Actuation Technique for Miniature Robots Developed using Multiphysics Simulation

Researchers at the French Atomic Energy and Alternative Energies Commission are making miniature robotic manipulators easier to build and operate. They hope to offer a less expensive actuator than those currently used in surgical devices; one day, it may revolutionize the methods seen on the operating table.

BY LEXI CARVER

Minimally invasive surgery depends on small, flexible tools with reliable actuation and consistent performance. Robotic devices have entered the operating room as assistants to procedures requiring hours of standing on the part of the surgeon. But many robotic surgery devices are expensive, bulky, and exhausting to operate. Christine Rotinat, researcher at the Systems and Technologies Integration Laboratory of the French Atomic Energy and Alternative Energies Commission (CEA LIST, Gif-sur-Yvette, France), has sought to create an alternative.

IMPROVING SURGEON EXPERIENCE THROUGH PHASE-CHANGE ACTUATION

Rotinat's goal was to provide surgeons affordable, versatile robotic tools that would reduce their pain following long procedures. The device would need to be inexpensive, miniaturized, produce high forces with relatively large displacements, exhibit reasonable electrical consumption, and follow medical guidelines. For instance, high voltages are unsafe, and magnetic fields cannot be present around equipment such as MRI machines.

Rotinat investigated miniature phase-change actuators, which create movement and force from the volume expansion that occurs when a material shifts from the solid to the liquid state. She needed a material with a high expansion rate and stress tolerance, and a phase change occurring at a temperature between the patient's body temperature and the authorized limit. Rotinat examined a microactuator created by Goldschmidtböing et al. that relies on paraffin, a wax hydrocarbon that expands 10-20 percent by volume when heated from a solid to a liquid. It was combined with carbon black particles, creating a conductive composite that would support Joule heating when an electric current passed through.

Goldschmidtböing's microactuator contains a chamber filled with conductive paraffin at a 2 percent carbon black concentration, covered by a silicon membrane and a metal sealing chip for applying a current, separated by an electrically insulating layer (see Figure 1). The paraffin expansion causes the silicon membrane to deflect outward, driving the movement of the actuator.

Rotinat and her team evaluated the mechanical behavior and control aspects of this composite in the CEA

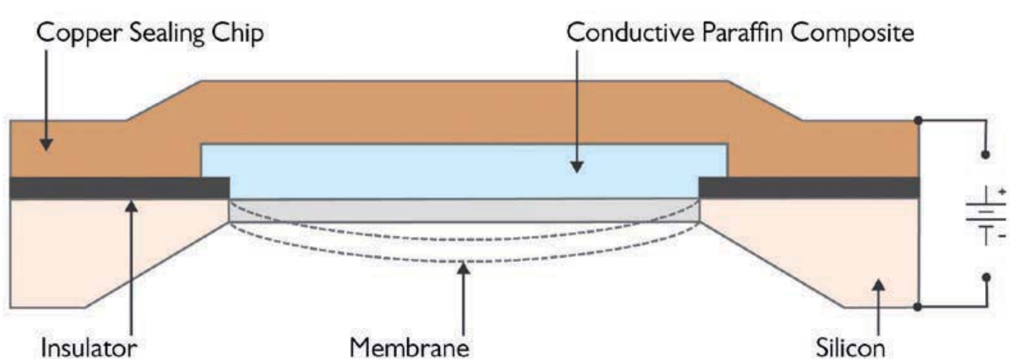

FIGURE 1. Schematic principle of a phase-change microactuator based on Goldschmidtböing et al.

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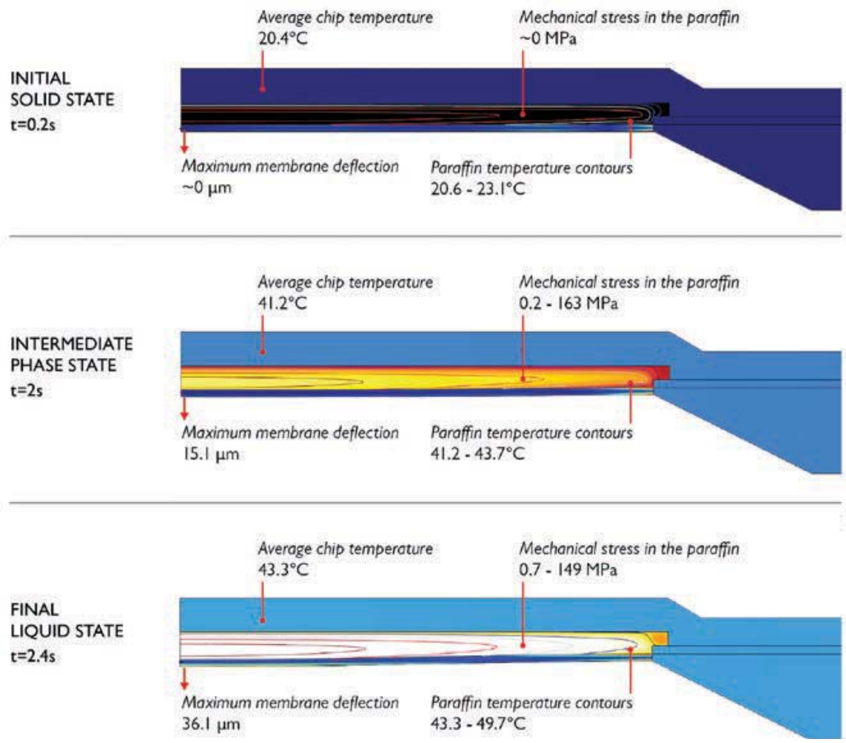

FIGURE 3. Validation model with results showing temperature ranges for the chip and paraffin, stress in the paraffin, and the deflection of the membrane.

LIST miniature actuator (see Figure 2), while her colleague Panagiotis Lazarou built a predictive model in COMSOL Multiphysics® to optimize its design. To simulate the composite behavior in the device, Rotinat and Lazarou calibrated their model based on the study of Goldschmidtböing's microactuator.

PREDICTING ACTUATOR BEHAVIOUR USING MULTIPHYSICS SIMULATION

Lazarou's simulation incorporated geometric, thermal, mechanical, and electrical parameters. "COMSOL enabled straightforward coupling of the physics involved," he explained. "This is a multiphysics problem with nonlinear electrical conductivity; density and specific heat capacity; and a changing viscosity, all of which affect the deflection." COMSOL allowed him to investigate exactly how each parameter influenced the displacement.

"We use COMSOL as a prediction tool," Lazarou remarked. "We can easily parameterize and change the actuator height, the membrane thickness, and the wax composite model. Moreover, resistivity increases as temperature rises, since the carbon particles spread apart when the paraffin expands." Lazarou approximated this behavior by modeling the electrical conductivity distribution (see Figure 2).

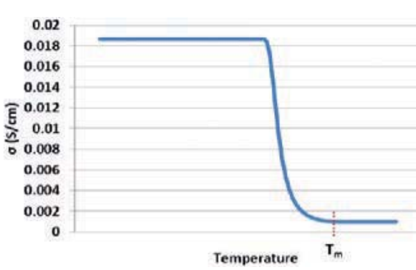

FIGURE 2. Approximation of the nonlinear electrical conductivity changing with temperature. Here, the melting temperature T_m is approximately 42.8°C.

The deflection of the simulated membrane (see Figure 3) was very close to the deflection exhibited by Goldschmidtböing et al., reflecting the accuracy of the model and the conductivity approximation. This allowed Rotinat and Lazarou to adapt the model and optimize the CEA LIST miniature actuator design.

THE NEW FACE OF ROBOTIC SURGICAL TOOLS

Lazarou successfully built a realistic multiphysics model of a phase-change actuator, simulating mechanical behavior and control aspects. He is applying his simulation to the design and optimization of the CEA LIST integrated miniature actuator, to produce the high loads and range of movement he and Rotinat envisioned. It will have low electrical consumption, meet medical requirements, and will lessen costs and the burden on surgeons. The prototype — which is to be completed in 2014 — will be thoroughly tested before being integrated into a robotic surgical tool. We'll soon see an affordable, easy-to-use surgical robot in the operating room. ■

Panagiotis Lazarou and Christine Rotinat working on a microactuator simulation.