ICPMS: It's Elemental

Many laboratories are turning to ICPMS because of its speed, sensitivity, and multielement capability.

Katie Cottingham

Although inductively coupled plasma MS (ICPMS) is a well-known method for trace element analysis in the environmental and geochemical fields, it is also being embraced by researchers in other areas because of its sub-parts-per-trillion detection limits and multielement, multi-isotope capability. The semiconductor, biomedical, nuclear, and pharmaceutical industries have all found applications for the technology.

But company representatives say that environmental laboratories still make up the largest segment of their customer base. As regulatory agencies reduce the acceptable levels for toxic elements in the environment, more laboratories are adopting ICPMS as their primary technique. "I think a lot of people are switching from atomic absorption to ICPMS because ICPMS gives you better detection limits, and it's much, much faster," says Ruth Wolf of PerkinElmer. Alternative techniques, such as atomic absorption and ICP optical emission spectroscopy, just don't have the sensitivity for most elements or high-throughput capabilities of ICPMS, according to experts.

Analytical Chemistry last reviewed ICPMS four years ago (**1999**, *71*, 811 A–815 A). Since then, the prices for several instruments have either declined or remained steady, but experts say that sales are increasing at a rate of ~10% every year. Quadrupole, sector, and TOF instruments are still available, and quadrupole machines continue to be the most popular. TOF ICPMS instruments, which came on the market in the late 1990s, have yet to make a big splash. In fact, company representatives estimate that quadrupoles account for 86% of ICPMS instrument sales, while sectors and TOFs make up 13% and 1%, respectively.

Tables 1, 2, and 3 list several ICPMS instruments. These lists are not meant to be comprehensive. Other companies not listed here, such as Shimadzu, only sell ICPMS instruments to customers in Asia.

Quadrupole, sector, or TOF?

ICPMS instruments vary in the type of mass spectrometer that is attached to the ICP ion source. Quadrupole mass spectrometers only allow ions of a specific m/z value to reach a detector, ejecting all other ions. Sector instruments use magnetic and electrical fields to focus a beam composed of spatially dispersed ions. Focusing permits ions of a particular m/z to reach the detector through a slit. In TOF instruments, ions travel through a tube at different velocities, depending on their m/z. All ions are detected, though lighter ions reach the end of the tube before heavier ions.

Quadrupole ICPMS systems have a foothold in laboratories that routinely analyze samples. "They've been on the market the longest, and they are the most bulletproof as a result," says Gary Hieftje of Indiana University. "A lot of time has been invested in developing the methods." Quadrupoles are generally the cheapest of the three types, and experts say these machines are versatile and robust.

According to Hieftje, magnetic sectors offer the highest resolution and sensitivity. "You can typically get between a factor of 10 or more lower detection limits with a sector field system than with a quadrupole, although newer quads are narrowing the gap," he says. Sector instruments with multicollector detectors (*Anal. Chem.* **2003**, *75*, 119 A–123 A) are big players in isotope ratio analysis. Roy Cohen of Nu Instruments says, "They were developed to do high-precision isotope analysis of a large range of elements in the periodic table, in particular, those that were previously inaccessible by established mass spec techniques, such as TIMS [thermal ionization MS]." Although other ICPMS instruments can perform iso-

Table 1. Selected quadrupole ICPMS instruments.[1]

Product	7500cs	ELAN DRC II	X Series CCT^{ED}	Varian ICPMS
Company	Agilent Technologies 395 Page Mill Rd. P.O. Box 10395 Palo Alto, CA 94303 www.agilent.com	PerkinElmer Life and Analytical Sciences 710 Bridgeport Ave. Shelton, CT 06484 www.perkinelmer.com	Thermo Electron ICP-MS Facility Ion Path, Road Three Winsford, Cheshire, CW7 3BX U.K. www.thermo.com	Varian, Inc. 3120 Hansen Way Palo Alto, CA 94304-1030 www.varianinc.com
Price (U.S.D.)	$190,000	$191,923	$170,000	$150,000
Stand alone or benchtop	Benchtop	Stand alone	Benchtop	Stand alone
Resolution	<0.5 at 10% peak height	<0.5 at 10% peak height; custom resolution capability	Typically 0.75 amu; switchable to 0.2 amu	500 or 0.5–1.5 amu, selectable across the mass range
Abundance sensitivity				
High mass side	5×10^{-7}	Better than 1.0×10^{-7}	5×10^{-7}	1×10^{-7}
Low mass side	1×10^{-6}	Better than 1.0×10^{-6}	1×10^{-6}	1×10^{-6}
Precision (RSD)	<2% over 20 min	<4% over 4 h	3% over 2 h	<3% over 20 min; <4% over 4 h
Scanning speed (amu/s)	2400	2400	5000	2000
Linear dynamic range (orders of magnitude)	9 using high-speed log amplifier	9 in a single, continuous scan	9	9
Collision cell technology	Proprietary Octopole Reaction System	Proprietary Dynamic Reaction Cell	Hexapole cell	Not currently available, but interferences fundamentally reduced in interface region and sample introduction system
Type of detector	Simultaneous dual-mode electron multiplier with high-speed analog mode	Discrete dynode detector	Discrete dynode electron multiplier	All-digital discrete dynode electron multiplier
Chromatography interfaces	GC and LC (Agilent); CE (Cetac interface with Agilent CE)	LC standard; GC as custom	GC and LC; bidirectional communication	LC
Special features	Extreme sensitivity for the lowest detection limits; uses simple reaction gases (hydrogen, helium) so side reactions that create new, unpredictable interferences are eliminated; polyatomic interferences are removed under one set of cell conditions irrespective of sample matrix	Single ion lens automatically optimizes on-the-fly for each element; patented technology provides maximum interference removal; quick-change cones and lens minimize maintenance; version 3.0 software enhances ease-of-use with one-button optimization; other models available include ELAN 9000 and ELAN DRC-e	Switchable resolutions; plasma interface design for low polyatomic interference species; tailored response for wide dynamic range measurement; intelligent monitoring of uptake and wash; scanning and peak jumping within a sample; semiquantitative and quantitative work within one analysis; other models are available	Patented 90° reflecting ion optics system for 1 billion counts/s sensitivity, low background, and low interferences; detector has an effective count rate upper limit that is 2500 times higher than standard pulse-counting multipliers, and its all-pulse design eliminates complicated and time-consuming analog-to-digital cross-calibrations

[1]Some companies offer multiple instruments. Contact the vendors for their full product lines.

topic analyses, Cohen argues that they cannot compete with the 10-ppm precision (0.001% RSD) that multicollector sectors can easily obtain.

Single-collector sector systems are frequently categorized with quadrupole instruments in terms of applications. Both types of instruments are cheaper, more common, and more flexible than multicollector instruments, according to experts. Single-collector sectors and quadrupoles are often used for isotope ratio measurements and elemental analyses, whereas multicollectors are dedicated to isotope ratios, says Thomas Rettberg of VHG Labs.

Many researchers view TOFs as niche instruments that are well suited for studies in which transient signals are produced, such as laser ablation experiments (*Anal. Chem.* **2003**, *75*, 341 A–347 A). Jay Kyne of GBC Scientific says that his company's target TOF buyer is "the high-end researcher who can't afford a sector, but can't do what they want with a quad." Although Don Potter of Agilent says that TOF ICPMS systems provide data for the full mass range of a short-lived signal, he also points out that they have a relatively low duty cycle. Lloyd Allen of LECO admits that duty cycle is a concern with these instruments, but only if a researcher is analyzing a small num-

Table 2. Selected sector ICPMS instruments.[1]

Product	Nu Plasma	Finnigan NEPTUNE	Finnigan ELEMENT2
Company	Nu Instruments Ltd. Unit 74 Clywedog Rd. South Wrexham LL13 9XS U.K. www.nu-ins.com	Thermo Electron Bremen Barkhausenstrasse 2, 28197 Bremen, Germany www.thermo.com	Thermo Electron Bremen Barkhausenstrasse 2, 28197 Bremen, Germany www.thermo.com
Price (U.S.D.)	INA	INA	INA
Stand alone or benchtop	Stand alone	Stand alone	Stand alone
Resolution	Up to 10,000	Three fixed settings: >400, >4000, >8000	Three fixed settings: >300, >4000, >10,000
Abundance sensitivity			
High mass side	0.5×10^{-6}	0.5×10^{-6}	3×10^{-5} (at $m = 238$)
Precision (RSD)	10 ppm	<10 ppm	<1%
Linear dynamic range (orders of magnitude)	INA	9 (analog: 50 V at 10^{11} ohms; counting: 1–10^6 counts/s)	9
Type of detector	Multicollector: 12 robust ceramic Faraday cups and 3 discrete dynode electron multipliers	Multicollector: 9 Faraday cups plus up to 8 ion counting channels (1 fixed channel and 8 movable detector platforms); each platform can be equipped with a Faraday cup and/or a package of ion counters	Single collector: discrete dynode detector; simultaneous analog and counting measurement; mass-independent automatic cross-calibration
Chromatographic interfaces	No	GC and LC	GC and LC
Special features	Patented variable-dispersion ion optics; demonstrated and delivered multicollector ion counting; true and pseudo high resolution; inherently low moleculars; multielement isotope analysis on same laser spot or sample; no moving Faraday or ion-counting collectors; open software code; grounded analyzer; small footprint	High sensitivity, resolution, and selectivity; interference-free analysis in complex matrixes; high-precision isotope ratio measurements; plasma at ground potential; easy adaptation of peripherals, stable mass bias; patented low-noise amplifier system for Faraday cups; multicollector detectors are variable in position and in type	High sensitivity, resolution, and selectivity; interference-free analysis in complex matrixes; no single-element optimization; matrix-independent universal methods; fast scanning: >30 samples/h, 30 elements in <2 min; isotope ratio measurements; multielement speciation analysis; direct analysis of phosphorus, sulfur, and silicon

[1]Some companies offer multiple instruments. Contact the vendors for their full product lines.

INA: information not available

ber of elements at once. If many isotopes (>~10) are monitored in an experiment, the effective duty cycle of a quadrupole system will decrease below that of a TOF instrument, he says.

Collision/reaction cells come of age

Polyatomic interferences are a major problem for the analysis of some elements. For example, $^{40}Ar^{16}O^+$ is a classic interfering species when detecting ^{56}Fe. To address this issue, researchers can use either a collision cell or a reaction cell. In collision mode, interfering polyatomic ions collide with an inert gas, whereas in reaction mode, interferents or the analyte ions undergo chemical reactions with a gas. Both technologies help prevent interfering species from spectrally overlapping with the target isotopes.

Experts report that collision and reaction cell technologies have made great strides in the past few years, allowing quadrupoles to perform as well as high-resolution sector instruments in reducing interfering signals. According to Potter, cells have also caught on as an alternative to the cool plasma technique, which was the traditional quadrupole method for dealing with interferences. Nearly all commercially available quadrupole systems can now be purchased with an optional cell. “Collision cell technology has emerged on the scene and really taken the whole field by storm,” says Hieftje. “It is, however, receiving lots of criticism.”

PerkinElmer’s proprietary Dynamic Reaction Cell (DRC) exemplifies the reaction cell approach. The DRC works with almost any gas, and users must decide which one is best for their needs. Hieftje says flexibility is the advantage of this type of cell: “It allows you to tailor the reaction to whatever problem you have.” But he warns that the multielement capability of ICPMS can be diminished if the reaction favors one analyte to the exclusion of others. Wolf says that although researchers could optimize conditions for each analyte and potential interference in a sample, most can find a compromise gas that works well for all the elements they want to monitor. Diane Beauchemin of Queen’s University (Canada) says that another

Table 3. Selected TOF ICPMS instruments.[1]

Product	Optimass 8000	Renaissance ICP-TOFMS
Company	GBC Scientific Equipment 48 New Templeton Rd. Hubbardston, MA 01452 www.gbcsci.com	LECO Corp. 3000 Lakeview Ave. St. Joseph, MI 49085 www.leco.com
Price (U.S.D.)	$225,000	INA
Stand alone or benchtop	Benchtop	Stand alone
TOF orientation	Orthogonal	Axial
Resolution	>2000 (m/z 238)	450 (m/z 208, 10% peak height, 10 ppb)
Abundance sensitivity		
High mass side	1×10^{-6}	1×10^{-6}
Precision (RSD)	<5%	<1% over 30 min; <3% over 3 h
Acquisition speed (spectra/s)	30,000	20,000
Linear dynamic range (orders of magnitude)	7	6
Type of detector	Discrete dynode multiplier	Discrete dynode electron multiplier
Chromatography interfaces	No	No
Special features	Well suited to water analyses and offers flexibility for transient signals; benchtop orthogonal acceleration TOF mass spectrometer; mass range 5–260 amu; automatic detector protection and user-selectable matrix elimination; 50 full mass spectra/s transient signal acquisition rate; Windows multitasking operating software	Simultaneous analysis of >100 isotopes, which enhances multielement determination of transient-based signals; the simultaneous nature of TOFMS also offers enhanced isotopic ratio precision without a sacrifice in the trace elemental analysis capabilities

[1]Some companies offer multiple instruments. Contact the vendors for their full product lines.

INA: information not available

disadvantage of this type of reaction system is that you don't always know which gas to add to the cell beforehand. Wolf notes that PerkinElmer offers its customers tables to help them determine the appropriate reaction gas for a large variety of analytes and sample types, as well as turnkey methods for specific applications.

A unique aspect of the PerkinElmer system is that the quadrupole in the cell is used as a second mass filter, not only as an ion guide. "The use of the quadrupole [in the reaction cell] as a mass filter can completely eliminate reaction byproducts," Wolf says.

Agilent's proprietary Octopole Reaction System is an example of a collision/reaction cell, which has both collision cell and reaction cell capabilities in one device. Because only two specific gases are used, the decision-making process is simplified. Helium, an inert gas, is used in the collision cell mode for every element, except selenium. The argon dimer interferes in the analysis of selenium, so hydrogen is used in a reaction mode in the cell.

New applications and beyond

Some companies now include LC and GC interfaces for their instruments, making it easier to use ICPMS for a wide range of applications, such as metal speciation and proteomics. "I'd say one of the biggest trends right now is the whole field of speciation," says Hieftje. "People are now very keenly aware of the fact that just knowing the metal concentration or the concentration of elements in a sample is not enough. We have to know what the oxidation state is and the other species with which they are associated." He says that the oxidation state of an element can determine its toxicity or bioavailability.

According to Potter, researchers in the speciation field typically couple GC or LC columns to ICPMS systems, and he is seeing a growing demand for instruments with the proper interfaces. Wolf says that the number of PerkinElmer users coupling HPLC systems to their ICPMS system is increasing as speciation enters the routine testing laboratory. "Coupling HPLC or IC to the ICPMS seems to be the preferred method as it has a wider applicability and does not require the precolumn derivatization of some GC-based separations," she says.

Proteomics using ICPMS is at an early stage, says Potter, but he predicts the field will grow over the next two to five years. With ICPMS instruments, researchers can measure trace metals and quantitate the amount of phosphorus in proteins.

There is room for improvement in the detector area of research, according to Rettberg. He says, "We have detectors we're happy with right now for what they can do, but an improvement in detectors will definitely open up some capabilities." Rettberg adds that the community is anxious to hear the details of a new multicollector detector under development by Hieftje, M. Bonner Denton at the University of Arizona, and David Koppenaal at the Pacific Northwest National Laboratory in a collaborative effort. Instead of detecting six to eight isotopes of one element, Hieftje says, "Here, the idea is to look at all the isotopes of all the elements at the same time."

Company representatives predict that although the TOF and sector systems will grow at a much slower pace, quadrupole ICPMS instruments are here to stay. "I don't see a real strong replacement for the quadrupoles in the next five years," says Potter.

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