partial_T H + \frac{1}{R}\partial_R \left[R H^3 \partial_R \left(\Delta H - \kappa_c^2 H + \frac{E}{H^3} \right) \right] - \frac{A}{R}\partial_R \left(R H^2 \partial_R \Theta \right) = 0.$$

Thinning dynamics

$$\partial_T H + \frac{1}{R}\partial_R \left[R H^3 \partial_R \left(\Delta H - \kappa_c^2 H + \frac{E}{H^3} \right) \right] - \frac{A}{R}\partial_R \left(R H^2 \partial_R \Theta \right) = 0.$$

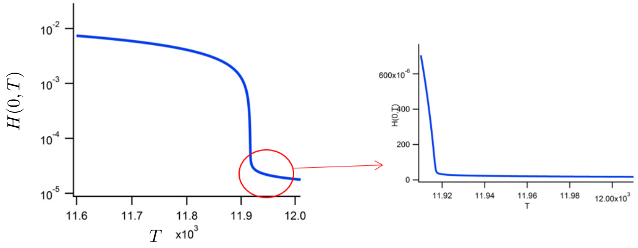
Numerical resolution:



Thinning dynamics

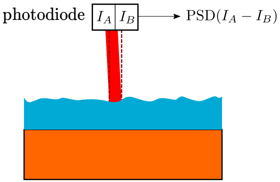
$$\partial_T H + \frac{1}{R}\partial_R \left[R H^3 \partial_R \left(\Delta H - \kappa_c^2 H + \frac{E}{H^3} \right) \right] - \frac{A}{R}\partial_R \left(R H^2 \partial_R \Theta \right) = 0.$$

Numerical resolution:

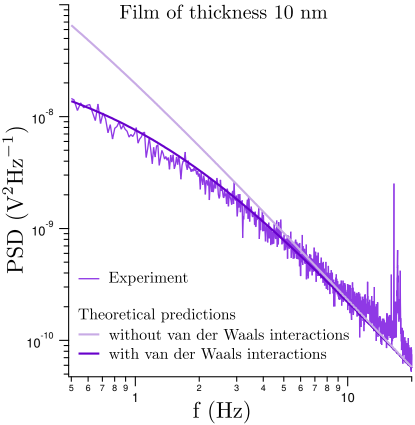


If $\mathcal{E}_{\mathrm{vdW}} \propto A_H/h^2$, $h_{\mathrm{stat}} = \left(\frac{A_H}{12\pi\gamma_\theta\theta_{\mathrm{max}}}\right)^{1/2}$: depends on the forcing.

Steady state thermal fluctuations



Pottier, Frétigny, Talini, PRL 2015.



Collaboration with Thomas Bickel (LOMA, Bordeaux, France).

Effect of the van der Waals interactions on the surface thermal fluctuations.

Conclusions and future work

Form nanometric films with Marangoni flow.

Thinning dynamics

- Non-zero stationary thickness that depends on the Marangoni forcing.
- Thin film equation: numerics agree with experiments.
- Exact form of $\mathcal{E}_{\mathrm{vdW}}$?

Conclusions and future work

Form nanometric films with Marangoni flow.

Thinning dynamics

- Non-zero stationary thickness that depends on the Marangoni forcing.
- Thin film equation: numerics agree with experiments.
- Exact form of $\mathcal{E}_{\mathrm{vdW}}$?

Steady state fluctuations

- Preliminary results: effect of air-solid van der Waals interactions through the liquid.
- Lower frequencies or thinner films: noise problem.