Electronic Supplementary Material (ESI) for ChemComm.

Supporting information

"Ballistic" waves among chemically oscillating micromotors

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Content

1. Fabrication of Ag Janus micromotors

Monolayer of poly(methyl-methacrylate) (PMMA) microspheres were formed at the water-hexane interface and then transferred on a silicon wafer based on a previous report.[1] Monolayer of SiO_2 microspheres, on the other hand, was directly formed on a piece of silicon wafer by spreading isopropanol solution containing particles. 50 nm of Ag layer was evaporated onto the monolayer of microspheres using an E-beam evaporator (HHV TF500). After sonication, Janus motors were released and dispersed in ultrapure water.

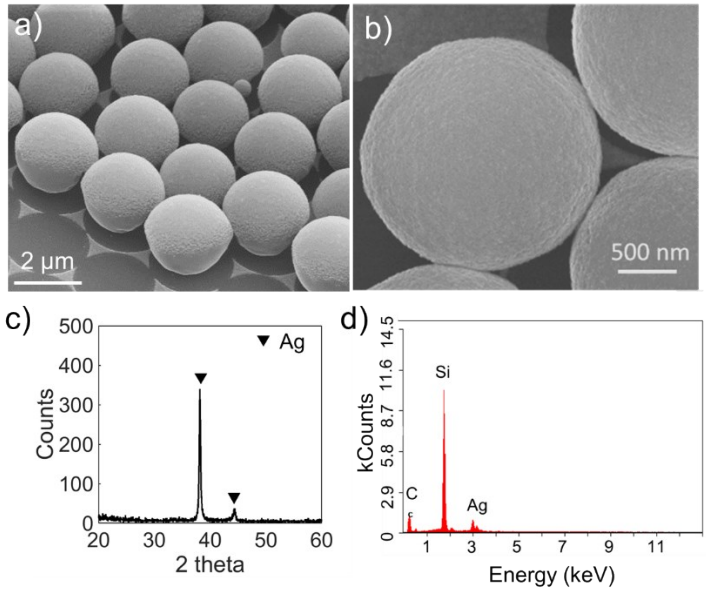

Fig S1 Characterizations of PMMA-Ag micromotors. a) and b) Scanning electron micrographs of PMMA-Ag particles; c) and d) XRD and EDS spectra of PMMA-Ag particles. Adapted with permission from Ref.2 and 3, Copyright 2018, and 2020 American Chemical Society, respectively.

2. Experimental setups

Micromotors were observed with an inverted microscope (Olympus IX71), typically with a 20x or 40x objective lens. UV light with 365 nm central wavelength was produced by an LED lamp (Thorlabs M365LP1-C1) and applied from above (a mercury lamp can also be used to activate micromotors). Videos were captured by a CMOS camera (GS3-U3-51S5C-C, Point Grey) at 30 frames per second (FPS). In a typical experiment, a suspension of PMMA-Ag or SiO_2-Ag motors with certain concentrations of H_2O_2 and KCl were added into a spacer and covered with a clean cover slip. After few minutes, micromotors mostly settled down on the glass substrate. Individual oscillation and motion waves can be observed after applying UV light.

In experiments with tracer particles, fluorescent polystyrene (PS) tracers with 1 μm in dimeter (Hugebio) was mixed into oscillatory motor system. As shown in Fig S1, micromotors with tracer particles were observed in an inverted microscope with green light (by filtering a halogen lamp light *via* fluorescent cube (Olympus)) illuminated from below to excite fluorescent tracers and UV

light illuminated from above to activate oscillatory micromotors. By carefully tuning the brightness of the background light, darker oscillatory motors and brighter tracers can be both recognized in a video.

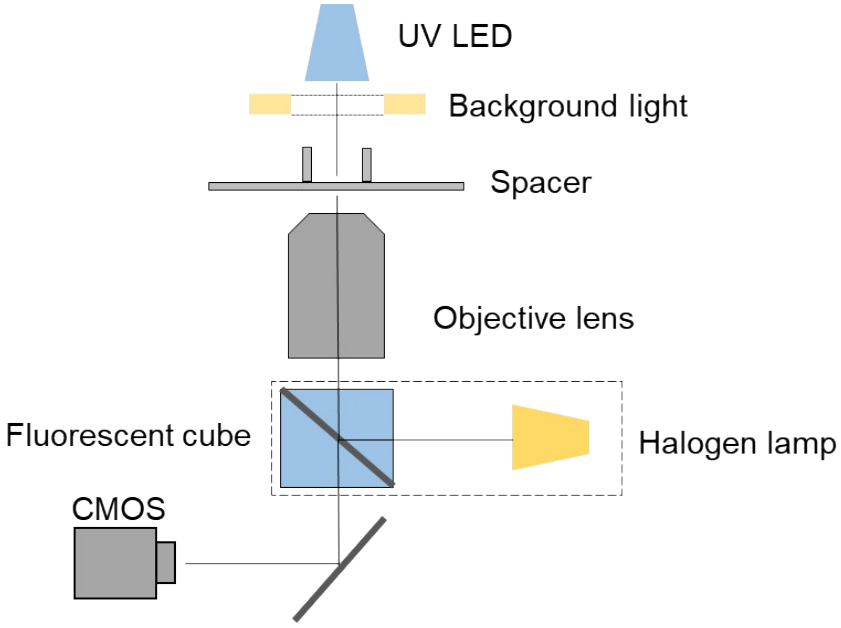

Figure S2 Experimental setups. A halogen lamp and a fluorescent cube (enclosed by dashed lines) are optional and only used in experiments with fluorescent tracers.

3. Particle tracking and calculations of individual motor speed and wave speed

Single motor tracking was achieved by MATLAB. Particles were distinguished from the background *via* a certain gray threshold. The coordinate of each particle was recorded to calculate their instantaneous speed and speed direction. In motion waves, motors whose speed exceeds a threshold (typically 5 μm/s) were marked as a red dot overlapping the original optical images to visualize the wavefront. Wave speed was calculated by measuring the traveling distance in a certain time interval in ImageJ.

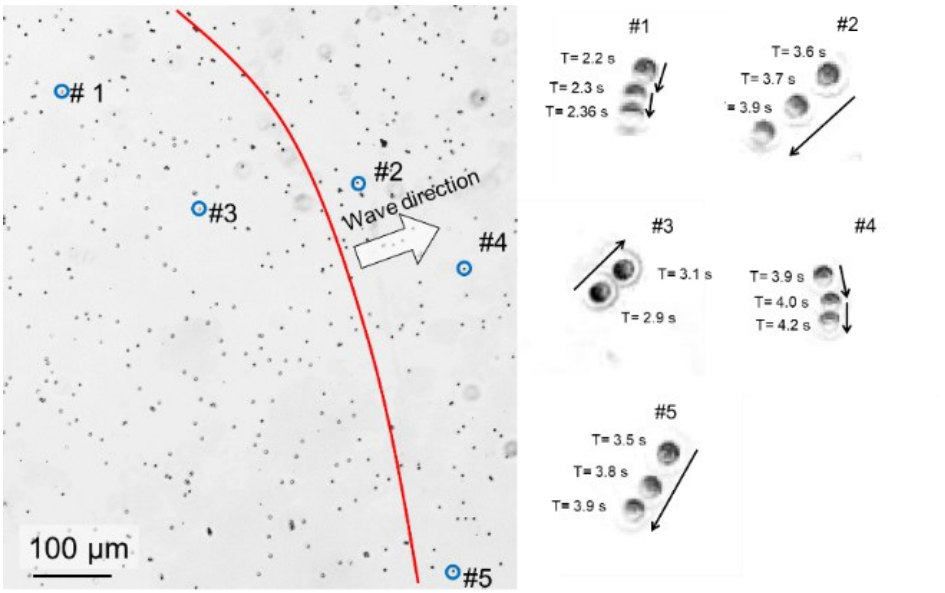

Figure S3 Orientation and moving direction of selected pulsing micromotors in a motion wave, suggesting that they pulsate into directions prescribed by their Janus interface, rather than along the wave direction.

4. Experiments of oscillating micromotors at different particle density

Particle density was tuned by changing the proportion of the original motor suspension while keeping the concentration of H_2O_2 and KCl constant. Particle density (ϕ) is the area ratio of all particles over the whole field of view. Area of each particle was calculated by particle recognition in MATLAB.

5. Experiments of oscillating micromotors with different medium viscosity

Medium viscosity was tuned by adding glycol into aqueous solution containing motors, H_2O_2 and KCl. The values of viscosity (mPa·s) was obtained based on measurements on aqueous solution with different mass fraction of glycol *via* a rotational viscometer (Genggeng shanghai company, NDJ-1). The viscosity of glycol aqueous solutions with different mass fraction is shown in Table S1.

Table S1 Viscosity sheet for glycol aqueous solutions

Mass fraction of glycol (%)	Average viscosity η (mPa·s)
0	1.1
10	1.5
20	1.9
30	2.4
40	3.1

6. Supporting videos

Video S1 Dynamic of single oscillating micromotor. SiO_2-Ag Janus micromotors with 1 wt % H_2O_2 and 400 μM KCl were illuminated with a UV LED lamp at 365 nm and 323 mW/cm^2 intensity applied from above.Video is sped up 5 times

Video S2 Representative ballistic wave of oscillatory PMMA-Ag Janus micromotors. PMMA-Ag Janus micromotors with 0.5 wt % H_2O_2 and 400 μM KCl were illuminated with a mercury lamp of 230 mW/cm^2 from above. The left panel shows the original video. In the right panel, the active micromotors and their velocity vectors are marked with red dots and blue arrows, respectively.

Video S3 A video showing the moving directions of micromotors at a wavefront along their orientation. PMMA-Ag Janus micromotors with 1 wt % H_2O_2 and 400 μM KCl were illuminated with a UV LED lamp at 365 nm and 323 mW/cm^2 intensity applied from above

Video S4 Active and inert microspheres in a ballistic wave. Waves travel across a population of PMMA-Ag micromotors (black dots) mixed with a small amount of fluorescent polystyrene tracer microspheres (appear white). One tracer spheres is highlighted with a white circle and trajectoties of PMMA-Ag micromotors were marked as blue lines. PMMA-Ag Janus micromotors with 1 wt % H_2O_2 and 400 μM KCl were illuminated with a UV LED lamp at 365 nm and 323 mW/cm^2 intensity applied from above

Video S5 Dynamics of individual oscillating micromotors and their ballistic waves at different particle density. SiO_2-Ag Janus micromotors with 0.5 wt % H_2O_2 and 400 μM KCl were illuminated with a UV LED lamp at 365 nm of 650 mW/cm^2 from above. The frist part of this video shows individual oscillating micromotors with particle area fraction φ=0.4%, 1.0% and 1.5%. The second part of video shows four ballistic waves with particle area fraction φ=0.8%, 1.3%, 1.4% and 2.5%.

Video S6 Dynamics of individual oscillating micromotors and their ballistic waves with different solution viscosities. SiO_2-Ag Janus micromotors with 0.5 wt % H_2O_2 and 400 μM KCl were illuminated with a UV LED lamp at 365 nm of 650 mW/cm^2 from above. The frist part of this video shows oscillating micromotors with five solution viscosities (1.1 mPa·s, 1.5 mPa·s, 1.9 mPa·s, 2.4 mPa·s and 3.1 mPa·s). The second half of the video shows motion waves with five solution viscosities (1.1 mPa·s, 1.5 mPa·s, 1.9 mPa·s, 2.4 mPa·s and 3.1 mPa·s).

Reference

1. L. M. Goldenberg , J. Wagner, J. Stumpe, B.-R. Paulke, E. Görnitz, Langmuir 2002, 18, 5627-5629.
2. C. Zhou, H. P. Zhang, J. Tang and W. Wang, Langmuir, 2018, 34, 3289-3295.
3. C. Zhou, N. J. Suematsu, Y. Peng, Q. Wang, X. Chen, Y. Gao and W. Wang, ACS Nano, 2020, 14, 5360-5370.