conjunction with ion beam etching means that three-dimensional elemental analysis is available to an investigator. Two manufacturers (Physical Electronics Industries, Inc., Edina, Minnesota, and Varian Palo Alto Vacuum Division, Palo Alto, California) had displays on scanning AES systems at this year's Pittsburgh Conference, although neither was being shown for the first time.

Scanning AES systems can provide several kinds of information in addition to the elemental analysis and depth profiling provided by normal AES. Measurement of the electric current to the sample due to absorption of the electron beam (the specimen current) during scanning gives rise to an image like that from a conventional SEM, but with a lower spatial resolution. So-called Auger images indicate where on the surface a particular element exists and are obtained by setting the electron energy analyzer to accept only electrons with energies corresponding to that element while scanning the area of the surface being imaged. The relative concentration of a given element at different points along a line on the surface can be obtained by measuring the magnitude of the Auger peak for that element while scanning along the line.

Other manufacturers are following a different approach to scanning AES by adding an electron energy analyzer to a SEM in order to obtain a submicrometer spatial resolution. There is, however, a substantial difference between the two cases. Being surface specific, AES and the other surface spectroscopies are tremendously sensitive to surface contamination. Some researchers can recount cases where they found contaminants in their spectra that were traced to a colleague's experiment on the other side of the laboratory with a material sufficiently volatile that some atoms drifted across the room to the sample under investigation. Although they image the surface of an object, SEM's are not as critically sensitive to impurities in most cases and thus vacuums obtainable with oil diffusion pumps [only 10^{-4} to 10^{-5} pascal (1 pascal = 7.53×10^{-3} torr)] have been good enough.

Unfortunately, at 10^{-4} pascal up to a monolayer of adsorbed gas can form each second, so that hydrocarbons from the diffusion pump oil quickly cover a sample's surface. Thus, makers of SEM's have had to redesign their instruments to incorporate an ultrahigh vacuum of 10^{-8} pascal or better in order to carry out AES. Ultrahigh vacuum has also permitted the use of a field emission electron gun with a concomitant fivefold increase in the obtainable spatial resolution. At very small beam diameters, a field emission electron source can be 1000 times brighter than the traditional tungsten or lanthanum hexaboride hot filament source. Spatial resolution is not the only consideration. For example, as the beam diameter decreases, the number of electrons in the beam and hence the Auger signal also decreases, and it takes longer to analyze a given surface area without losing accuracy. And maintenance of an ultrahigh vacuum becomes more crucial than ever.

At the Pittsburgh Conference, Coates and Welter Instrument Corporation, Sunnyvale, California, Etec Corporation, Hayward, California, and VG Scientific Ltd., Sussex, England, all offered high-resolution scanning AES systems based on SEM's, with VG claiming a 500-

Pittsburgh Highlights

Small Companies Are Big Successes

It was hard to miss the splashy exhibits of the large instrument manufacturers at the Pittsburgh Conference. The Perkin-Elmer Corporation, for example, spread their display over 20 booths and a seminar room, and they sent 43 representatives to the conference. Nestled among displays of such giants were the one-booth displays, complete with hand-lettered black and white signs, of the small companies. Although unobtrusive, the small companies cannot be overlooked. They constitute a significant fraction of the exhibitors at the conference and, in most cases, offer products available from no other companies.

The task of founding a small company and attracting sufficient business to make the company profitable would seemingly be difficult in even the best economic times. Yet, according to Harold Sweeney of Koppers, Inc., of Monroeville, Pennsylvania, who helps each year to organize the Pittsburgh Conference, very few small companies go under and new ones are continually being formed. Most that exhibit one year and not the next fail to do so because they have been absorbed by large companies. Several small companies present at the conference last year, however, decided not to exhibit this year because they now have so much business they can fill no new orders.

Most founders of small companies start out by working for large companies, then get ideas for the development of unique products and strike out on their own. This means that small companies often turn out to be the source of new concepts in research instrumentation. For example, Laser Analytics, Inc., of Lexington, Massachusetts, makes the world's only infrared spectrometer with a laser light source—a development that gives their machine a spectral resolution at least two orders of magnitude better than that of instruments that use conventional sources of infrared light. Philip Goetz of the Pen Kem Company of Croton-on-Hudson, New York, points out that his 12-person company makes the first commercially available instrument for measuring zeta potentials. Although the company was incorporated only 4 years ago, they have already sold hundreds of instruments to customers in 16 countries.

Vincent Coates who, by himself, runs Nanometrics, Inc., of Chatsworth, California—a company that advertises the "world's first computerized microspectrophotometer and accessories"—has more experience than most in founding small companies. After working for a large company for 22 years, he and a partner started their own company. The company did very well and soon grew until it consisted of 75 people, whereupon Coates and his associate sold it to a large company and Coates founded Nanometrics. With this experience Coates has developed some theories to explain why small instrument companies are so often successful.

Coates attributes the ease with which small instrument companies become established to the fact that research instrumentation is one of the few areas in which a small company can develop a product just as well as a large company. Makers of most research instruments are not hindered by federal regulations, such as those that force pharmaceutical firms to employ extensive tests to demonstrate the safety and efficacy of their products. Nor must makers of research instruments produce large numbers of their product before they can become profitable, as must automobile manufacturers, for example. Thus research instrumentation remains an open field for a person with a good idea and small companies continue to proliferate.—G.B.K.

angstrom resolution in the scanning Auger mode. (The spatial resolution in the scanning AES mode is always poorer than in the SEM mode because the incorporation of the electron energy analyzer necessitates placing the sample farther from the aperture of the electron focusing optics.) The price of this fine a resolution, however, is high. Between $175,000 and $250,000 is charged by VG for their scanning Auger system, as opposed to a little more than $80,000 for the basic Varian apparatus.

Surface scientists working in fundamental research laboratories have known for years that no single surface analysis technique can completely characterize a surface. Hence, they have tended to build experimental apparatuses much in the way of a hi-fi enthusiast by assembling a system from components. Their ultrahigh vacuum systems often contain a half dozen or more ports, each of which can incorporate the necessary source and detector for a different spectroscopic technique. The advantage of such multipurpose vacuum systems is that many techniques can be used with full confidence that the sample surface will not have been contaminated in the time it takes to switch from one measurement tool to another. And the cost of a separate vacuum system for each technique is avoided.

As an example where combining techniques is useful, AES, which is easy to use for identifying elements present on a surface, yields information on chemical bonding only with much effort on the part of the researcher. Electron spectroscopy for chemical analysis (ESCA), which is also known as x-ray photoelectron spectroscopy (XPS), contains this information in a much more accessible form than does AES in most cases. X-rays incident on a solid surface knock out inner shell electrons from surface atoms. Those electrons close enough to the surface to escape without loss of energy are collected and the energy is analyzed just as in AES. But in ESCA, the kinetic energies of the photoelectrons depend on both the identity of the surface element and its chemical bonding state. Because x-rays do less damage to surfaces, ESCA can also be used on delicate materials, such as polymers, where AES is inappropriate.

But ESCA is not the general-purpose technique that AES is. Because ESCA peaks are often narrower than AES peaks, a more sophisticated energy analyzer is required than for AES. Partly for this reason and partly because of the higher cost of x-ray sources as compared to electron guns, ESCA apparatuses are usually more expensive. (DuPont Instruments, Wilmington, Delaware, however, exhibited an ESCA system designed for industrial quality control, the base price of which is about $55,000, comparable to a basic AES system.) Moreover, a highly skilled operator is needed for ESCA. Finally, because x-rays cannot easily be focused and moved around in the way electron beams can, ESCA cannot be used in a high spatial resolution, scanning mode.

Offered at the Pittsburgh Conference were versions of combined ESCA-AES spectrometers by AEI Scientific Apparatus Ltd., Manchester, England, GCA/McPherson Instrument, Physical Electronics Industries, Inc., and VG Scientific Instruments Ltd. The GCA/McPherson and VG spectrometers also include ultraviolet sources in addi-

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Lasers Finally Making It in Commercial Instruments

Lasers have found many uses in the laboratories of talented chemists who are able to construct their own instruments. Few commercial spectrometers, however, have been equipped with them— except for Raman spectrometers, where laser light sources are imperative for reasonable sensitivity. But this year instruments incorporating lasers were present in substantial numbers.

Not all the instruments use lasers as a light source for spectroscopy. Fourier transform infrared spectrometers displayed at the Pittsburgh Conference, for example, contain helium : neon or similar lasers as an internal reference standard for accuracy in wavelength determination. A laser microprobe displayed by Jarrell-Ash of Waltham, Massachusetts, employs laser energy from a xenon-pumped neodymium glass laser to vaporize very small (about 25 micrometers in diameter) portions of a sample for elemental analysis. The vaporized sample is excited to emission by an electrical discharge and the emission spectrum is analyzed in a conventional spectrograph. The $60,000 system requires no sample preparation, and the analysis is nondestructive.

A laser-illuminated instrument for measuring zeta potential—the effective negative charge on the surface of a colloidal particle—was exhibited by the Pen Kem Company of Croton-on-Hudson, New York. The instrument has a rotating prism used in conjunction with a microscope to measure the rate of migration of such particles in an electrophoresis cell. Use of a helium : neon laser in the $8500 Laser Zee Meter gives an order-of-magnitude increase in sensitivity, the company claims; the laser source also transmits less heat to the sample so that thermal convection is minimized. Spectrex Corporation of Redwood City, California, displayed a $6900 instrument in which a scanning helium : neon laser counts the number of particles in fluids. The instrument is unique in that the sample does not have to be pumped through a chamber or orifice for counting, as is the case with conventional particle counters.

Three other new instruments incorporate a laser as a light source for spectroscopy. Chromatix, Inc., of Mountain View, California, demonstrated a low-angle light scattering photometer based on a helium : neon laser. This application is similar to Raman spectroscopy in that measurement of scattered or reflected light requires a light source of very high intensity. The light source in the $19,500 instrument can be collimated into a very narrow beam, furthermore, to reduce light scattering by dust and air bubbles. Molectron Corporation of Sunnyvale, California, uses a nitrogen-pumped tunable dye laser in conjunction with a specially designed photometer to perform spectroscopy in the ultraviolet region (from 215 to 750 micrometers). The $12,000 instruments incorporating lasers were as easy to use as a conventional spectrometer, but gives an increase of 100,000-fold in average power from the light source.

The most technologically advanced instrument is an infrared spectrometer, produced by Laser Analytics, Inc., of Lexington, Massachusetts; it is the first commercial spectrometer to incorporate a tunable diode laser. Because of the laser, the $19,500 instrument provides a spectral resolution 10,000 times better than that of conventional infrared spectrometers.

Laser spectrometers are obviously still specialty instruments. But the growing number of such instruments is heartening to the many chemists who think that the laser is the instrument light source of the future.—T.H.M.