Infrared laser induced thermocapillary deformation and destabilization of thin liquid films

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A thin liquid film on a partially wetting substrate can be destabilized by means of an air-jet [1]. The liquid film will rupture at multiple points and this will lead to a residual droplet pattern on the substrate. In this study, we deform and rupture thin liquid films by means of infrared (IR) illumination [2,3].

Fig. 1 shows a schematic image of the experimental setup. We deposit a thin liquid film of a non-volatile liquid on a wetting or partially wetting substrate by spin-coating. The initial film thickness is approximately 5 µm. During the experiment, the substrate is rotating while an IR laser beam heats up the substrate and liquid film (the diameter of the beam is approximately 200 µm). This will induce a non-uniform temperature distribution that drives the thermocapillary flow of the liquid. We measure the deformation of the thin film using dual-wavelength interference microscopy.

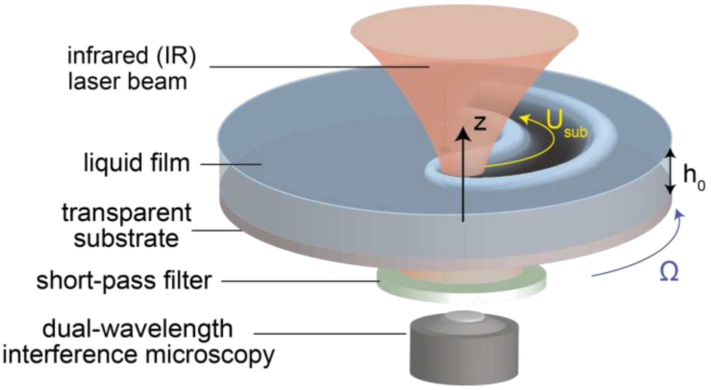

Fig.1: Schematic experimental setup (not to scale).

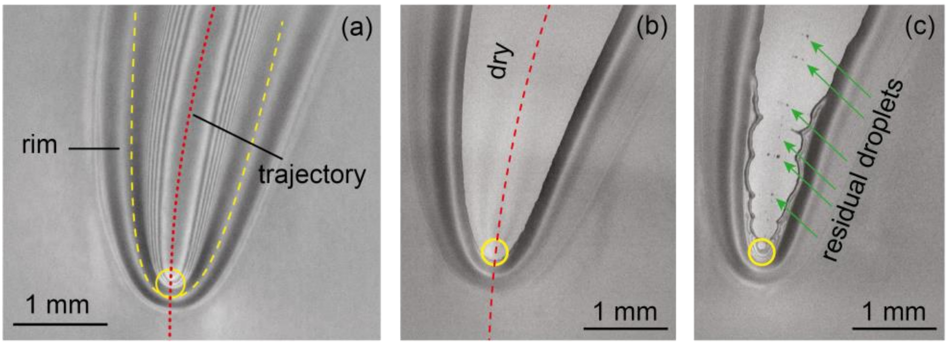

Fig. 2: Interference micrographs of (a) the deformation on a wetting substrate and (b,c) the deformation and rupture on a partially wetting substrate for different substrate speeds.

Fig. 2(a) shows the deformation of the thin film on a wetting substrate. The substrate speed U_{sub} was 5 mm/s, the laser power $P = 8$ W. The yellow circle indicates the size and position of the laser beam. The red line indicates the trajectory of the laser beam. We studied the effect of P and U_{sub}.

Fig. 2(b,c) shows the deformation and break-up of the thin film on a partially wetting substrate. In both cases $P = 8$ W whereas U_{sub} was 5.3 mm/s for (b) and 8.2 mm/s for (c). Fig. 2(b) shows that a completely dry track is formed along the laser trajectory. The first dry-spot rapidly dewets the substrate, up to the rim of the deformation. This prevents the formation of other dry-spots. However, when we increase the substrate speed (Fig. 2(c)) we see that residual droplets are deposited on the substrate. We measured the critical substrate speed at the transition from the 'dry'-regime to the 'residual droplets'-regime for different laser powers.

We developed a numerical simulation that combines a heat transfer model with a thin film model, based on the lubrication approximation [4] and a phenomenological expression for the disjoining pressure [5]. Our simulation reproduces the critical speed from the experiment well.

References

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