Model is first to compare performance of 'biosensors'

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Researchers have developed a new modeling technique to study and design miniature "biosensors," a tool that could help industry perfect lab-on-a-chip technology for uses ranging from medical diagnostics to environmental monitoring.

The experimental devices represent a new class of portable sensors designed to capture and detect specific "target molecules," which will allow the sensors to identify pathogens, DNA or other substances.

Now researchers at Purdue University are the first to create "a new conceptual framework" and corresponding computational model to relate the shape of a sensor to its performance and explain why certain designs perform better than others, said Ashraf Alam, a professor of electrical and computer engineering.

Findings also refute long-held assumptions about how to improve sensor performance.

The researchers tested and validated their model with experimental data from various other laboratories.

"Many universities and companies are conducting experiments in biosensors," Alam said. "The problem is that until now there has been no way to consistently interpret the wealth of data available to the research community. Our work provides a completely different perspective on how to analyze their data and how to interpret them."

Research findings are detailed in a paper that appeared in the Dec. 21 issue of the journal *Physical Review Letters*. The paper was written by electrical and computer engineering doctoral student Pradeep Nair and Alam.

Biosensors integrate electronic circuitry with natural molecules, such as antibodies or DNA, which enable the devices to capture target molecules. In efforts to design more sensitive devices, engineers have created sensors with various geometries: some capture the biomolecules on a flat, or planar surface, others use a single cylindrical nanotube as a sensing element, and others use several nanotubes, arranged in a crisscrossing pattern like overlapping sticks.

Researchers have known for several years that smaller devices are more sensitive than larger ones. Specifically, the most sensitive devices are those built on the scale of nanometers, or billionths of a meter, such as tiny hollow nanotubes made of carbon.

"But we haven't really known why smaller sensors are more sensitive," Alam said.

One obstacle in learning precisely why smaller sensors work better is that the analysis is too computationally difficult to perform with conventional approaches. The Purdue researchers solved this problem by creating a model using a mathematical technique called Cantor transformation, which simplified the computations needed for the analysis.

"That is the most important aspect of this work," Nair said. "You could not effectively analyze the physics behind these biosensors by using brute force with massive computing resources. It either could not be done, or you would not be able to get consistent results."

The new model explains for the first time why a single nanotube

performs better than sensors containing several nanotubes or flat planar sensors and refutes the predominant explanation for why smaller sensors work better than larger ones.

"Everyone presumes that the nanometer-scale sensors are better simply because they are closer to the size of the target molecules," Alam said "This classical theory suggests that because larger sensors dwarf the molecules they are trying to detect, these target molecules are just harder to locate once they are captured by the probe. It's like trying to see a small speck on a large surface. But that same target molecule is no longer a speck if it lands on a probe closer to its own size, so it's much easier to see.

"What we found, however, was not that smaller sensors are better able to detect target molecules, but that they are better able to capture target molecules. It's not what happens after the molecule is captured that determines how well the sensor works. It's how fast the sensor actually captures the molecule to begin with that matters most."

The distinction is important for the design of biosensors.

The reason smaller sensors capture molecules more effectively is because using a single nanotube sensor eliminates a phenomenon called "diffusion slow down." As a result, target molecules move faster toward single nanotubes than other structures.

The new model developed by the Purdue researchers determined that "the smaller the better," Alam said.

"This acceleration starts coming in when you make sensors on the size scale of tens of nanometers. That is when you will get a real advantage."

Future work will concentrate on applying the model to the performance

of a "fractal sponge," which is a shape containing many pores. Such a shape is important for applications in drug delivery and filtration.

Source: Purdue University