



# Multiphysics Simulations Enable Development of Fast, Cheap MEMS-Based Bacteria Detector

Winner of 2011 Create the Future Design Contest aims at reducing food-borne infections.

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**F**ood-borne *E. coli* and salmonella bacteria cause thousands of infections annually, leading to human and animal deaths and to significant economic losses. The deadliest *E. coli* outbreak in recorded history, centered in Germany last summer, caused at least 50 deaths and more than 4,000 reported cases of poisoning in more than a dozen countries, with economic damages in the hundreds of millions of Euros.

Such outcomes could be avoided with better and less expensive bacteria detection technologies. The widely used plate count method takes 24-48 hours because bacteria need that long to grow into detectable colonies. That's too long for most food industry applications because food needs to be delivered and sold fresh.

Newer alternatives also fall short. Polymerase chain reaction (PCR) testing takes only three hours but costs about \$50 per test — too expensive for routine use. Labeled detection and fluorescent imaging technology, meanwhile, can detect a single bacterium but requires specialized laboratories and procedures, and is even more expensive.

Fortunately, a promising MEMS (microelectromechanical system)-based

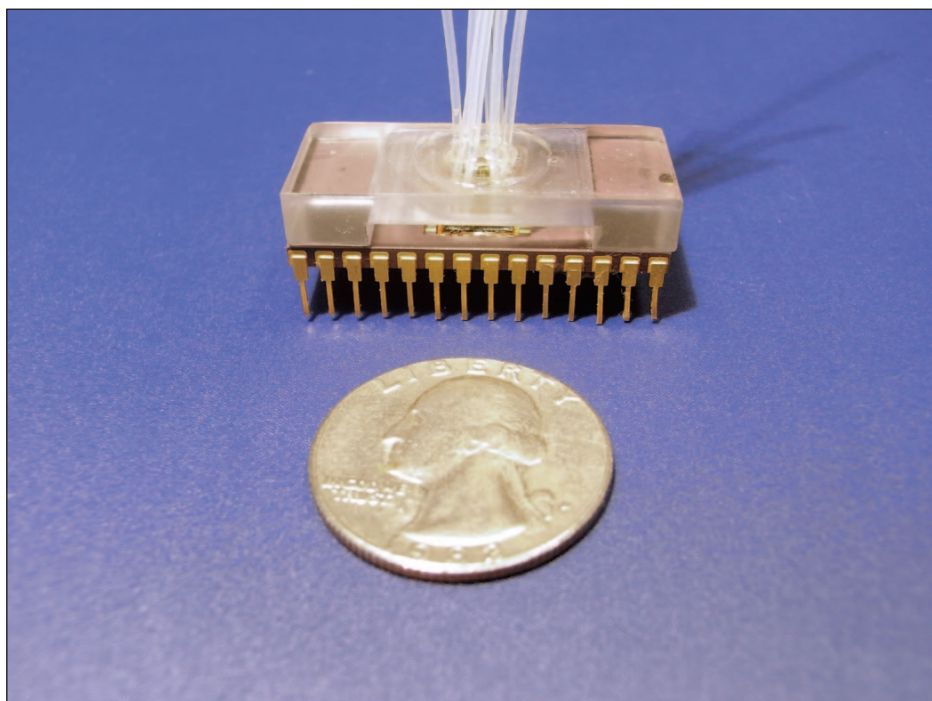


Figure 1. Prototype of the  $\alpha$ Screen bacteria-detection system near a U.S. quarter coin for scale.

and accurate bacteria detection with a coin-sized, cheap, easy-to-use and disposable device (Figure 1).

$\alpha$ Screen was the winning design of the 2011 edition of the popular Create the Future Design Contest. Launched in 2002 by the publishers of *NASA Tech Briefs* maga-

$\alpha$ Screen is being developed by Monika Weber, PhD. Candidate in Electrical Engineering at Yale University, and a team she is leading in Professor Mark Reed's nanotechnology group there. As Grand Prize Winner, Weber received a \$20,000 cash prize, which she donated to Yale to help fund prototype development.

" $\alpha$ Screen technology has great potential to reduce infectious disease in developing countries where people lack resources and can't afford healthcare," Weber said. "About four percent of all deaths worldwide are from diarrhea, mostly caused by bacteria. As a fast, low-cost technology,  $\alpha$ Screen will help solve a critical world problem. The ultimate goal is the detection of hundreds of different bacterial diseases."

## How It Works

The advent of nanoscale field-effect transistors (FETs) has led to new ways

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solution developed with the aid of multiphysics simulation software is on the horizon. Now undergoing prototype testing,  $\alpha$ Screen technology combines a novel way to separate bacteria from blood, and a nanoscale sensor to detect the bacteria. It holds the promise of fast

zine to help stimulate and reward engineering innovation, the annual event has attracted more than 7,000 product design ideas from engineers, entrepreneurs, and students worldwide. Principal sponsors of the 2011 contest were COMSOL, PTC, and Tech Briefs Media Group.

The Yale University design team that won the 2011 Create the Future Design Contest consisted of (from left) team leader Monika Weber, Christopher Yerino, Hazael Montanaro, Kane Siu Lung Lo, and Professor Mark Reed. The prototyping team consists of Weber and (not pictured) Kara Brower, Brian Goldstein, and Phillip McCown, with Professors Mark Reed and Tarek Fahmy as advisors.



to detect proteins and other biological markers in fluids. In theory, systems can be engineered so that a specific target's proximity alters a FET's gate potential, thereby modulating its drain current and signaling the target's presence.

But in practice, acceptable performance is difficult to achieve because targets are often carried in high-ionic fluids like blood, and the tiny FETs have ultra-low operating currents easily overwhelmed by ionic charge.

"We are developing a way to separate bacteria from blood components, such as red and white blood cells, using a

non-uniform electric field. We use asymmetrically placed electrodes to generate a specific frequency within a microchamber to create an electric dipole moment. Then, we use dielectrophoretic force to move the bacteria into microchannels and to transport them along for the next step, which is to submerge and concentrate the bacteria in a low-ionic solution," Weber said.

"Next, in the detection part of the device, we have functionalized the FET sensors with bacteria-specific antibodies for bacteria selectivity and specificity, so they will be able to detect any targets that may

be present. These transistors use nanowires as active channels and are built using standard, low-cost semiconductor-industry CMOS fabrication technology."

The entire bacteria-separation portion of  $\alpha$ Screen was modeled from late 2010 to early 2011 using COMSOL Multiphysics (Figure 2). Subcomponents for the detection portion, meanwhile, have been prototyped and are now undergoing testing. The device will be the size of a coin, and the projected cost per test will be as low as \$1.

"Without COMSOL, I am sure we wouldn't have ended up with such a good design, and it also probably would have taken years to test and optimize rather than weeks," Weber explained. "We simulated all of the physics involved along the entire path from sample injection to detection, encompassing all forces, all trajectories, everything," she said.

"Now that we have gotten access to the most recent version of COMSOL, I am looking forward to the LiveLink™ for CAD interoperability features. Professor Reed's laboratory has extended technical computing resources, and these options will make our lives much easier by integrating COMSOL more tightly within that environment," said Weber.

### Commercialization Plans

"We have decided to commercialize this technology, and as a first step, we have applied for a grant from funding agencies to target the development of this device for infectious disease control in developing countries," Weber said.

"We believe it has tremendous potential to revolutionize diagnostics in the developing world, and we are committed to making that happen." ■

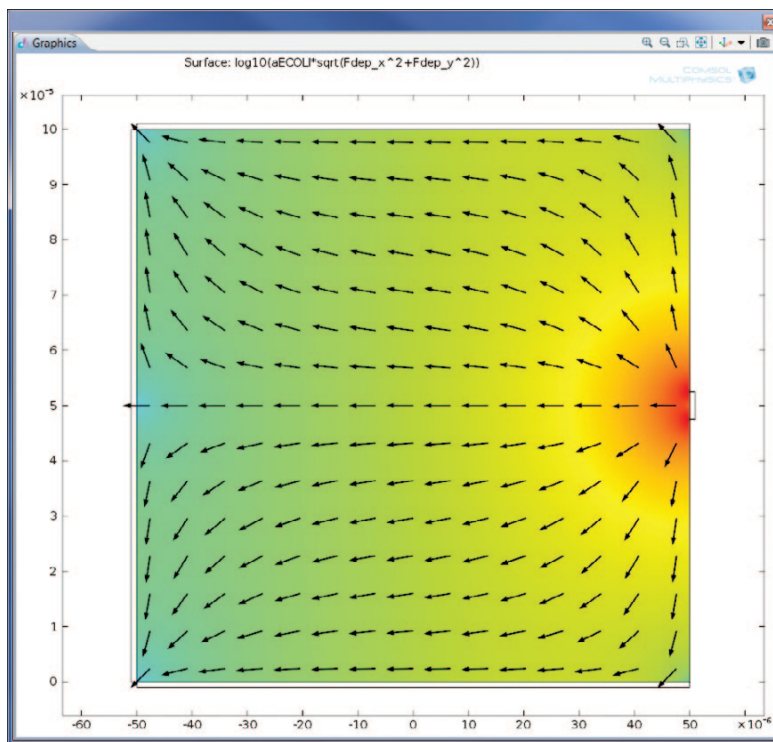


Figure 2. COMSOL particle-tracking simulation of dielectrophoretic force on *E. coli* bacterium inside a microchannel.