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DYNAMIC GEOMETRY OF DROPLETS IMPINGING ON SUPERHEATED SURFACE

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Leidenfrost transition, Thermal dimples, Droplet heat transfer, Infrared imaging

ABSTRACT

Droplets impingement is encountered in spray cooling, inkjet printing and combustion engines(Kim 2007; Driessen and Jeurissen 2015; Shaw, Wei, and Dwyer 2004). Events preceding and post the impact of a liquid droplet on solid surface is an interesting problem. Incoming of high speed imaging systems capable of filming the ultrafast (time scale ≈ µs-ms) dynamics ushered a curiosity wave to absorb nuances of drop impact on solid substrate(Li et al. 2017; Langley, Li, and Thoroddsen 2017). Arguably, and proven both experimentally and theoretically, the ambient air act as a temporary barrier against contact between impinging liquid and solid(Bouwhuis et al. 2012; Homayonifar et al. 2008; Tran et al. 2013; Throddsen et al. 2005; Mehdi-Nejad, Mostaghimi, and Chandra 2003). Similarly, a comprehensive picture of Leidenfrost drop levitating on its own vapor and consequently killing desired heat transfer for thermal management is yet to be presented. Through this article, we aim at understanding the temporal evolution of droplet shape impinging on superheated surface.

Burton et al.(Burton et al. 2012) used laser interferometry technique to observe the geometry vapor layer under a static Leidenfrost drop, however (i) droplet impingement needs investigations into dynamic leidenfrost droplets, (ii) temporal evolution should be observed (rather than steady state geometry of drops) to understand the pre- and post impact events and (iii) also, experiments should be performed in transition boiling regime to understand the onset of Leidenfrost boiling. Shirota et al.(Shirota et al. 2016) used total internal reflection (TIR) technique to image the air layer of length scale ≈ 100nm underneath droplets in transition boiling regime and concluded that droplet forms dimples owing to build up of pressure. However, as noted by Burton et al.(Burton et al. 2012) and also experimentally observed by Ma et al.(Ma, Liétor-Santos, and Burton 2017) that droplets exhibit a complex geometry rather than just a classical dimple shape, and we also observed more than just dimples using high speed thermography (Figure 3). Although, classical dimples model might hold true for droplets of length scale of capillary length, however lift-off instability as predicted by Kolsinki et al.(Kolinski, Mahadevan, and Rubinstein 2014) for droplets impingement on surfaces at room temperature should grow stronger due to pressure build up for leidenfrost droplets of all sizes greater than capillary length. Hence our goal is to visualize the missing picture of complex dynamics of droplet impacting on superheated surface.

We performed experiments with ethanol drops (1.8mm diameter) on a sapphire substrate (100 mm diameter, 650µm thick, University wafers USA) coated with conductive ITO layer (700 nm thick, Diamond coatings UK), which acts as heat source for our experiments. We used high speed infrared thermography (IR Camera, 870Hz, FLIR SC5600, USA) to capture the thermal footprint of droplets on

ITO surface. Also, as shown in Figure 1, we would use TIR technique in synchronization with IR to clearly distinguish wetted and non-wetted areas.

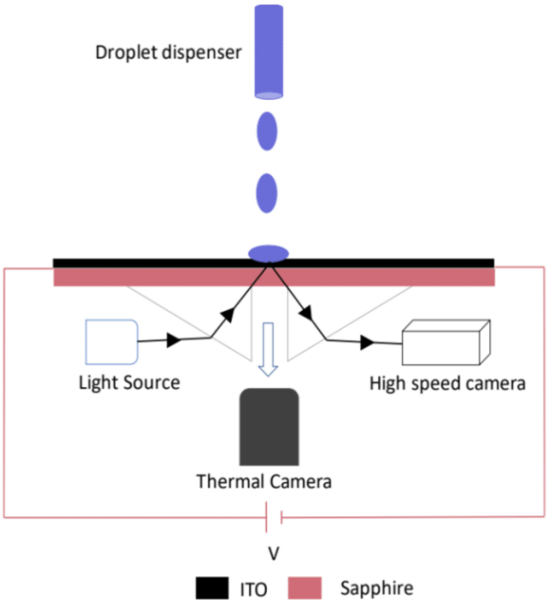

Figure 1. *Schematics of experimental setup for capturing the geometry evolution of droplets impinging on superheated surfaces. Thermal camera underneath allowed us to capture the thermal footprint of droplets on ITO surface. Total internal reflection imaging (added to the setup, results not presented here) would help us determining whether droplets contact the surface or not.*

The thermal footprint of droplet impinging on superheated surface captured using an infrared camera underneath is shown in Figure 2. The experiment was performed at a superheat (surface temperature of solid – boiling point of fluid) of $\Delta T = 92K$ and images were captured at intervals of $\approx 1.12ms$. We inferred from these experimental observations that vapor is entrapped underneath as the central zone of thermal is hotter than peripheral region around it. We further plotted the temperature profile along horizontal diameter of thermal footprint and results are shown in Figure 2. These thermal dimples fall in line with the claims made in support of role of air/vapor in drop impact(Tran et al. 2013).

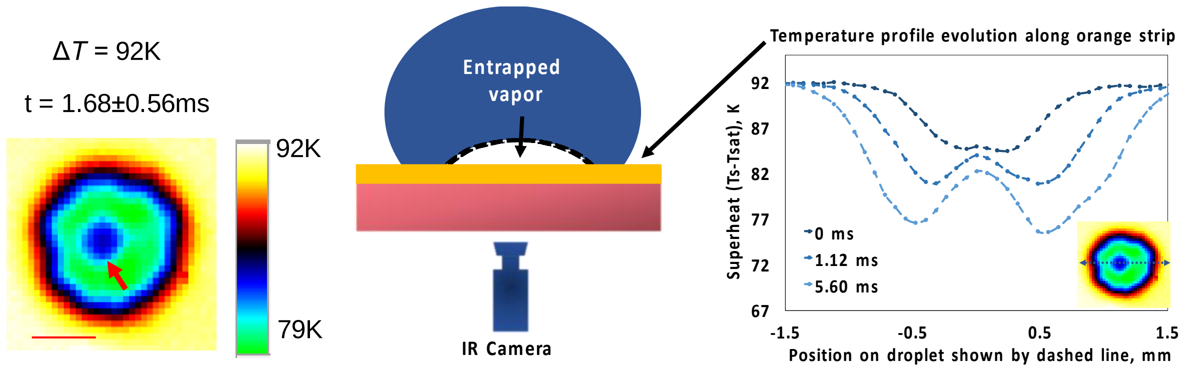

Figure 2. Thermal footprint of droplet impinging on heated substrate captured using an infrared camera underneath. The temperature profile along diameter of thermal footprint is shown for three time instances. Scale bar equals 1mm.

Figure 3 shows the temporal evolution of thermal footprint of droplets corresponding to experiments performed at $\Delta T = 92K$. Observations suggest that there is possibly a vapor escape mechanism for the droplets impacting on superheated surface. Roughly, the dimple opens up for about 2.3ms and then reseals itself to form a closed dimple as shown in Figure 3. There have been reports in literature predicting that shear stress at vapor-liquid can be high enough to disturb the air entrapment(Liu, Tan, and Xu 2015), however more experimental investigations are needed to deduce the overall geometry of vapor layer beneath droplets.

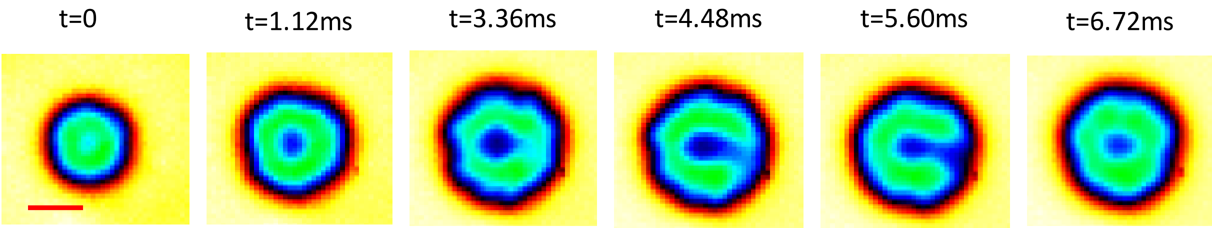

Figure 3. *Temporal evolution of complex droplet geometry upon impact on superheated surfaces. Scale bar equals 1mm.*

We observed that there is vapor entrapment underneath droplets as reported in literature too, however we also found a simultaneous vapor escape mechanism which hasn't been covered yet. Understanding of the mechanism propelling this escape phenomena can equip us with a strategy to further accelerate the escape rate so that thermal management could be achieved at high temperatures too. We have integrated thermography with high speed TIR imaging so that details of thermal footprint could be further understood as shown in Figure 1, although results are not presented here. We also plan on to integrate reflection interference imaging so that complete profile including the levitated portions of droplets could be seen.

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