

## Electronic Supplementary Information

### Highly efficient chemically-driven micromotors with controlled snowman-like morphology

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## **Chemicals**

Sodium hydroxide (pellets), Silver nitrate (ACS reagent  $\geq 99\%$ ), L-ascorbic acid (ACS reagent  $\geq 99\%$ ), hydrogen peroxide (30% wt.), ethanol, 3-trimethoxysilyl propyl methacrylate (TPM,  $\geq 98\%$ ), 1-hydroxycyclohexyl phenyl ketone (HCPK), dodecyl trimethylammonium bromide (DTAB,  $\geq 98\%$ ) and isopropyl alcohol were purchased from Sigma-Aldrich. Ammonia solution (25% wt.) was provided by Acros Organics. Deionized (DI) water (Millipore, 18.2 m $\Omega$ ) was used in all experiments.

## **Synthesis of Ag Particles**

In a 30 ml glass vial, 0.05 g of L-ascorbic acid was dissolved in 10 ml DI water. The solution was magnetically stirred at 400 rpm and 20  $\mu$ l of NaOH (1 M aqueous solution) was added. Next, 0.1 ml of AgNO<sub>3</sub> (0.5 M) was injected rapidly into the vial. The reaction was left undisturbed for 5 minutes, followed by 5 minutes of sonication. The synthesized Ag particles were collected by centrifugation at 750 rpm (Eppendorf centrifuge, 5810) for 5 minutes and washed three times with DI water before they were stored in 10 ml of DI water for later use.

## **Preparation of hTPM**

10 ml of DI water was first put in a 30 ml glass vial, followed by addition of 1 ml of TPM oil dropwise under vigorous magnetic stirring. The mixture was stirred until a clear solution was obtained (~1 hr). The solution was named hTPM and was used as the TPM precursor in all the syntheses involving TPM.

## **Synthesis of TPM tracer particles**

13.3 ml of DI water and 3.5  $\mu$ l of the ammonia solution were first put in a 30 ml glass vial, followed by the addition of 0.7 ml of hTPM. The mixture was gently shaken with hand, which was left undisturbed for 40 minutes before 50 mg of HCPK was added and photo-polymerization was triggered under UV illumination for 20 minutes (365 nm, 5.6 mW/cm<sup>2</sup>, Spectroline XX-15A benchtop UV lamp). The resulted TPM particles were collected by centrifugation at 2000 rpm for 15 minutes and were washed twice with ethanol and three times with DI water. The diameter of TPM spheres was determined to be  $0.6 \pm 0.03$   $\mu$ m by dynamic light scattering measurements.

## **Synthesis of Ag-TPM Janus particles**

In a 30 ml glass vial, 12.8 ml of DI water and 0.2 ml of the Ag stock solution were first added, followed by the addition of 3.5  $\mu$ l of ammonia solution. The mixture was sonicated for 1 minute before the addition of 1 ml of hTPM. The reaction mixture was left undisturbed for 40 minutes. Subsequent photo-polymerization step was the same as described for the synthesis of TPM particles. The collection and washing steps for Ag-TPM Janus particles were similar to the TPM particles, with the centrifugation speed and time kept at 750 rpm and 5 min, respectively.

## **Wetting enhancement of Ag-TPM particles**

Deeper encapsulation of Ag seeds into TPM was achieved by introducing 50  $\mu$ l of 0.05 M DTAB aqueous solution, which was added to 12.8 ml DI water prior to adding

anything else. The subsequent synthesis steps were the same as described for Ag-TPM Janus particles.

### **Dewetting of Ag-TPM particles**

Dewetting of Ag-TPM particles was achieved by introducing 1 ml of 1 M NaOH in 1 minute before the photo-polymerization. The dewetting process was monitored under an optical microscope, which was stopped by photo-polymerization at the desired levels of dewetting.

### **Catalytic reaction rate measurement**

The rate of reaction 1, or catalytic decomposition of  $\text{H}_2\text{O}_2$  into  $\text{H}_2\text{O}$  and  $\text{O}_2$ , was measured by collecting the amount of  $\text{O}_2$  generated. The rate of reaction 2 was measured by measuring the concentration of  $\text{Ag}^+$  ions in the filtered reaction mixture using inductively coupled plasma optical emission spectrometry.

### **Video microscopy experiments**

Video microscopy experiments were performed in a home-made cell that was made by fixing a Teflon ring (internal dimension: 1 cm; outer dimension: 2 cm; height: 1 cm) on a clean glass coverslip. The coverslip was cleaned with isopropyl alcohol and DI water. We first dilute the original  $\text{H}_2\text{O}_2$  solution which is 30w% by a factor of 30. Then we further diluted the fuel in our home-made reaction chamber. The total sample volume was kept 360  $\mu\text{l}$  with varying amounts of hydrogen peroxide mixed with DI water to reach the desired fuel concentrations. The particle concentration is kept very low while the total sample volume is 360  $\mu\text{l}$ . We expect negligible change in the fuel concentration during the experimental time, which is typically five minutes. There might be a slight decrease of fuel concentration in the long duration experiment, which was 20 minutes. All experiments were performed at room temperature. Bright-field images at a field of view of  $187 \times 187 \mu\text{m}^2$  ( $2048 \times 2048$  pixels<sup>2</sup>) were acquired at 5 frames per second.

### **Characterization**

The optical images were captured on an Olympus IX73 inverted microscope equipped with a 60 $\times$  oil-immersion objective lens (PLAPON; NA=1.42) and a xiQ digital camera (Ximea). The videos of the micromotors moving at high speeds were recorded with a Prime-BSI camera (Photometrics). SEM images were acquired on a FEI-Scios field emission scanning electron microscope (FEI-SEM) operated at 5 kV. Zeta potential was measured on a NanoBrook 90PlusPALS zeta sizer. Powder X-ray diffraction (XRD) analysis was conducted on an X'Pert Pro system (3KW, Cu KR radiation;  $\lambda = 1.5406 \text{ \AA}$ ). The ICP analysis was performed on an Avio 200 ICP-OES (Optical Emission Spectrometer) PerkinElmer. The surface roughness of the particles was measured on atomic force microscopy (AFM) (Bruker Dimension Icon) equipped with a Nanoscope 5 controller.

### **Finite elemental analysis**

To predict the motion of the Ag-TPM Janus particle, we performed finite element analysis. The model consists of a Janus particle placed in a large fluid domain. The concentration field is described by the steady state diffusion equation:

$$\nabla \cdot (D\nabla c) = 0$$

where  $D$  is the diffusion coefficient of the electrolyte,

$$D \equiv 2D_+D_- / (D_+ + D_-),$$

where  $D_+$  and  $D_-$  are the diffusion coefficients for  $Ag^+$  and  $OH^-$ , respectively. We set an ionic flux at the interface of Ag/solution,  $J_0 = -D\nabla c \cdot n$  and  $-D\nabla c \cdot n = 0$  at the inert surface on TPM. Far from the particle, the concentration is set to 0. The flow field is governed by the Stokes equation,

$$-\nabla P + \eta \Delta \mathbf{u} = 0$$

and the fluid is assumed to be incompressible,  $\nabla \cdot \mathbf{u} = 0$ , where  $P$  is the pressure,  $\eta$  is the dynamic viscosity of the fluid. The concentration gradient induces a slip velocity at the interface of the particle/solution according to equation,

$$v^s = \left[ -\frac{\epsilon \zeta}{4\pi\eta} \frac{k_B T D_+ - D_-}{e D_+ + D_-} + \frac{\epsilon}{2\pi\eta} \left(\frac{k_B T}{e}\right)^2 \ln \left(1 - \tanh^2 \left(\frac{e\zeta}{4k_B T}\right)\right) \right] \nabla(\ln c) \cdot (I - nn)$$

where  $\zeta$  is the Zeta potential of the particle. In the particle frame of reference, the velocity far from the particle is equal to the swimming velocity,

$$\mathbf{u}(\mathbf{r} \rightarrow \infty) = U^a$$

To obtain the propulsion velocity for a given particle, we first solve for the concentration fields numerically, then the slip velocity is computed. Inserting the boundary conditions and requiring the particle is force free, the Stokes equation was solved numerically to obtain the  $U^a$ . The simulation results are presented in figure 2 of the main article.

### Diffusion limited reaction rate

Consider a spherical catalytic particle immersed in a solution of  $H_2O_2$  with a concentration  $c_0$ . When the catalytic reaction is fast, the reaction rate is limited by the diffusion of the  $H_2O_2$  molecules to the catalytic particle. The concentration at surface is zero,

$$c(r = R) = 0$$

Far away from the sphere, the concentration is  $c_0$ ,

$$c(r \rightarrow \infty) = c_0$$

Solving the Laplace equation  $\Delta c = 0$  with above boundary conditions yields the result,

$$c = -\frac{R}{r} c_0 + c_0$$

The flux at the surface is,

$$J(r = R) = -D\nabla c = \frac{c_0 D}{R}$$

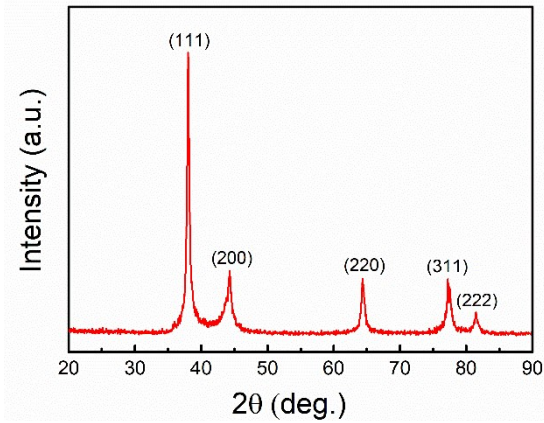


Fig. S1 XRD patterns of Ag particles.

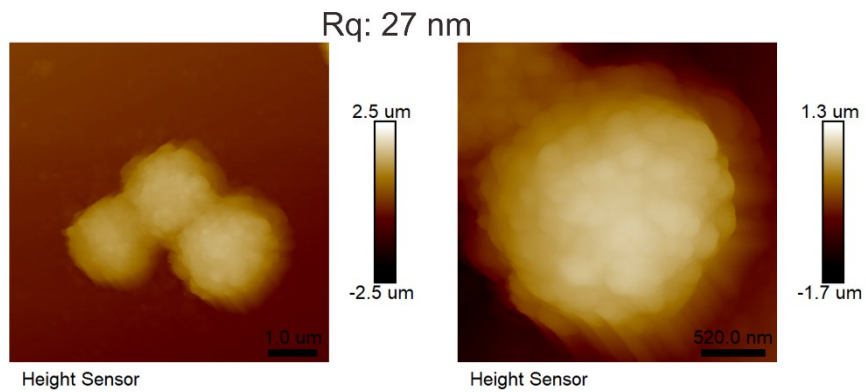


Fig. S2. Surface roughness characterization of Ag particles by AFM.

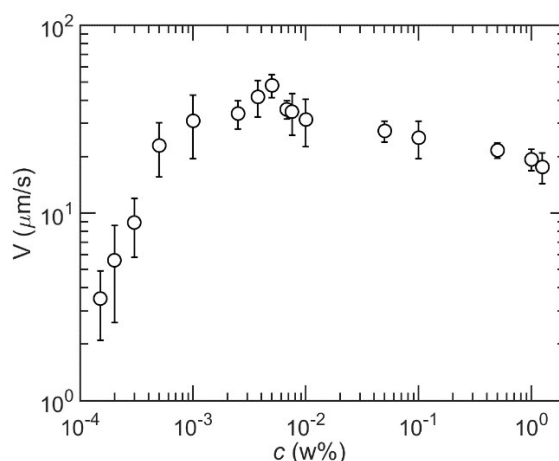


Fig. S3 Fuel-dependent speed of Ag-TPM micromotors.

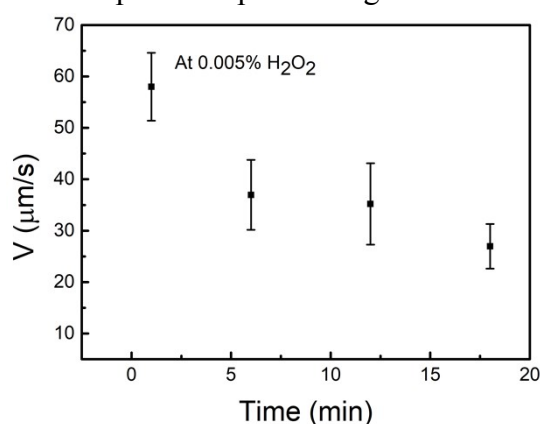


Fig. S4 Time-dependent speed of Ag-TPM micromotors.

### Description of videos

Video S1: Active motion of Ag-TPM micromotors in 0, 0.00015, 0.0003, 0.0005, 0.0025, and 0.005 w% of  $\text{H}_2\text{O}_2$ , respectively.

Video S2: Time-dependent active dynamics of Ag-TPM micromotors in 0.005 w% of  $\text{H}_2\text{O}_2$  after 0, 6, 12, and 18 minutes, respectively.

Video S3: Shape-dependent active motion in 0.005 w% of  $\text{H}_2\text{O}_2$  for Ag-TPM micromotors synthesized in the presence of DTAB, without wetting control, and with 30, 60, and 120 minutes of dewetting, respectively.

All videos are played at 2X of real speed.