The University of Edinburgh

Droplet moving over a sharp transition of wettability on the hydrophobic surface

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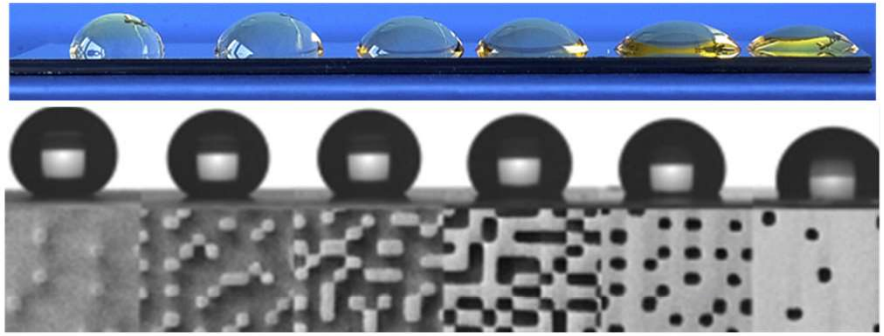
04/12/2018

Background

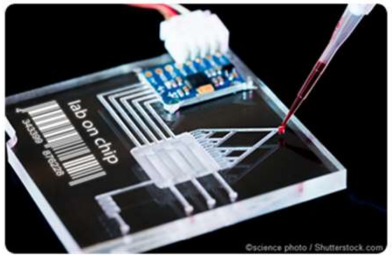
Hydrophobic surface

MacGregor-Ramiasa MN, Vasilev K. Advanced Materials Interfaces. 2017 Aug;4(16):1700381.

Gradient: chemical(above) or roughness (below)



Gradient → Less hydrophobic



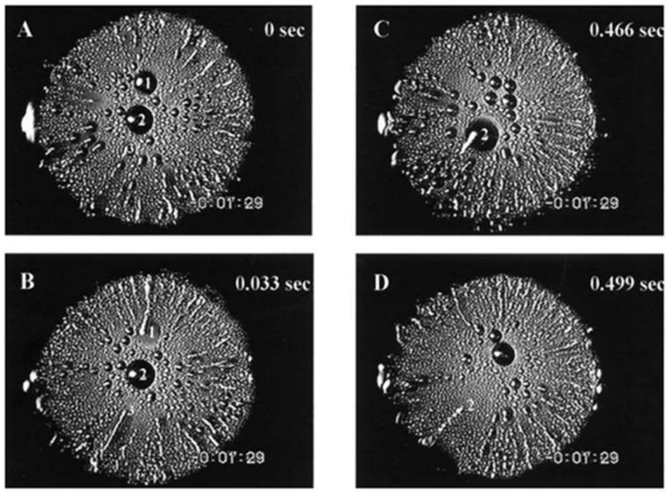
microfluidic system

Accuracy

Avoid Interference

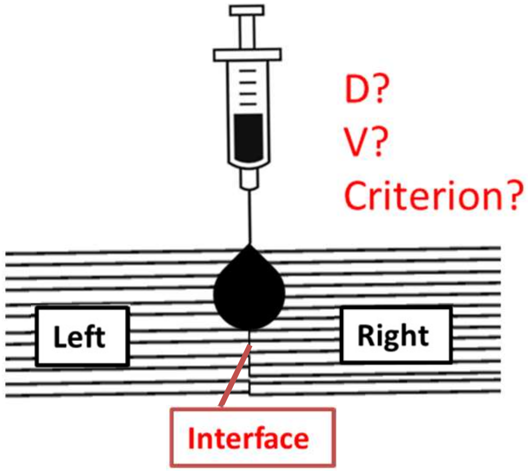
Drop-wise

Efficiency



Heat transfer enhancement

S. Daniel, *Science (80-.).*, 2001, **291**, 633–636.



Setup

Surface design

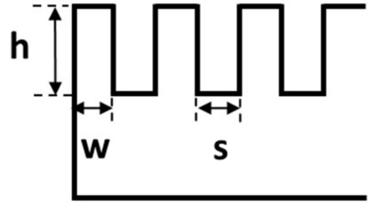
microstructure

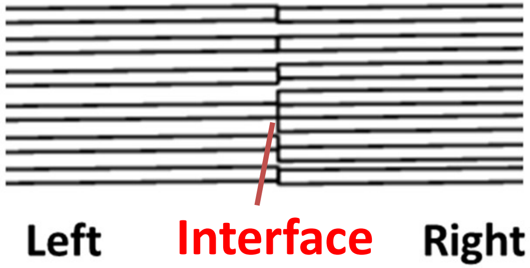
Width: 10 µm

Spacing: 5-90 µm

Height: 20 µm

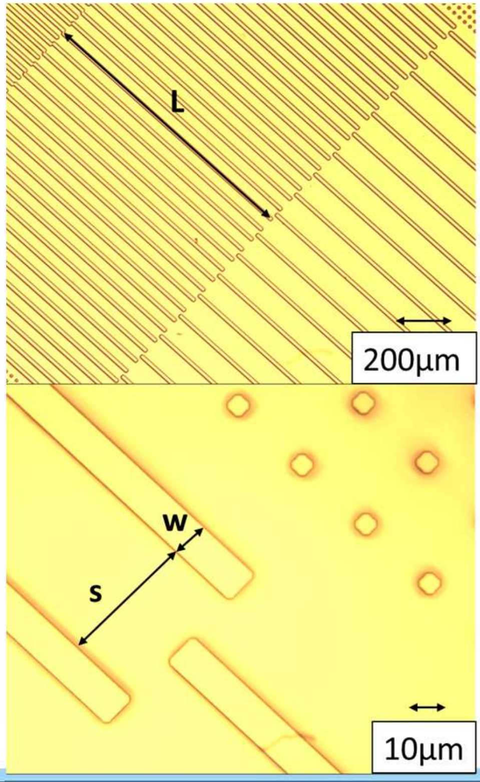
Contact Angle: 110-155°

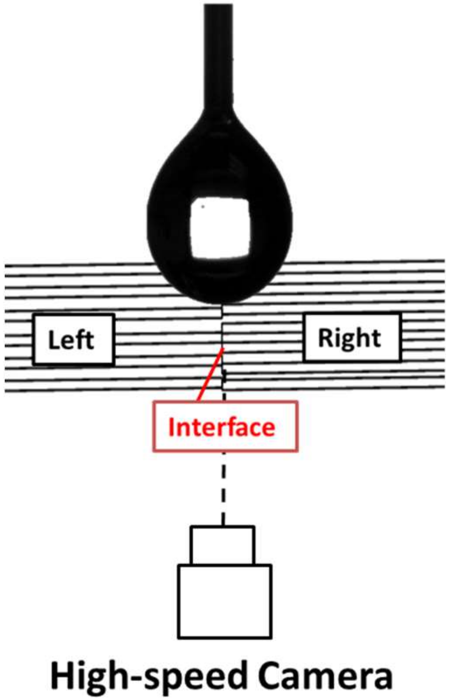


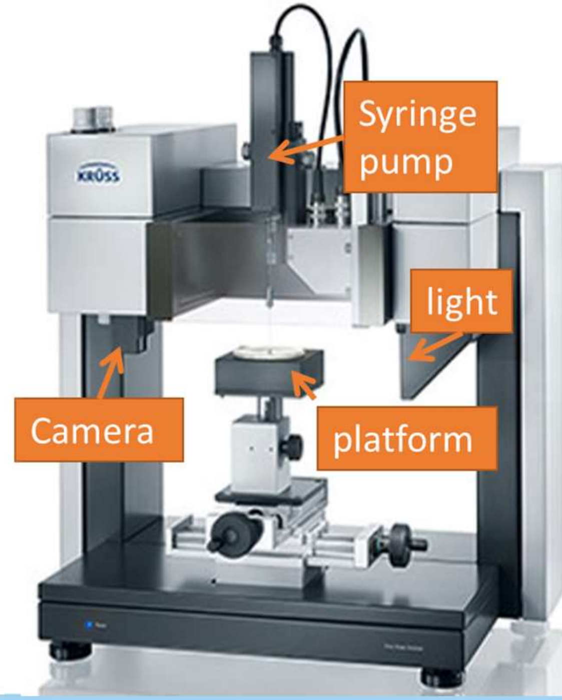


9 kinds of surface units

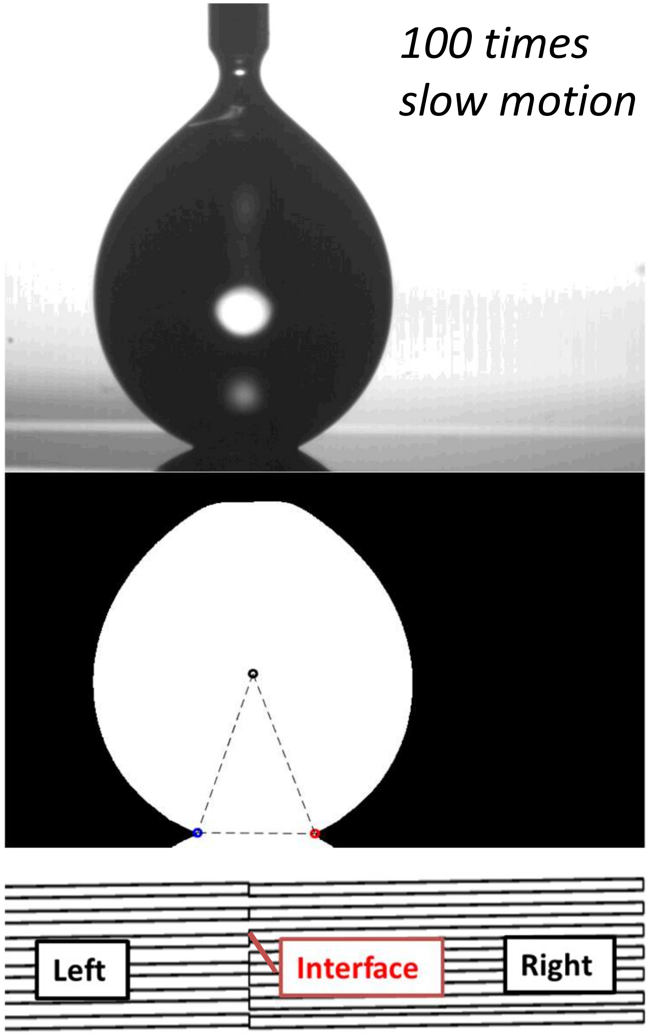
$$\frac{9*8}{2} = 36 \text{ combinations}$$

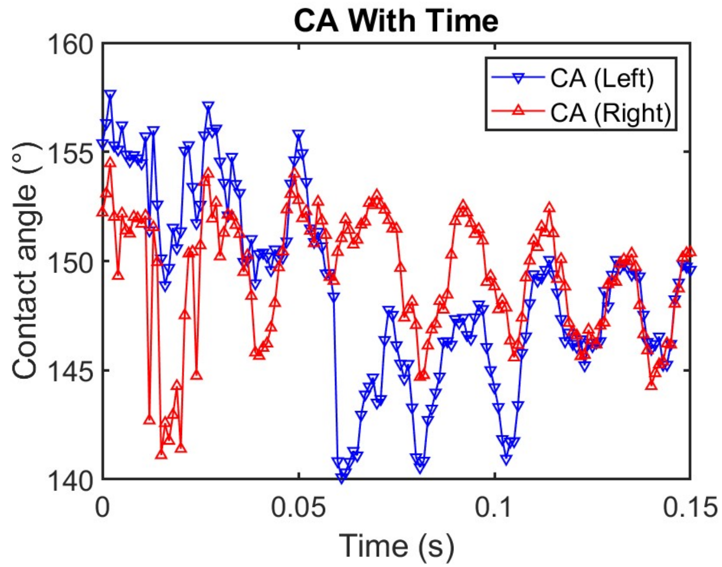


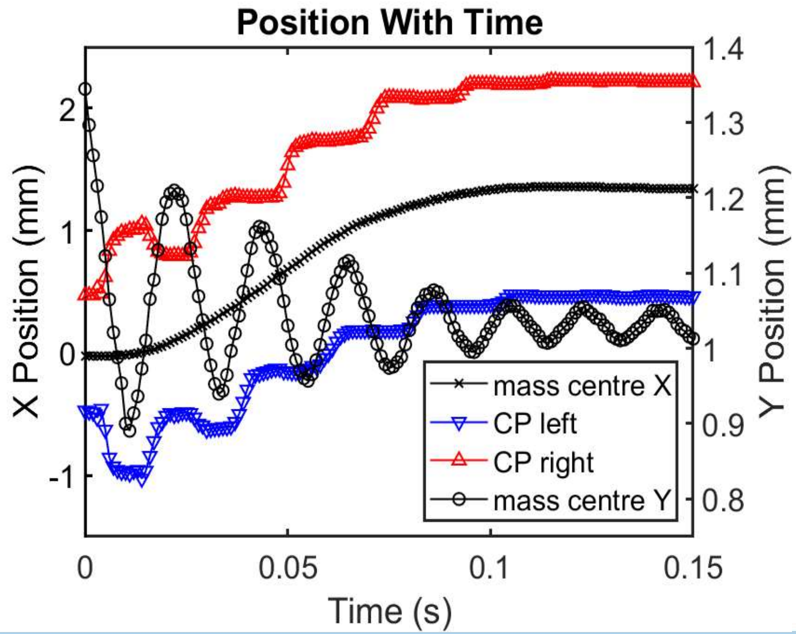




Methodology





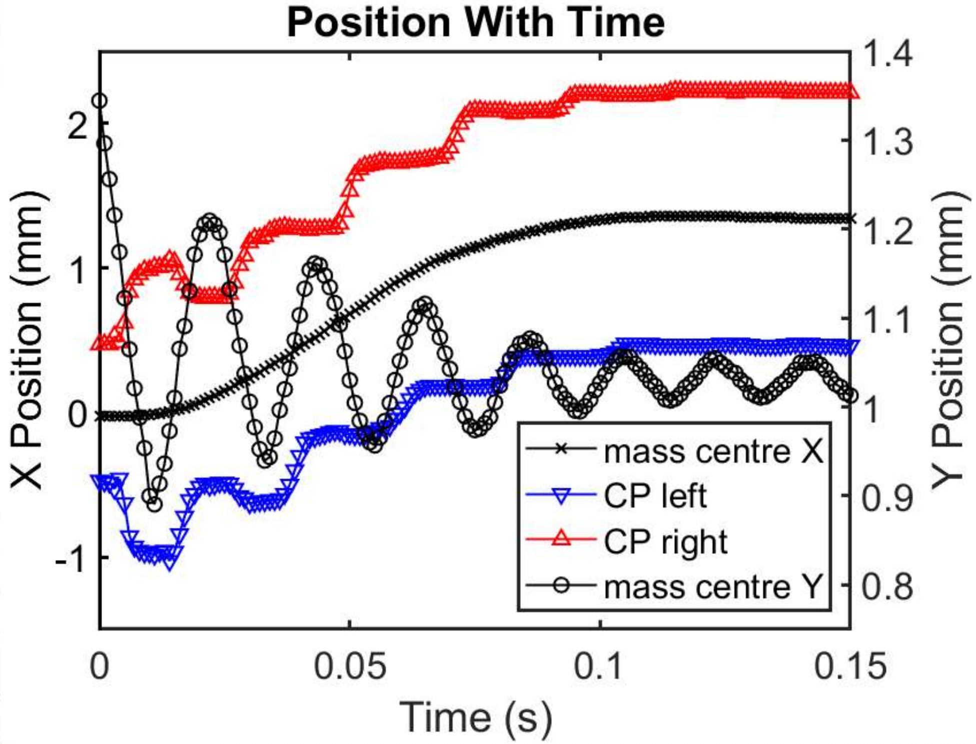


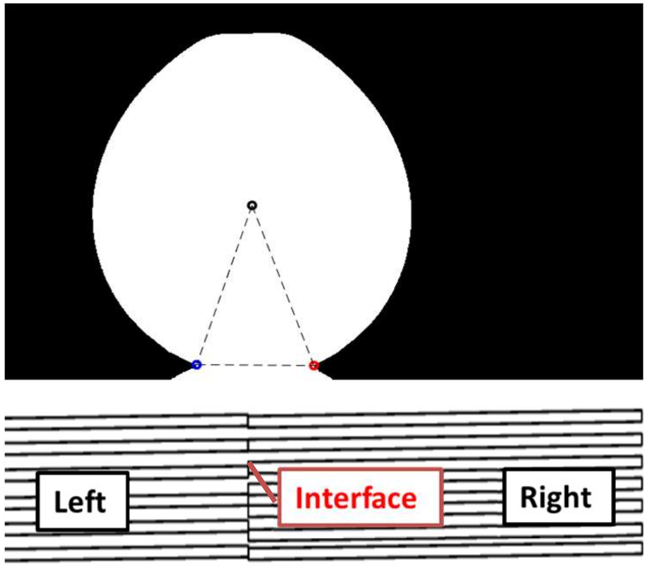
Motion analysis

Horizontal 'drift' —— mass centre

Driving Force: $F_d = \gamma R(\cos\theta_{eq}^R - \cos\theta_{eq}^L)$

Resistance:
$f_v \sim \beta V$
f_f
$f_h \sim \theta_{ad}^L, \theta_{re}^L, \theta_{ad}^R, \theta_{re}^R$





Damped Oscillation

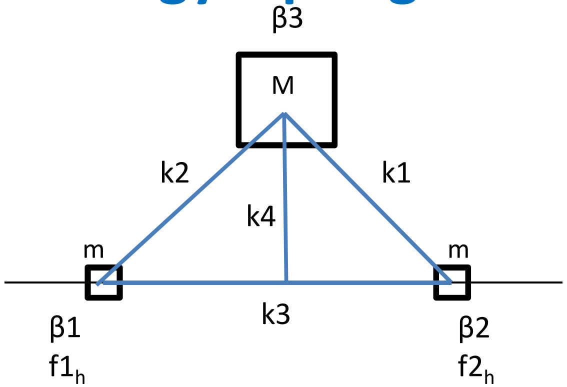
Motion activation

More than superposition

Drift ⇆ Oscillation

Motion analysis

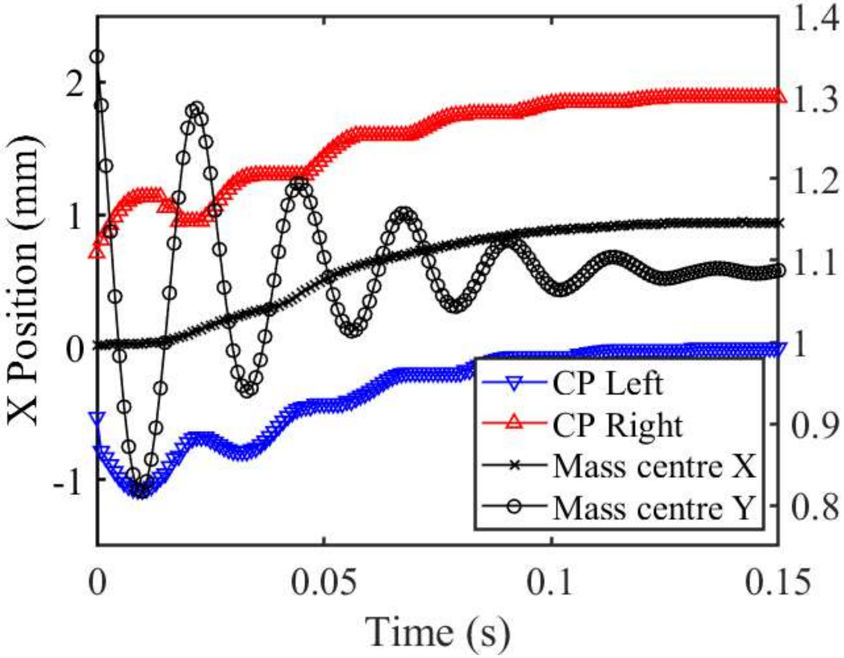
Analogy: Spring model

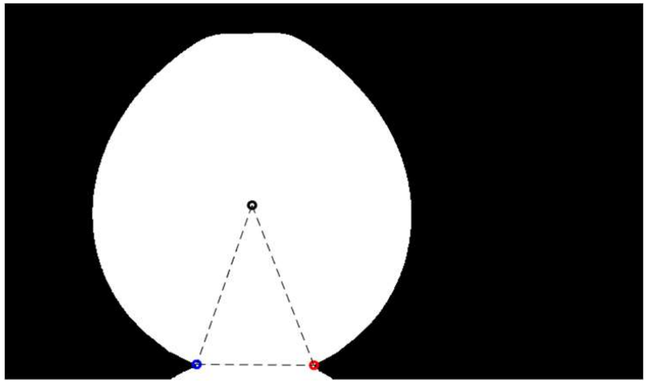


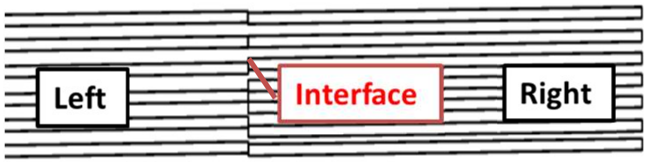
M>>m

F_d, f_f, f_v, f_h

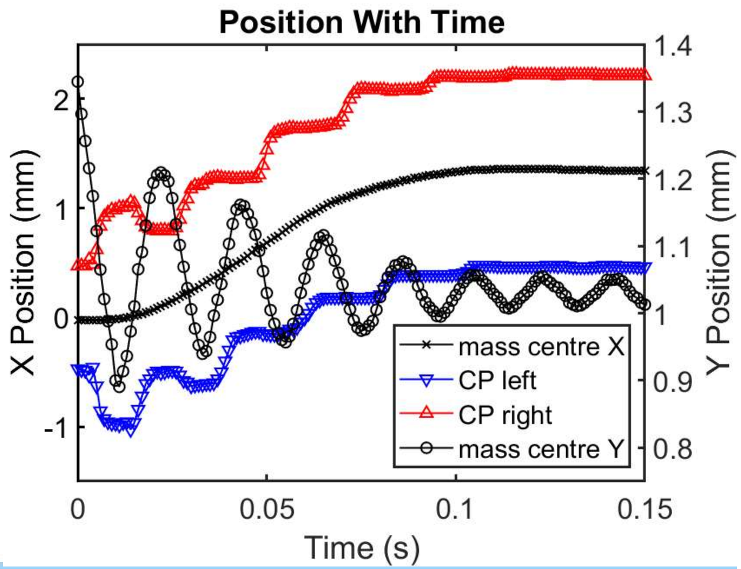
Spring model result







Experimental data



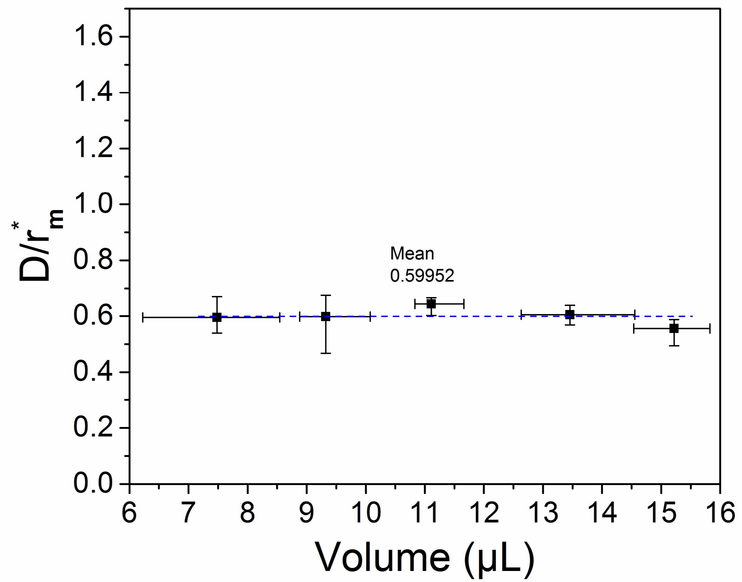
Volume and Height

Volume influence

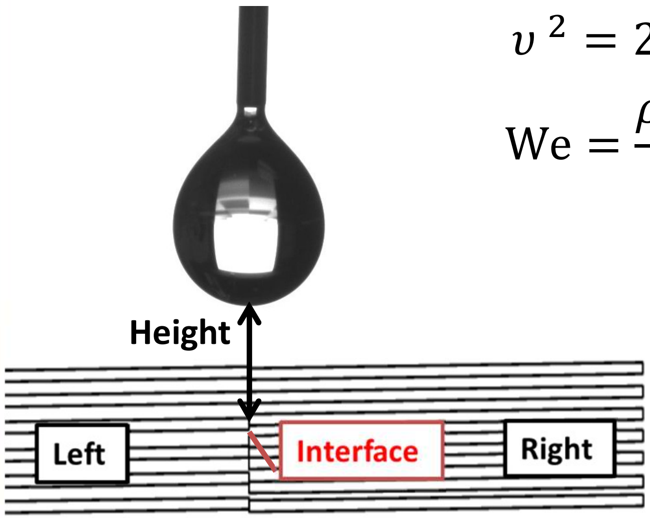
Normalized displacement

$$r^*_{l,r} = \left(\frac{3V}{\pi}\right)^{1/3} \left(1 - \cos\theta_{eq}^{L,R}\right)^{-2/3} \left(2 + \cos\theta_{eq}^{L,R}\right)^{-1/3}$$

$$r^*_m = (r^*_l + r^*_r)/2$$

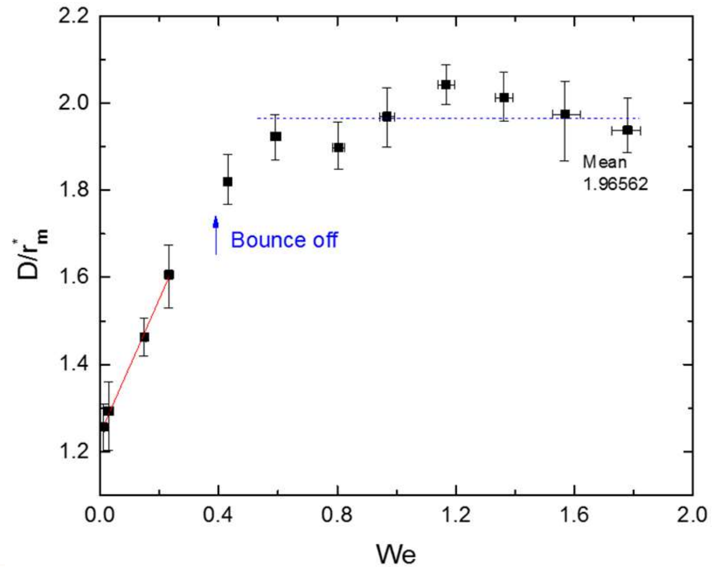


Height influence



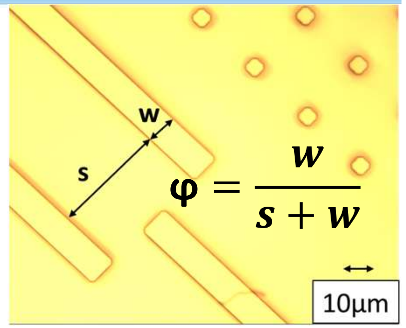
$$\upsilon^2 = 2gH$$

$$\text{We} = \frac{\rho\upsilon^2}{\gamma} = \frac{2gH}{\gamma}$$



Motion Criterion

Overall cases: motion distance



$$\Delta\varphi = \varphi_R - \varphi_L$$

$$\bar{\varphi} = \frac{(\varphi_R + \varphi_L)}{2}$$

Driving force

Caused by gradient

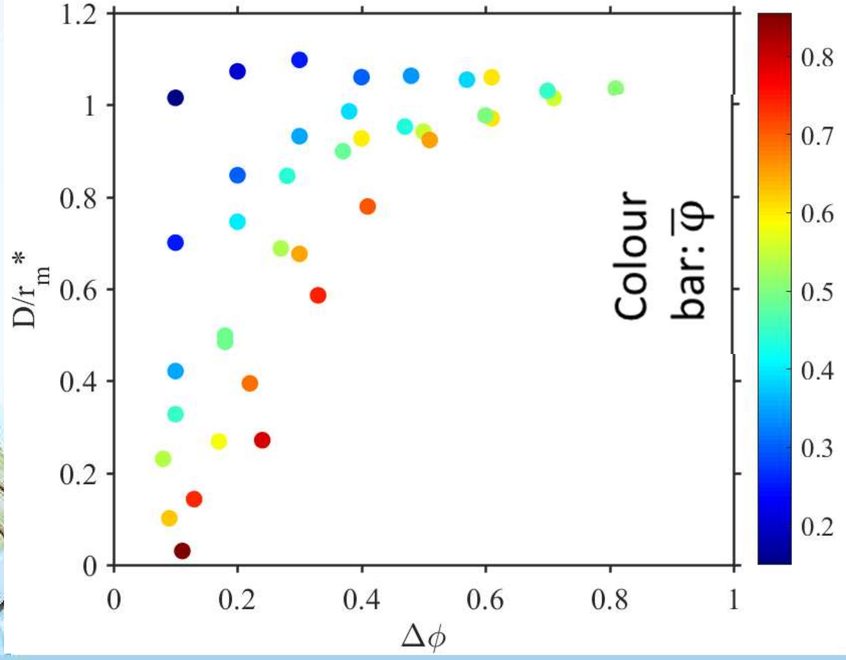
$$F_d = \gamma\left(\cos\theta_{eq}^{R} - \cos\theta_{eq}^{L}\right) = \gamma(1 + \cos\theta_Y)\Delta\varphi$$

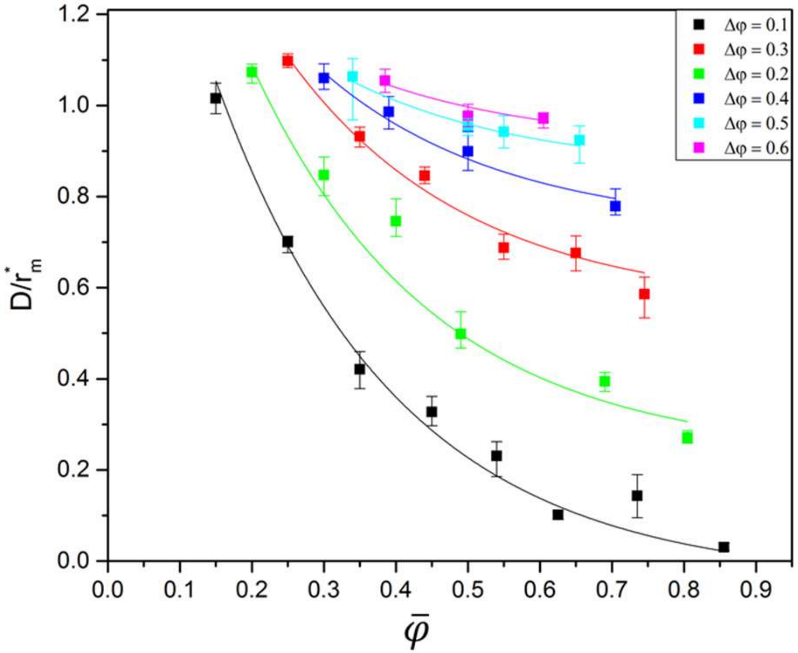
Resistance

Friction and hysteresis

'sliding' and 'static' friction force

$$F_r:\ f_f\ , f_h \sim \bar{\varphi}$$

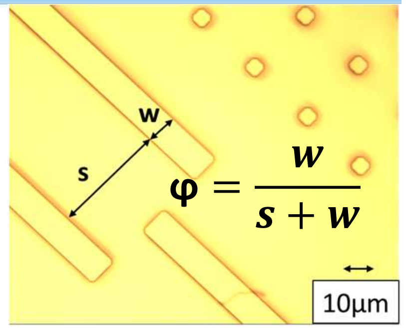




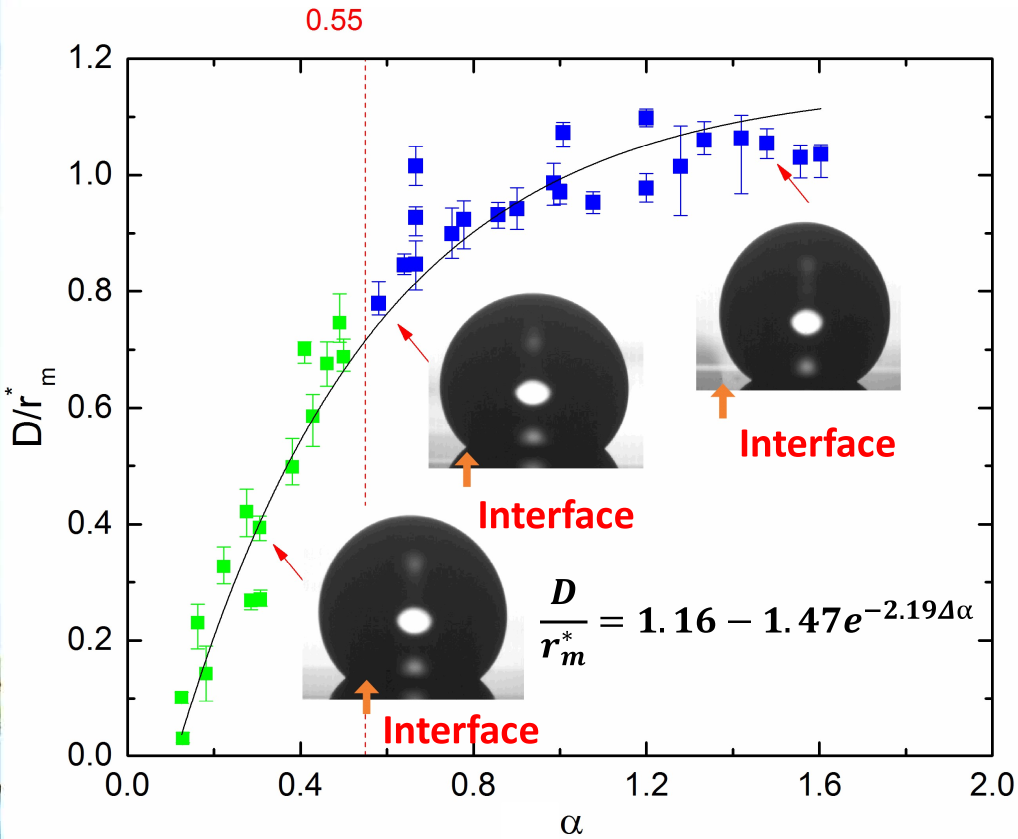
Criterion: α

Overall cases: motion distance

$$\alpha = \frac{2(\varphi_R - \varphi_L)}{\varphi_R + \varphi_L} = \frac{\Delta\varphi}{\overline{\varphi}} = \frac{F_d}{F_r}$$



$$\varphi = \frac{w}{s + w}$$



Driving force

$$F_d = \gamma(\cos\theta_R - \cos\theta_L) = \gamma(1 + \cos\theta_Y)\Delta\varphi$$

Resistance

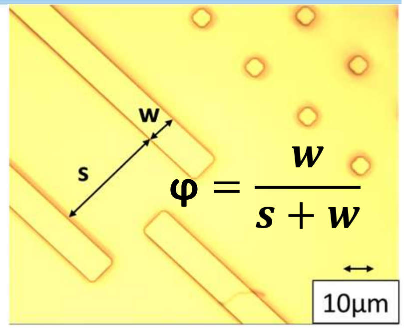
Friction and hysteresis

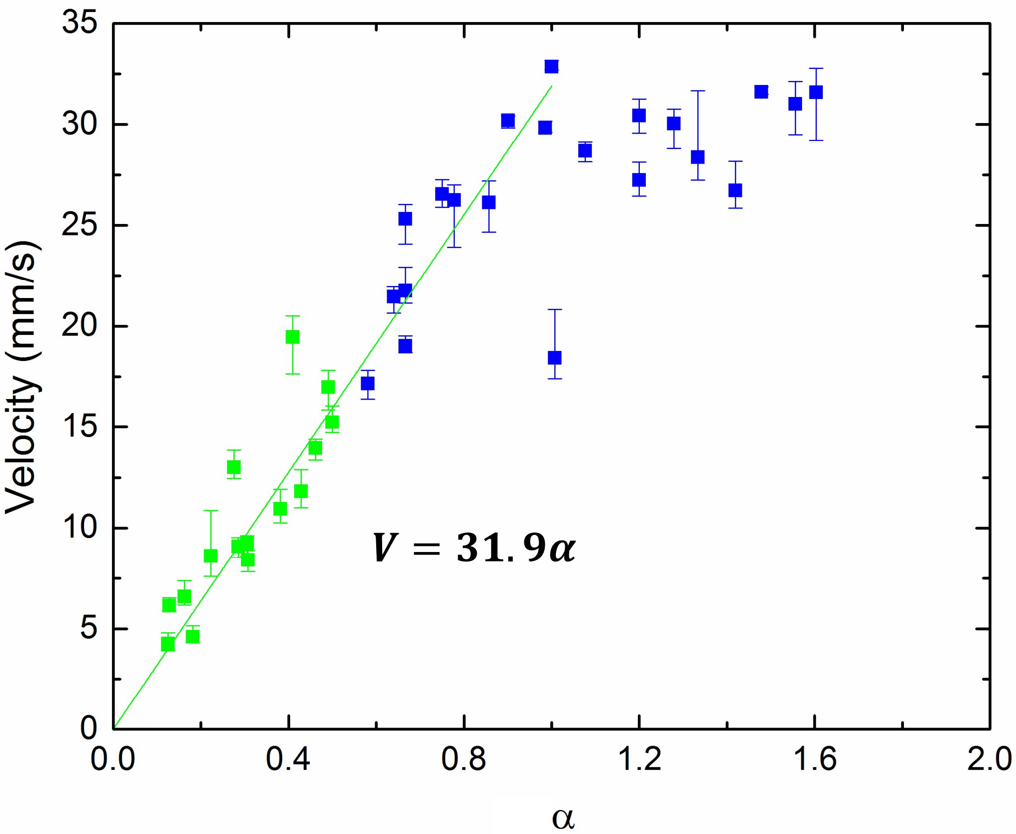
$$F_r \sim \overline{\varphi}$$

Criterion: α

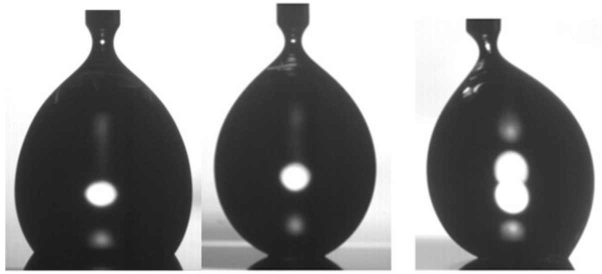
Overall cases: Average Velocity

$$\alpha = \frac{2(\varphi_R - \varphi_L)}{\varphi_R + \varphi_L} = \frac{\Delta\varphi}{\overline{\varphi}} = \frac{F_d}{F_r}$$





Initial deposition



$\alpha = 0.18$ $\alpha = 0.67$ $\alpha = 1.56$

Viscous force f_v?

$f_v \sim \beta V$

Conclusion

Single motion analysis:

Coupling of two motion behaviors

Analogy method: spring model

Overall cases:

Volume has little influence

Increase with We at a small range

A criterion combining F_d and F_r

Fundamental understanding

Beneficial for Microfluidic device design

Thank you for your attention!