Designing Catalytic Nanomotors by Dynamic Shadowing Growth

Yiping Zhao and John Gibbs
Nanoscale Science and Engineering Center
Department of Physics and Astronomy
The University of Georgia, Athens, GA 30602

Catalytic nanomotors move autonomously by deriving energy directly from their environment mimicking biological nanomotors which are motor proteins that perform a wide range of complex functions at the cellular level and are responsible for the majority of active transport and other movement within cells. They gain mobility by chemical reactions greatly sped-up by onboard catalysts. Recently, researchers have fabricated inorganic catalytic nanomotors with the hope that complex functional machines may one day perform intricate tasks at the cellular and sub-cellular levels. Various design techniques have produced several nanomotor structures including hetero-sectioned Ni/Au nanorotors, Pt/Au nanorod structures, gear-shaped rotary structures, self-propelling plates (macro-scale), and spherical nanomotors. The control of micro-scale and nano-scale motors is the first step toward designing functional machinery at these scales. Therefore, design focusing upon the type of motion desired is a positive step toward the creation of functional nanomachines. In this study, we show that, using a relative simple nanofabrication technique called dynamic shadowing growth (DSG), one can fabricate a large number of nearly identical nanomotor structures with different motion performance.

DSG is a physical vapor deposition technique in which the substrate is rotated in the polar and azimuthal directions by two stepper motors programmed by a computer. At a large deposition angle (generally > 75°) between the vapor flux and the substrate normal, porous nanorod arrays with different morphologies such as tilted, C-shape, S-shape, L-shape, zigzag, vertical, and helical structures can form on stationary or rotational substrates via geometric shadowing effect. By simply changing the deposition angle, the size and separation of nanorods can be tuned. During deposition, by changing source materials, one can design multilayer hetero-nanorod structures. It is a sophisticated technique to fabricate catalytic nanomotors.

Using DSG technique, we have designed different kinds of catalytic nanomotors, such as rotary nanorod nanomotors, L-shaped nanomotors, spiral nanomotors, index-shaped multicomponent nanomotors, and tadpole like nanomotors. Figure 1 shows the fabrication of the index-shape nanomotors and their motion is shown in Fig. 2. We have determined the nanomotors' motion direction and obtained the driving force per unit area per H_2O_2 concentration. With the obtained quantitative results, we can predict the motion behaviors of different nanomotors. In addition, with the systematically change the structural parameters of the nanomotors, the motion behavior can be tuned systematically. We have also investigated self-organized catalytic nanomotors consisting of more than one individual part. We observe random self-organization through Brownian interactions as well as an increased incidence of organization in the presence of H_2O_2. A flexible swimmer with a joint of two linked sub-structures is also presented. In order to improve the yield of the self-organized nanomotor systems, we intentionally assemble of a "helicopter" nanomotor consisting of a V-shaped nanomotor (with Ni section) and a half-coated Ni microbead by magnetizing the Ni sections and mixing the particles together, and we show that ~ 25% of the Ni microbeads assemble in this manner.

Our study demonstrates that DSG is a flexible fabrication method to design different catalytic nanomotors, and self-organization is promising for the fabrication of multi-component catalytic nanomotors with independent parts working in coordination. Combining current techniques utilizing self-organization with the manual manipulation of particles with magnetic and electric fields, thermal and chemical gradients, and other methods are a means for realizing complex nanomachinery which may allow for major technological advances in the nano and microscopic realms.

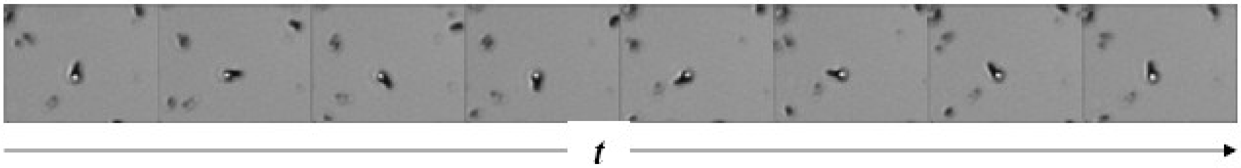

Fig. 2 Rotation of nanomotor shown at every 20 frames at a rate of 23 frames per second; time increases from left to right.