Marangoni flows induced by atmospheric-pressure plasma jets

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Atmospheric-pressure plasma jets have generated significant interest for their versatile applications in material processing and surface modification. We studied the interaction of atmospheric-pressure plasma jets of Ar or air with liquid films of an aliphatic hydrocarbon on moving solid substrates. The hydrodynamic jet-liquid interaction induces a track of lower film thickness. The chemical plasma-surface interaction oxidizes the liquid, leading to a local increase of the surface tension and a self-organized redistribution of the liquid film.

We used a commercial atmospheric-pressure plasma jet (KinPen 09, NeoPlas Tools), operated at a flowrate of approximately 1 l/min at normal incidence onto the substrate (Fig. 1). We used either Ar gas or purified air. We adjusted the electrical power input such that the visible length of the plasma jets was maintained at about 3 mm. The exit nozzle diameter is D ≈ 1 mm. The substrates were rotated at a constant angular velocity Ω. The radial distance of the plasma jet from the (vertical) axis of rotation was approximately 1 cm, which implies that a value of Ω = 1 rpm corresponds to a translation speed of U ≈ 1 mm/s.

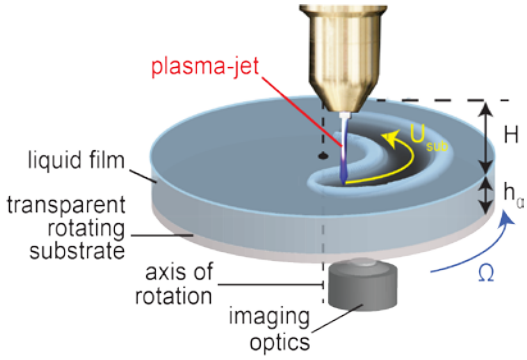

Fig. 1: Experimental setup [1].

The stagnation pressure and wall shear stress of the gas flow induce a depression in the liquid film along the jet trajectory. Depending on the rotation rate, the remaining film thickness along the track centerline is in the range of approximately 0.1–1 μm. The grayscale fringes in Fig. 2 represent curves of constant film thickness. The most striking feature as a consequence of Ar plasma jet treatment is the formation of a pair of rims extending parallel to the centerline of the jet trajectory with initial separation d_{rim} ≈ 2 mm, as indicated by the red arrows in Fig. 2. The rims move towards each other and merge within 5–9 min. Moreover, the rims tend to become unstable and break up into a series of droplets that grow and coarsen in time, as visualized e.g. in Fig. 2. We systematically studied the effect of the substrate rotation rate Ω. Moreover, we developed a numerical model that qualitatively reproduces the formation, instability and coarsening of the flow patterns observed in the experiments.

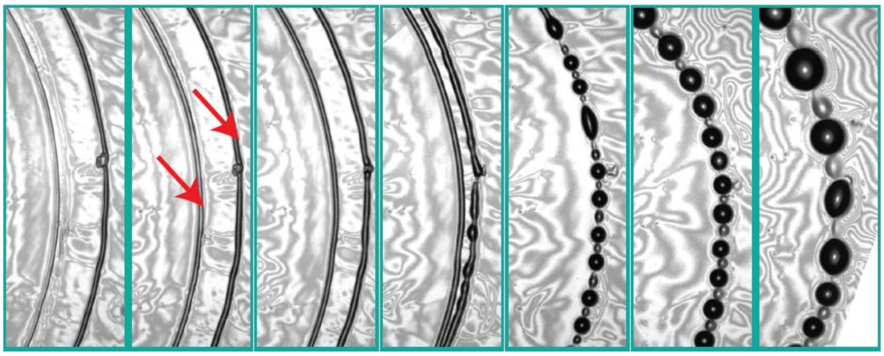

Fig. 2. Optical micrographs of an aliphatic thin liquid film on a rotating substrate (Ω = 1 rpm) at 1, 2, 3, 5, 9, 17 and 33 minutes after interaction with an atmospheric Ar plasma jet [1]. Image widths 4 mm.

Monitoring the liquid flow has potential as an in-situ, spatially and temporally resolved, diagnostic tool for the plasma-liquid surface interaction. On the other hand, the plasma jets provide a versatile tool for inducing thickness- or composition modulations in a liquid coating prior to the drying or solidification stage.

References

1. C. W. J. Berendsen, E. M. van Veldhuizen, G. M. W. Kroesen and A. A. Darhuber, J. Phys. D: Appl. Phys. **48** (2015) 025203.