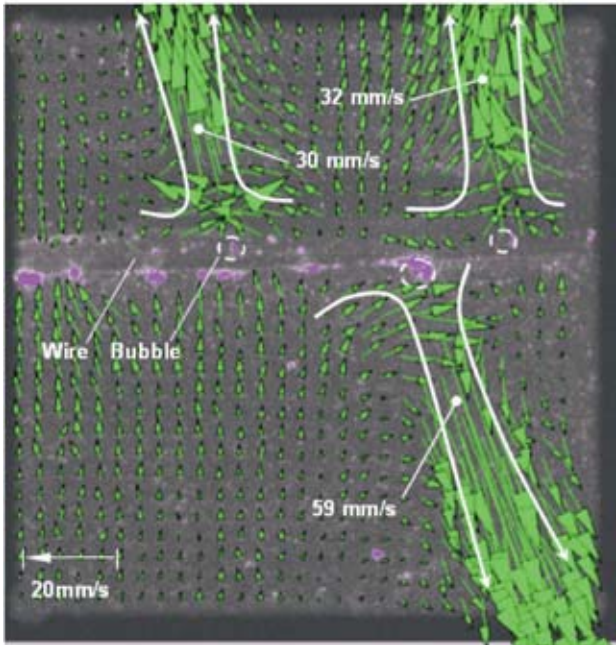
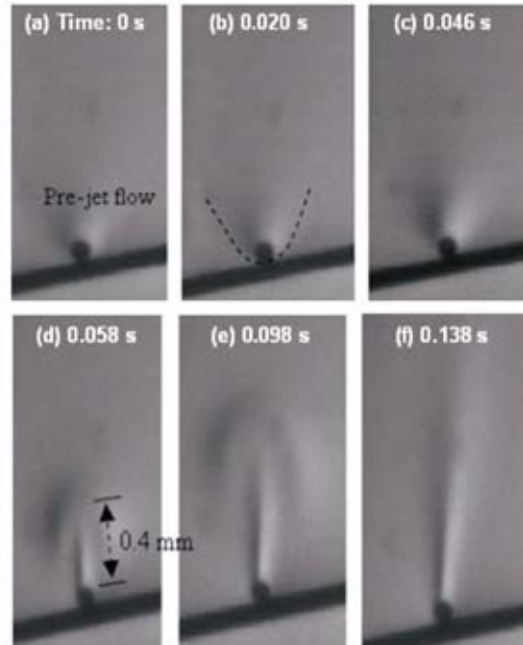


Velocities measured with PIV in bubble-top jets (water,  $T_{wire} = 378$  K,  $T_{bulk} = 320$  K)



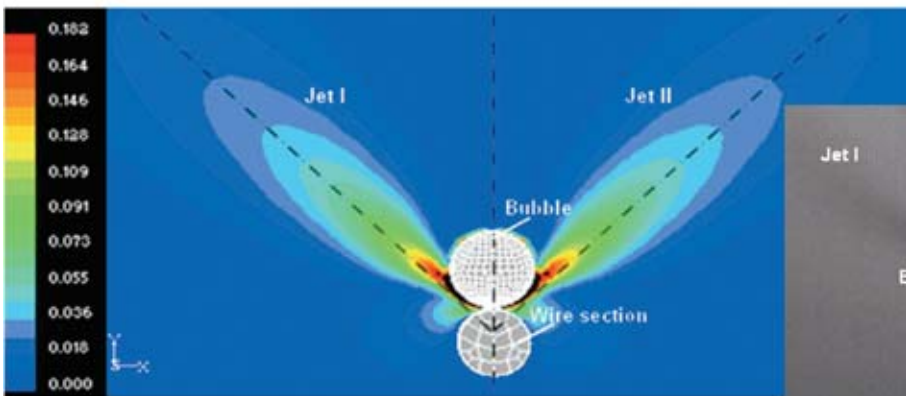
Two stages of the bubble-top jet formation process: Incipience (a)-(c), and Growth (d)-(f) (water,  $T_{wire} = 376$  K,  $T_{bulk} = 330$  K)



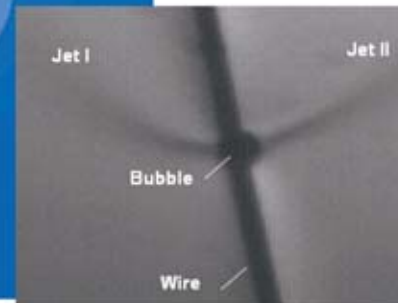
**Bubble-top jet flow**

- Hot liquid is pumped by Marangoni flow from around the bubble and the heater wire up into the bulk liquid.
- Maximum velocity above the bubble is some distance above the bubble top.
- Pumping effect enhances the single-phase heat transfer, and creates strong interactions among neighboring bubbles.

Simulation of butterfly-like structure of multi-jet flow: Velocity contours [m/s] (water,  $T_{wire} = 385$  K,  $T_{bulk} = 335$  K)



Experimentally visualized butterfly-like structure of multi-jet flow (water,  $T_{wire} = 376$  K,  $T_{bulk} = 330$  K)



**Multi-jet flow**

- Multi-jet flow with symmetric butterfly-like structure was predicted in simulation and confirmed in experiment.
- Multi-jet flows tend to form with larger bubbles; phase-change heat transfer plays an important role in controlling the jet structure.

**Jet Flows Around Microbubbles In Subcooled Boiling**

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Strong jet flows were observed emanating from micro bubbles on a 100  $\mu\text{m}$  diameter wire during subcooled nucleate boiling. The flow velocities were visualized with high-speed photography and quantified with a PIV analysis. The bubble-top jet flows were characterized by a single jet at the bubble top. Both experiments and simulations indicated that the bubble-top jet flows are induced by Marangoni effects due to temperature gradients near the wire, rather than

due to condensation at the bubble top. The evaporation and condensation does, however, control the jet flow intensity. Multiple jets from a single bubble were sometimes observed on bubbles that were generally larger than the heater wire. The jets were driven by the Marangoni flow at cool regions on the bubble sides resulting from upward flow of subcooled liquid.