Supporting Information For:

Rational Design and Synthesis of Catalytically Driven Nano Rotors

Lidong Qin, Matthew J. Banholzer, Xiaoyang Xu, Ling Huang,
and Chad A. Mirkin*

Department of Chemistry and International Institute for Nanotechnology,
Northwestern University, 2145 Sheridan Road, Evanston, IL 60208
Email: chadnano@northwestern.edu

1. Synthesis of Au-Pt-Au Nanorods

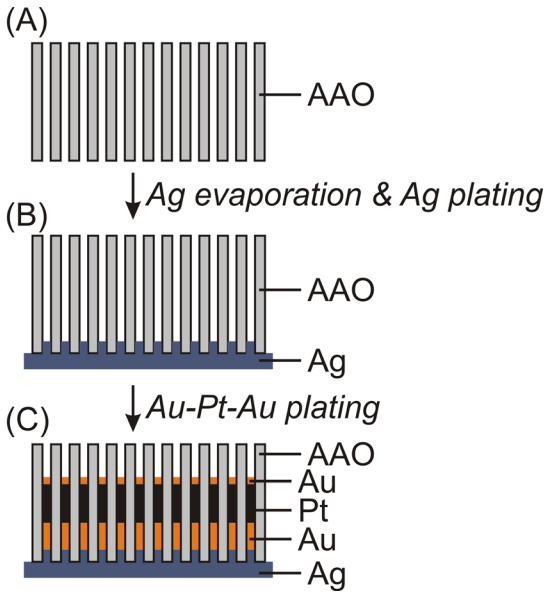
Au-Pt-Au nanorods were synthesized through template directed electrochemical deposition. (Scheme S1) Anodic aluminum oxide (AAO) templates with pore diameter of 360 nm were purchased from Whatman Inc. A 150 nm-thick Ag layer was evaporated onto the back of the templates.

All electrochemical deposition was carried out using Ag/AgCl as reference- and Pt counter- electrodes, respectively. An Ag layer of 1 μm was deposited into the template under the potential of –900 mV using ACR Silver RTU plating solution from Technic Inc. This first layer was used to reduce the surface roughness from Ag coating. (Scheme S1B) Subsequently, the target Au-Pt-Au rods were deposited on top of the Ag layer and the length of each segment were controlled by changing charge applied during each deposition step. (Scheme S1C)

Au was deposited by using Orotemp 24RTU solution purchased from Technic Inc. A 1.67-μm long Au segment was synthesized by applying 5 C of charge under –900 mV. After Au deposition, the template together with the electrochemical cell was thoroughly rinsed with nanopure water for 5 times with 5 minutes intervals between rinses.

The plating solution to deposit Pt was composed of 1 mg/ml H_2PtCl_6 (Aldrich) aqueous solution. Using the same setup mentioned above, 3.33-μm long Pt segment can be synthesized by applying 18 C of charge under –250 mV bias. After the Pt deposition, the complete electrochemical setup was again rinsed 5 times with 5 minutes intervals between each wash.

The final endcap Au segment was deposited using the same method as the first Au segment but only 60 mC of charge was passed. The length of this passivating layer was 20 nm. After electrochemical depositions, the Ag layer was removed by concentrated HNO_3 solution and the AAO template was removed by 3 M NaOH solution. The Au-Pt-Au rods were then rinsed three times with nanopure water.



Scheme S1. Synthesis of Au-Pt-Au nanorods. (A) Graph of AAO template with pore diameter of 360 nm. (B) Coating the AAO templates with Ag and growing a short Ag layer using electrochemical deposition. (C) Growing Au, Pt, and Au three-segment nanorods. The last 20 nm Au segment is a passivating layer to avoid catalytic reaction on Pt end.

The Au-Pt-Au nanorods were characterized by optical microscope (Zeiss Axiovert 100A with a CCD camera). Nanorods with one end of yellow Au contrast and

the other end of gray Pt contrast are shown in FigureS1. The third 20 nm Au segment is beyond the optical resolution. The length of Au segment is 1.67 μm and the one of Pt is 3.33 μm.

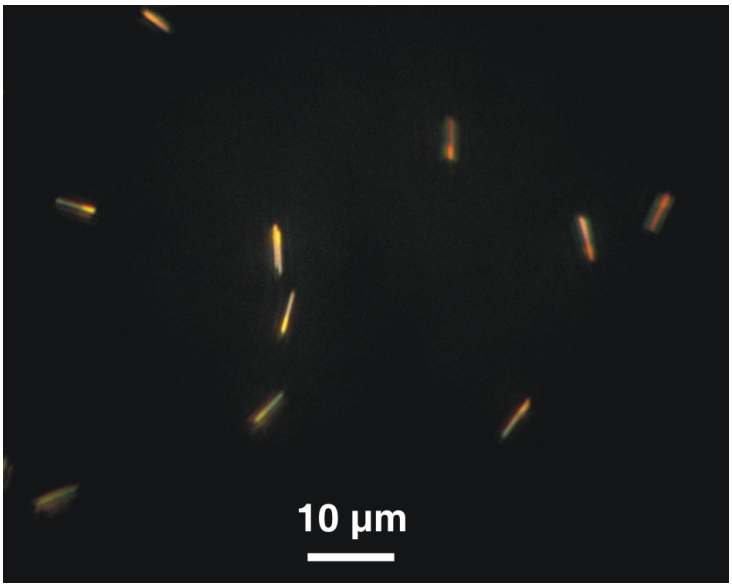
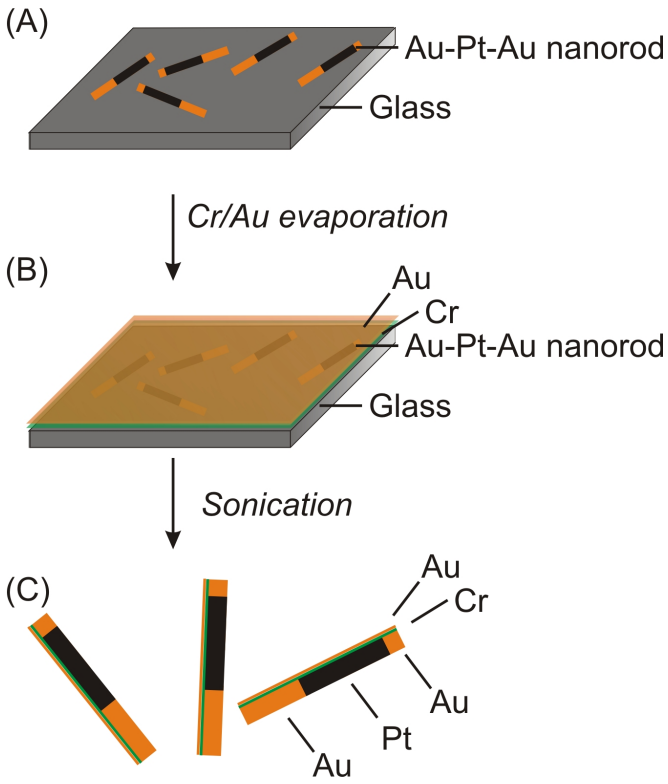


Figure S1. Dark field optical image of Au-Pt-Au nanorods.

2. Preparation of Side Coating

The as-prepared Au-Pt-Au nanorods were dispersed in aqueous solution and then dropped onto piranha pretreated glass substrates. After the glass slides dried, they were coated with 10 nm Cr and 40 nm Au in a thermal evaporator. The Cr adhesion layer helped the coating binding to glass substrates. Upon sonicating the glass slides in an ethanol bath, the nanorods with a half coating were removed, while the residual Cr/Au remained attached to the slides. The nanorods with half coating were rinsed three times with ethanol, three times with water, and were then collected and suspended in aqueous solution. (Scheme S2)



Scheme S2. Asymmetric coating on Au-Pt-Au nanorods. (A) Dispersing nanorods on glass substrates. (B) Coating the whole glass substrate with 10 nm Cr and 40 nm Au. (C) Sonicating substrates to release nanorods with half-coating

3. Characterization of the nanorotor structure

In order to demonstrate the success of the electrochemical deposition and the thermal evaporation (Scheme S2 A and B), the rods were analyzed by energy dispersive X-ray spectroscopy (EDX). An Au-Pt-Au (length ratio, Pt: Au = 1: 1) nanorod after Cr evaporation but prior to Au evaporation was investigated. At this stage of the synthesis, the Au evaporation layer did not cover the whole nanorod, making the Au and Pt sections clearly resolved. Five EDX spectra (Figure S2A) were taken from five spots on the Au-Pt-Au nanorod located from top to the bottom (Figure S2B) with the location marked with white arrows. Note that when using secondary electron detection, FESEM contrast

for Au and Pt is not obvious so EDX must be used to gain reliable data. The X-ray energy of the two elements was clearly differentiated. Au peaks are in the upper two spectra taken from the top of the nanorod and Pt peaks are in the lower three spectra from the bottom (Figure S2A). The Cr evaporation layer was also seen in the EDX spectra (Figure S2A).

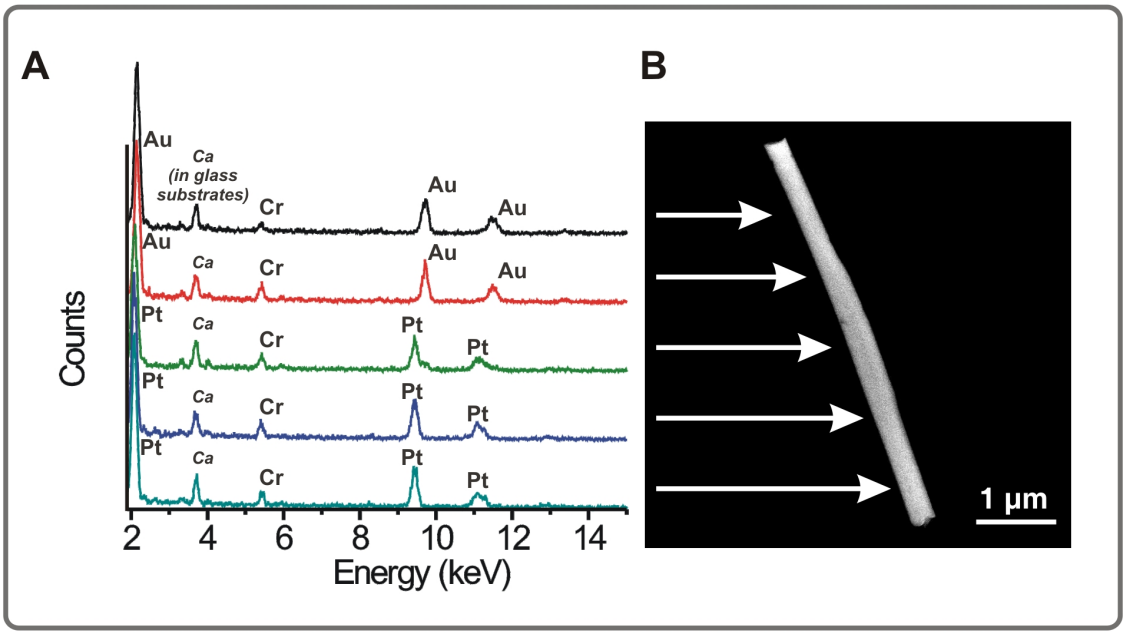


Figure S2. (A) EDX spectra taken on five different spots located on one Au-Pt-Au nanorod. (B) SEM image of a Au-Pt-Au nanorod.

4. Nanorotor Movie recording

10 µl of NRB aqueous solution (containing 1×10^5 NRB) was then mixed with 1 ml 3% H_2O_2. The mixture was dropped instantly on a glass bottom dish (MatTek Corporation) which was itself located over an optical microscope (Zeiss Axiovert 100A with a CCD camera). Rotations were observed and recorded by the microscopye.

A rotation movie of $Au_{1.67}$-$Pt_{3.33}$-$Au_{0.02}$ with Cr/Au coating is shown in **Video S1**.

A rotation movie of $Au_{1.67}$-$Pt_{3.33}$-$Au_{0.02}$ with Cr/Au coating is shown in **Video S2** In this video, as the nanowire rotation along its long-wire axis (out of the plane of the slide) the Au leading edge can be briefly seen, indicating that the Pt section is pushing the nanorod.

5. Analysis of Video S2.

To demonstrate the rotating direction, the Au-Pt-Au (length ratio, Pt: Au = 2: 1) was soaked in a 0.5% H_2O_2 solution. The resulted rotating speed is 4.6 rpm, much slower than the one in 3% H_2O_2 solution. This slower rotation speed allowed us to investigate rotation direction easily. In some of the experimental situation, the Au semi-cylindrical coating is partially exposed to observer, which allowed us to recognize the orientation of the nanorods and also the leading edge of the rotation. A representative movie was recorded in Video S2 and its snapshots were partially collected in Figure S3. With careful investigation, one can see the rotation is counterclockwise and the gray Pt contrasts are always on left side at the bottom, which indicates pushing force is dominated on the exposed Pt section.

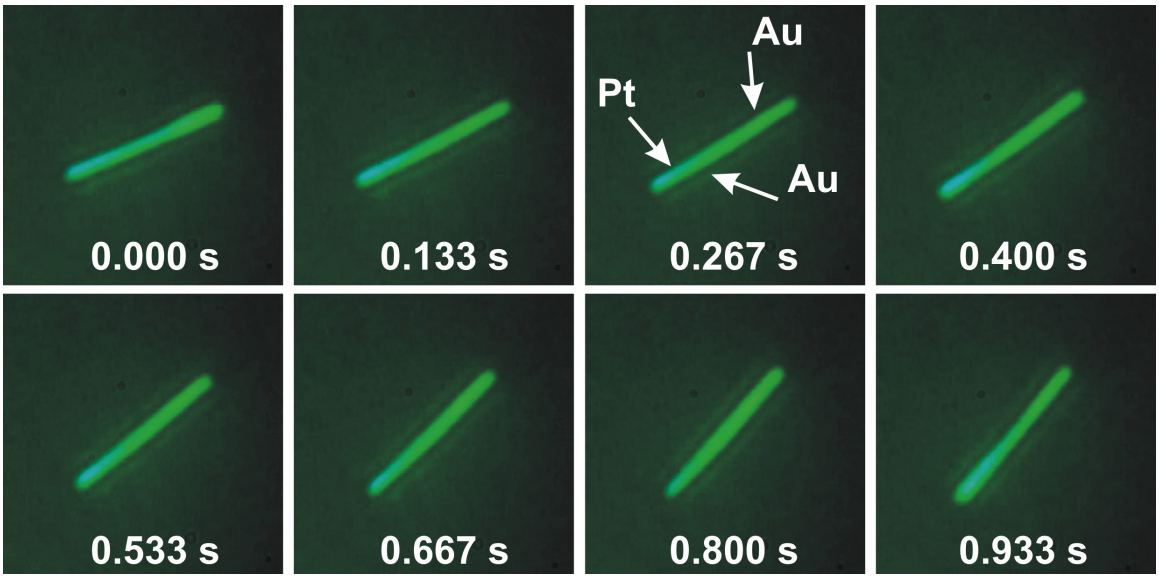


Figure S3. Snapshots of Video S2. The images were exported from the video with the interval marked in each image. In order to obtain the contrast of the Au side coating, all the images were linearly applied with a 10% reduction in brightness and a 10% increase in contrast (CorelDRAW 11).