Electro-Guided Self-Propelled Droplets

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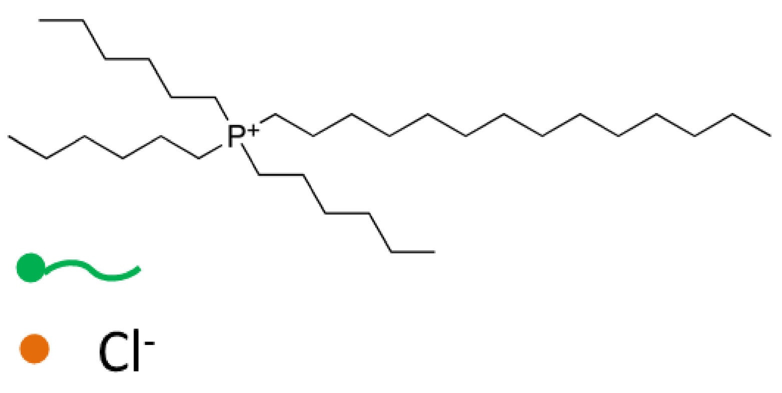
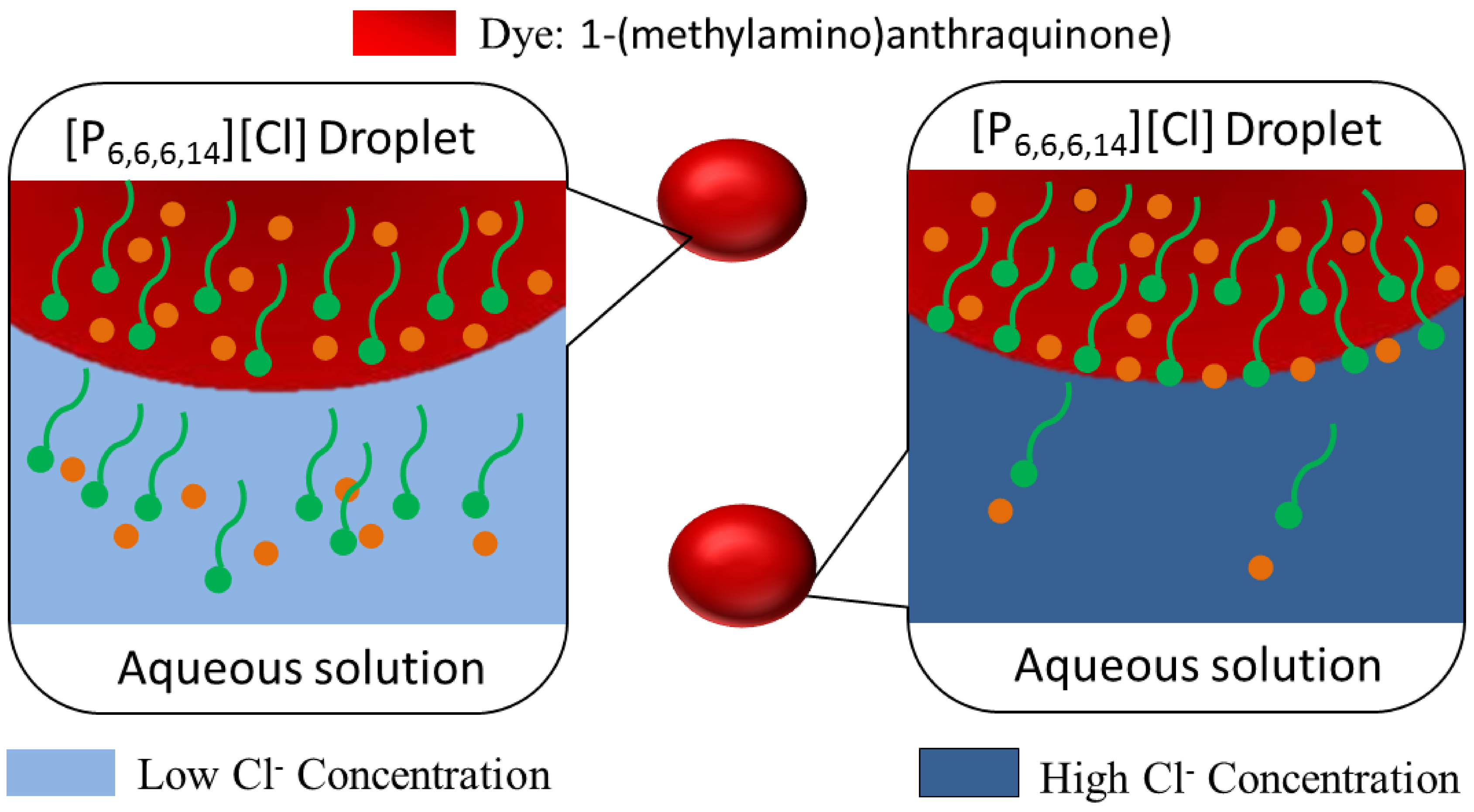
Introduction

Stimuli-responsive materials have gained much attention recently as means for fluid flow control within the microfluidic field. The ability to contactless control droplets within microfluidic devices offers new and interesting possibilities such as cargo transport to desired destinations and dynamic sensing. Herein we report for the first time the movement and guidance of an ionic liquid droplet through electro-stimulation. This type of triggered surfactant release through electro-stimulus aims to develop new methods for controlling droplet movement within microfluidic devices, as well as developing biomimetic synthetic motors.

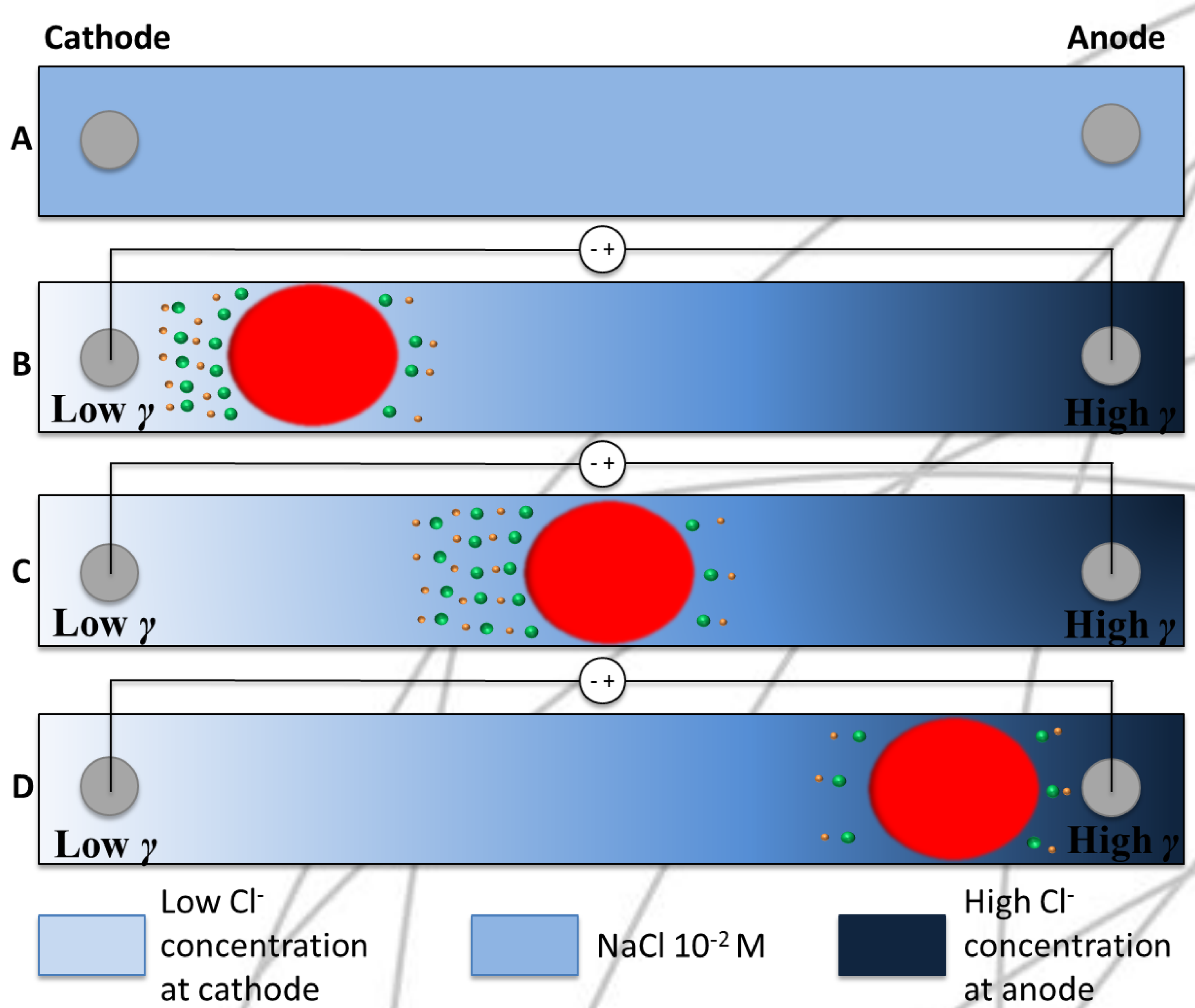
Droplet composition and movement

These single component droplets are composed of an Ionic Liquid (IL), namely Trihexyl(tetradecyl)phosphonium chloride ($[P_{6,6,6,14}][Cl]$), with a small amount of red dye for visualization. The $[P_{6,6,6,14}]^+$ is a very efficient cationic surfactant. Once released, the $[P_{6,6,6,14}]^+$ cation will lower the surface tension of the aqueous solution, causing the droplet to move towards the area of higher surface tension.





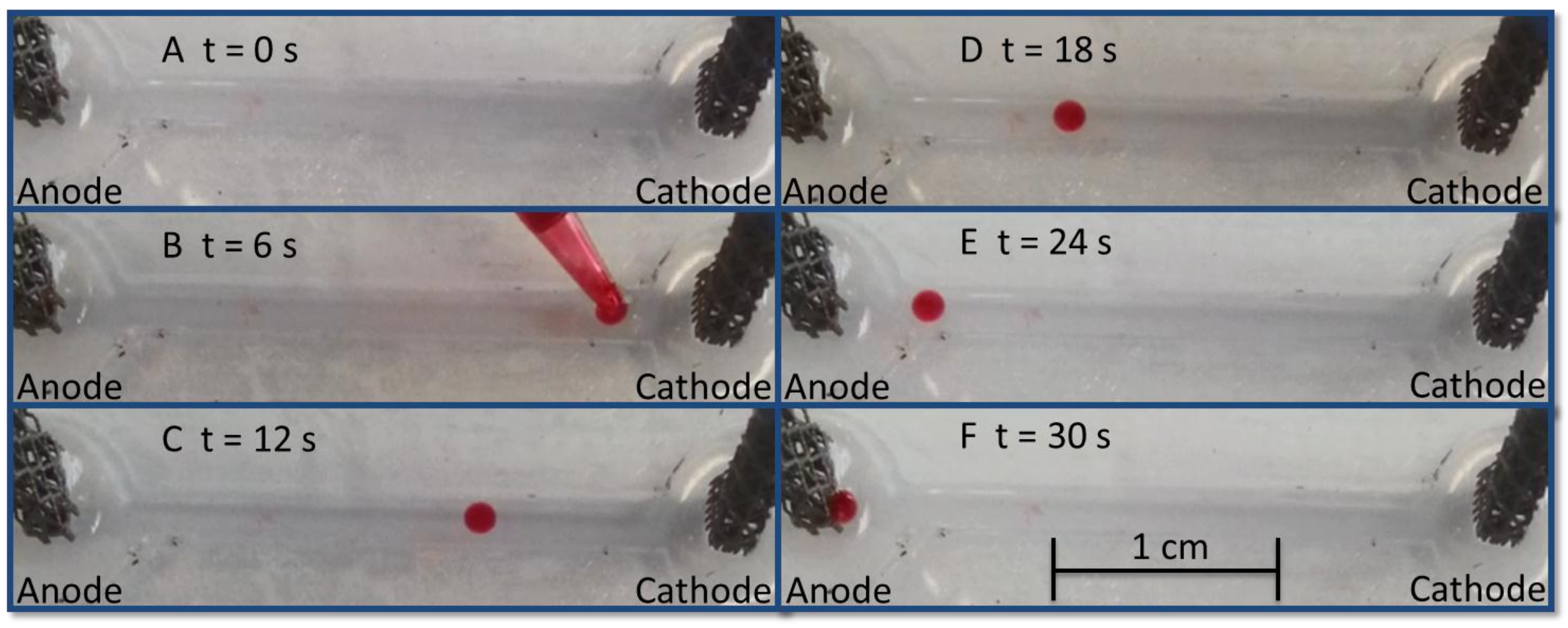
The motion of these discrete droplets was controlled by the triggered release of the $[P_{6,6,6,14}]^+$ surfactant. In this work, the droplets were guided to specific destinations in open fluidic channels through Cl^- gradients. These Cl^- gradients were electro-generated using carbon printed or porous titanium electrodes.



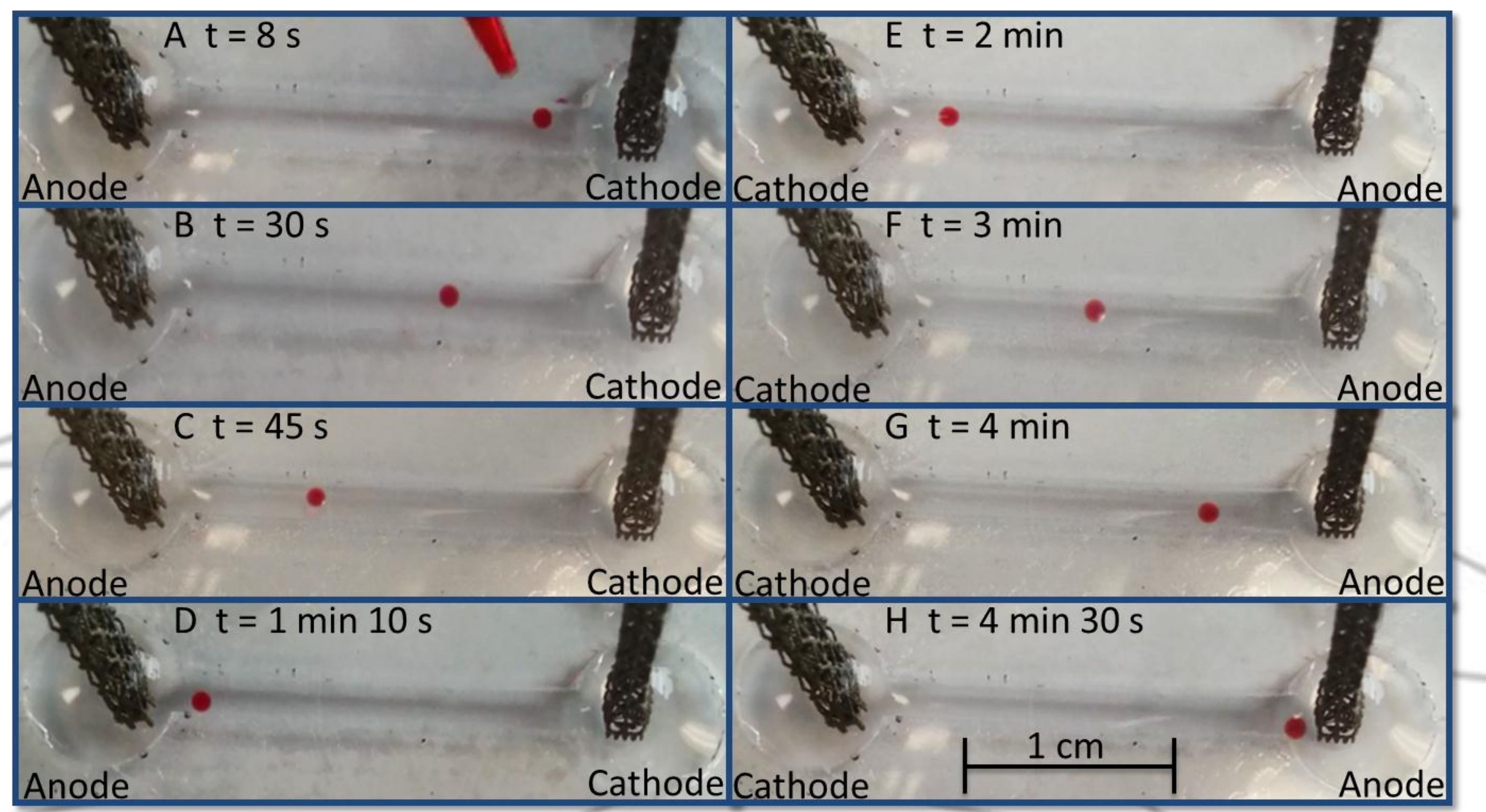
The surface tension gradient is created by the asymmetric release of $[P_{6,6,6,14}]^+$ from the IL droplet into the aqueous phase. The rate of $[P_{6,6,6,14}]^+$ release depends on the concentration of the chloride in the aqueous solution, as the formation of free $[P_{6,6,6,14}]^+$ (the active surfactant at the air-aqueous interface) through dissociation of the relatively closely associated $[P_{6,6,6,14}][Cl]$ ions in the IL depends on the local Cl^- concentration at the IL-aqueous boundary.

Electro-guided droplet movement

To create a Cl^- gradient through electro-simulation the channels are initially filled with an electrolyte solution (NaCl 10^{-5} - 10^{-2} M). Titanium electrodes are then inserted into the solutions at either end of the channel. By applying an external electric filed (5 V) to the solution a droplet can be moved from the cathode (-) to the anode (+).



Once the voltage has been applied to the solution, the mobile cations migrate towards the cathode (Na^+ ions towards the starting position) and the mobile anions migrate toward the anode (Cl^- ions towards the destination), creating a Cl^- gradient for the droplet to follow. The direction of movement of the droplets reverses if the polarity of the electrodes is reversed.



Future work

Arrays of channels which have embedded titanium electrodes will be printed using an Objet350 Connex Printer (for the channel) and Realizer SLM-50 3D printer (for the electrodes). With these channels it is expected that further functionality can be added to the droplets. This includes having the droplets merge once they have reached the destination. In this fashion, the droplets can act as externally controllable micro–reactors for chemical reactions.

Conclusions

To our knowledge, this is the first demonstration of electro-stimulated movement of a simple, single component droplet based on an ionic liquid at the air-liquid interface. The use of electro-generation of ion-gradients in the external aqueous environment allows for on-demand droplet movement, with the potential for direction and speed control within the microfluidic device. We envision that these droplets could be used for directed transport of molecular cargo to desired destinations and dynamic sensing of the fluidic environment during movement.

Acknowledgments

Science Foundation Ireland under the Insight initiative, grant SFI/12/RC/2289, European Union Marie Curie People Programme Mask: PIRSES-GA-2010-269302