Supporting Information

Unconventional Locomotion of Liquid Metal Droplets Driven by Magnetic Fields

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Keywords: Liquid metal; Locomotion; Actuator; Lorentz force; EGaIn

Supporting Information S1: Experimental Setup

The experimental setup is given in Figure S1, in which an aluminum frame contains a PMMA channel, a DC motor (Leadshine 57HS09), and four permanent magnets. The PMMA channel (height of 8 mm) with a semi-circular (10 mm in diameter) cross section groove was fabricated by milling. The PMMA channel was held by a cantilever, and the motor was fixed on the base of the aluminum frame. Permanent magnets were fixed to the output shaft of the motor that is controlled by an MCU (Arduino Carduino UNO R3).

Locomotion videos of liquid metal droplets were captured using a digital single lens reflect camera (Canon 5d mark II) equipped with a macro lens (Sigma 105mm 1:2.8 DG Macro HSM). The transient images are extracted from these videos.



Figure S1. Experimental setup of the actuation platform.

Supporting Information S2: Sequential snapshots demonstrating the locomotion of EGaIn droplet in HCl solution

Since the oxide layer on the surface of EGaIn droplet can be removed by hydrochloric acid (HCl) solution, we discovered that locomotion of an EGaIn droplet can be induced using magnetic field in HCl, as shown in Figure S2 (also see Movie S1, Part 2). Interestingly, we found that the actuating speed of EGaIn droplet in HCl solution (~22 mm/s) is much lower than the speed observed in NaOH solution (~50 mm/s). This is probably due to the fact that the HCl solution (0.5 mol/L) used in this experiment is not able to efficiently remove the oxide layer formed on the surface of EGaIn droplet and therefore, generating a larger frictional force. The actuating speed of the droplet increased to ~36 mm/s after increasing the concentration of HCl to 1 mol/L, indicating that HCl solution with a higher concentration is able to efficiently remove the oxide layer to reduce the frictional force for realizing a higher actuating speed. However, we did not observe the increase of the actuating speed when we further increase the concentration of HCl to 2 mol/L. We believe the additional surface charge contributed by the formation of gallates ([Ga(OH)₄]⁻) in NaOH solution can induce a stronger Eddy current (and thus, a larger Lorenz force), leading to a higher actuating speed, while no such a gallate can be formed in an acidic environment.¹



Figure S2. Sequential snapshots of the locomotion of an EGaIn droplet in 0.5 mol/L HCl solution. The motor rotated at a speed of 625 RPM.

Supporting Information S3: Sequential snapshots demonstrating the locomotion of copper ball in the rotating magnetic field

Similar to solid gallium ball, the direct contact between the copper ball and the bottom of the groove makes the ball rolling in the opposite direction (clockwise) of the rotating magnet, as shown in Figure S3 (also see Movie S6).



Figure S3. Sequential snapshots for the locomotion of a copper ball. The motor rotated at a speed of 417 RPM.

Supporting Information S4: Self-rotation of EGaIn droplets in grooves with different diameters

In order to verify the cause of self-rotation for the EGaIn droplets, we conducted experiments using PMMA channels with different groove diameters of 60 and 80 mm. The axis of the magnets keeps rotating along a circle of 70 mm in diameter. When inducing a larger magnetic flux density to the inner hemisphere of the EGaIn droplet using a smaller (60 mm) diameter groove, we observed that the droplet self-rotate in the counterclockwise direction (Figure S4A). On the controversy, the droplet rotated in the clockwise direction when using a larger (80 mm) diameter groove to induce a larger magnetic flux density to the outer hemisphere of the droplet (Figure S4B).



Figure S4. Schematic and sequential snapshots showing the self-rotation of an EGaIn droplet. Schematic and sequential snapshots showing the self-rotation of a 0.2 mL EGaIn droplet in a groove with (A) 60 mm, and (B) 80 mm diameter.

Supporting Information S5: Locomotion of EGaIn droplets at different temperatures



Figure S5. Plot of locomotion speed vs. temperature of the liquid metal droplet.

In this experiment, the experimental setup was pre-placed in a refrigerator (SIEMENS BCD-174) or an oven (101-00A, Luyun Co. Ltd) to control the temperature. We measured the temperature using a non-contact infrared thermometer (UNI-T UT300S) before and after experiments; the average of these two values was used to represent the experimental temperature since the temperature change is very small over a short period of time (less than 2 minutes).

Supporting Information S6: Investigating the long-term actuating performance



Figure S6. Plot of locomotion speed vs. time.

Reference

S.-Y. Tang, V. Sivan, P. Petersen, W. Zhang, P. D. Morrison, K. Kalantar-zadeh, A. Mitchell and K. Khoshmanesh, *Adv. Funct. Mater.*, 2014, **24**, 5851-5858.

Movie S1. Locomotion of EGaIn droplet.

- Movie S2. Locomotion of solid gallium sphere.
- Movie S3. Self-rotation of EGaIn droplet.
- Movie S4. Chasing of three EGaIn droplets.
- Movie S5. Oxidizing/reducing of EGaIn droplet.
- Movie S6. Locomotion of copper ball.
- Figure S1. Experimental setup of the actuation platform.
- Figure S2. Sequential snapshots of the locomotion of an EGaIn droplet in 0.5 mol/L HCl solution.
- Figure S3. Sequential snapshots for the locomotion of a copper ball.
- Figure S4. Schematic and sequential snapshots showing the self-rotation of an EGaIn droplet.
- Figure S5. Plot of locomotion speed vs. temperature of droplet.
- Figure S6. Plot of locomotion speed vs. time.