Self-assembly of impinging ferrofluid droplet

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Introduction

The unique liquid nature and strong magnetic response ability enable ferrofluid droplet to split and self-assemble into reconfigurable three-dimensional structures. Although the manipulation of ferrofluid droplet in a static or quasi-static state has been well studied, the splitting and self-assembly of ferrofluids in a dynamic state remain unexplored. Here, we report the impingement-assisted self-assembly of ferrofluids on superhydrophobic surfaces whereby the required magnetic field is greatly reduced. In particular, the coupling between the magnetic field strength and Weber number endows a precise regulation of the ferrofluid post-impact dynamics, which facilitates the optimization of the self-assembly behavior.

Methods

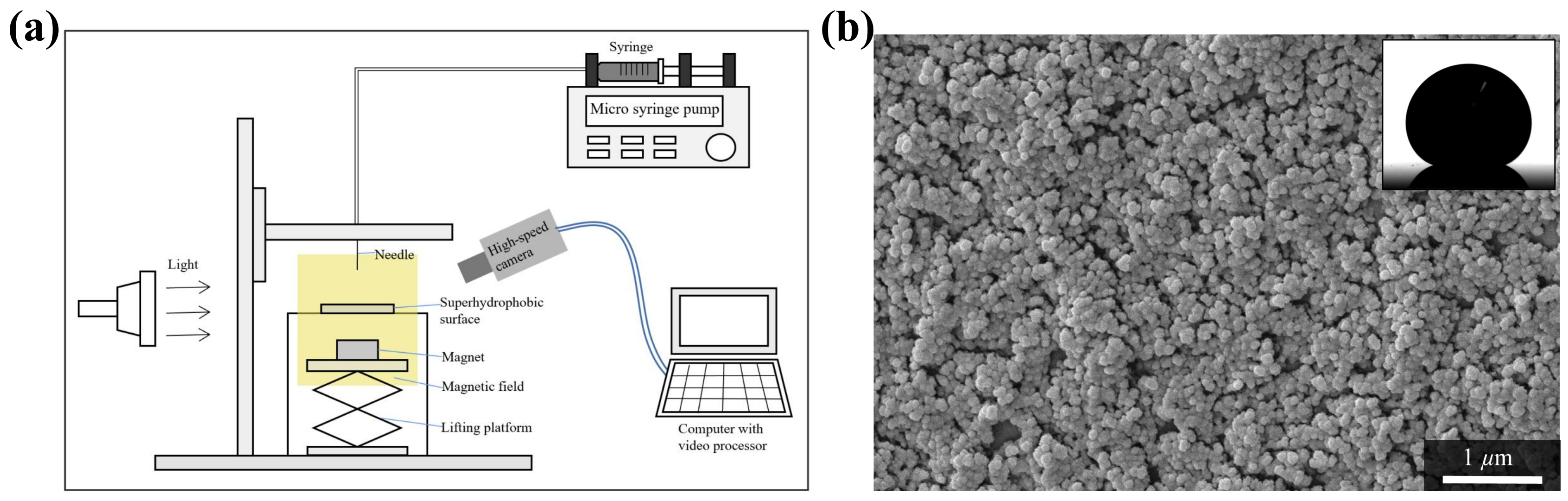

Fig. 1. (a)The schematic diagram of experimental setup. By changing the distance between the magnet and the sample, the magnetic field strength can be adjusted and ferrofluid droplet impinging dynamics and self-assembly behavior were captured using a high-speed monochrome camera. (b)SEM image of the as-prepared superhydrophobic substrate with nanotextures, demonstrating contact angle of water based ferrofluid droplet about 156°.

Results

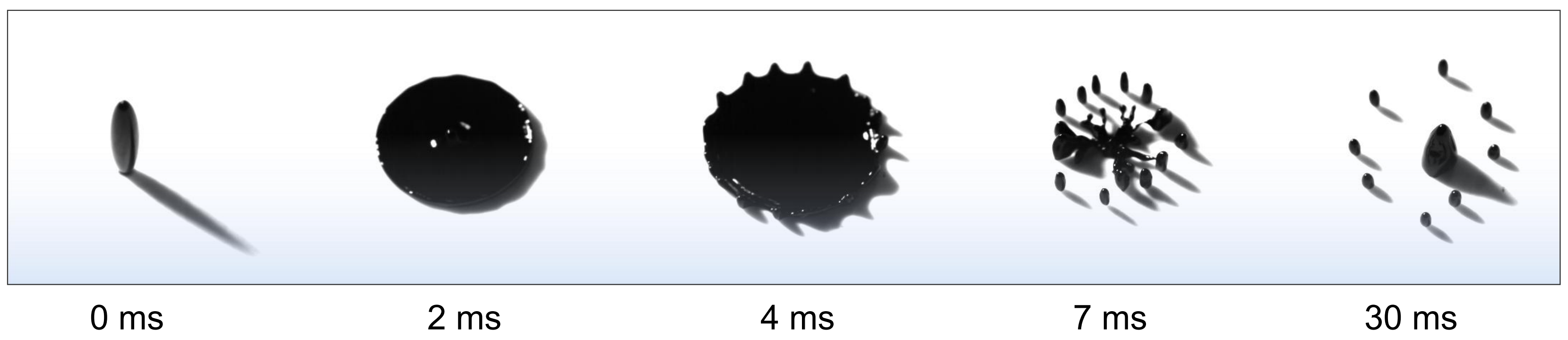

Fig. 2. Top-view time-lapse images captured via high-speed imaging of ferrofluid droplet impacting and self-assembly on superhydrophobic surfaces (*B* = 90 mT, We = 116).

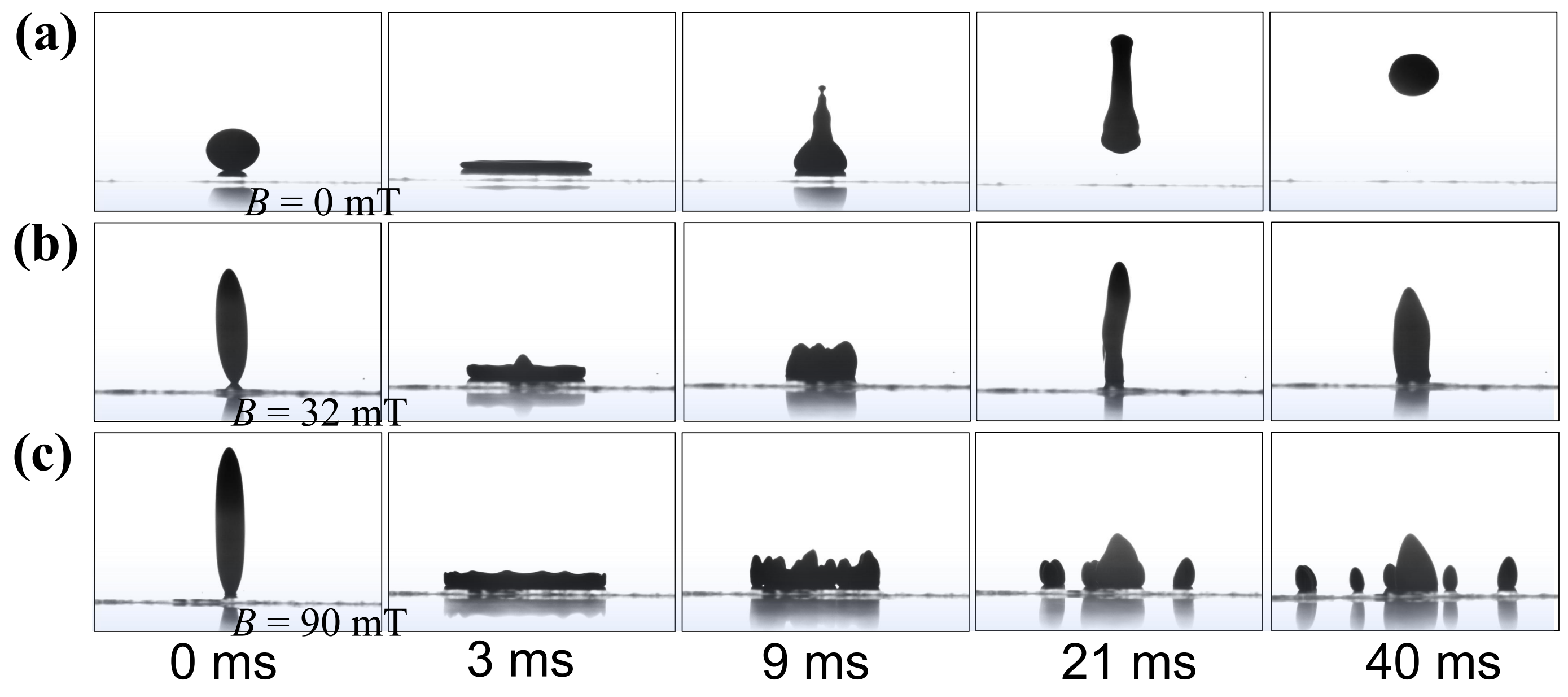

Fig. 3. Side-view time-lapse images of ferrofluid droplet with We = 68 impact resulting in (a) bouncing at B = 0 mT, (b) sticking without splitting (transition) at B = 32 mT, (c) splitting and self-assembly of satellite droplets on superhydrophobic surfaces, respectively.

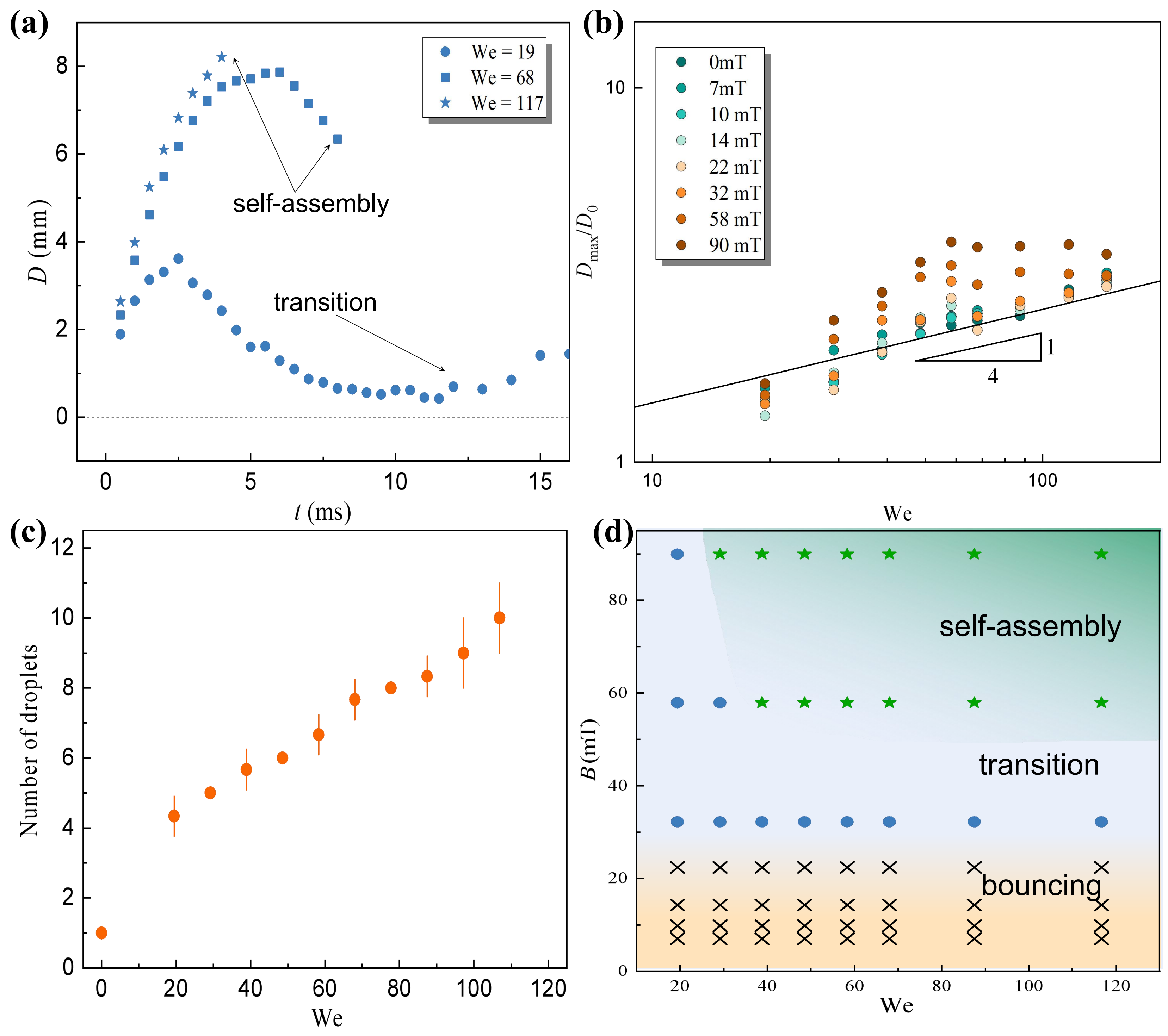

Fig.4 Ferrofluid droplet dynamics characterization. (a) The temporal evolution of contact line dynamics under different We with a constant B = 90 mT. (b) The normalized maximum spreading diameter as a function of *We*. (c) Number of created daughter droplets after impingement as a function of We(*B* = 90 mT). (d) Experimental phase diagram revealing the occurrence of self-assembly of impacting ferrofluid droplet by changing We and B.

Theoretical analysis

Previous study suggested the droplet splitting is related to the Rosensweig instability and the threshold for the self-assembly can be estimated according to the critical wavelength:

$$\lambda_c \approx 2\pi\sqrt{\gamma \Big/ \frac{d}{dz}\left(\mu_0 HM\right)}$$

Only when the droplet size D_0 is larger than λ_c, the splitting and self-assembly occur. According to the experimental results, the required magnetic field strength should be much higher than that for impinging droplet, which verifies that the impinging behavior contributes the generation of the highly ordered patterns and enable the self-assembly at a relatively low magnetic field strength.

Conclusion

Due to the synergetic effect of both the magnetic field and kinetic energy of droplet on governing the droplet dynamics, the required magnetic field strength for the occurrence of splitting is significantly reduced, which further promotes the self-assembly behavior of created daughter droplets compared to regularly static counterparts governed by Rosensweig instability. Thus, we believe our results can provide important insight into complicated dynamics of ferrofluid subject to the magnetic field.