Understanding Contact Freezing: Ice Nucleation at the Contact Line Triggered by Transient Electrowetting Fields

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Concept

Ice particles in the clouds can affect cloud lifetime, precipitation, radiation. Ice nucleation is the first step for ice formation in the atmosphere. Immersion and contact modes are thought to be the two most important modes for heterogeneous ice nucleation. One mystery is why the freezing temperature is higher when an ice nucleating particle collides with a supercooled water droplet (contact mode) compared to when the ice nucleating particle is immersed in the droplet (immersion mode). Understanding the mechanism of contact freezing will help us to better predict ice formation in the atmosphere. In this study, we simulate the transient contact between a particle and a droplet using the technique of electrowetting. The resulting disturbance of the contact line of a supercooled droplet shows that a moving boundary along the substrate can trigger ice nucleation at a much higher temperature than in a static droplet.

Experimental Setup

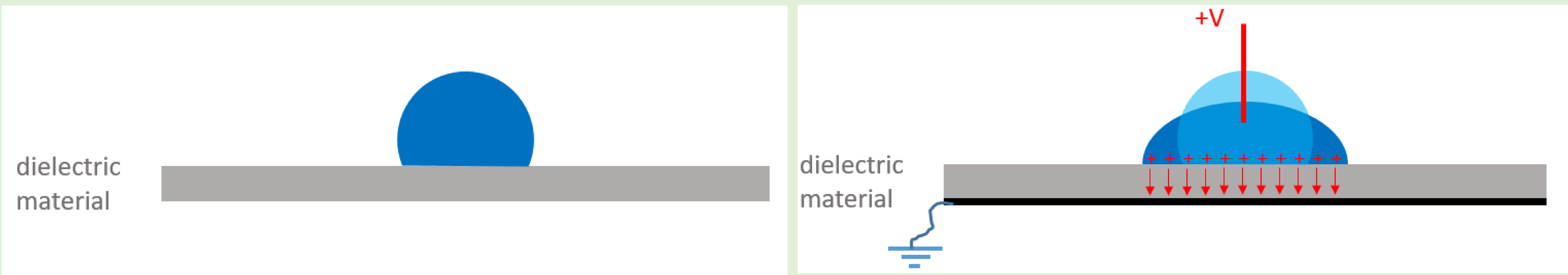


Fig. 1 Standard electrowetting setup: (a) without and (b) with electric field.

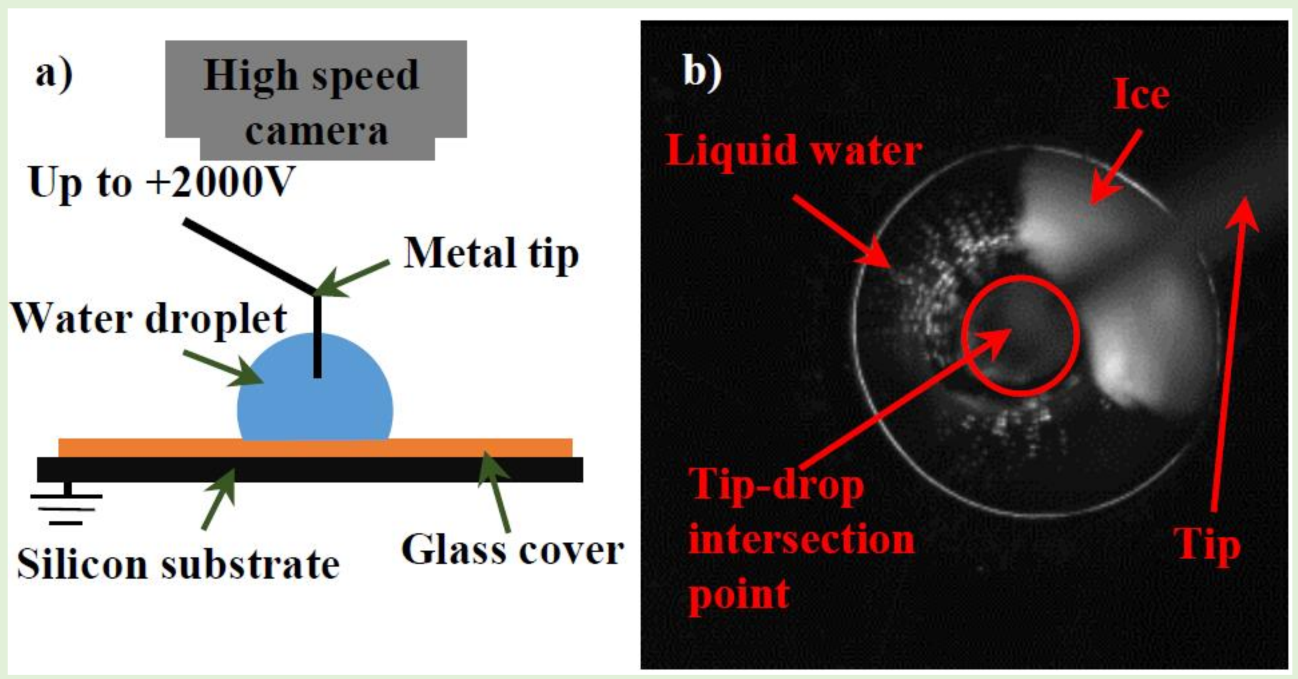
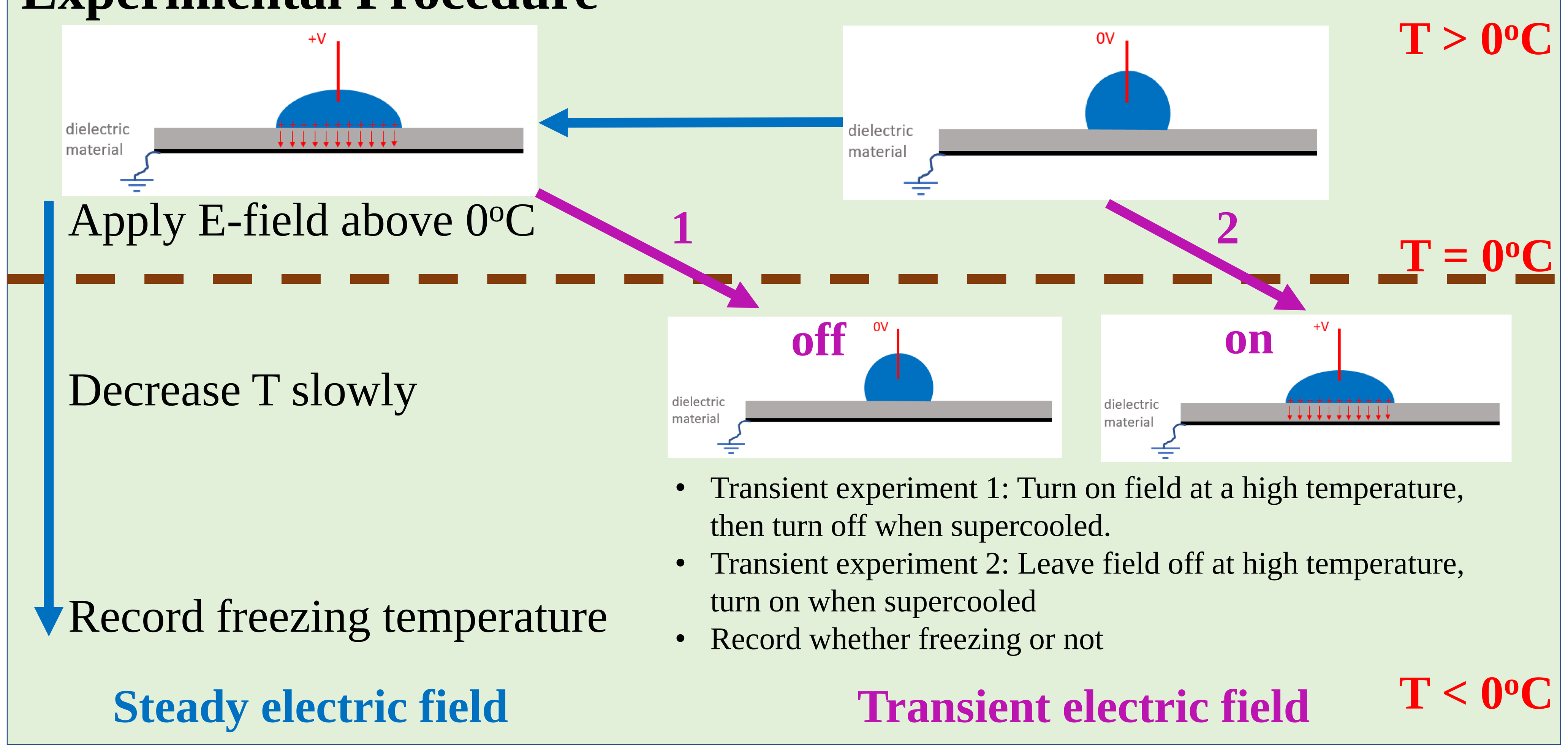


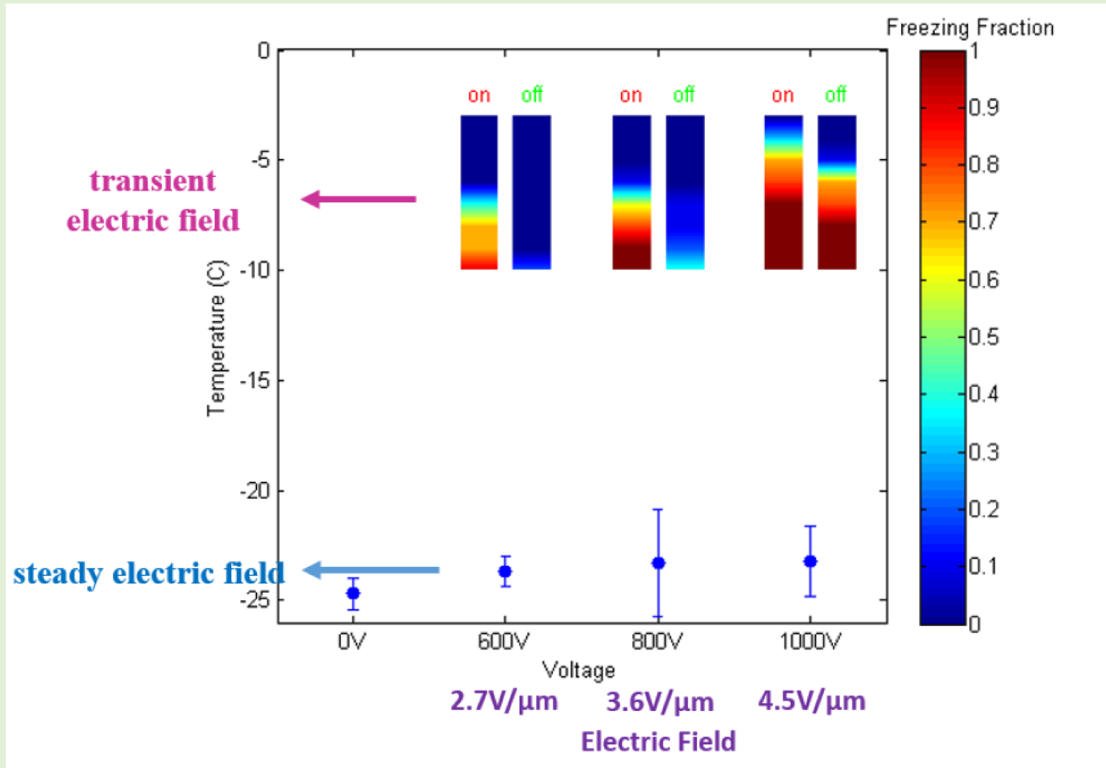
Fig. 2 (a) Sketch of the experimental setup from the side, illustrating the electrowetting geometry. (b) Top view of a crystallizing droplet from the high speed camera.

Experimental Procedure



- Transient experiment 1: Turn on field at a high temperature, then turn off when supercooled.
- Transient experiment 2: Leave field off at high temperature, turn on when supercooled
- Record whether freezing or not

Main Result



The freezing probability is strongly enhanced during the transient droplet motion
(i.e., field switched on or off when droplet is supercooled).

Fig. 3 Freezing temperature for steady electric field and the freezing fraction for transient electric field.

Example Drop Freezing Events

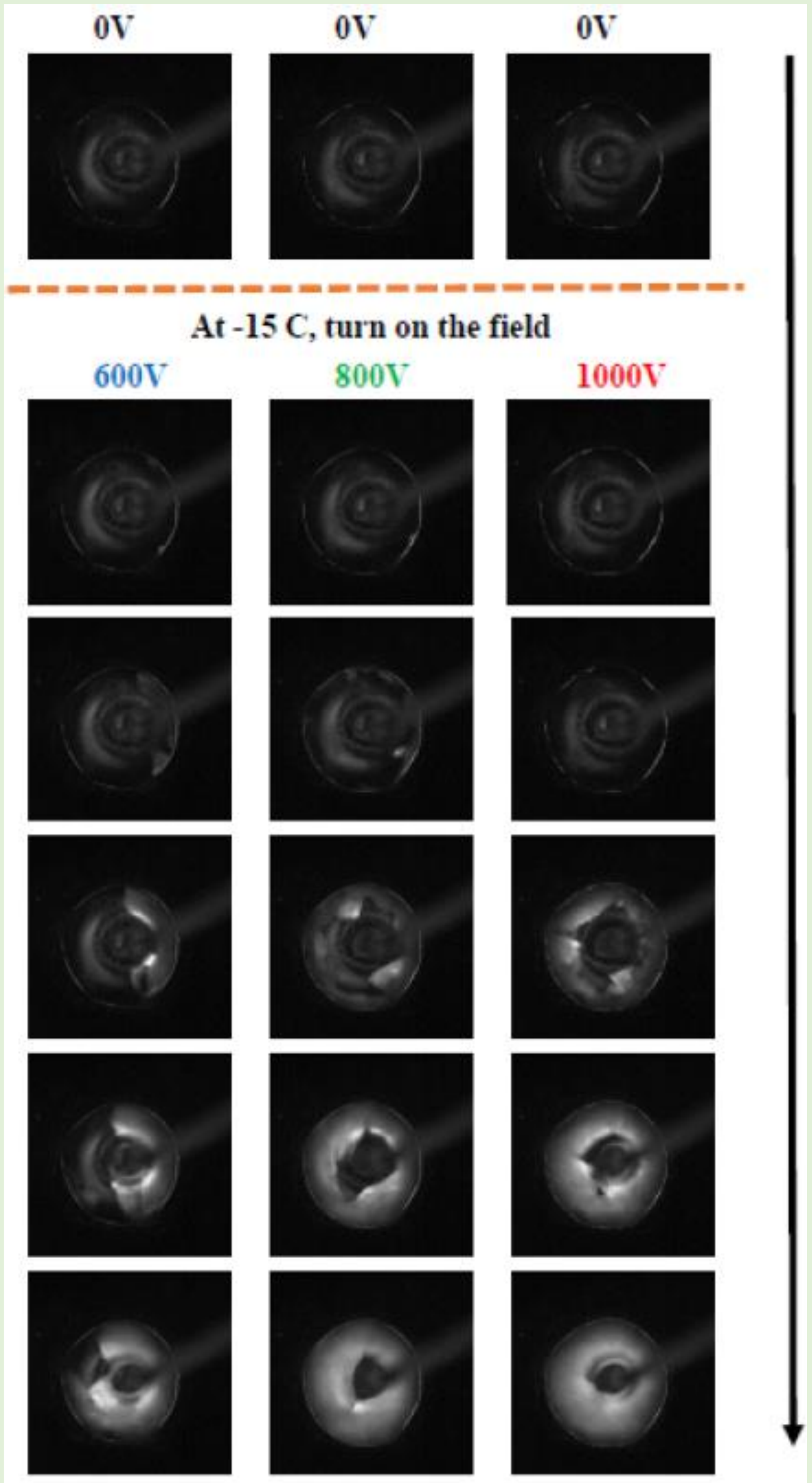


Fig.4 Time-lapse views of crystallization after switching on three voltages at −15 °C. Each frame in one column is separated by 4 ms.

Discussion

Three interesting observations:
1. Boundary movement
2. Freezing always starts from edge
3. Nucleation at multiple points

Possible mechanisms:

1. Effect of electric field?
No. Because electric field alone doesn't change the freezing the freezing temperature significantly.

2. Effect of transient electric field?
No. Because without boundary movement, no freezing occurs if we turn on/off the electric field. The boundary movement is limited by solid wall or graphene layer.

3. Effect of contact line movement
Likely. Recent experiments show that vibration alone can also trigger ice nucleation. Freezing also starts from the edge and can occur at multiple points sometimes. We believe this provides a link to understanding the mechanism for contact ice nucleation in the atmosphere.

Acknowledgement

A special thanks goes to Adam Laxo (MTU Physics) and Weilue He (MTU Biomedical Engineering), who helped with experiments on electrofreezing. This research was supported by the DOE Office of Science as part of the Atmospheric System Research program through Grant No. DE-SC0011690.

Reference

Yang, Fan, Raymond A. Shaw, Colin W. Gurganus, Su Kong Chong, and Yoke Khin Yap. "Ice nucleation at the contact line triggered by transient electrowetting fields." *Applied Physics Letters* 107, no. 26 (2015): 264101.