Organized Self-Assembly of Janus Micromotors with Hydrophobic Hemispheres

Wei Gao, Allen Pei, Xiaomiao Feng, Camille Hennessy, Joseph Wang*

Department of Nanoengineering, University of California, San Diego, La Jolla, California 92093, United States.

* Address correspondence to josephwang@ucsd.edu.

SI Videos Captions

SI Video 1. The self-assemblies of OTS modified Janus micromotors: doublet and triplet.

SI Video 2. Janus motor assembly: dynamic 'switch' from doublet to triplet.

SI Video 3. Control experiments of Janus micromotors with and without hydrophobic coating.

SI Video 4. Self-propelled tetrahedral structure based on the assembly of four Janus micromotors.

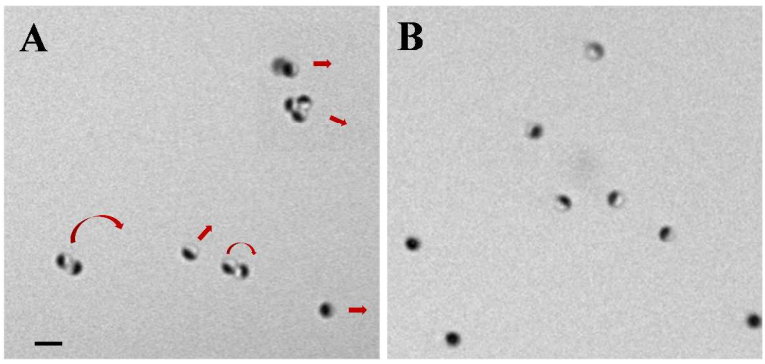
SI Video 5. Assemblies of Janus motor/non-motor microparticles.

SI Video 6. 'On-the-fly' capture of a non-motor particle by a triplet micromotor assembly.

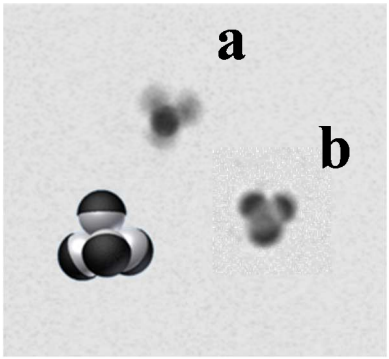
SI Video 7. Organized multiple cargos loading.

SI Video 8. Motor/non-motor interaction: rotational motion with the non-motor anchored to the glass surface.

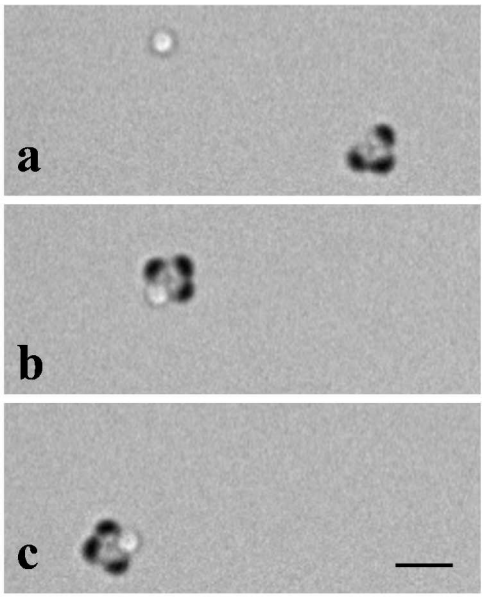
SI Figures



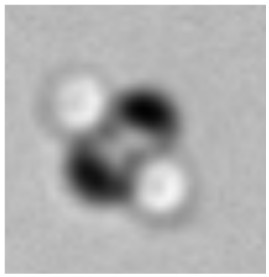
SI Figure 1. Control experiments (taken from SI Video 3): Janus micromotors with (A) and without (B) hydrophobic coating. The latter offers simultaneous movement of single, doublet, and triplet motor assemblies. Scale bar, 2 μm. Conditions, as in Figure 1.



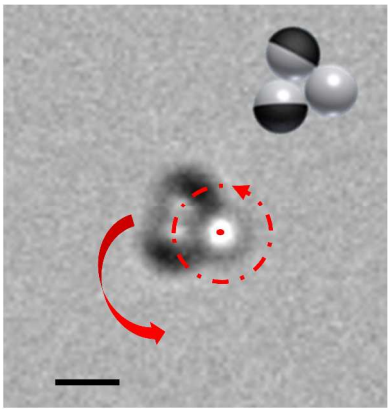
SI Figure 2. Self-propelled tetrahedral structure based on the assembly of four Janus micromotors: (a) and (b) show optical microscope images of the same tetrahedral structure at different times (taken from SI Video 4). Conditions, as Figure 1.



SI Figure 3. 'On-the-fly' capture of a non-motor particle by a triplet micromotor assembly. Time-lapse images of a, b, and c have been taken from SI Video 6 in 1 second intervals. Scale bar, 3 μm. Conditions, 5% hydrogen peroxide.



SI Figure 4. Symmetric assembly of the 2 motor/2 non-motors.



SI Figure 5. Motor/non-motor interaction: rotational motion with the non-motor anchored to the glass surface (taken from SI Video 7). Scale bar, 2 μm. Conditions, as in Figure 1.

Experimental Section

Synthesis of Janus micromotors. The micromotors were prepared using silica microparticles (1.21 μm mean diameter, Bangs Laboratories, Fishers, IN, USA) as the base particles. 20 μL of silica particles were first dispersed into ethyl alcohol (A407-4, Fisher, Pittsburgh, PA, USA) and centrifuged. Then, the silica particles were redispersed in a small amount of ethyl alcohol, to which 200 μL of methylene chloride (D143-4, Fisher, Pittsburgh, PA, USA) and 15 μL of n-octadecanetrichlorosilane (OTS) (104817, Sigma-Aldrich, St Louis, MO, USA) were added. The particles were then stirred for 3 minutes at room temperature for the reaction to occur. To remove any unreacted OTS, the particles were then centrifuged and washed four times in anhydrous hexane (H292-500, Fisher, Pittsburgh, PA, USA) to a final volume of 400 μL. The sample was then spread onto glass slides and dried uniformly to form particle monolayers. The particles were sputter coated with a 20 nm Pt layer using a Denton Discovery 18. The deposition was performed at room temperature with a DC power of 200 W and Ar pressure of 2.5 mT for 15s. In order to obtain a uniform Janus half-shell coating, rotation was turned off and the sample slides were set up at an angle to be parallel to the Pt target. After the fabrication, the Janus particles were detached from the substrate via sonication or pipette pumping and were mixed with an aqueous solution of hydrogen peroxide. The suspension was placed onto a glass substrate where the particles settle due to gravity. Previous work on hydrophobic interactions of SAM/Au/polystyrene Janus particles found that the range of allowed attractive bonding angles increases with the ionic strength of the solution. However, our Janus particle motor assemblies are observed to assemble in a wide range of possible rotational orientations even in deionized water due to the decreased inter-particle coulomb repulsion effects between the Janus particles associated with the hydrophobic modification of the silanol groups.

Reagents and Solutions. In order to propel the catalytic Janus particles, aqueous hydrogen peroxide solutions with concentrations ranging from 10 % were used as chemical fuels. The motor-motor assembly experiments were carried out by mixing 5 μL motors (taken from glass slides by pipette) and 20% hydrogen peroxide solutions, while the motor/non-motor assembly experiments by mixing the 5 μL motors, 5 μL non-motor and 30% hydrogen peroxide solutions. The non-motor solution was prepared by adding 1 mL ultrapure water (18.2 MΩ·cm) to the modified silica particles after the hexane dry. For the motor/single non-motor interaction experiments, 50 times diluted particles were used. The original concentration was used for the motor/multiple non-motor interaction,

Equipment. Videos were captured by an inverted optical microscope (Nikon Instrument Inc. Ti-S/L100), coupled with 60× objectives, and a Hamamatsu digital camera C11440 using the NIS-Elements AR 3.2 software.