New motor first to be powered by living bacteria

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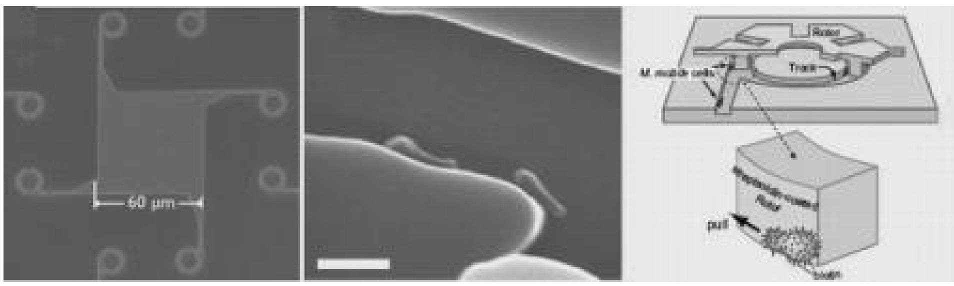

The scanning electron micrograph at left shows an overview of the silicon track, designed to coax the bacteria into moving in a uniform direction around the circular tracks. In the center, two cells glide along the wall in the track. The illustration at right of a circular track shows how the bacteria bind to and pull the rotor. Image credit: Yuichi Hiratsuka, et al.

A new motor designed by scientists from Japan offers the best of both worlds: the living and the non-living. The group built a hybrid micromachine that is powered by gliding bacteria which travels on an inorganic silicon track and pushes a silicon dioxide rotor. The combination takes advantage of the precise engineering of synthetic devices along with the efficient energy conversion and potential for self-repair of biological systems.

Yuichi Hiratsuka and his colleagues used a species of bacteria called *Mycoplasma mobile* to power their micromechanical motor. *M. mobile*, which has micrometer-sized cell body that glides continuously over solid surfaces, can move at speeds of up to 5 micrometers per second. Scientists aren't sure what causes the bacteria to move, other than that several proteins are involved, but Hiratsuka's group was still able to take advantage of the gliding ability by using entire *M. mobile* cells. The whole cells have been observed to work "more efficiently and intelligently" than nature's smaller motor machines (e.g., proteins and molecules), the scientists reported.

"Mycoplasma is just one example of microorganisms with interesting and potentially useful properties," Hiratsuka told *PhysOrg.com*. "For instance, there is a gliding bacterium that moves using energy provided by photosynthesis. Chlamyodomonas swim toward light (phototaxis), and Dictyostelium amoeba crawl toward a specific chemical substance (chemotaxis). Though there is no way we can predict what exciting micro devices will result from these organisms, for mycoplasma, we can suggest using it as a micro pump in a microTAS. This would eliminate the need for external pumps and pipes, becoming a 'true' on-chip device. We might also construct electric generator systems, which convert abundant chemical energy, glucose in the body, into electric energy. In far future plans, we would like to make micro-robots driven by biological motors, which could move around and do mechanical work in the micrometer world."

The mycoplasma-driven motor consists of a square central basin where the *M. mobile* are deposited. As the pear-shaped cells glide throughout the square, they eventually reach a side and move along it until approaching an entrance to one of four circular tracks. The entrance ways ensure that a majority of bacteria glide in the same direction around the tracks, which are each fitted with rotors that have protrusions in the track to allow the bacteria to bind to and pull the rotors (see figure).

Although an efficiently simple design, the tiny size of the motor (e.g., each rotor is 20 micrometers in diameter) required special fabrication techniques. *M. mobile* cells require sialic proteins (in this case, fetuin was used) to glide over solid surfaces. The scientists created a top layer of gold on the silicon track, and then deposited the sialic-acid-containing fetuin on selected lithographic micropatterns to compel the desired movement of the bacteria.

"Originally, we were studying the basic science of biological motors, so we routinely observed the motilities of motor proteins or bacterial or eukaryotic cells under a microscope," said Hiratsuka. "Those graceful motilities driven by biological motors were so attractive and we started thinking of creating hybrid devices that integrate inorganic materials and biological materials. Several years ago, we succeeded in developing a system in which microtubules powered by the kinesin motor move in one direction in circular micro tracks [Ref#1 in paper]. As a natural continuation of this work, we attempted to make a micro rotary motor driven by the kinesin-microtubule system. But this turned out to be rather difficult due to technical problems. Meanwhile, we saw a presentation by Prof. (Makoto) Miyata of Osaka City Univ., who is now our close collaborator, showing a movie of mycoplasma cells gliding unidirectionally on glass surfaces. It immediately occurred to us that we should be able to make micro rotary motors if we used these bacterial cells instead of the kinesin-microtubule system."

Although Hiratsuka's group used a slower-moving mutant strain of *M. mobile* for binding purposes in this study, they observed significant results on the premier run. Once the bacteria reached the circular tracks, the rotors began moving within minutes at rates of up to 2.6 rpm. Even though they could not observe the number of cells pushing the rotors in this set-up, the scientists estimated that only a few cells are needed to drive motion. Further, the team predicts that improving the directional uniformity of the bacteria, as well as increasing the sialic acid content on the track, are achievable goals that will allow more cells to drive a larger number of rotors at a higher rpm.

Hiratsuka *et al*. also proposed in their study genetically engineering *M. mobile* for stronger binding to the track and rotors, as well as adding chemicals to the bacteria that urge the cells to move in a uniform direction with chemical clues. In order to avoid potential biohazards, however, the scientists also considered an interesting alternative stemming from the work of scientists Uenoyama and Miyata: *M. mobile* "ghosts," which are not alive due to partial membrane dissolution, but still demonstrate gliding.

Citation: Hiratsuka, Yuichi, Miyata, Makoto, Tada, Tetsuya and Uyeda, Taro Q. P. "A microrotary motor powered by bacteria." *Proceedings of the National Academy of Sciences of the United States of America*. vol. 103. no. 37. 13618-13623.

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