LIGHTS UP
Global LED market set to switch on

- Advances in stent manufacturing
- Tabletop SEMs
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- Microfactories
- ICOMM, SME conference previews
- Fab Update, About Tooling, Laser Points

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Micromilling webinar
With toolmakers around the world looking for new ways to revive their businesses, the fast-growing micromilling segment offers new potential opportunities for moldmakers to enter a lucrative market niche and differentiate themselves from lower-wage competitors. Of course, with sub-micron tolerances and tool tips that can hardly be seen by the naked eye, micromilling presents moldmakers with many challenges. To help moldmakers overcome some of these challenges, MICROmanufacturing teamed up with Cimatron Ltd., Novi, Mich., to present a Webinar titled, “Capitalizing on the Growing Demand for Micro Milling”.

Mask aligner system
A leading supplier of equipment and process solutions for the semiconductor industry, SUSS MicroTec Group, Garching, Germany, offers the MA200 Compact mask aligner system that is said to combine high resolution with high throughput and submicron precision. SUSS offers a video report providing an overview of its MA200 Compact mask aligner system.

World’s smallest electrically pumped laser
In just 18 months, several physicists at the Quantum Optoelectronics Group at ETH Zurich, a science and technology university in Zurich, Switzerland, developed the smallest electrically pumped laser, according to a university news report. The new microlaser is 30µm long and 8µm high, with a wavelength of 200µm. The centerpiece of the microlaser is an electric resonator, consisting of two semicircular capacitors connected via an inductor.
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ON THE COVER
Design by Tom Wright.
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Swarming robots—and other cool stuff

Robotics researchers have yet to develop a microscale R2-D2 or other type of droid popularized by the “Star Wars” series. And it’s unlikely they will any time soon. Why? Because of the herculean challenge of cramming all of R2-D2’s superhuman capabilities into a 3mm³ package.

This has led a growing number of researchers to turn their attention to developing microrobots that mimic insects—not people. They contend that hundreds or thousands of relatively simple robots, each performing a limited number of tasks and acting collectively, can accomplish much more than a highly sophisticated robot.

The idea for “swarm robotics,” not surprisingly, sprang from behavioral studies of ants, bees and other social insects. Similar to their six-legged counterparts, members of a robot swarm move and communicate with one another when tackling a job. A wireless transmission system facilitates communication.

Swarms could be used to assemble microscale systems, perform internal and external medical procedures, in search-and-rescue and surveillance operations, and for military and aerospace applications.

Pioneers in the study of swarm robotics include a consortium of European university researchers involved in a project called I-SWARM (Intelligent Small-World Autonomous Robots for Micro-manipulation). The group, launched in 2004 with funding from the European Commission, has devised a microrobot smaller than 4mm³. It incorporates a flexible printed circuit board and is powered by a solar cell. Three vibrating legs propel the robot while a fourth guides its movement.

Another early stakeholder is BAE Systems Inc. In 2008, the multinational corporation signed a $38 million agreement with the U.S. Army Research Laboratory to lead a micro-robot project aimed at improving “military situational awareness.” Prototypes have been developed, including a fly-like robot that weighs less than an ounce and has a 1.18” wingspan. Carbon joints allow its wings to beat 110 times per second.

Robotics is the subject of two pieces in this edition of MICROmanufacturing. One is our “Tech News” interview with a University of Maryland researcher studying ways to mass-fabricate microrobots. The second is an article on choosing a robotics system for micromanufacturing applications (“Miniature Movers”).

Other cool features in this issue:
- Overview of—and opportunities to be found in—the burgeoning LED market (“A Glowing Report”).
- Advancements in laser-machining technology that are improving stent production (“New Life”).
- Inspection devices that combine the best features of optical and conventional scanning electron microscopes (“Tabletop Inspection”).
- Challenges when moving from macro to micro molding (“Micro Shot”).
- How a small-hole expert produces 0.003”-dia. holes in the tips of vacuum tweezers (“Micromachining”).

Finally, be sure to check out our “Last Word” column, written by Dr. Jong-Kweon Park of the Korea Institute of Machinery & Materials. He discusses past and ongoing microfactory developments. Dr. Park doesn’t, however, speculate on whether these tabletop factories will be operated by teeming swarms of microrobots.

Enjoy the issue.
**Microrobotics: going mobile**

“Big” and “lumbering” are two words most people associate with robots. But that may change as a result of ongoing efforts to develop a new generation of robots that are mobile, nimble and microscaled.

In the field of microrobotics research, three areas are emerging. The first is mobile, autonomous microrobots, which are millimeter-sized robots with sufficient power and control to “jump” and “crawl.” These microrobots would offer numerous advantages because of their size and low power requirements. For example, they could be used to add mobility to sensors in large-scale sensor networks.

One big area of interest is mobile sensor platforms, said Sarah Bergbreiter, assistant professor in the Department of Mechanical Engineering and the Institute for Systems Research, University of Maryland. “For example, to enhance search-and-rescue operations, such as in an earthquake, you might sprinkle sensors carrying detectors over the rubble. They would move down into the rubble to sense if someone is alive.”

In addition, users may want sensors that can move to locations other than where they were first deployed, such as to fill gaps in an information network or relay data from hard-to-reach areas. “If you want to deploy a sensor network over a bridge, for example,” said Bergbreiter, “you could dump the sensors on a pylon and they would crawl up and set themselves in place.”

Another area that shows promise for microrobotics is medical systems. Examples of how they could be used include a remotely controlled drug-delivery system and a magnetic-based controller outside the body that manipulates and directs the movements of a device inside the body.

The third area is to develop microrobotic systems that interact, said Bergbreiter, a capability currently employed to manipulate carbon nanotubes. Such systems have been commercialized. Companies offer systems that fit inside a scanning electron microscope that allow movement of objects from outside the SEM.

“If you want to assemble a carbon nanotube in a particular fashion, you can use this manipulation system to move a small actuator inside the SEM and actually push around the nanotube,” said Bergbreiter.

As for the commercialization of the other research areas—mobile sensor platforms and medical devices—Bergbreiter is not aware of any commercially available microrobotic systems for medical applications. She estimates such a system is 5-plus years away.

And fully autonomous, mobile platforms, though available, are not ready for commercialization. “Small, mobile platforms still pose challenges [in terms of developing their] mechanisms,” Bergbreiter said. “There will be prototypes, certainly, within the next 5 years, but to get to the level where they can be manufactured on a large scale and be effective in a given environment will take 15-plus years.”

—Susan Woods, Contributing Editor

**Microwelding: photons vs. electrons**

When it comes to joining microcomponents for electronics, medical and other precision applications, two of the most commonly used processes are electron beam welding (EBW) and laser welding (LW).

According to Richard Trillwood, president of EBE Inc., Anaheim, Calif., the processes offer similar capabilities. Both are fast and noncontact, leave relatively small heat-affected zones (HAZs) and produce strong welds. But there are also significant differences between EBW and LW, he said.

“Below about 400w, both processes produce similar welds in many applications,” explained Trillwood, who has more than 40 years’ experience with EBW. “Beam definition and tooling arrangements are similar. The biggest differences are the vacuum needed for EB microwelding and the relative difficulty of using lasers to join materials that have high reflectivity or thermal conductivity.”

EBW is performed in a vacuum to prevent beam dispersion and eliminate weld oxidation. Trillwood, who
founded EBE in 1991, noted that typical microapplications include joining of medical, semiconductor and electronic components. LW relies on a shielding gas, usually argon, to protect welds from oxidation. According to Trillwood, it is often used for light-duty, high-volume applications, such as continuous-seam welding of hypodermic tubes for the medical industry.

With no vacuum required, LW can sometimes offer faster cycle times and lower cost than EBW, Trillwood said. But, he added, modern vacuum systems, properly designed fixtures and faster EBW speeds can minimize throughput and cost differences between the two processes.

“For small parts, the pump-down time needed for EBW can be amortized over each component,” Trillwood explained. “For a fixture with 100 small components and a chamber evacuation time of 45 seconds, the time difference between EB and laser [welding] processes becomes insignificant.”

EBE provides contract EBW and LW services, and manufactures equipment for those operations. The company’s turnkey welding systems include the Beamer line of EBW machines. Available with chambers 12”, 18”, 24” and 36” on a side, the units can weld materials down to 0.001” thick and offer 2-, 3- and 4-axis CNC work manipulation. Users can select various options, including chamber-extension tubes, wire-feed capability and shuttle systems for high-production operation.

For more information, contact EBE Inc. at (714) 491-5990 or visit www.ebeinc.com.

—Jim Destefani, Freelance Writer

**Enduring nanopower**

U.S. Photonics Inc., Springfield, Mo., is developing a lithium-ion, high-density nanobattery composed of microscopic cells that extend battery life and reduce recharging time. The Endure nanobattery utilizes arrays of individual nanosized cell containers.

“That is unique,” said Jake Conner, company president.

The other distinguishing feature is its ability to be formed or rolled into a prismatic cell. This could be used to produce flexible flat batteries that can be form-fit.

The company has a prototype and plans to release “engineering tool kits” for testing within 6 to 9 months. During the next year, it will produce limited-run, specialty-application batteries. Long-term plans include selling the technology license to a battery-manufacturing company.

The nanobattery can be configured and connected to scale the power
output, allowing for a limitless-capacity battery or a programmable voltage. The nanobattery also provides a virtually instantaneous recharge. Battery cells can be wired together in parallel, creating instant-charging capability.

Through the isolation of each cell, the nanobattery ensures continued reliability, according to the company. “The anodes are connected in rows, and the cathodes are connected in columns, so any of the individual cells in the array can be charged and discharged (independently),” Conner said. “If a group of cells is damaged, the entire battery (will not) fail.”

U.S. Photonics uses femtosecond laser machining to make the micro-size cell containers. The company developed a mask/imaging technique to deliver femtosecond laser energy to the Kapton separator/cell containers that ablates the unwanted Kapton without leaving char, ash or a heat-affected zone.

“This process is rapid and allows for the creation of millions of individual cells in minutes. The accuracy allows good registration of the cells with the respective anode and cathode layers,” Conner said.

—S. Woods
Drilling microholes requires expert approach

Drilling a 0.003" hole is no small task. Virtual Industries Inc., a manufacturer of vacuum systems, discovered this when it needed vacuum tweezer tips capable of handling parts as small as 100μm. Based on experience with larger tips, the Colorado Springs, Colo.-based company knew local machine shops would no-bid such a small tip, so it turned to its subsidiary, Prime Axis Manufacturing LLC, also in Colorado Springs. In the following, the author explains, step by step, how Prime Axis solved the problem.—Ed.

To produce vacuum tweezer tips, we not only needed 0.003"-dia. carbide microdrills, which only a limited number of toolmakers produce, but also ones with a 0.040" flute length. The toolmaker we were buying from, however, stopped offering drills that size as a standard item and required a minimum order of 100 drills to produce them as specials. That meant spending about $7,000 on drills at the time, which we didn't want to do.

Fortunately, Harvey Tool Co. LLC, Rowley, Mass., began offering 0.003"-dia. drill bits with the appropriate flute length as an off-the-shelf item, so we used those. The drills are uncoated.

Material selection

We considered several different materials for the tip—brass, Torlon plastic and electrostatic-dissipative (ESD) Delrin plastic—and evaluated their characteristics to select the one that would satisfy Virtual Industries’ customer base.

We determined the fibers used in the fabrication of Torlon tended to redirect the 0.003"-dia. drill bit, causing tool breakage, which eliminated that choice. Brass is easy to machine but might physically damage the delicate parts a tweezer tip handles, so it was also eliminated.

The ESD Delrin seemed like the logical choice. It has a surface resistivity of $10^8$ to $10^{10}$ ohms and bleeds off any buildup of electrostatic charge. That is a concern when handling microparts, because it only takes a few electron volts to cause a part to stick to the tip and not release. In addition, an electrostatic charge can damage electrical and microcircuitry components. Delrin is also soft, so it will not physically damage parts.

Although we knew the material’s characteristics were appropriate, we experienced a problem with tool breakage because the center of the ESD Delrin bar stock—where the hole is drilled—has a lot of porosity as a result of how it’s produced. Every few parts the drill would hit a small pore, which would cause the tool to break. After spending time adjusting the feeds and still breaking several hundred dollars worth of drills, I located a supplier for Delrin with much lower porosity and overcame the problem.
Process selection
Several ways exist to manufacture these small tips, which have a ±0.0005" tolerance. One method is to turn the larger features, which include a 0.060" OD that tapers at about 20° along a ¾" length to an 0.008" OD at the tip, on a CNC lathe and drill the 0.003" hole at the tip and a connecting 0.020" hole at the back of the part as secondary operations on a CNC mill. The smaller hole can’t be drilled on the lathe because it has a maximum spindle speed of 5,000 rpm, which isn’t fast enough to achieve a suitable surface footage for the tiny tool. Although this method worked, it requires a part to be set up and run on two separate machines. This drove up the manufacturing cost.

The second method is to use a CNC Swiss-style machine with optional live tooling. This arrangement is advantageous because the part turns at 7,500 rpm while the drill also turns at 7,500 rpm in the opposite direction. Countering the part against the drill bit produces an equivalent drill speed of 15,000 rpm.

Spinning the drill bit helps eliminate the drill drifting off center because the faster something is spun, the more likely it is to stay centered. The high speed also prevents burr formation when drilling a 0.003” hole into plastic. In addition, the higher spindle speed reduces breakage of the $55 drills.

Feeding at the appropriate rate also eliminates burr formation. If the feed is too high, the drill pushes the material too aggressively and causes burrs to form. A high feed also generates thick chips, which can clog the flutes and cause a drill to snap. On the other hand, too low a feed rate causes the drill to rub rather than cut the workpiece. A feed of 0.0005 ipr proved to be a happy medium. Pecking is required to control chip length and prevent flute loading. The pecking depth is 0.004” for about half the 0.049”-deep hole. The tool is then retracted every 0.003” for the remainder of the hole.

Other considerations
When drilling a 0.003” hole, applying fluid to cool the part and aid chip removal must be balanced against distorting the true position of the drill bit. At the higher spindle speeds, it is critical to keep the tool cool. Instead of coolant, however, we use a cool-air unit to maintain the required temperature and help remove chips so the bit does not melt its way through the part.

Chip control is also critical so the flutes do not become clogged with plastic chips and tear at the ID, making it larger than the drill bit. We keep the cool-air unit about 2” to 3” from the tool/workpiece interface to prevent the high-pressure air from breaking the drill.

Typically, the supplier provides extruded plastic rods ground to a ±0.0005” tolerance. Grinding the OD to this tolerance ensures the process is repeatable. To prevent having to adjust the Swiss-style machine’s guide bushing—which supports the material during machining—we create two groups of bars: those up to 0.5005” and ones as small as 0.4995”. Having two groups of bars at opposite ends of the tolerance range prevents having to adjust the guide bushing after machining each rod, which lessens the chance of making inaccurate parts or galling them. If the guide bushing is adjusted too loose, we cannot make accurate parts, and if the guide bushing is too tight, the material can gall and get stuck in the bushing.

We produce about 700 parts in each run. We manufacture a complete part in roughly 50 seconds, including turning, profiling and drilling.

About the author: Patrick Lemos is part owner of Prime Axis Manufacturing LLC, Colorado Springs, Colo., and has more than 20 years of experience manufacturing small to medium-size parts. Telephone: (719) 572-0577. Web: fwww.primeaxismfg.com.
Solving Z-axis challenges during stereolithography processes

The increasing miniaturization of products and devices requires designers to iterate their designs at ever-smaller scales to arrive at a final design. Unfortunately, they often find themselves hamstrung by the lack of prototyping tools that traditionally have helped drive their iterations.

The latest 3-D printing technologies were not designed to operate at meso- to micro-scales, and even the venerable stereolithography (SL) technology is stretched to its limits. Those involved in SL—suppliers and users alike—continually work to improve the process, equipment and materials. At FineLine Prototyping, we have addressed certain X-, Y- and Z-axis limitations associated with the process: X and Y in the imaging plane of the equipment, and the Z-axis for building up layers to form the parts.

This article addresses Z-axis challenges and the means employed to overcome them to ensure the production of accurate meso- and micro-scale parts.

Understanding Z-axis layers

FineLine’s high-resolution SL process features 0.002”-thick layers. A part is built from the bottom up by stacking layers one on top of the other to form a 3-D part to the specified height. This might lead one to assume that if a part has features at least one layer thick, they should come out accurately in the final part. Unfortunately, given how the process and materials work, this usually is not possible. The first layer of any feature, whether it is on the bottom of the part or it forms a “shelf” higher up somewhere, will cure down into the liquid resin by several layers—sometimes as much as 0.016”.

Several combined factors contribute to this “thick first layer” effect, commonly known as overcure. In a nutshell, it is the result of the:

- cure kinetics of the photopolymer

Dead-flat leveling of the resin does not occur. There are always areas that are shallower and deeper.
process;
- need for process latitude; and
- development of material properties
  through energy exposure.

Let’s look briefly at each.

Cure kinetics: Any photopolymer
used in an SL process requires a certain
amount of energy to initiate the cure
that turns the liquid into a solid. This is
called critical energy, or Ec. The resin
will not form a solid until it absorbs suf-
ficient laser-light energy to reach Ec.

Also associated with Ec is depth of
penetration, or Dp. This property of the
material indicates how deeply the resin
will cure when the surface reaches the
Ec level. Most materials on the mar-
ket today have a Dp of 0.004” to 0.007”.
This means we need to cure down more
than a single layer (0.002”) in order to
make a solid part.

Process latitude: The need to have a
reliable production process for making
parts leads to further increases in the
cure depth of the Z-axis. This need af-
fecteds cure depth two ways.

1. If we establish the process such
that we apply sufficient energy to cure
the resin, then we are left with no tol-
erance for process drift. Imagine if the
laser’s power drifts just a tad out of cali-
bration, or a batch of resin has a slightly
higher Ec than the specified value or the
temperature drifts a bit. These things
happen in real processes, and when op-
erating right at the edge, a build occa-
sionally fails.

2. During the process of building a
part, a recoat step occurs in which fresh
resin is spread on the previous layer and
a recoating arm passes over it. Dead-
flat leveling of the resin does not occur.
There are always areas that are shall-
ower and deeper. If the minimal depth
of cure is shallower than the deepest
area, the layer being processed won’t
adhere to the one below it. The result
will be delamination—a fancy word for
a failed build.

Development of material properties:
Many materials will not exhibit the me-
chanical properties they were designed
to unless they have been exposed to
a specified amount of energy. SL res-
ins need to absorb the correct amount
of light in order to achieve the desired
stiffness, strength, hardness and tem-
perature resistance.

The first layer will measure anywhere
from 0.0055” to 0.016” thick, depending
on the material. Does this mean a part
will always be too tall by this amount?
No. To counter overcure, we carefully
deploy a tool called Z-axis compensa-
tion, or Zcomp.

Applying Zcomp

To understand Zcomp more clearly,
imagine building a small part com-
prised of eight layers. Each layer is
0.004” thick, for a total height of 0.032”.
The dotted line in Figure 1 describes
the profile we want to accurately image
with the part layers. As layers are added
during the build process, the part can
become too tall because of the overcure
required for SL to function correctly
(Figure 2).

As can be seen, the material cured
down more than the desired one-layer
thickness of 0.004” on the first layer
(green sections). Notice, too, the excess
material on the three-layer shelf on the
continued on page 49
Fiducials: how to be where you need to be

When running a job on a laser—or any other tool—it is frequently required that the processing toolpath be aligned to existing features. Generally, the sharper and smaller the alignment feature the more accurate the alignment.

A camera- or optical-based vision system usually is used. The alignment process can be performed manually or automatically. Accuracies on the order of microns are possible with systems that incorporate high-resolution motion stages and cameras, and crisp fiducials.

A fiducial, or fiduciary marker, is an object in an imaging system’s field of view that appears in the image produced and serves as a point of reference or a measure. One fiducial is usually designated “primary” and is used to adjust the X/Y offset. Secondary fiducials are used for other operations. Fiducials are not all the same, requiring operators or automated vision systems to take these differences into account. Figure 1 shows several common markers.

Some general characteristics of fiducials are:

**Shape.** Choosing an optimal fiducial mark for a specific application depends on the requirement. For instance, the crosshair-shape that is easy for a human to employ may not be appropriate for a machine vision approach capable of edge detection. Some fiducials contain a combination of features, which allows the same unit to work well with different detection methods. For example, the bow-tie shape has two rounded edges on the outside to generate a circle, as well as a crosshair in the middle for manual alignment.

**Size.** Smaller and crisper fiducials provide better alignment. Minimum diameter is determined by the optical system and the resolution of the motion hardware. Maximum size is determined by the field of view of the imaging system. Fiducial marks located on the same part should not vary in size by more than a few percentage points.

**Clearance.** A clear area, devoid of any other circuit features or markings, should be maintained around the fiducial mark. The size of the clear area should be, minimally, equal to the radius of the fiducial mark. When possible, the amount of clearance around the mark should equal the mark’s diameter.

**Edge Clearance.** A fiducial mark should be located no closer to the edge than 7.62mm (0.300”), per Surface Mount Equipment Manufacturers Association Standard Transport Clearance.

**Material.** The material will be dictated by the part, but etched metals, organics and raw ceramics are common. The main points are mark resolution, permanence and contrast.

**Contrast.** Most machine vision recognition systems perform best when a consistent high contrast is present between the fiducial mark and the base material.

**Flatness.** The flatness of the fiducial surface should be 15μm (0.0006”) or flatter.

To illustrate how fiducials are used, consider a simple 2-D printed circuit board (Figure 2). The number of alignment points...
defined in the toolpath determines the accuracy level to which a PCB panel can be aligned. The global alignment features should be placed as far apart as possible for the best results and, in all cases, should be sited outside the laser processing area.

If specific panel components require high processing accuracy, it may be best to use more local fiducials. However, this also increases cycle time, as there are more alignments per panel.

One of four possible levels of alignment could be used. One-point alignment corrects an X/Y off set between an alignment point on the panel and the reference point in the file.

Two-point alignment corrects panel rotation and X/Y offset. The X/Y offset is calculated using an average of the offsets of the two aligned points. The angular correction is derived from the offset angle of the two aligned points.

Three-point alignment corrects for X scaling and Y scaling (stretch and shrink) in each axis. The average offset of the three points is used to derive the X/Y offset. The angular offset is calculated separately in each axis and is, effectively, an orthogonality (skew) correction. Four-point alignment corrects for X and Y linear scaling (keyhole scaling), in addition to what three-point alignment corrects for. It accounts for both X as a linear function of Y and Y as a linear function of X.

For products that tend to distort during the manufacturing process, such as PCBs, three- or four-point alignment is commonly needed. For stable, rigid products made from metals, silicon, glass and ceramics, one- or two-point alignment generally suffices.

For a manual-alignment procedure, continued on page 45

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 Someone challenged us to a little game of chess.
(We chose 1:48 scale.)

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A Blum laser tool setter mounted on a Microlution 5100-S machine tool.

Obviously, the old trick of pinching a piece of paper between the tool and workpiece is not effective in the microworld. These small, fragile tools are difficult to view, even with an optical microscope. As a result, new measurement strategies are required. A combination of workpiece probing and tool setting can provide an effective approach to achieving precise registration.

Applying tool setters
A way to optimize precision in micromachining is to apply tool setters that allow on-machine tool location and size measurement. However, not all tool setters are useful for microapplications.

The challenges of using tool setters in micromachining must be understood within the context of spindle speed requirements. It’s typical to use pressurized air-bearing spindles that operate at speeds from 60,000 to 250,000 rpm. These spindles can produce high error motions due to their relatively low stiffness. Hybrid ball bearing spindles have a stiffness of around 60 newton/μm, while high-speed air bearing spindles can have a stiffness as low as 1 newton/μm. These conditions, combined with misalignment of the tool in the collet, can produce tool runouts from 1μm to 10μm, and these values can vary with spindle speed and tool changes. Measuring the tool diameter at zero speed will not provide useful calibration information. Ideally, the spindle should be operating at full speed during measurement and should not stop before engaging the workpiece.

To address this issue, several companies have introduced noncontact, high-resolution laser tool setters for micromanufacturing (see photo, left). These tool setters can measure with the spindle operating at up to 150,000 rpm. Integral air jets on some tool setters keep cutting tools clean. This can be vital for measurement because chips and dirt particles can be nearly as large as the tool itself. Solvents such as isopropyl alcohol or acetone, combined with an air blast, can effectively remove fluids and particles.

One disadvantage of laser tool setters is they only detect tool diameter and position in one direction. Typically, the tool setter is oriented to measure in a direction that is planar with the structural loop of the machine tool (typically the Y-axis). Due to thermal variations, this direction experiences more displacement, for which the tool setter must compensate.

The entire perimeter of a tool is used during milling, and measuring tool runout in all directions is important. It is a misnomer that once tool runout is measured in one direction it is the same in all directions. This is the case for collet-placement errors, but not spindle rotation errors. Spindles can scribe a multilobed profile as they rotate, and this...
profile can vary with speed, balance and bearing properties. In micromachining applications, it is advantageous to measure tool runout using multiple tool setter configurations, each oriented to a machine axis.

Plan ahead

Workpiece probing for micromanufacturing applications can be a challenge, but careful planning can prevent headaches later in the process. A touch probe placed on a machine axis or in the spindle can register workpiece datums, as in macromachining. Touch probes are commercially available that achieve the precision required for micromachining.

Relying on micromachined features for datum references is not ideal because typical touch probes are a few millimeters in diameter and the probing forces are several newtons. Preparing accurate reference datums on the workpiece in advance can help calibrate workpiece position. These datums may be ground holes or squarely machined edges.

Standard 3-axis machine configurations can create a measurement challenge. The datum references on workpieces generally register a Cartesian reference frame. It is ideal to align the axes of the machine tool to the axes of the workpiece reference frame. In the absence of a rotary stage, the workpiece needs to be “tapped” into alignment with a semirigid tool, such as the handle of a screwdriver. After alignment, the workpiece must be carefully fixed in place with screws or adhesive.

Given the angular precision required for microfeature alignment, this can be a tedious process. Software can be used in the alignment process, but any machine tool inaccuracies will reduce part precision. If the workpiece is mounted to a rotary stage, however, the touch probe can determine the misalignment and adjust the workpiece using the stage.

Pallet systems also can alleviate some of the burden of workpiece alignment. For example, products from System 3R USA Inc., Elk Grove Village, Ill., and Erowa Technology Inc., Arlington Heights, Ill., are available for micromanufacturing (see photo on page 19). For delicate, ultra-precision tooling, our shop uses in-house palletization systems to achieve precision and accuracies below 0.5μm.

Placing the workpieces on pallets and orienting the reference frame to the pallet-locating elements eliminates the need to calibrate each workpiece. In our operation, the pallets are placed on chucks, which are then mounted to the worktable. Subsequent pallet placement will repeat the first pallet’s alignment, assuming the pallet-locating features and reference frame are aligned.

System 3R and Erowa offer calibration targets for defining a standard reference frame. Calibration is required once per machine tool, and the alignment is good for the life of the chuck.

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As a result, aligning a workpiece on a 3-axis machine requires just one tedious operation.

Relational measurement

After determining the position of the tool with respect to the tool setter and the position of the workpiece in relation to the workpiece probe, the position of the tool setter with respect to the workpiece probe must be determined. This will close the measurement loop and provide the position of the tool with respect to the workpiece (see diagram on page 17).

The simplest approach is to measure the spherical probe directly with the tool setter. Shining a laser beam at a ruby sphere, which most touch probes incorporate, results in accuracy errors because the ruby is transparent. This results from the light beam continuing to the sensor even when the probe is in the path. Probe manufacturers offer alternative, nontransparent probe materials, such as alumina and carbide, which can avert this problem.

As the tool is traversed from the tool setter to the workpiece, errors accumulate due to geometry and encoder accuracy. The same situation occurs as the workpiece probe is moved from the tool setter to the workpiece. While both of these displacements may be precise, or repeatable, the positional accuracy can vary by several microns.

This accuracy problem can be minimized by placing the machine probe as close to the cutting tool as possible and by placing the tool setter as close to the workpiece as possible. In many instances, machine tool probes can be placed directly in the spindle taper and be operated via infrared or radio signals. This allows wireless communication, which, in turn, permits probe mounting with regular tool changes.

Unfortunately, machine tool probes are not available for the small tapers in many high-speed micromachine spindles. Mounting the probe near the spindle on the machine tool stage, however, can be adequate for most applications, and help compensate for errors.

As micromachinists attempt to effectively apply smaller microtools, these tools must be in registration with the workpiece. Employing measurement strategies designed specifically for micromachining can go a long way toward reaching this goal.

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A Glowing Report

Fast-growing optoelectronics market offers opportunities

By Dennis Spaeth, Electronic Media Editor

Where there’s $1.1 trillion, there’s bound to be stiff competition. So it goes for the global electronics market.

Competition is all the more fierce in the U.S. for microelectronics, considering that nearly all semiconductor products have to go through Asia for at least part of the manufacturing process. Yet there are domestic opportunities for U.S. micromanufacturers willing to compete for a portion of two emerging optoelectronic markets—light-emitting diodes and optical-network laser transmitters. As several of the analysts contacted for this report agreed, the LED market in particular looks quite bright.

Just how much manufacturing for those markets will remain in the U.S. is uncertain, but this much is clear: LEDs are the fastest-growing segment of the microelectronics market.

LED market could top $6 billion

To understand just how strong the outlook for LEDs is, Rob Lineback, a senior market research analyst with IC Insights Inc., Scottsdale, Ariz., offered some perspective on the broader microelectronic market, which—for the purposes of this article—is synonymous with the semiconductor market.

“The four legs to the table for the semiconductor industry,” noted Lineback, “are integrated circuits (IC), optoelectronics, sensors and actuators, and discrete components. When you say microelectronics, most people probably think of integrated circuits because of the microprocessors and controllers, but all of this could be considered microelectronics. These are all semiconductors.”

Overall, the semiconductor industry generated sales of $235.4 billion in 2009. As the major segment, IC sales accounted for about 84 percent of that total.

The other three segments combined accounted for about $38.6 billion in semiconductor sales last year. Though they represent a much smaller piece of the pie, these three areas are growing faster than ICs, Lineback said.

The discretes, such as transistors, totaled $15.2 billion in 2009, while the sensors and actuators market—which includes microelectromechanical devices—was credited with $5.1 billion, according to IC Insights research.

The remaining $18.3 billion went to the optoelectronics segment. Despite an overall 5 percent drop in sales for this segment from 2008 to 2009, the LED portion grew by 12 percent, to $5.7 billion, in 2009, Lineback said.

And 2010 promises a 19 percent growth rate for the LED market, bringing it to about $6.7 billion this year.

“There are a lot of people looking at the LED
“And, of course, the Holy Grail for LEDs is room lighting,” he continued. “That puts big dollar signs in everybody’s eyes.” Up and down the electronics food chain, from wafer fabrication equipment manufacturers to chip makers, everyone is looking hard at this category, Lineback noted.

IC companies are looking at what types of tools are needed, and whether they can apply their IC manufacturing technologies to the LED segment and other emerging optoelectronic markets.

This much is clear: LEDs are the fastest-growing segment of the microelectronics market.

Currently, the LED portion of optoelectronics is the second-largest segment of the category. Image sensors are the largest, accounting for $6.4 billion in revenue in 2009. However, analysts expect these two segments to switch places over the next 5 years.

The primary growth driver in the LED market is high-brightness (HB) LEDs. They are finding their way into thin monitors and televisions, providing back lighting for the displays. But the huge growth in this market will come when HB LEDs begin to break into room lighting.

“LEDs (are expected to) replace fluorescent lighting in offices,” said Lineback. Such lighting already is available commercially, though the cost is in the hundreds of dollars, compared to a few dollars for a fluorescent light or an incandescent bulb.

Opportunity knocks

This expected growth could be an opening for micromanufacturers. For a closer look at what the LED opportunities are for U.S. micromanufacturers, visit the Web site for the U.S. Department of Energy’s Solid-State Lighting program at www1.eere.energy.gov/buildings/ssl. Charged with advancing the development and market introduction of energy efficient white light sources for general illumination, the DOE site lists a number of R&D projects in progress at universities and private companies throughout the country.

For instance, the Georgia Institute of Technology is working on the epitaxial growth of gallium nitride (GaN) LED structures on sacrificial substrates, which could easily be removed from the GaN LED by using a wet chemical etchant.

Or take a look at the project being undertaken by Cree Inc., Durham, N.C. Building on its experience with thin-film LED products and packaged LEDs, Cree is working on photonic-crystal LEDs—specifically to improve light extraction efficiency compared to conventional LEDs.

Plus, a project undertaken by Philips Lumileds Lighting Co., San Jose, Calif., is focused on electrical injection efficiency and optical extraction efficiency improvement, high-power LED package design and reduction in package thermal resis-
Beyond R&D, meanwhile, there are other opportunities. On Feb. 24, for instance, the Satellite Beach, Fla.-based Lighting Science Group Corp., which develops, manufactures and markets LED lighting solutions, announced a nationwide marketing and supply agreement with Senergy USA LLC, a New York City company that supplies municipalities with environmentally friendly lighting solutions that offer cost savings.

The Lighting Science Group, which touts itself as a global leader in public infrastructure LED lighting products, will work with Senergy to use the Florida company’s PROLIFIC roadway lighting product to replace inefficient high-pressure sodium, cobra-head street lights.

"The combination of the Senergy solution and the Lighting Science PROLIFIC roadway luminaires is an excellent way to address the estimated 40 million street lights in the U.S. and contribute to the LED lighting revolution for roads, streets and highways," said Lighting Science CEO Zach Gibler.

At the moment, Senergy and Lighting Science are working on six pilot programs with more than 200,000 street lights nationwide. The pilot programs are showing energy consumption reductions of as much as 67 percent, while meeting or exceeding existing safety standards, according to Lighting Science.

With the Senergy program and the PROLIFIC light unit, a medium-sized municipality with 12,000 street lights could save more than $700,000 per year, cut its carbon footprint by nearly 3,500 metric tons and save nearly 5 million kilowatt hours a year.

"We’re sort of at this intersection right now," said Fred Maxik, chief scientific officer for Lighting Science Group. "Until the last 12 months, white LEDs were not really bright enough to get into all the application spaces. But as we’ve gotten

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**LEDs at a glance**

**THE ORIGINS OF LIGHT-EMITTING diodes (LEDs) can be traced back to 1907, when British inventor Henry J. Round with Marconi Labs first noticed the electroluminescence that resulted by running electricity through silicon carbide—a semiconductor.**

However, it wasn’t until 1962 that Nick Holonyak Jr., who then worked for General Electric, invented the first practical LED. And from that point on, the efficiency and output of LEDs have increased to the point today where they can replace incandescent light bulbs, fluorescent lights and the compact fluorescent light bulbs—both in terms of brightness and energy efficiency.

The only downside at the moment continues to be the cost of high-brightness LEDs compared to incandescent and fluorescent lighting. Think hundreds of dollars for a HB LED compared to a few dollars for an incandescent or fluorescent bulb.

As the manufacture of HB LEDs improves and usage increases, cost will become less of a factor. One reason for the high cost of HB LEDs is that part of the manufacturing process involves applying a thin film of gallium nitride via a chemical-vapor-deposition method of epitaxial growth onto sapphire wafers. The resulting GaN LED must be removed from the sapphire wafer and transferred to a heat sink for fabrication of the overall device.

—D. Spaeth

An LED consists of a chip of semiconducting material doped with impurities to create a p-n junction. As in other diodes, current flows easily from the p-side, or anode, to the n-side, or cathode, but not in the reverse direction. Charge-carriers—electrons and holes—flow into the junction from electrodes with different voltages. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon. LEDs are usually built on an n-type substrate, with an electrode attached to the p-type layer deposited on its surface. The wavelength of the light emitted, and therefore its color, depends on the band gap energy of the materials forming the p-n junction.
to this next level of LED brightness and efficiency, they are continually enabling the next application space."

As the adoption of HB LEDs as a lighting source picks up speed, added Maxik, there will be more opportunities for micromanufacturers to create value-added components in the HB LED lighting market, including lighting that incorporates other devices, such as sensors.

“There are a lot of areas where we could add value,” Maxik said, “and a small shop with the ability to deal with micromanufacturing has that possibility. We work with a couple of local companies on that basis, and a couple of non-local companies.

“And we do some of this work ourselves,” Maxik continued. “So from a sampling standpoint, we have our own abilities to do wire bond and die bond. Obviously, as soon as we get to [a sizable production] scale, we would outsource that piece.”

Given that the lighting market is fragmented, there is always opportunity within different segments. “And,” he added, “these niches are very desirable, particularly for a small shop. If you build the expertise to move into that niche, your expertise can run for generations.”

Another opportunity for micromanufacturers is in making molds for LED lenses and molding the lenses. In addition to traditional glass lenses, some moldmakers are using silicone to make optical-quality lenses for LEDs.

**Lasers and LEDs**

JP Sercel Associates Inc., a Manchester, N.H.-based laser systems company, has found a way into the LED market. One system offered by JPSA incorporates an excimer laser to separate GaN-based LED devices from their sapphire substrates, enabling the re-use of the sapphire substrate and, thereby, reducing overall fabrication costs. Another laser system enables JPSA customers to scribe the devices so they’re easy to singulate. (For more information on LEDs, see sidebar on page 22.)

Meanwhile, Cree Inc., Durham, N.C., is doing its part to render the incandescent light bulb obsolete by replacing it with LED lighting. Among the few companies to produce LEDs domestically, Cree highlighted its work at the Hyatt Regency Grand Cypress Resort in Orlando, Fla. The Hyatt recently completed a major renovation that included the replacement of traditional lighting fixtures with...
A Glowing Report continued

LEDs in its 54 hallways and 10,000-sq.-ft lobby, Cree reported. Projects like these are what will help the LED portion of the optoelectronics market overtake image sensors by 2014, according to IC Insights. The total image sensor market is projected to be about $11.7 billion in 2014, while the LED market is expected to reach $12.2 billion that year.

“Image sensors saw tremendous growth in the early part of last decade—from about 2000 to 2005,” Lineback recalled. “And a lot of it was driven by (first-time purchases of) camera phones and digital cameras. Now those have become replacement markets.”

Companies are searching for the next big growth application for image sensors. One possibility may be medical applications, including the use of swallowable camera pills to replace traditional X-rays, Lineback observed.

Automotive is another potential growth area for image sensors. These devices are expected to be used in safety applications, such as in devices that can scan for dangerous conditions down the road, alert the driver if the vehicle exceeds the speed limit and, possibly, make sure the driver isn’t drifting off to sleep.

Though the automotive segment has been less than 1 percent of the image sensor market, it will grow to 17 percent over the next 5 years, Lineback projected.

Laser diode comeback?

Of the three main drivers of the optoelectronics market—image sensors and LEDs being the two largest—laser diodes seem poised to make a major comeback, Lineback suggested.

In 2001, laser diodes had just begun to enter the market when the Internet bubble burst, damaging prospects for technology companies that supported fiber optics and laser transmission systems. That technology is used in devices such as DVD players, but the technology “has had a tough time for the past 9 years,” Lineback observed. However, there is renewed interest in the technology because of its role in increasing Internet transmission speeds.

Over the next 10 years, the optoelectronics segment of the semiconductor industry will get a major boost from industry giant Intel, which has announced its plans to use a laser transmission system to interconnect all of its chips inside PCs, according to Lineback.

Speaking at the 2010 Consumer Electronics Show in January, Intel CEO Paul Otellini said the company’s Light Peak technology, which can transmit data at up to 10 GB/sec., has the potential to replace all the cables connecting consumer electronic systems today, such as VGA, Ethernet and DVI. “There’s growing support for this across the industry,” Otellini said. Sony and Nokia both have announced their support, he noted, adding that “others are working on systems around it. You can expect PCs to have this technology about a year from now,” said Otellini.

Light Peak consists of a controller chip and an optical module that would be included in platforms supporting the technology. The optical module performs the conversion from electricity to light and vice versa, using miniature lasers and photo detectors, according to information on the Intel Web site. Intel will supply the controller chip, and it is working with other component manufacturers to deliver Light Peak components. The company expects the components to ship this year.

The optical fibers used in Light Peak are 125μm in diameter, while the vertical-cavity, surface emitting lasers are 250μm × 250μm.

“When you start replacing wire with fiber optics,” said Lineback, “that’s when optoelectronics becomes more of a mainstream technology and less of a niche technology.”

For the next 5 years, optoelectronics growth will be driven by HB LEDs, CMOS image sensors and optical-network laser transmitters—with the advent of optical interconnects providing another boost in revenue in the 10- to 15-year timeframe, according to Lineback.

So for this reason as well, many companies are looking for opportunities in the optoelectronics market. So far, Lineback added, Intel and a few other companies are working hard to put optoelectronics into silicon. Think camera cell phones.

“The hope is, one day, to replace the electron with light as much as you can, where it makes sense,” he said. For the near term, however, this portion of the optoelectronics market, which stood at $265 million in 2009 and is expected to... continued on page 45
The job shop sign says: “You want quick, cheap and top quality? Pick two.” Said less bluntly, every manufacturing operation involves compromises.

The handling and assembly of small parts is no exception. The most basic approach, moving the parts manually with human fingers and tweezers, requires minimal capital investment but produces slow and inconsistent results. Automating a process increases speed and consistency, but it also requires planning, choice and investment.

Choosing an automation method requires juggling the elements of the manufacturing speed-cost-quality equation. One approach to automation is custom designing and building a material handling system specific to the process at hand. These so-called “hard” automation arrangements can be engineered and fine-tuned to maximize efficiency. However, if the parts being handled change, or the process is updated, the dedicated tooling must be replaced.

According to Jay Hallberg, regional sales manager for Epson Robots, Carson, Calif., robotic technologies can be a productive alternative. If there is no variety and no expected engineering changes, hard automation is fine, he said. “But what you are doing is spending a lot of money for hard tooling. And if anything changes, so does a lot of tooling.”

A robotic automation system, however, can facilitate changes. “You are buying flexibility,” he said. “With a robot, it could be a matter of a 5-minute program change and it’s done.” And if a process is eliminated entirely, software and ancillary tooling changes can enable the robots to be redeployed.

According to Mike Cicco, director of material handling for Fanuc Robotics America Inc., Rochester Hills, Mich., a robot is a flexible tool. The robot comes with a programmable controller. After the program is written, the end user or a robotic-systems integrator can develop end-of-arm-tooling to grip the item to be moved, and write a custom code to make the robot move as desired.

Robot-programming software is generally proprietary to the robot maker, but actual programming methods are standard.
**Miniature Movers continued**

Robot programming is not complicated, according to Matt Lorig, product manager for Mitsubishi Electric Automation Inc., Vernon Hills, Ill. In most cases, it’s done by a method called “teaching.” A typical program might involve moving a number of items from point A to point B, with a stop for inspection in between. Using a control box called a teach pendant, the robot is moved to the required positions and those points are recorded in the program. “With lines of code, you then tell the robot how fast to go from point A to point B, if it’s got to be in a straight line, if it has to go around an obstacle or do different things to maximize acceleration,” said Lorig.

**Size doesn’t matter**

From a micromanufacturing standpoint, the size of the parts being handled usually doesn’t affect the programming process, according to Cicco. “The good thing is, whether you are programming a gigantic robot picking up a car or a small robot picking up a part of a cell phone, they’re programmed exactly the same.” He noted that robotic programming language is different than machine tool G code. “You can put in a G code and it tells the machine tool to move someplace. You do the same thing with a robot; there is a line of code to tell a robot to move to a certain point. But with robots there are a lot more things that happen besides moving the machine and turning a spindle on. When you grip or polish things, the code gets a lot more complex.”

To deal with that complexity, Fanuc and other robot builders have developed intelligent robotics technologies. “In assembly, we try to figure out how people use their eyes and their hands to put things together,” Cicco said. “We have given the robots a sense of touch with force sensing and a sense of sight with machine vision.”

Force sensing, Cicco noted, allows a robot to imitate human hands in the act of press-fitting two parts together. Like a human assembling parts, the sensors enable a robot to sense a misfit and “wiggle” the part in whatever direction required until it snaps into place.

In a vision-identification system, the camera looks for parts of a specific shape, size or color. Lorig said current smart-machine vision cameras gather and store the data regarding a part’s location and then pass it to the robot. The user defines a primary pick point in the workspace and the camera locates the part, for example, 2” east and 6” west of the primary pick point. The robot then moves to the primary pick point, after factoring in the offset, and picks up the part.

Choosing the best alternative from the wide variety of available robot styles and sizes involves “sort of a tree logic,” Hallberg said. “You look at reach and payload first. In micromanufacturing and assembly, the payloads are very light. Then reach becomes an issue: How much reach does you really need? We want to tailor that choice to the smallest robot with adequate reach, because the smaller the robot, the faster and more repeatable it is.”

Microscale repeatability is a key concern, according to Cicco. Most robot programming involves teaching the unit to move one way then return to a starting point. “When you start getting into micro, being able to get back to the same spot becomes really, really important,” he said. “If you can’t handle ±20 μm, it just doesn’t work.”

Lorig noted that repeatability and precision are two different things. While repeatability addresses consistency in returning to a certain spot, precision with regard to a robot, or any machine for that matter, varies with the makeup of the product itself, the tolerances and the thermal expansion. Accuracy and repeatability are associated; the more precise a robot is, the better its repeatability will be. However, he said, due to individual manufacturing variations, robot manufacturers generally don’t predict precision on a per-unit basis.

**Small SCARA**

As an example of a robot tailored for small-part applications, Hallberg cited Epson’s G1 selective compliant assembly robot arm (SCARA) robot. The 1-kg capacity G1 is available with either a 175mm or 225mm reach. With 120mm of Z-axis travel, 3-axis (X, Y and Z) and 4-axis (X, Y, Z and theta, or rotational) versions are available.

The 3-axis unit has applications in simple pick-and-place operations, but the 4-axis unit provides greater flexibility, according to Hallberg. A 3-axis unit, for example, can pick up a simple round part, such as a washer, and place it over a post. “But 5 years down the road, what if there is a nib or hash mark or some orientation feature on the part that needs to be rotated into a specific position for assembly? With a 3-axis you can’t do it,” he said. “For a slight difference in price, most people will buy a 4-axis.”

Hallberg said the robot’s movements are repeatable to ±5μm. An industry-standard test of a robot’s speed involves a pick-and-place sequence of 1” up, 12” over, 1” down and return; with a 0.5kg load, the G1 completes the cycle in 0.29

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Miniature Movers continued

seconds. Typical users of the machines include medical and electronics manufacturers and microinjection molders. A medical manufacturer, for example, might use the unit to assemble the small precision parts of a cardiac pacemaker.

Epson reports that the 225mm reach of the G1 robot can handle many applications that would require 250mm-reach versions of other SCARA robots. The reason, Hallberg explained, is because the relationship between the unit’s rotating joints is equalized, enabling the arms to tuck close to the base. The result is a wider working range than other SCARA robots of the same size. There is no dead spot in the middle close to the base, he said.

Five-joint rigidity

Like SCARA robots, the 4-axis RP-series microassembly robots from Mitsubishi Electric employ parallel rotating joints to produce X- and Y-axis travel in a horizontal plane, and a vertical Z-axis that also rotates, permitting 4th-axis movement. However, unlike the single, centrally jointed arms of SCARA robots, RP robots have two arms arranged in a five-joint closed link construction. The smallest version of the robot, the RPI-AH, has a work envelope of 150mm × 105mm and 30mm of Z-axis travel. It can handle a maximum payload of 1 kg and provides repeatability of ±5μm.

Typical applications for RP robots include semiconductor processes and assembly, small parts assembly and material processing, as well as small-scale sealing and trimming. According to Lorig, the design provides sufficient rigidity to enable cycle times in the area of 0.28 seconds for a 25mm × 100mm × 25mm pick-and-place test cycle.

Parallel Flexibility

Fanuc Robotics recently introduced its M-1iA parallel-link robot, which offers more flexibility than what SCARA-style robots typically provide, according to Cicco. Fanuc took the parallel-link robot technology used in other industries and added a 3-axis, articulated wrist to enable 3-D part movement.

The M-1iA robot has a load capacity of 0.5 kg and provides repeatability of ±20μm. The robot is available in a 4-axis version with a single-axis wrist and a 6-axis version with a 3-axis wrist. The 4-axis model is for simple assembly operations such as part picking for kitting; the single-axis wrist offers speeds up to 3,000 degrees/sec. The 6-axis design enables part feeding from the sides of a work zone, increasing the usable workspace.

The light weight of the parallel links enables the robot to move quickly. “There is not really any real mass at the end of the arms,” Cicco said. “All the motors and castings are contained above, like a puppet master.” Typical applications for the robot include microassembly, electronics manufacturing and electronics testing.

Choose your robot

Industrial robots vary widely in configuration and capacity, and each style has characteristics that make it the best choice for certain micromanufacturing applications.

Parallel-link robots: The end effector, or tool, is linked to the power source via parallel links, or beams, in a configuration reminiscent of hexapod machine tools or the motion systems of flight simulators. These robots are applied in assembly,
pharmaceutical production and food processing.

Fanuc’s Cicco said the first step in a typical micromanufacturing application of a parallel robot like the company’s M-1iA might involve using machine vision to find and identify tiny electrical components, such as resistors, capacitors and chips in storage bins. Then the robot would move the parts to appropriate locations on a circuit board, orient them correctly and, finally, insert their submillimeter-diameter connecting wires into the board. Cicco said the parallel robot’s approximately 10'-dia. work envelope, 500-g payload capacity, ±20 µm repeatability and 0.3 seconds for the 1"-12"-1" standard pick-and-place cycle make it suitable for high-speed assembly of very small parts.

Articulated robots: This style of robot resembles a human arm and is frequently used in painting, welding and material handling. The robot arm has at least three rotary links and often rotates on a base. They are the most flexible robots, but are generally somewhat slower than application-specific robots.

Cicco said an articulated robot can provide the same repeatability as a parallel robot, carry a larger payload and offer a larger work envelope. The difference is slightly lower speed; Fanuc’s LR Mate 200iC robot can cover a 24'-dia. radius around its base and handle a 5-kg load, while it performs the 1"-12"-1" test cycle in 0.7 seconds.

SCARA robots, like the G-1 from Epson (shown at left), have two parallel rotary joints that determine X and Y positioning, as well as a sliding shaft at the end of the arm that moves in the Z-axis. If the Z-axis rotates, it provides a 4th (or theta) axis of movement. SCARA robots are compact, fast and accurate, with somewhat less flexibility than articulated-arm robots, but cost less. The robot design provides rigidity in the Z-axis and some compliance in the X and Y axes, making them good candidates for certain assembly applications. The two-link arm creates a cylinder-shaped work envelope and enables the robot to reach into an area, giving it the capability to move parts into or out of a machine or container and work in confined spaces. SCARA robots generally have a smaller footprint than other robot styles.

Hallberg outlined a typical micromanufacturing application where an Epson G3 SCARA robot was guided with a vision system to find and pick up 0.100'-dia., 0.130'-long medical device components that were arrayed at random on an indexing conveyor. The parts featured a small ID projection, which had to be oriented for assembly. The robot passed the part over a second video camera to find the projection and used that information to rotate the part radially to fit the device. It was a “very small part with very little clearance,” Hallberg said.

Cartesian robots: These systems are comprised of linear slides that determine X, Y and Z movements and operate inside a rectilinear workspace. They may be called gantry robots when the horizontal slide is supported on both ends and can handle comparatively larger loads than SCARA robots. Cartesian robots are accurate and used in assembly, pick-and-place and dispensing operations. A typical dispensing situation, Hallberg said, was a DNA-testing process where the robot put micro droplets of fluid into 0.25'-dia. test tubes. The test tubes were presented to the robot on pallets in groups of 600. Because the application didn’t require movement of parts from one area to another, the Cartesian robot’s rectilinear work area, speed and accuracy made it the best choice.

Robotic integrator RobotWorx, Mentor, Ohio, says that among the important factors to consider when selecting a robot are the unit’s number of axes, working envelope, carrying capacity, speed and repeatability.

Epson’s Hallberg said that the single-digit repeatability of microassembly robots, coupled with the precision of machine vision systems, make mechanical issues—such as the dexterity of the grippers used to pick parts—the only factors limiting how small a part a robot can handle. Consequently, the combination of small size, proprietary shapes and varying levels of complexity can make automating micromanufacturing and assembly with robots a creative effort.

Hallberg said, “When you get into micro, there isn’t a lot of off-the-shelf material available. When things get really, really small, it’s really application-dependent.” He said it is probably best to work with a supplier that focuses on the assembly and handling of microparts.

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Micromolding is used to make parts that can be best measured in microns, as well as tiny features on larger parts. Though similar in some respects to molding at the macroscale, micromolding of plastics and silicone presents its own set of special challenges. Today, micromolders are meeting these challenges in a variety of ways, including improvements in molding equipment and processes.

Making the molds

As in conventional molding, a key to successful micromolding is mold construction. Because the features in micromolds generally are much smaller than those in normal molds, makers of micromolds must hold extremely tight tolerances. At Albright Technologies Inc., Leominster, Mass., a moldmaker and micromolder of silicone for medical applications, mold tolerances are generally 0.0001", according to David Comeau, CEO.

To create features, Albright uses microend-mills ranging from 0.003" to 0.005" in diameter. After a micromold is built, it must be polished to remove tool marks, which Comeau described as “big scratches” on the surface. This task can be difficult at the microscale, “where you might have to polish something that is 0.010” wide and 0.005” deep,” Comeau said.

At Albright, polishing of micromolds is a manual process in which paste containing fine diamond grits is rubbed against the mold surface using a small tool. While this process produces the desired results, it can be expensive and time-consuming. In addition, Comeau noted, those undertaking it must be careful not to polish away sharp edges that are needed to properly mold the microparts.
Machines for micromolding

In micromolding, material is injected into molds by machines with extremely compact injection units. One such machine, known as the Babyplast, injects material volumes as small as 4cm³. The purpose of the small injection unit is to reduce material residence time, during which plastics can degrade due to exposure to heat.

Some high-end engineered materials are more sensitive to heat than more common plastics, according to Tony Brusca, president of Alba Enterprises Inc., a machine distributor in Rancho Cucamonga, Calif., that sells the Babyplast.

In some cases, however, microparts require complex molds that are too large to fit into small machines like the Babyplast. Microparts “tend to be intricate,” said Paul Ziegenhorn, president of Matrix Tooling Inc./Matrix Plastic Products, a full-line injection molding company in Wood Dale, Ill. “So even though a part might be small, the mold might have to be [relatively] large to hold all the mechanical features, such as slides and lifters, needed to make the details on the part.”

Therefore, Ziegenhorn continued, “we run some very small parts on 22-ton, electric-injection molding machines. These machines have larger barrels, and you have a residence-time issue if you have an oversized barrel. So we have to manage the process to get the material through the barrel as quickly as we can before it starts to degrade.”

Occasionally, the result is material waste, which can be costly. “Some of the implantable products we mold are made of resins that cost well over $3,000 a pound. And if we produce any waste or scrap, it can’t be reused,” Ziegenhorn explained. “So we’re trying to balance the need of the customer—which is to spend the least amount possible on the resin—with the fact that a particular part requires a mold that is a certain size.”

Faster flow

Molded microparts tend to have thinner walls than their larger counterparts. In molding, thinner walls result in faster cooling and solidifying of the plastic.

Therefore, “the thinner the wall, the faster you have to fill the mold,” noted Carol Barry, a professor in the department of plastics engineering at the University of Massachusetts-Lowell. According to Barry, micromolds must be filled in no more than 0.2 seconds, compared to approximately 1 to 5 seconds taken to fill conventional molds.

Among other things, faster injection means higher pressures in micromolding machines. While a conventional machine might have a maximum injection pressure of approximately 20,000 to 25,000 psi, micromolding machines can go up to 35,000 psi, according to Barry. She added that these higher pressures make the machines more expensive to buy than conventional systems.

In addition to pressure, temperature can have a major impact on micromolding. In conventional molding, “you run (the mold) at the coldest temperatures you can get away with, because cooling is what dictates the cycle time,” Barry explained. In micromolding, however, higher mold temperatures can decrease material viscosity and, thereby, improve flow.

On the downside, those who crank up mold temperatures to improve material flow risk degrading the material. Types of degradation that can be caused by high mold temperatures include diminished mechanical properties and burned spots on parts, according to Ron Peterson, vice president of Micromold Inc., Riverside, Calif.

To prevent such unsatisfactory results, micromolders improve material flow by molding parts at the highest temperature that does not cause the plastic to degrade. Higher mold temperatures can be achieved by techniques such as infrared heating of the mold surface and blowing hot air on the mold, according to Barry.

But Barry also pointed out an important negative consequence of using such
Four types of micromolding

Micromolding can take a number of different forms. Here are four styles used to meet the needs of various industries that rely on microparts.

Insert molding. Thermoplastic is injected around discrete parts loaded into a mold. By reducing assembly and labor costs, insert molding can be a cost-effective alternative to conventional methods of joining parts together. It can also reduce the size and weight of parts by eliminating fasteners and connectors.

For insert micromolding, Alba Enterprises Inc. offers a vertical version of its Babyplast machine. “Some insert molding is done in horizontal machines, but vertical machines are preferable,” said Tony Brusca, the company’s president. In a vertical machine, the mold face is horizontal, so parts laid on the face remain in place. In a horizontal machine, however, the mold face is vertical, which means parts on the face must be held in place during molding.

According to Brusca, insert micromolding is like conventional insert molding except the parts are much smaller, with weights measured in tenths, hundredths and even thousandths of a gram. Applications for parts made using insert micromolding include electronic devices and medical implants.

Lead-frame molding. In this process, a continuous strip (commonly metal) is fed through the mold cavity and overmolded with plastic. The final products can be cut into individual pieces or rolled onto a reel for shipping.

Like insert molding, lead-frame molding can be challenging at the microscale, according to Aaron Johnson, marketing manager for Accumold LLC, a molding firm in Ankeny, Iowa. One important factor is the size of the gap that allows the lead to fit in the mold. If the area around the lead is too big, the part exits the mold with flash. If the area around the lead is too small, the part can be damaged or even crushed during the process. Sizing the gap is a “critical part of lead-frame molding and must be done with exactness,” Johnson said. “Doing it on a microscale, where everything is smaller, adds to the complexity.”

Lead-frame molding is done to protect delicate electronic components from moisture, handling and other threats. The finished parts are commonly used as connectors or packaging when leads need to be soldered to a circuit board or other electronic device, according to Johnson.

Two-shot molding. This in-mold assembly process can streamline manufacturing and allows tailoring of part performance using different materials, according to Carol Barry of the University of Massachusetts-Lowell.

To produce better microparts, Accumold has constructed its own two-shot micromolding machine. “We’re bringing the advantages of traditional two-shot molding into the micro arena,” Johnson said. Unlike two-shot machines for larger parts, he added, “our system was designed to focus on making

Micro Shot continued

techniques: The higher the mold temperature, the longer the cooling time. Therefore, micromolders can follow high-temperature filling with a relatively low cooling temperature to shorten cycle times. The cooling temperature in this case is “a standard mold temperature that would be used in conventional molding. But it’s much colder than what would be used for the filling stage,” Barry explained.

Take the best shot

Compared to conventional molding, precise shot control is more important at the microscale to ensure consistent parts. “If you’re molding a wastebasket, and the material volume you put in the mold is 5 percent more or less [than the correct amount], it’s not going to make any difference,” Albright’s Comeau said. “But when you’re making a small part, you need to put in the exact volume every time.”

One way to achieve precise shot volume is accurate positioning of the injection stroke. For this reason, the Babyplast machine includes a linear positioning system that controls the movement of the plunger, which pushes plastic into the mold.

Such plungers are key features of two-stage micromolding machines. In a conventional injection-molding machine, a screw rotates to melt the plastic and builds up a shot that is injected into the mold. If the screw has a relatively large diameter, a large amount of plastic builds up in front of the screw, making it difficult to tightly control shot size, Barry noted.

Two-stage injection units usually include a screw, which efficiently plastificates the material, and a plunger, which injects it. In micromolding, screws can go down to around 12mm to 14mm in diameter and still retain the necessary mechanical strength. But even this screw size delivers too much plastic to allow the most-precise shot control. The
A two-shot micropart molded in a continuous process. The clear material is a hard ABS and the white center ring material is a soft TPE. The single process reduces assembly costs.

microparts with multiple materials.” The system can offer cost savings in assembly and allow production of microparts that would be extremely difficult to make using conventional assembly techniques.

Another option for two-shot molding of microparts is the horizontal version of the Babyplast, which can be equipped with a second injection unit. The two-shot Babyplast can make two-material products, such as brush heads for cleaning between teeth or accessing small areas in electronics applications. “A hard plastic could give the part some strength, and that could be overmolded with a softer material for [improved] touch and feel or other needed properties,” Brusca said.

Materials and molds for micro-optical parts. Micromolding techniques also can produce very small optical parts, such as lenses for medical and telecommunications applications. Materials used for these parts include optically clear plastics such as polycarbonate, and translucent options, like amber-colored Ultem, according to Johnson. He also noted that making molds for micro-optical components can require special processes, such as diamond turning and micromilling. Diamond turning, a process wherein a lathe is fitted with a single-crystal-diamond tool, produces surfaces that appear highly polished even at extremely high magnification.

—W. Leventon

plunger, on the other hand, might have a diameter as small as 5mm, enhancing shot size control, according to Barry.

For the smallest shot sizes, micro-molders can use “plunger-plunger” injection units. They come with a plasticating plunger, which melts the plastic, and an injection plunger, which forces the plastic into the mold. On the downside, Barry pointed out that plungers don’t provide the most efficient plastication.

For better results in this area, Brusca said, the Babyplast machine includes a cylinder containing heated ball bearings to effectively break up plastic pellets fed into the cylinder. A piston pushes the plasticized material out of the cylinder so it can be injected by a second “shooting piston” measuring 10mm in diameter. The plastic also passes through a ball check valve that prevents backflow of the material, further improving shot control.
Altering the process

In addition to alterations in molds and machines, micromolding can be facilitated by process changes. For example, consider mold venting. In conventional molding, vents are cut in the side of the mold to remove air from the cavity region. This technique would fail, however, during micromolding because the mold fills so fast that there would not be enough time for all the air to escape through the vents. Therefore, air would be trapped and compressed in the cavity. This, Barry explained, can prevent plastic from filling out the cavity, or it can even burst into flame, burning small sections of parts in the mold.

One solution to microscale venting problems is to pull a vacuum in the mold before injection. “When we’re doing microscale features, that tends to give us much better edge definition,” Barry said.

Another critical part of the micromolding process is inspection. Even the tiniest flaws in molded microparts can be important, but spotting these flaws is difficult. “One of the biggest problems we have is that it’s just hard to see the parts,” Ziegenhorn said. Therefore, operators at Matrix inspect the parts as they are molded with microscopes and vision systems at the machines.

Microscopic inspection can help molders of microparts achieve repeatability. In cases like this, Albright uses the appearance of flash—excess molding material that penetrates into mold gaps—to set up repeatable processes. “An acceptable part doesn’t have any flash on it. So we can put a part under a microscope, see that we’ve got flash on it and then keep adjusting the machine until we eliminate the flash,” Comeau explained. “This allows us to set up [the process]. And once it’s running, unless the parameters change, the parts come out consistent.”

Flash can be caused by a failure in the process or the mold, according to Micromold’s Peterson. Because no deviation is allowed in his firm’s micromolding processes, Peterson and his colleagues focus on tooling when flash appears. “We blow parts up 240× and look them over completely for any signs of flash. It could just be sticking out a half a thousandth, but we’re going to go after it in the tooling,” he said. The reason for taking such pains over such a small amount of flash? “If it’s a brand-new tool and you have a little bit of flash when you’re starting up, it does not get better in time. It gets worse.”

By paying attention to such details on micromolds and micromolding machines, micromolders can effectively convert conventional molding techniques to fit their application-specific processes.

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Matrix Tooling/Matrix Plastic Parts uses 3-D stereoscopes at the press to view intricate part details. The stereoscope has the capability of sending 3-D images and live video feeds.
The coronary stent industry—the one-time medical device juggernaut that posted double-digit growth just 5 years ago, then swiftly dove into a double-digit tailspin—is making a comeback. After 2 years of near-stagnation due to concerns about safety and overuse, which have been addressed (see sidebar, page 38), the $1.8 billion stent market posted a 3 percent gain in 2009, said Venkat Rajan, medical devices manager at market research firm Frost & Sullivan, San Antonio.

While that’s positive news for stent manufacturers, significant challenges remain. And laser machining technology promises to play an increasingly key role in helping them meet those challenges.

Competition and innovation

In 2000, Cordis Corp., a Johnson & Johnson company based in Miami Lakes, Fla., and Boston Scientific Corp., Natick, Mass., were the sole suppliers of U.S. Food and Drug Administration-approved drug-eluting stents. (Ninety percent of stents sold are DES vs. 10 percent bare metal.) Today, the OEM competitive pool has doubled, with Abbott Vascular, a division of Abbott Laboratories, Abbott Park, Ill., and Medtronic Inc., Cleveland, bidding for a share of the profits with their FDA-cleared products. About 10 other companies are at work developing their own stents. Moreover, during the past 10 years, dozens of contract manufacturers have entered the industry.

To effectively compete in an increasingly crowded field, OEMs and contract manufacturers depend on continual technological innovation to lower costs, improve quality or both. According to Dan Capp, vice president of sales development for Laserage Technology Development Corp., Waukegan Ill., advances in laser stent-cutting technology in recent years have focused on laser workstation motion components, controllers (software) and the lasers themselves.

Built upon granite bases, laser workstations incorporate the laser, linear-motor motion systems, direct-drive rotary axes, laser control electronics, and CAD/CAM and control software. The stent-cutting operation starts with stainless steel, chrome-cobalt-alloy or Nitinol tubes with diameters ranging from 0.020” to 0.250” loaded...
**New Life continued**

into the workstation. As the software directs the intricate movements of the workpiece, the laser cuts the stent pattern into the tube material.

“I describe the traditional laser cutting process as basically melting the material and blowing it away with high-pressure assist gas, such as oxygen or an inert gas,” said Stefan Quandt, medical device sales manager for Rofin Sinar Inc., Santa Clara, Calif., which manufactures laser workstations. “Most stents today are cut with a 2-axis rotation of the tube. With 2-axis motion, your laser beam will always cut toward the center of the tube, which makes the profile of the stent strut look V-shaped. Three- and 4- axis motion also is available if, for example, you want the strut profile to be angled differently or for achieving true through-holes.”

Quandt added that stent makers often ask his company for advice on making the production process simpler, faster or more efficient. “Many of the improvements in laser workstations during recent years have been incremental,” he said. “However, system components and processes can be improved for specific stent products to optimize the manufacturing process for customers. For example, there are different ways to hold the stent tube in a bushing and guide it. For tube materials that show inconsistent tolerances in diameter, an advanced tube holder was developed. Also, users may substitute the standard tube guiding material in our bushings with other materials to reduce friction inside the bushing.”

**Precise motion control**

Since stent struts can be as small as 0.0025” in width, precise laser cutting is essential and depends on advanced motion control technology. For the past 40 years, Aerotech Inc., Pittsburgh, has been making motion control and positioning systems for governmental, research and industrial applications, including laser workstations. Ron Rekowski, Aerotech’s division manager of advanced automation, said the company has introduced two key developments in recent years. “One is the optimized mechanical structure,” he said. Traditionally, motion platforms were comprised of various
components—linear and rotary stages—bolted together.

“We looked at that platform a few years ago and found that a fundamental limitation on increasing processing speeds was the stiffness of the system,” said Rekowski. As a result, Aerotech incorporated into its VascuLathe laser motion machine an integrated linear-rotary design capable of providing throughput two to five times greater than component systems, while still providing micron-level dynamic tolerances.

“The stent struts could be on the order of 70μm wide, and they might have features with a radius of 20μm,” said Rekowski. “With features of this size, it is critical to track part geometry very precisely [because] overshooting into a corner can undercut a strut and reduce its yield strength.

Aerotech has also improved its motion control software, according to Rekowski. “We can allow customers to program one global feed rate for the part they’re running,” he said. “The controller automatically slows down when it comes across geometries with extremely small features.” For example, if the radii of a part’s diameter decrease, the program automatically decreases the feed rate and, in turn, increases it on long, straight sections of the stent. “Our software can now handle all that optimization directly; we remove that from the customer’s responsibility,” Rekowski said.

Laser innovations

Cleveland-based Norman Noble Inc’s unveiling last September of its UltraLight athermal laser—capable of machining metals and polymers without risk of producing heat-affected zones or burns—provided the latest example of evolving laser machining technology. News of UltraLight arrived as the stent industry was largely migrating from YAG lasers to the more-precise fiber lasers.

“When stent manufacturing started more than 10 years ago, the standard tool was the lamp-pumped Neodum YAG laser with a wavelength of 1,064nm,” said Rofin Sinar’s Quandt. “But during the past few years, users have been adopting the fiber laser as the standard laser due to its high beam quality and higher frequency. Cutting speeds up to twice as fast [as the previous technology] are achieved, resulting in higher throughput. Also, finer cuts can be achieved—for example, a 0.0006” cut width in materials with 100μm-wall thickness. In the coronary stent field, the 20μm to 25μm cut was standard with the lamp-pumped YAGs, but with the fiber laser, it’s possible to cut a similar stent with a narrower cut width.”

Compared to YAGs, fiber lasers are up to 30 percent more energy-efficient. Also, fiber lasers typically require new lamps every 50,000 hours compared to every 500 hours for YAGs, so their maintenance needs are lower.

As with YAG lasers, standard fiber lasers also produce a heat-affected zone (HAZ) on stents. “There are ways to limit the laser heat input into the materials; for example, when pulsing the laser, you would reduce the cut width or pump a liquid through the tube material during the process,” said Quandt. “However, there’s always some HAZ, which means that a laser-cut metal stent always requires post processing (chemical etching and electropolishing).”

But since Norman Noble’s new UltraLight femtosecond laser cuts material without producing a HAZ, post-processing, save for electropolishing, is a non-issue. The UltraLight incorporates the SmartLight MD50 femtosecond fiber laser introduced last year by Raydiance Inc., Petaluma, Calif. The SmartLight (50-microjewel-per-pulse) system cuts
Stent market takes hit, but staging comeback

FOR THE BETTER PART OF 2007 and 2008, the once-booming drug-eluting stent (DES) market had flattened. Studies pointing to stents causing blood clots, and surgeons’ overuse of the instruments to prevent—rather than to open—occluded arteries raised fears and questions.

“Some of the clinical literature asked doctors to take a step back and identify which patients were appropriate for the stents as opposed to overusing them,” said Venkat Rajan of Frost & Sullivan. The double-digit market growth of 2005 and 2006 plummeted.

But as researchers looked further into DES’s possible hazards during 2007 and 2008, mounting evidence showed that the risks had been exaggerated; health-care agencies and organizations, such as the Mayo Clinic, deemed the devices “safe and a good option for many people,” with the proviso that patients take blood thinners, as prescribed.

The turnaround helped restore market confidence in drug-eluting stents, but whether the current technology will once again post double-digit gains is questionable, largely because surgeons’ overuse of stents has apparently ceased.

Rajan estimated that U.S. demand for stents accounts for 45 percent of the $1.8 billion global market (90 percent of which consists of DES vs. bare metal stents).

“I believe 2009 was the first year in the last three that the market grew a bit, about 3 percent,” said Rajan. “So we believe that the market has been adjusted; there seems to be a better sense of when stents should be used. There’s still a huge need for these technologies, due to cardiac disease rates. But I don’t think the market will grow as people once projected,” he said, adding that he anticipates an annual expansion of about 3 percent for the next 3 years.” Further growth, he added, will be largely dependent on new product introductions, while market shrinkage could occur if new safety concerns arise.

—D. McCann

New Life continued

materials very differently than continuous-wave lasers, which heat materials from a solid to a liquid that eventually combusts or turns into a gas, according to Adam Tanous, director of marketing for Raydiance.

“With the femtosecond fiber laser, you’re delivering 50 microjoules of power in 800 femtoseconds,” said Tanous. “You get extremely high peak power, and instead of a thermodynamic transition, you have an electronic process.” The laser ionizes the material at the target, he continued, which strips off electrons that form a plasma plume above the target. The positive ions left at the target repel each other and, through coulombic expulsion, material is ejected from the target area. And it all happens in the time frame of an 800-femtosecond pulse—material is ablated away before heat can diffuse beyond the ablation volume and cause thermal damage.

The technology eliminates costly and time-consuming chemical-etching post-processing, which reduces stent manufacturers’ yield, according to Tanous. In addition, without thermal effects, the femtosecond fiber laser is capable of ma-
chining ever-finer stents, a key feature considering the growing emphasis on minimally invasive surgical procedures.

**Polymer stents**

The biggest advantage of the ablation laser technology may be its ability to machine what many observers are certain is the future of stent industry: biodegradable polymer stents. With melting points ranging between 175°C and 200°C, the polymer is too fragile to be cut with heat-based lasers. Unlike metal stents, which can cause blood clots, the bioabsorbable devices have thus far proven to be without hazards. A study published in the March 2009 issue of the medical journal *The Lancet* detailed the results of a 2-year clinical trial of a bioabsorbable DES made by Abbott Laboratories.

Among the findings:
- Zero-percent rate of stent thrombosis (blood-clot formation) for all patients for 2 years;
- No occurrence of major adverse cardiac events between 6 months and 2 years;
- Bioabsorption of the stent 2 years after implantation;
- Restoration of vasomotion (ability of the blood vessel to contract and expand); and
- Reduced plaque in treated arteries.

Recent advances in stent production have been more evolutionary than revolutionary, according to Frost & Sullivan’s Rajan. “I think the next leap in technology will probably be in 6 years or so, if biodegradable stents [pending FDA approval] come to the market. There are companies developing them now; they essentially just dissolve, so there’s no long-term risk.”

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Tabletop SEMs (scanning electron microscopes) combine the best features of optical microscopes and traditional SEMs, surpassing the imaging capabilities of optical microscopes while reducing the cost, time and complexity associated with conventional SEMs.

“The tabletop SEM bridges the gap between optical microscopy and full-blown electron microscopy,” said Jacco Schipperen, CEO of Phenom-World BV, Eindhoven, Netherlands, which manufactures the Phenom tabletop SEM. (The company’s U.S. dealer is located in Hillsboro, Ore.

Tabletop SEMs are used to inspect microelectromechanical systems (MEMS), semiconductors, composite materials, pharmaceuticals, glass, textiles, fiber optics and cutting tools. Applications include failure analysis, research, contamination identification, defect documentation and layer-integrity evaluation.

Beyond glass lenses
Optical, or light, microscopes rely on transparent glass lenses and light to magnify images. The user can view the image directly through an eyepiece or indirectly on a computer monitor. With the latter method, a camera or digital imaging system captures the image, which is then sent to the computer screen.)

Optical microscopes are easy to use but are generally limited to a maximum magnification of about 1,500×. There is also a need to change the objective lens to obtain high magnification. Furthermore, the depth of focus is limited and resolution is around 200nm.

For about the same cost as optical microscopes, tabletop SEMs provide magnification ranges from 10× to 30,000×, depending on the model. For some units, digital zoom capabilities can increase magnification even more. Resolution is from 20nm to 30nm.

“Depth of focus is a major advantage of tabletop SEMs over optical microscopes,” said Michael Wolfe, technical sales specialist and team leader for the NeoScope tabletop SEM from Nikon Instruments Inc., Melville, N.Y. “At high magnifications on an optical microscope, only a small plane of the sample can be in focus at one time. But the tabletop SEM allows the user to visualize an entire object, in focus, at high magnification.”

Time and money
The advantages of tabletop SEMs over conventional SEMs are threefold: they are easier to use and save time and expense.

Conventional SEMs create an image by scanning a beam of electrons over the sample surface. This produces signals that contain information about the sample surface and elemental composition, which is captured and displayed digitally.

In general, conventional SEMs operate at magnifications of 100,000× or higher and resolution is 5nm or better, but they are complex and require a trained technician. A traditional SEM often has a complicated user interface, and loading a sample and focusing the image takes several minutes.

The tabletop SEM eliminates variables and automatically adjusts focus, brightness and contrast. The user interface is simple to operate; a new user can be trained quickly, usually in less than an hour.

Using traditional SEMs is typically a slow

A Phenom tabletop SEM was used to examine wear patterns and fault fractures in this drill bit.

By Susan Woods, Contributing Editor
process. “For an SEM to work it has to be in a vacuum,” said Phenom-World’s Schipperen. “Every time you load and unload samples, you have to evacuate, or pump-down, the vacuum chamber, which can take 5 or 6 minutes.”

A tabletop SEM vacuum system typically provides rapid pump-down, from 20 seconds to 1 minute, allowing analysis to begin sooner. “Some of this is predicated on tabletop units having smaller chambers,” said Greg Ott, president of ASPEX Corp., Delmont, Pa., manufacturer of the PSEM eXpress tabletop unit.

Phenom’s unit incorporates a sample cup that attaches to the machine instead of using a stage in the vacuum chamber. Only the cup has to be evacuated—not the entire chamber. Pump-down time is less than 30 seconds.

However, using the sample cup instead of a stage limits the sample size. “That is the tradeoff with the Phenom,” said Schipperen. “The maximum sample size is 1” in diameter. That is still pretty big for a sample size, though. If you are going to enlarge something up 10,000×, you don’t need a lot of it.” The manufacturer does offer larger, customized sample containers.

The maximum sample size for most tabletop units is around 70mm in diameter × 50mm high.

Also making things faster and easier, tabletop SEMs eliminate the range of accelerating voltages from which the user must choose. Conventional SEMs feature accelerating voltages ranging from approximately 0.1kV to 30kV. The higher the voltage, the deeper the penetration of the beam into the sample. However, the higher voltage can damage some beam-sensitive samples and decrease the image surface detail. Higher accelerating voltages are also required for energy-dispersive X-ray analysis systems, used for elemental identification.

Most tabletop models offer users just a few accelerating voltages, such as 5kV, 10kV, 15kV and 20 kV. “The lower voltages give you better surface imaging,” said Robert J. Gordon, vice president of the Nanotechnology and Life Science Division of Hitachi High Technologies America Inc., the Pleasanton, Calif., manufacturer of the TM-1000 and TM-3000 tabletop SEMs. “At lower voltages, the beam is not as energetic and you can use beam-sensitive materials.”

Another feature that makes tabletop SEMs easy to use is they are not as affected by noise and vibration as traditional SEMs. Imaging at high magnification in a conventional SEM requires an environment free from vibration, ambient noise and electromagnetic interference. “Because tabletop SEMs have lower magnifications, vibration is not always a major factor,” said Wolfe. Most of the tabletop units feature vibration-dampening systems as well.

One dramatic difference between conventional and tabletop SEMs is cost. Traditional SEMs start around $120,000 and go up to $700,000. Tabletop models start around $65,000. Leasing is an option, but most customers purchase them outright.

Another difference is maintenance. “I used to shudder when I heard there was a problem with our [conventional] SEM,” said Courtney Martin, manufacturing engineer at Adaptive Materials Inc., an Ann Arbor, Mich.-based fuel cell manufacturer that uses the Hitachi TM-1000. “Conventional SEMs require constant care and preventative maintenance for their multiple parts, and ample training to get great images.”

Maintenance issues are typically minimal with tabletop SEMs. One consumable is the filament, the source for electron generation. Most tabletop SEMs feature a tungsten filament, which is simple for the user to replace. However, they typically have just a 200-hour life.

The Phenom unit’s lanthanum-hexaboride source provides 1,500 hours of operation. “It lasts longer and gives a brighter image than the tungsten, but is quite a bit more expensive,” said Schipperen. The

The tabletop SEM bridges the gap between optical microscopy and full-blown electron microscopy.
**Tabletop Inspection continued**

manufacturer offers a filament-replacement service, which is required every 18 months to 2 years, on average.

**Helping small and large**

The small footprint of the tabletop SEM allows for installation into available laboratory space or areas close to production lines. Because a tabletop SEM is about half the cost of an entry-level, conventional SEM, smaller operations can purchase the tabletop unit and immediately process samples, rather than outsourcing the job.

A medical device manufacturer in Irvine, Calif., uses a TM-1000 to evaluate the drug coating on the outside surface of stents to save money and time. “Before the purchase, we would [send stents] to a lab with an SEM and a technician able to operate it,” said the company’s chief technical officer. “We would have to observe [the inspection process] and tell the technician where to look and what images to take.”

He added that the outside lab charges $30 a picture on top of $200 to $250 an hour for using the machine, which can add up to several thousand dollars quickly. “Now, we are free to take as many pictures as we want.”

Similarly, having multiple tabletop SEMs in-house allows departments in larger organizations to acquire their own unit instead of having to send samples to a “core” lab within their facility. “Even Intel, which has very expensive microscopes, uses tabletops to allow better throughput in their failure-analysis lab,” said Gordon. “They can quickly look at a sample and determine if it needs to (be inspected) on more expensive and elaborate equipment.”

Typically, most organizations with a need do not use just a tabletop SEM. “We use all three (optical microscopes, conventional SEMs and tabletop units) for several reasons,” said Karmin Olson, lead engineer—fabric filter, GE Energy, Lee’s Summit, Mo. “The traditional SEM allows us to change the working distance and angle of the sample while under vacuum. The optical microscope is used for samples that are wet or contaminated with hydrocarbons or in cases where color differences are key. The Phenom is best for high-magnification, high-resolution images.” GE Energy uses the Phenom to analyze fabric filters used in industrial baghouses.

Tabletop SEMs have limitations, but for most applications they are more than capable. “About 80 percent of the use of SEMs is 20,000× magnification or less. There are a lot of applications that are in this range,” said Schipperen.

**About the author:**

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Comparison of a solar cell with the Hitachi TM-3000 tabletop SEM at accelerating voltages of 5kV and 15kV. Higher voltage provides deeper penetration into the sample and increased image resolution. Lower voltage provides better surface detail.

The Phenom tabletop SEM features a sample cup (shown at bottom left) instead of a stage.
A Glowing Report continued from page 15 grow to $717 million by 2014, will remain a small piece of the overall market.

Broader picture

The performance of the optoelectronics sector is particularly significant when you consider that the overall electronics market was $1.1 trillion in 2009, down 11 percent from 2008, when it was $1.24 trillion. According to IC Insights records, that’s the first time the electronics industry has ever recorded a double-digit decline. And it’s only the third time since the mid-1970s that the industry has declined at all. Historically, according to IC Insights, the market has averaged 4 to 6 percent annual growth.

For its part, the semiconductor industry had revenue of $238 billion in 2009, down 10 percent from $264 billion in 2008. For the optoelectronics segment to record just a 5 percent drop in this environment was actually very positive, according to IC Insights. In fact, it appears that semiconductors fared better than expected in the first quarter of 2010 and could see less of a decline than originally estimated—so much so that the original estimate for 15 percent growth this year could climb to 20 percent. That would put semiconductor sales for the year at about $270 billion to $280 billion.

Gartner Inc., Stamford, Conn., another information technology research firm, predicted similar growth for semiconductors fared better than expected in the first quarter of 2010, and could see less of a decline than originally estimated—so much so that the original estimate for 15 percent growth this year could climb to 20 percent. That would put semiconductor sales for the year at about $270 billion to $280 billion.

A remarkable recovery, to be sure, noted Walker. The current recession could have been much worse for electronics firms, but they learned some lessons from the 2000-2003 downturn.

From a financial standpoint, Walker explained, the electronics industry is in better shape than other industries, such as automotive and housing. This recession has been different from previous recessions. In 2000, the tech-heavy NASDAQ stock exchange started a 3-year collapse, dropping from a high of 5048.62 on March 10, 2000, to just 1279.24 on March 12, 2003. In contrast, consumer markets were not affected nearly as much during that period.

“If you look at what happened in the overall economy,” he continued, “consumers had a little bit of a recession then, but nothing like we’ve had in the past 2 years. In a way, that period, from 2000 to 2003, was worse for the semiconductor industry than this current recession.

Back then, the industry took until 2003—2 years—to recover and reach a utilization rate of 85 percent. “In this most recent recession, we did that in three quarters,” said Walker. “We were down in January of last year in the 40 percent utilization range, and by December we were up to the 85 percent utilization range. Everybody understood what to do this time. We turned off the spigot; we didn’t spend on capital equipment. And, consequently, a lot of companies had cash. They were able to weather the storm. And we adjusted inventories much faster.”

Overall, micromanufacturers seeking to expand their horizons need only look to the emerging markets mentioned here for potential new business. If the analysts’ predictions hold true, the future may indeed be so bright that you will need to wear shades.

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LASERpoints

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the operator watches a monitor and uses the X/Y jog to align a set of camera crosshairs to the fiducial. The camera is either in-line with the laser or, more commonly, set at a known offset to the laser beam. This offset is factored into all positional calculations. Once the first alignment is complete, the process is repeated for the other points. Upon completing the last alignment, calculations are made and the toolpath is defined, with respect to the new alignment and camera-offset information.

The automated machine vision method is much faster and more accurate than the manual approach, but it costs more. Automated alignment is particularly valuable when producing large lots, but less so with small lots.

Many alignment pitfalls can be avoided and the process will run more smoothly if parts are designed with alignment in mind.

About the author:

Ronald D. Schaeffer, Ph.D., is CEO of PhotoMachining Inc., a high-precision laser job shop and systems integrator in Pelham, N.H. E-mail: rschaeffer@photomachining.com.
The 5th International Conference on MicroManufacturing will focus on processes, equipment and systems for fabricating miniature parts—those having dimensions ranging from a few micrometers to tens of millimeters. The event takes place April 5-8, 2010, at the Lowell Center at the University of Wisconsin in Madison.

“The conference offers a venue for the latest fundamental and applied research results to be presented and discussed,” said Frank Pfefferkorn, conference chairperson. “We want to bring the community that does cutting-edge research together, including those in industry, academia and government labs.”

The event—jointly organized by the International Conference on MicroManufacturing from the U.S. and the International Conference on Multi-Material MicroManufacture (4M) from Europe—brings together a worldwide community of micromanufacturing experts. “Close to 50 percent of the participants will be from outside the U.S,” said Pfefferkorn.

The conference also features 17 industrial exhibitors from three countries and six industry sponsors, including MICROmanufacturing magazine.

Speakers will address theoretical and applied research issues related to manufacturing, assembling and measuring components and systems with microscale features. These include descriptions of applications of current and emerging micromanufacturing methods and equipment, including some that bridge the nano- and macro-worlds. Ninety-seven abstracts have been accepted from 21 countries.

The biggest benefit for attendees is to see micromanufacturing experts present their latest research results. “If there is something that interests an attendee, he can actually talk to the expert in person, not just read a paper,” said Pfefferkorn. “They can make that connection.”

Current research will be presented in the following micro areas: mechanical machining; EDM and ECM; metrology; microfactories; process control; biomedical applications; forming, embossing and extrusion; materials-related issues; modeling and simulation; laser-based processes; and joining and assembly.

Four keynote presentations will be given over the course of 2 days:
- “Micromanufacturing for medical devices: A case study,” by Sarah Audet, director, Technology Planning, Medtronic Inc., Cleveland.
- “Microtransfer printing and its use in unconventional electronic systems,” by John A. Rogers, professor, Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign.
- “Dimensional metrology for micromanufacturing—tolerance verification on the microscale,” Hans Nørgaard Hansen, professor, Department of Mechanical Engineering, Technical University of Denmark, Lyngby.

The event also features a tour of the Advanced Manufacturing and the Polymer Processing Laboratories in the University of Wisconsin mechanical engineering building. Experimental equipment on the tour includes that used in micro/nano thin-film sensor fabrication and characterization, pulsed-laser micropolishing, nanocrystalline diamond coating of microtools, micro-endmilling, nano-cellular polymer processing and nano-particle reinforced casting.

Pfefferkorn believes the conference provides an opportunity for an exchange of information from across all disciplines and backgrounds. “It helps disseminate the latest developments in micromanufacturing,” he said.

For more information about the technical program and content, contact Conference Chairperson Frank Pfefferkorn, associate professor, Mechanical Engineering, University of Wisconsin-Madison at (608) 263-2668, or pfefferk@engr.wisc.edu.

For local information and logistics, registration issues, travel or letters of invitation, contact the conference planning services manager: Patti Thompson, The Pyle Center, University of Wisconsin-Extension at (608) 262-1122, or patti.thompson@ecc.uwex.edu.
**METAL FOILS.** Ulbrich Stainless Steels & Special Metals Inc. produces specialty metal foils less than 0.0015” thick. The UltraLite line’s thinnest foil is 0.0005”. Applications include flexible foil heaters and sensor diaphragms. Manufacturing the UltraLite line requires stringent rolling, slitting, annealing and finishing processes, which the company performs in a specially designed facility. The company serves a variety of industries, including aerospace, automotive, nuclear and solar energy, medical equipment and electronics.

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**PNEUMATIC SPINDLES.** NSK America Corp.’s HPS-series air motor spindles provide 25,000- and 50,000-rpm spindle speeds for small-hole drilling and light milling. The tool-changeable spindles allow for transfer from the machine magazine to the main spindle without connecting the air supply. The company guarantees spindle taper to be less than 1µm TIR. A positioning block to mate the spindle with the machine is provided.

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**LINEAR MOTOR SLIDE.** PI (Physik Instrumente) LP’s P-653 piezo linear motor slide is 8mm long. It can replace classical drive elements, such as miniaturized motor-leadscrew systems or other linear motors, according to the company. The stage offers 2mm travel, submicron resolution and 0.15 newtons of holding force. Other features include a true linear motor slide that provides no rotary conversion loss, velocity up to 200 mm/sec., millisecond responsiveness and an OEM drive for high-quantity applications preassembled and mounted on a printed circuit board.

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**MICROMOLDING.** SMC Ltd. is a medical device manufacturer that offers medical micromolding services, including implantable micromolded devices. The company can deliver yields of 10,000 parts or 10,000 shots/lb. minimum, including the runner. Micromolding part sizes are 0.003 cu. in. and smaller, and part weights are 0.045 g or lighter. Part geometries can be attained in a range of materials, including PEEK, Ultem, bioresorbable and other engineered resins.

(715) 247-3500  
www.smcltd.com

**ABRASIVE BLAST MACHINE.** Media Blast and Abrasive Inc.’s PrecisionBlast direct-pressure machine is equipped with a 110-sq.-ft. cartridge filter that provides filtration down to 0.5µm. The unit comes with a 550-cfm exhaust blower with an exhaust silencer. The pneumatic separator/reclaimer cleans the abrasive and recycles it back inside the cabinet; it cannot transfer into the dust collector. Other features include a ¾”-ID Rotech nozzle and 6”-dia. work ports.

(714) 257-4084  
www.mediablest.com

**MASK ALIGNER.** SUSS MicroTec Inc. says its MA200 Compact submicron-precision mask aligner is a full-field lithography system that offers high overlay accuracy. The flexible robot handler allows for wafer handling with two or four cassettes. The footprint is 2.12m². The system features alignment accuracy of 0.5µm, resolution of 3µm (proximity)/0.8µm to 1µm (vacuum contact) and throughput greater than 100 wafers per hour (including auto-alignment). The MA200 can expose a 200mm wafer in a single full-field shot.

(802) 244-5181  
www.suss.com
Whether the challenge is creating micro-parts or microfeatures on macroparts, attendees at the MicroManufacturing Conference & Exhibits will find several resources to help them improve their manufacturing processes. The event, hosted by the Society of Manufacturing Engineers, takes place April 14-15, 2010, in Mesa, Ariz.

With MICROmanufacturing as a media sponsor, the conference presents information on machining, molding, assembly, forming and metrology. Attendees will learn about cutting-edge technology, gain a better understanding of techniques and applications, learn effective solutions to real-world problems and network with experts and peers.

The 2010 NanoManufacturing Conference & Exhibits is co-located with the micro-manufacturing conference. Attendees of the nano conference will learn about the latest applications and trends in top-down fabrication and bottom-up assembly, explore ways to make products and obtain benchmark information from other nanomanufacturers worldwide.

When participants sign up for one conference, they can attend any presentation in the other conference as well. Those who arrive a day early, April 13, can attend three workshops:
- Micromanufacturing fundamentals,
- Understanding nanotechnology: integration and current applications, and
- Micro and nano metrology.

Wednesday, April 14:
Track 1—Micromachining: selective polishing; laser; waterjet; Swiss-style machines; EDMs; contactless micromilling; and deburring, deflashing and edge finishing.

Track 2—Micromolding: metal-injection molding; molding PEEK; Exact Dosing system; panel discussion; microfluidics; micromolding challenges; and material selection.

Track 3:
- Microassembly and MEMS (a.m)
- Microforming and fabricating (p.m.): mica free form; UV direct-write fabrication; modulation-assisted machining; and silicon-dioxide fabrication

Thursday, April 15
Micrometrology: 3-D surface profilometry; video and multisensor measurement; and systems and sensors.

Wednesday, April 14
- Keynote: How small can you go? Daniel Herr, Semiconductor Research Corp.
- Also: Nanomanufacturing with biomolecules; nanoparticle-based biosensor; environmental, health and safety (EHS) issues; photovoltaics; force-sensing touch screen; carbon nanotubes; and ceramic nanoparticles.

Thursday, April 15
- General Session: “Make it small, measure it accurately,” by Michael Postek, National Institute of Standards and Technology
- Also: Breakthrough companies; Feynman’s Pathway; and a panel discussion.

Attendees can also attend two tours. At Plastic Design Corp., participants will see micromold machining, the molding process and micrometrology. The second tour features Arizona State University’s Flexible Display Center/Solar Power Laboratory. The Solar Power Laboratory, co-located with the FDC, focuses on nanotechnology approaches to solar energy conversion. The tour also includes ASU’s Biodesign Institute.

Attendees can visit the trade show on April 14 from noon to 6:30 p.m. They will have the opportunity to visit with exhibitors during lunch, the afternoon break and the networking reception from 4:30 to 6:30 p.m. Approximately 40 exhibitors are participating.

For more information, contact SME public relations, (313) 425-3187; Fax: (313) 425-3406. E-mail: communications@sme.org. Web: www.sme.org.

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**Fab Update**

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part’s right-hand side.

The extra material is due to the overcure of layers No. 1 and 6. The blue portion is excess material from layers No. 2 and 7 curing through layers No. 1 and 6, respectively. That material is called print-through. Together, overcure and print-through add the equivalent of about three layers’ depth—an unacceptable error.

We deploy Zcomp to raise the bottom of every feature by the amount we know will exist due to overcure and print-through. In effect, we skip drawing the first two layers and start with the third (Figure 3). Note the tiny amount of residual print-through on the bottom of the main section. We purposely leave that excess material and remove it post-process to achieve the best possible finish and flatness.

In practice, the precise amount of Zcomp applied is a function of the material, build style and equipment used. Because of the size of microscale SL parts and the tight tolerances involved, the machines must be rigorously maintained. This ensures that Zcomp is predictable from part to part and keeps process drift in check.

*About the author:* Rob Connelly is president of FineLine Prototyping, a Raleigh, N.C., company offering rapid-prototyping services, including stereolithography, selective laser sintering and 3-D printing. Phone: (919) 781-7702. E-mail: rob@finelineprototyping.com.
Feasibility of Laser Induced Plasma Micromachining (LIP-MM)  
Kumar Pallav, Kornel E. Ehmann

In this paper, researchers outline the feasibility of a new fabrication process to address the shortcomings of microEDMing and conventional ultrashort laser micromachining. The microEDMing process is limited by its need for conductive electrodes and workpieces, and electrode wear and compensation strategies, whereas the problem with ultrashort laser micromachining is attributed to complex process control mechanisms. By contrast, the micromachining process discussed in the paper uses a laser beam to generate plasma in a dielectric near the workpiece surface. The resulting explosive expansion results in material removal by mechanisms similar to those of microEDMing.

From the chapter titled, Precision Assembly Technologies and Systems, 2010, in the book series titled “IFIP Advances in Information and Communication Technology”. The full study is available for purchase at www.springerlink.com.

Laser Micromachining for Fatigue and Fracture Mechanics Applications  
M.C. Gupta, B. Li, S. Gadag and K.C. Chou

Researchers in this study use a laser micromachining (LMM) method to initiate flaws for fatigue and fracture mechanics applications. Dynamic response of moving energy pulses during LMM of titanium alloy (Ti–3.5Al–2.5V) was numerically simulated using temperature-dependent thermophysical properties and 3-D heat transfer code. Researchers used nonlinear finite element analysis (FEA) to perform stress and strain testing of a titanium tube with an OD of 9.53mm, a wall thickness of 0.8mm and a longitudinal LMM notch 0.23mm deep and 1.83mm in length. For comparison, they also investigated an EDM tube with the identical notch profile as the laser-prepared tube. When the two tubes were subjected to inner pressures, the calculated hoop stress and strain amplitudes at the notch root of the EDM tube were about 64 percent and 63 percent, respectively, of the stress and strain amplitudes in the laser-prepared tube. Fatigue life due to the crack-initiation process can be minimized using the LMM method. Researchers determined that the LMM method is more appropriate than EDM for accomplishing flaw formation to study fatigue and fracture behavior of various materials.


Pulsed-laser Polishing of Micromilled Ti-6Al-4V Samples  
Tyler L. Perry, Dirk Werschmoeller, Xiaochun Li, Frank E. Peiffer, and Neil A. Duffie

Researchers studied pulsed-laser micropolishing (PLµP) to reduce the surface roughness of micromilled Ti-6Al-4V samples. Polishing was performed using a 1,064nm Nd:YAG laser in Q-switch mode at a repetition rate of 4kHz, 50µm to 70µm laser spot size, and pulse duration of 650 nanoseconds. The researchers observed surface cracking when polishing the samples in air, which was due to the formation of oxides on the workpiece surface. Researchers used Argon, an inert shielding gas that’s heavier than air, to prevent oxidation during laser polishing. This approach produced a reduction in average surface roughness by a factor of two. Also, the PLµP process reduced surface scratches on Ti-6Al-4V samples. Journal of Manufacturing Processes, 2009. The full study is available for purchase at www.sciencedirect.com.

High-Aspect-Ratio Micromolds for the Electroplating of Micro-Electro Discharge Machining Tools  
Onwusa Traisighachol, Hans H. Gatzen

Researchers detail their use of ultraviolet lithography with high-aspect ratio micromolds to electroplate microEDMs. Using SU-8, a negative photoresist, for the electrodeposition of the electrodes, they fabricated micromolds with heights from 200µm to 650µm and aspect ratios up to 26:1. Researchers also used SU-8 as an insulator to protect the sidewalls of the electrodes from corrosion. The fabrication of the SU-8 micromold was optimized to avoid cracks and delaminations. In the experiments, electrodes made of copper, tungsten copper and cobalt ferrous were deposited into these high-aspect-ratio microstructure technology micromolds.

In addition, researchers discuss their technique for electroplating in deep micromolds. Microsystem Technologies, 2010. The full study is available at www.springerlink.com.

Focused Ion Beam Micromachining and Microassembly  
Hongyi Yang, Svetan Rachev

The ability to manufacture and manipulate microscale components is critical to the development of microsystems. This paper presents the researchers’ technique to manipulate micro and nano parts using an integrated focused ion beam (FIB) system composed of a scanning electron microscope, a micromanipulator and a gas injection system. Currently, the smallest gears manufactured with traditional techniques reportedly have a modulus of 10µm. Using the FIB technique, the researchers fabricated microgears with a modulus of 0.3µm, and the gears were fabricated with 30 times more precision than other methods.

From the chapter, Precision Assembly Technologies and Systems, 2010, in the book series titled “IFIP Advances in Information and Communication Technology”. The full study is available for purchase at www.springerlink.com.
Microfactory workshop
To promote collaborative R&D into microfactory technologies, the 7th International Workshop on Microfactories (IWMF2010) will be held Oct. 24-27, 2010, in Daejeon, Korea. This international workshop is held biennially and provides researchers and engineers an opportunity to see technologies that have been developed for microsystems and micromachining. Some of the new technologies expected to be demonstrated at IWMF2010 are:

- microassembly, microhandling and microrobots;
- micromachining;
- micromanufacturing applications;
- and microsystems for various mechatronic, medical and biotechnology applications.

More than 400 researchers and engineers are expected to attend the IWMF2010 from around the world. For more information about the workshop, visit www.iwmf2010.com.

About the author: Dr. Jong-Kweon Park is general chair of The 7th International Workshop on Microfactories. He is also a principal researcher for the Korea Institute of Machinery & Materials, Nano Convergence & Manufacturing Systems Research Division. Phone: +82 42 868 7116, E-mail: jkpark@kimm.re.kr.

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microfactory consists of independent modules for various manufacturing tasks, such as assembly, laser processing and quality inspection. The TUT team demonstrated a system for manufacturing custom implants using laser machining (Figure 2). This system can be controlled and monitored via mobile devices.

Other integrated programs for system and technology development—including micro-assembly, integrated machining processes and mass production of microparts—are currently in progress elsewhere in Europe.

In the U. S., R&D is proceeding on miniature systems at universities and private companies, and some commercial systems are on the market. For example, Microlution Inc. produces 3-axis and 5-axis micromilling machines.

Other Asian countries, such as Singapore, Taiwan and South Korea, are also engaged in R&D focused on microfactory systems. The Korea Institute of Machinery and Materials (KIMM), Daejeon, Korea, has carried out cooperative research programs with industries and universities on microfactory technology since 2004. This program includes development of desktop-size machines for micromachining, microforming, EDM/ECM, inspection/measurement and assembly. KIMM built and demonstrated an integrated system for micropump manufacturing in 2007. Currently, the institute is developing machining systems for industrial applications, such as manufacturing biomedical implants and microlens modules for mobile phones.
Downsizing factories for micro production

Demand for micro products is increasing. However, many manufacturing systems for these products are the same ones employed for larger products. They occupy excessive space and consume more energy than is needed for micromanufacturing operations. There is great potential to reduce the physical scale of many manufacturing processes used to produce small mechatronic and other micro/meso-scale products.

Small-scale micromanufacturing systems that do not exceed desktop size are typically called "microfactories." Their development is being driven by the fact that creating micro/meso-scale components and features may be achieved more efficiently by machine tool systems many orders of magnitude smaller than those currently used for such applications.

As micro feature dimensions decrease, machine tool acceleration must increase to accommodate rapid changes in toolpath direction. Without an increase, tool velocity will be reduced and tool life will suffer. Since small machine tools have less inertia than larger ones, they need less force to achieve these accelerations and, therefore, they consume less power. These machines generate smaller thermal errors and have smaller footprints. As a result, microfactories have the potential to achieve acceptable performance at greatly reduced cost.

Microfactory developments

Since the late 1990s, research institutes and universities around the world have primarily driven the development of microfactories. One of the first efforts was housed in a large suitcase that included a micromilling machine, a press and a robot with a manipulator. It was built and demonstrated by the former Mechanical Engineering Laboratory, Japan, which is now a part of the National Institute of Advanced Industrial Science and Technology (AIST), Tokyo. Researchers at AIST have since developed desktop-sized and smaller manufacturing systems. Other organizations, including industry groups in Japan, are continuing to develop and apply new microfactory concepts.

One example is R&D performed by the Desktop Factory Forum, a regional consortium of 20 Japanese companies and academic organizations focused on miniature manufacturing systems. Group members have developed and implemented various desktop machines for their own use (see Figure 1). Collaborative development of microfactories—focusing on processes, machines and systems—also has been carried out by European industry groups and universities. One example is a microfactory developed by Tempere University of Technology (TUT), Finland, for manufacturing and assembly of small parts and products. The reconfigurable

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