Dynamic Interaction between the Fast Microscale Rotors

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Supporting Information (4 pp.)

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1. Microrotor preparation and characterization

Synthesis of the Bimetallic Nanorods

The AuRu bimetallic nanorods were made by an electroplating method as described elsewhere in detail.[1] Anodic alumina membranes (Whatman Inc., NJ, 2 cm diameter) containing cylindrical pores (nominally 200 nm in diameter) were employed as the templates for nanowire growth. Scanning electron micrographs showed that the diameter of the rods made from these membranes was 370 nm. A thin sacrificial layer (300 nm) of Ag was evaporated onto one side of the membranes to serve as the working electrode contact. A Pt wire (0.3 mm diameter) was used as the counter electrode, and a 3-mm-diameter Ag/AgCl (3M NaCl) electrode (BAS) was used as the reference electrode. Deionized water (18 MΩ cm) purified by a Barnstead Nanopure system was used in all experiments. Approximately 8-10 µm of additional sacrificial Ag was electroplated into the membrane at a current of -5 mA to fill the branched section of the pore. The electrodeposition was done using a Pine Instruments bipotentiostat, model AFCBP1. Ag, Au and Ru nanowire segments were grown using commercially available plating solutions obtained from Technic Inc. Ag was electroplated at -5 mA for 50 min; Au was plated at -5mA for 9 min 20sec; and Ru was plated at -0.65V for 40 min. After electroplating, the nanorod-filled membranes were immersed in 5M HNO3 to dissolve the Ag sacrificial layer and then immersed in 5 M NaOH to dissolve the alumina membrane. Then the nanorods were centrifuged and rinsed in deionized water four to six times to remove the remaining NaOH. Following that the rods were centrifuged and rinsed in pure ethanol solution (ACS/USP Grade) twice to remove the DI water. After removal of the template, the rods were suspended and stored in ethanol solution.

Multilayer Evaporation Coating

The AuRu nanorod suspension in ethanol was spin coated onto a premium clean glass slide by a spin coater at 270 rpm to form a dispersed layer of rods. The rod-coated microslide was then inspected by optical microscopy to make sure that the rods were coated evenly onto the glass slide to prevent formation of rod aggregates, as well as to confirm that there was no contamination from the ethanol coating procedure (Figure 1). The coated glass slide was then moved into the evaporator for side-coating. The first layer coated was Cr, with a thickness of 10nm. The second layer was SiO_2, with a thickness of 50nm. The third layer was Cr again, with a thickness of 10nm. The fourth layer was Au, with a thickness of 55nm. The final layer was Pt, with a thickness of 30nm. After evaporation coating, the glass slides were carefully sonicated in a DI water bath for 3 to 5 min to remove the rods from the glass slide without detaching any of the $Cr/Au/Pt/SiO_2$ film on the glass that was not attached to the nanorods. The rotors suspended in DI water were then separated from the glass slides. The suspension was centrifuged in DI water twice and rinsed with fresh DI water. The rotors were collected and stored as suspension in DI water.

Figure S1: Optical image of the AuRu rods spin-coated onto a clean glass slide.

Characterization
FE-SEM images were obtained with a JEOL 6700F FE-SEM at 5kV, 20 µA.

2. Observations of Rotor Movement

The movement of the rods in H_2O_2 solution was observed using a Zeiss-Axiovet 200 inverted optical microscope. A digital camera linked with the microscope was used to record the results in video format at a rate of 30 frames/s. In a typical experiment, a suspension of the rotors in aqueous 15 wt % hydrogen peroxide was placed on a circular glass slide (VWR micro cover glass, 25mm Circle) sealed with a home-made chamber as shown in Figure S2. The trajectory and the rotational speed of the rods were measured by analyzing the video captured through our microscope setup using PhysVis motion analysis software (Kenyon College). For purpose of the trajectory tracing, the center of the rods in each frame was chosen as the tracking point. For the rotational speed, the differences in the directionality of the two ends of the rods in each frame were recorded and converted to angular difference over a set period of time.

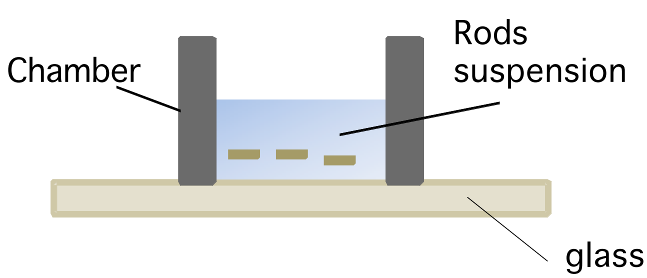

Figure S2: The experimental setup for observing rod movement (side view)

To observe the Brownian movement of unpowered rotors, we used the same batch of rotors, but we recorded their behavior in DI water. We then recorded the Brownian behavior and compared them with H_2O_2-activated rotors of similar conditions.

To study the interactions of rotors, we chose pairs of rods that had the same length of 3.5+/-0.6µm, were in close proximity, and had a starting center—to-center distance of about two body length. The speeds of the rotors in these experiments were selected in the 180+/-90 rpm range for meaningful comparisons between samples. The minimum distance data were obtained by tracking and comparing the distance between rods via frame-by-frame measurement. We compared 30 pairs of samples each from the Brownian and rotor experiments and their minimum distance data set is tabulated for rods rotating in the same direction in the histogram below (Figure S3):

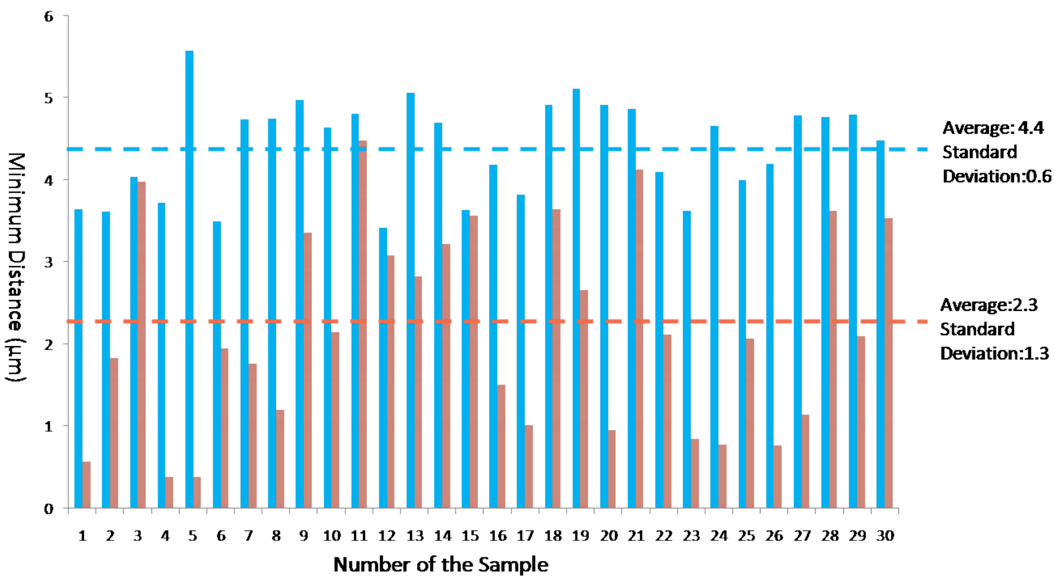

Figure S3. Histogram of the minimum center-to-center distance for powered rotors turning in the same direction in 15% H_2O_2 (blue) and unpowered rotor (red) interactions. Dashed line represents the average value for samples of the corresponding color-coded type.

Literature Cited

1. Martin, B. R.; Dermody D. J.; Reiss, B. D.; Fang, M.; Lyon, L. A.; Natan, M. J.; Mallouk, T. E. *Adv. Mater.* **1999**, *11*, 1021-1025.