SUPPORTING INFORMATION

Shape-dependent motion of structured photoactive microswimmers

Dylan Nicholls,† Andrew DeVerse,† Ra'Shae Esplin,† John Castañeda,† Yoseph Loyd,† Raaman Nair,† Robert Voinescu,† Chao Zhou,‡ Wei Wang,‡ & John G. Gibbs*,†

†Department of Physics and Astronomy, Northern Arizona University, S San Francisco St, Flagstaff, Arizona 86011, USA

‡School of Materials Science and Engineering, Harbin Institute of Technology (Shenzhen), Shenzhen, Guangdong 518055, China

*Email: john.gibbs@nau.edu

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1. System Characterization

1.1 Janus particle fabrication and experimental setup

SiO_2 microbeads of diameter 1.5μm, 2.01μm and 3.17μm were purchased from Bangs Laboratories, Inc. (Fishers, Indiana) and were diluted in ethanol. After, the colloidal suspension was placed into an ultrasonic bath for 30-60 seconds. The SiO_2 bead/ethanol colloid was then deposited onto an oxygen plasma cleaned Si(100) wafer and allowed to air dry. TiO_2 purchased from Kurt J. Lesker (Jefferson Hills, Pennsylvania) was evaporated under vacuum onto the SiO_2 beads, asymmetrically coating only one side to a maximum thickness of ~50nm. The SiO_2/TiO_2 Janus particles were annealed in a tube furnace either at 500℃ or 800℃ for 3 hours. The Janus micromotors were then suspended into pure water by submerging a piece of the wafer in the solution, then placing into an ultrasound bath for ~45 s. Later, various concentrations of hydrogen peroxide were added to the colloidal suspensions for activation.

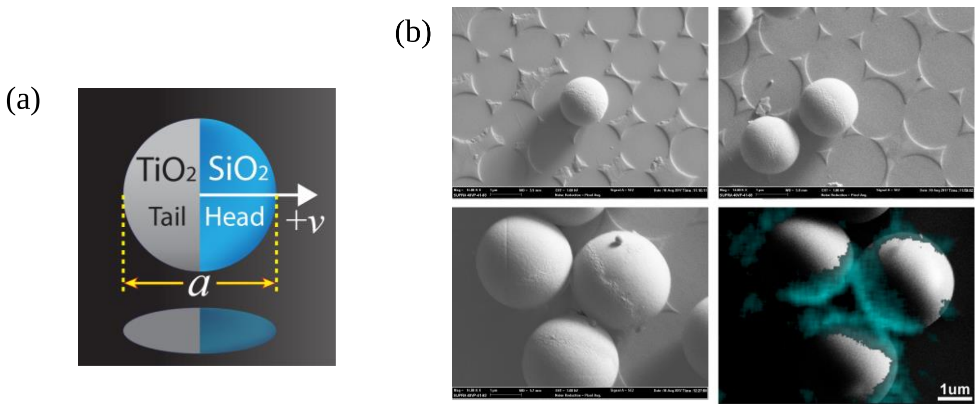

Figure S1. (a) Schematic of a photoactive Janus sphere. Definition of the diameter of the swimmers and the convention adopted for positive (+*v*) swimming direction toward the SiO_2 side. The "head" and "tail" are at the location of the SiO_2 and TiO_2 materials, respectively. (b) The scale of the SEM images are the same. The top-left, top-right, and bottom-left are spheres of diameter : a = 1.5μm, 2.01μm, and 3.17μm, respectively. The bottom right image shows a chemical map overlaid upon the SEM image of the 3.17μm Janus spheres (bottom-left). The blue/green color shows the location of elemental titanium.

The Janus spheres were exposed to UV light and hydrogen peroxide. An optical Zeiss AxioScope.A1 was employed for observing the active particles within an observation cell (see main text). The same fluorescence microscope was also used to expose the particles to UV light at a wavelength of $\lambda = 365$nm. The Janus spheres moved toward the TiO_2 coating, called the "tail" as shown in Figure S1 (a), to coincide with the tails of the structured particles in the main text. Similar to the structured swimmers, we define the positive (+v) direction to be toward the silica head (see Figure S1 (a)).

We investigated the motion of the Janus spheres with three different radii: a = 1.5μm, 2.01μm, and 3.17μm, shown in the SEM images of the top-left, top-right, and bottom-left of Figure S1 (b), respectively. These SEM images are on the same scale illustrating the differences in the diameters. The image on the bottom-right shows a chemical map obtained by energy-dispersive X-ray spectroscopy (EDX) overlaid upon the SEM image of the 3.17μm Janus spheres in the bottom-left image.

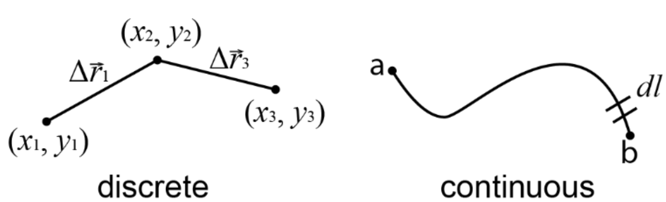

Figure S2. Schematic showing discrete vs. continuous particle trajectories.

1.2 Measuring motor dynamics

To measure the speed, we first measured the total path-length, which goes from *a* to *b* in the schematic in Figure S2, but since the videos are sequential images, we only have discrete data points, so the path is broken into discrete segments, $\Delta\vec{r}$, how far the particle has moved from one frame to the next, then added all of these segments to get the approximate total path length. For each frame i, we determined $|\Delta\vec{r}_i| = \sqrt{(x_{i+1}-x_i)^2 + (y_{i+1}-y_i)^2}$, which is the distance a single particle has moved from its position in frame i in the past (x_i, y_i) to its position in the current frame $i+1$, (x_{i+1}, y_{i+1}). The 2D positions were converted from pixels to µm before this process took place. The particle's speed was then approximated from the path length divided by the total amount of time, T, that the particle needed to complete its journey

$$v \simeq \frac{1}{T}\frac{1}{n-1}\sum_{i=1}^{n-1}|\Delta\vec{r}_i| \tag{1}$$

where n is the total number of frames.

We also measured the mean-squared displacement (MSD) for a fixed lag time, Δt, given by

$$MSD = \langle|\Delta r(\Delta t)|^2\rangle = \frac{1}{n-1}(|\Delta r_1(\Delta t)|^2 + |\Delta r_2(\Delta t)|^2 + \cdots) = \frac{1}{n-1}\sum_{i=1}^{n-1}|\Delta r_i(\Delta t)|^2. \tag{2}$$

Note that as the lag time Δt increases, the total number of data points n (frames) which we average over, decreases, leading to larger error in the MSD. However, we measured v for small Δt's only (*Phys. Rev. Lett.* **99**, 048102 (2007)). For active Janus spheres moving in 2D, the MSD is given by

$$\langle|\Delta r(\Delta t)|^2\rangle = 4D\Delta t + \frac{1}{2}v^2\tau_R^2\left(\frac{2\Delta t}{\tau_R} + e^{-2\Delta t/\tau_R} - 1\right). \tag{3}$$

We can determine the speed also from Eq. (3) by recognizing that for $\Delta t \ll \tau_R$, Eq. (3) takes on the form

$$\langle|\Delta r(\Delta t)|^2\rangle = 4D\Delta t + v^2\Delta t \tag{4}$$

The meaning of $\Delta t \ll \tau_R$ is that the time lag is much shorter than the rotational diffusion time

$$\tau_R = \frac{8\pi\eta R^3}{k_B T} \tag{5}$$

where η is the viscosity, and $R = a/2$ is the radius of the spherical particle. Therefore, if we fit the MSD for short times (e.g. 0 – 1 s.) only (Eq. (4)), we can extract the diffusion coefficient and the speed of the particles.

1.3 Relationship between annealing temperature and speed

In Figure S3, we show the effects of annealing the Janus spheres at two different temperatures: 500℃ and 800℃. The mean-squared displacement is significantly higher for the particles annealed at the former temperature *vs*. the latter. We suspect this effect is a result of the lower temperature favoring the anatase crystal phase of TiO_2. Therefore, all of the swimmers in this study, including the structured swimmers in the main text, were annealed at 500℃. Also apparent from Figure S3 is that there seems to be effectively no concentration-dependence of hydrogen peroxide on the MSD for both samples.

1.4 Speed *vs*. diameter and concentration dependence

In Figure S4, we show the relationship between speed and the diameter of the Janus spheres along with dependence upon hydrogen peroxide concentration (for low concentrations of ≤ 1% hydrogen peroxide (V/V)). Again, if there is a dependence upon concentration, it is not apparent from our data. We expect that the overall speed of the Janus sphere should obey a $v \propto 1/R$ dependence (Phys. Rev. E **85**, 020401(R) (2012)). Moving from the 1.5μm to the 2.01μm diameter particles, it appears there is some reduction in speed. However, the 3.17μm spheres do not appear the follow the trend. The origin of this discrepancy is presently unclear.

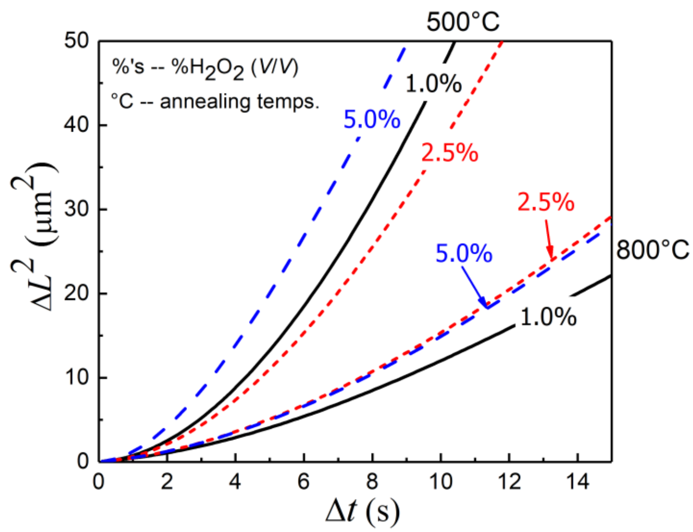

Figure S3. MSD curves (10 particles for each curve) for Janus spheres annealed at two different temperatures: 500℃ and 800℃. For each sample, we also used three concentrations of hydrogen peroxide, and found no quantifiable relationship between MSD and concentration. However, the particles annealed at 500℃ vs. 800℃ are more active, and so this temperature was used throughout this study.

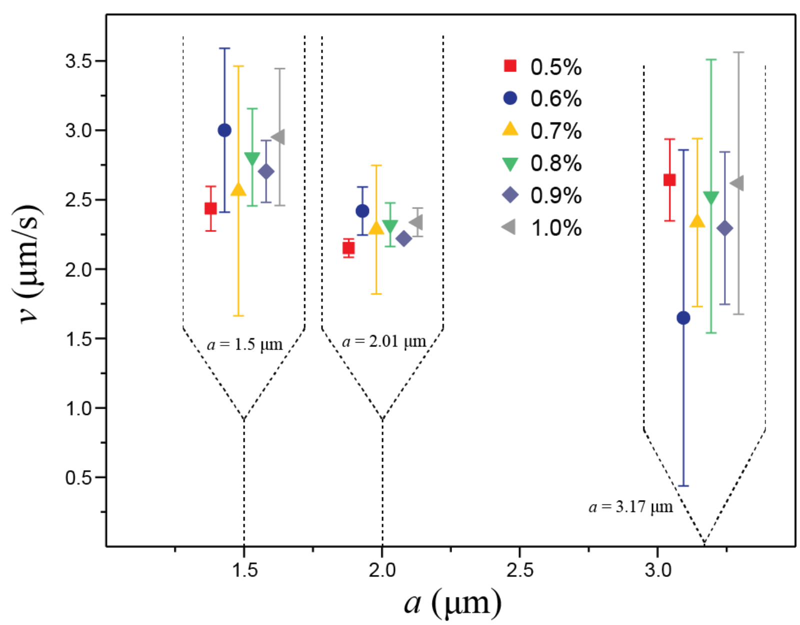

Figure S4. Speed-dependence for Janus spheres of different diameter. There are only three sizes reported. The data points for the different concentrations are artificially spread out for clarity. The data points inside of the dashed lines therefore correspond to the same diameter.

2. VIDEO DESCRIPTIONS

The following descriptions of the supporting videos are provided justifying their appearance in this publication. The following four videos (.avi) are provided:

V1. 3.2μm diameter Janus spheres moving in 1% H_2O_2 (V/V) under UV illumination.

V2. Short-tailed ($a = 3.2\mu m$ and $l = 1.5\mu m$) structured swimmers in 1% H_2O_2 (V/V). At the beginning of the video, the UV light source is off. After ~3 seconds, the source is turned on as indicated by the overlaid text in the video.

V3. Long-tailed ($a = 3.2\mu m$ and $l = 3.8\mu m$) structured swimmers in 1% H_2O_2 (V/V) under UV illumination. Some of the spherical heads detached from the tails as can be seen in this video. The swimmer to focus upon is indicated by a flashing red box at the beginning of the video and is the largest particle visible.

V4. Demonstration of broad-tailed swimmers moving faster than their narrow counterparts for the $a = 2\mu m$ and $l = 2.2\mu m$ morphology. In the video, there are two narrow-tailed swimmers and one broad-tailed swimmer, the latter of which is darker in the video and swims significantly faster than the other two particles.

Note that all four videos are played back at $3 \times$ their original speeds to help illustrate the dynamics.

3. ADDITIONAL REFERENCES

(1) Howse, J. R.; Jones, R. A. L.; Ryan, A. J.; Gough, Vafabakhsh, T. R.; Golestanian, R. Self-Motile Colloidal Particles: from Directed Propulsion to Random Walk. *Phys. Rev. Lett.* **2007** *99*, 048102.

(2) Ebbens, S.; Tu, M.-H.; Howse, J. R.; Golestanian, R. Size Dependence of the Propulsion Velocity for Catalytic Janus-Sphere Swimmers. *Phys. Rev. E* **2012** *85*, 020401(R).