Electronic Supplementary Information (ESI)

Magnetic matchstick micromotors with switchable motion modes

Xiaoliang Zhang,[a] Wenqing Xie,[a] Huaguang Wang,*[a] Zexin Zhang*[a,b]

[a] College of Chemistry, Chemical Engineering and Materials Science, Soochow University, Suzhou 215123, China.

[b] Center for Soft Condensed Matter Physics and Interdisciplinary Research, and Institute for Advanced Study, Soochow University, Suzhou 215123, China

* E-mail: hgwang@suda.edu.cn, zhangzx@suda.edu.cn

1. Supporting Videos

Videos were recorded at 10 frames per second by a Basler ACE camera fitted on an Olympus IX73 microscope.
Video S1. Showing the switching of the motion modes of magnetic matchstick micromotors by an external magnetic field (AVI format). The color coding of the trajectory corresponds to timestamps: blue (t = 0 s) and red (t = 12 s)

2. Supporting Figures

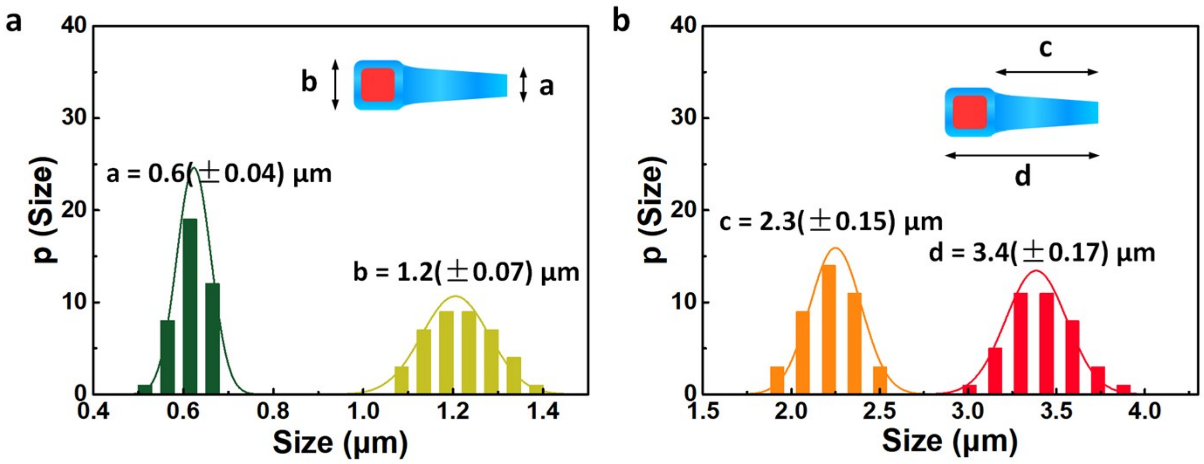

Figure. S1 Size distribution of magnetic matchstick micromotors. The average diameter of the head and tail of the magnetic matchstick micromotor are 1.2 ± 0.07 μm and 0.6 ± 0.04 μm, respectively. The total length of the magnetic matchstick micromotor and the length of the SiO_2 rod are 3.4 ± 0.17 μm and 2.3 ± 0.15 μm, respectively. The average values were calculated from measurements of ~ 40 micromotors.

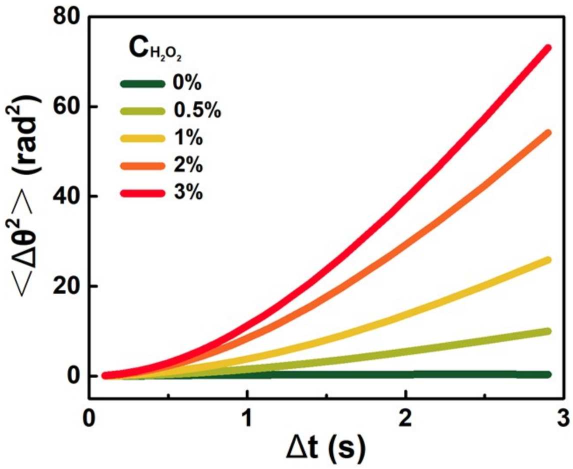

Figure. S2 Mean-squared angular displacements (<$\Delta\theta^2$>) for the magnetic matchstick micromotor at different H_2O_2 concentrations.

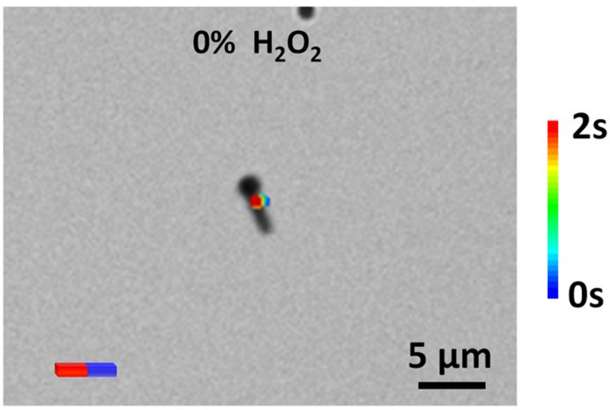

Figure. S3 Trajectory of the magnetic matchstick micromotor moving under an external magnetic field in deionized water (i. e. 0% H_2O_2).

3. Materials and Methods

3.1 Materials

All the reagents were analytical grade and used without further purification. Polyvinylpyrrolidone (PVP, Mw= 58 000), 1-pentanol (>99%), ammonium hydroxide solution (28 wt% in water), sodium hydroxide (NaOH), anhydrous ethanol (>99.5%), sodium citrate tribasic dihydrate (ACS reagent, >99%), tetraethylorthosilicate (TEOS, >99%), iron (III) chloride ($FeCl_3$) hexahydrate, and hydrogen peroxide (H_2O_2) were obtained from Sigma-Aldrich (Shanghai) Trading Co., Ltd. Deionized water was produced by a Milli-Q Ultrapure Water System (MilliporeSigma) and was used to prepare all aqueous solutions in this work.

3.2 Synthesis of α-Fe_2O_3 particles

Monodisperse α-Fe_2O_3 microcubes were prepared via the typical gel–sol process as described in a previous report[1]. Briefly, 100 mL of 2 M $FeCl_3 \cdot 6H_2O$ solution, 90 ml of 6 M NaOH solution, and 10 mL of deionized water were stirred and mixed thoroughly. Then the solution was moved into a 250 mL Pyrex bottle. Then the Pyrex bottle was put in an oven maintained at 100°C and react for 8 days. The final products were separated by centrifugation and washed repeatedly with deionized water and absolute ethanol, and then dried in air at 60°C for 12 h.

3.3 Synthesis of magnetic matchstick particles

In a typical experiment, 1.0 g of PVP (Mn = 58 kg/mol) was completely dissolved in 10 mL of 1-pentanol by sonication for 1 h. When PVP was dissolved, a dispersion of α-Fe_2O_3 microcubes in water was added, and 1 mL of anhydrous ethanol, and 100 µL of sodium citrate aqueous solution (0.18 M), and 200 µL of ammonia (28 wt % in water) were added into 1-pentanol solution with PVP and mixed by hand shaking for a minute. Then, 100 µL of TEOS was introduced into the mixture. After all, ingredients were mixed by hand shaking for a minute, and the bottle was left to age at 30°C for 12 h. The products were collected by centrifugation and cleaned with a mixture of water and ethanol several times.

3.4 Preparation of magnetic matchstick micromotors

To fabricate the magnetic matchstick micromotors, a monolayer of magnetic matchstick particles was first formed on a glass slide by suspension casting. Then the monolayer of the magnetic matchstick particles was coated with a thin layer of Pd by sputtering with a Q150T metal sputter (Quorum Technologies). Finally, the magnetic matchstick micromotors were collected by sonication in ethanol and washed three times with distilled water.

3.5 Characterizations of magnetic matchstick micromotors

The morphology of the magnetic matchstick particle and the magnetic matchstick micromotor were examined by Scanning Electron Microscope (SEM, SU8010, Hitachi).

3.6 Optical Video Microscopy

The motion of magnetic matchstick micromotors was observed and recorded at 10 frames per second by a Basler ACE camera fitted on an Olympus IX73 microscope. For microscopy samples, the magnetic matchstick micromotors were dispersed in H_2O_2 solutions and the dispersion was loaded in a simple rectangular inspection chamber made of glass slides and epoxy glue. To study the effect of H_2O_2 concentrations on the motion of magnetic matchstick Janus micromotors, the concentrations were varied systemically from 0 to 3.0 %.

3.7 Analysis of the Motion of magnetic matchstick micromotors

The magnetic matchstick micromotor in optical micrographs was identified by image analysis using Image J (NIH), to obtain the micromotors' positional coordinates, x and y, as well as their orientation angles, θ. The positional and orientation data were further analyzed using in-house computer programs written in IDL (Exelis) to calculate speed (v), angular speed (ω), and mean-square angular displacement ($\langle \Delta\theta^2 \rangle$) of the magnetic matchstick micromotors.

3.7 Finite Element Modeling

Our numerical model was implemented in COMSOL Multiphysics package (version 5.2a) in a 2D axisymmetric configuration to reduce the computational cost. The diameter of the head and tail of the magnetic matchstick are 1.2 µm and 0.6 µm, respectively. The total length of the magnetic matchstick micromotor and the length of the SiO_2 rod are 3.4 µm and 2.2 µm, respectively. The active surface of the magnetic matchstick micromotor was modeled as a source of solute with a flux of 4.38 $mmol/m^2 \cdot s^{-1}$. The diffusion constant of O_2 in water is 2.1×10^{-9} m^2 s^{-1}. The particles lay upon an inert substrate.[2]

References

1. T. Sugimoto, M. M. Khan and A. Muramatsu, *Colloids Surf. A Physicochem. Eng. Asp.*, 1993, **70**, 167-169.
2. X. Liang, F. Mou, Z. Huang, J. Zhang, M. You, L. Xu, M. Luo and J. Guan, *Adv. Funct. Mater.*, 2020, **30**, 1908602.