Mass spectrometry in your hand

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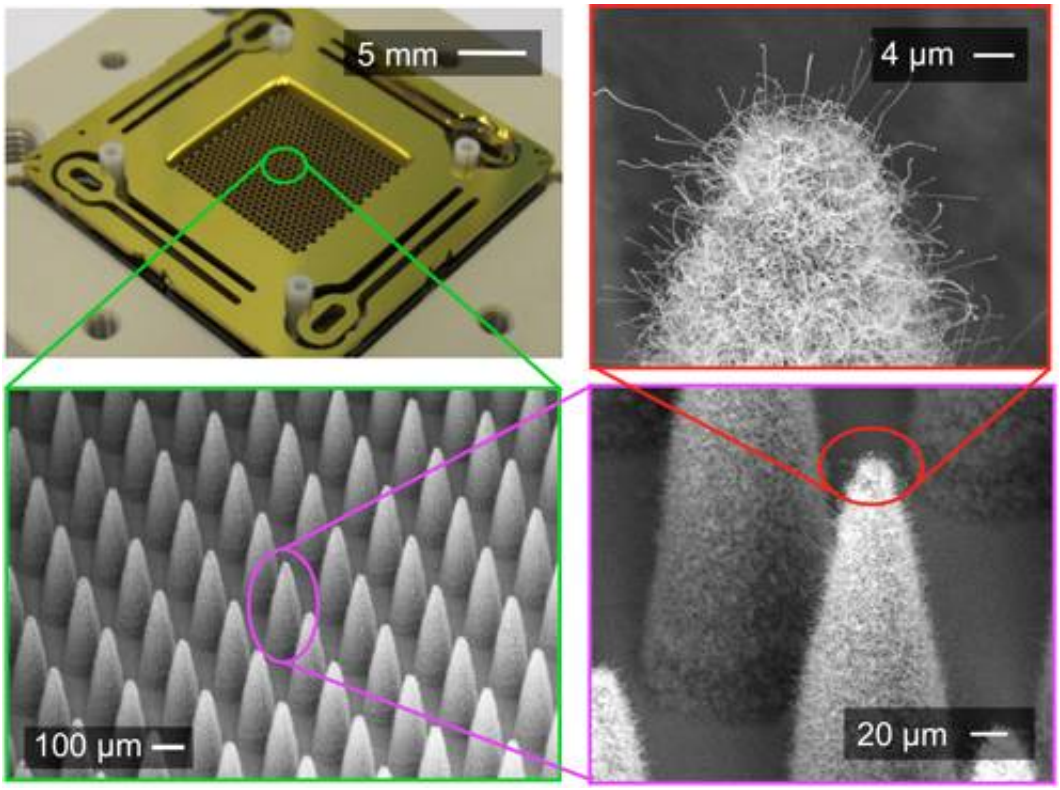

Electrospray ionization technology

If you're out in the field doing environmental testing, food checks, forensic work, or other chemical analysis, mass spectrometry is an extremely accurate detection tool with one huge drawback: You can lose days in sending samples back to the lab for analysis. MIT researchers now have developed technologies that promise to enable mass spectrometers that are handheld and much more inexpensive than today's

lab systems.

"The opportunity in mass spectrometers is to bring the analytical power of brick and mortar laboratories into the field," says MIT's Microsystems Technology Laboratories (MTL) Principal Research Scientist Luis Velásquez-García. "We think we could make something the size of a smartphone that does the same analyses as much larger systems without sacrificing performance, and at a fraction of the cost. This will allow us to put mass spectrometry in many places where it can't be done now."

To quantitatively determine the chemical composition of a sample, a mass spectrometer vaporizes the sample material (if it is not already a gas) and ionizes it. The ions are accelerated through a mass analyzer where electromagnetic forces are applied to them, allowing them to be separated out by their mass-to-charge ratios, Velásquez-García explains. The results are then analyzed to identify chemical elements in the sample.

Velásquez-García and other researchers at MIT's MTL have engineered nanoscale versions of key components for mass spectrometry—most notably, ionizing sources for liquids and gases, a "quadrupole" that sorts out the chemical compounds, and a chip-scale vacuum pump—as well as technologies for mass production of these components.

Other contributors to the work include MTL head Professor Akintunde Ibitayo Akinwande; Postdoctoral Associate Arash Akhavan Fomani; MIT Provost and former MTL head Martin Schmidt; Visiting Professor Carol Livermore, now at Northeastern University; and many other colleagues.

Advantages of miniaturization

Made from arrays of self-aligned nanoscale conical tips, the low-voltage

miniaturized gas ionizer can work at vacuum pressures that are orders of magnitude higher than today's commercial systems, making ion production greatly more efficient and minimizing requirements for vacuum pumping, Velásquez-García says.

The quadrupole—four parallel rods that create an oscillating electrical current—can be microfabricated in batches and can sort out the sample's chemical constituents with performance similar to that of the state-of-the-art systems.

Using more standard chip fabrication techniques, MIT researchers also have engineered a chip-scale three-stage vacuum pump with a minimum number of moving parts, which could support a miniaturized mass spectrometer.

Miniaturization creates multiple advantages. "If you make systems smaller they probably consume less power, operate with smaller voltages, and can have higher throughput through multiplexing," says Velásquez-García. "Miniaturization also can make the system less needy of special conditions—in this case, because these mass spectrometer components require substantially less of a vacuum than current systems, the system will consume a lot less energy and be a lot more portable."

Moreover, the ability to make batches of microfabricated components may drop system costs from tens of thousands of dollars to hundreds of dollars. With that kind of pricing, these miniaturized systems could satisfy many applications that currently don't use mass spectrometry because of the cost, like monitoring carbon dioxide and carbon monoxide levels in buildings, Velásquez-García says. A number of entrepreneurs see an opportunity to integrate downsized mass spectrometry with other business equipment, such as wireless routers or small cell base stations, to analyze office air quality.

The liquid ionizers MIT developed build on an electrodynamic phenomenon called high-electric-field electrospray, which applies voltages to liquids with electrical properties to create sprays of evenly dispersed charged particles. "For different applications, the particles can be droplets, ions or fibers," explains Velásquez-García. "Our contribution is to come up with very large electrospray arrays that work uniformly, at a low voltage, and can satisfy many of these applications." Besides portable and miniaturized autonomous mass spectrometry, other applications include nanosatellite propulsion, high-throughput nanomanufacturing and chip cooling.

Studying different ways to exploit electrospray, MIT researchers also have created methods to lay down nanothin films at atmospheric pressure and low temperatures, which allows printable analytic sensors. The lab is also working with an industry partner on a gas sensor. Velásquez-García hopes to extend the technology to make a printing head that can integrate with 3-D printers.

Related MIT high-electric field technologies could impact many industries in roles such as biochemical analysis, drug manufacturing, plasma diagnosis for chip manufacturing, and soft-tissue imaging via X-ray machines that fit on a desktop.

Nanospinning off fibers for other applications

MTL researchers have also pioneered another electrospray technique called nanospinning, in which an electrostatic field drives a fluid containing dissolved plastic through arrays of nanotech cones into streams that can create fibers around 200 nanometers across.

The cones can be packed in very dense arrays, "so we can dramatically improve the throughput of electrospinning," says Velásquez-García. "If you want to buy an electrospinning source in the market now, it has one

or two emitters and it's a very expensive machine. We already have created a source that emits a hundred times more."

Fabricating cones with nozzles much tinier and more tightly structured than those of commercial systems, he expects to be able to reach the high density of emitters demonstrated in earlier electrospray technologies, with almost a thousand emitters packed into one square centimeter.

High-throughput nanospinning manufacturing can make fibers for a variety of applications including air and liquid filtration, body armor, capacitors, electrodes for fuel cells, solar cells, tissue scaffolding, wound dressing, solar cells, and a wide range of other roles for materials that need a very fine mesh or high surface-to volume-ratio.

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