Fuel Cell Industry Report

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MATERIALS AND MANUFACTURING

Entegris opens production line to mold polymeric fuel cell plates

Fitting the right material and manufacturing method to specific performance and operating requirements allows weight and cost reduction in fuel cell systems, such as bipolar and end plates and balance of plant (BOP) components.

Calling upon its 36 years of expertise in materials integrity management for the microelectronics and life sciences markets, Entegris Inc. has entered the brave new world of the fuel cell industry. On Jan. 27, the company opened a dedicated manufacturing line for polymer composite bipolar and monopolar (or end) plates at one of its five plants in Chaska, Minn. John Goodman, president of the Entegris fuel cell market segment, states that "the opening of this production cell is very important to our overall commercialization strategy. Our approach to the new market for fuel cells is to provide comprehensive value and multiple capabilities so customers can outsource to fewer companies. We're also focused on providing systems-based architecture."

State-of-the-art molding machines

Goodman estimates about 10% of the 100,000-sq.-ft. Chaska Plant 1 is dedicated to plate production, and additional floor space will be utilized as demand grows. The plates are compression molded using customized, state-of-the-art molding machinery. "The machines we have are relatively unique, with design features that I would say are unmatched elsewhere," Goodman states. "We're molding plates primarily with flow fields designed by the OEMs for their specific product, but we are also producing blank plates that the OEMs then machine, or we offer machining services to our customers if they require that. Most of these plates are suited to proton exchange or polymer electrolyte membrane fuel cells [PEMFCs] in systems that will be fueled by hydrogen or with direct methanol."

The surfaces on fuel cell stack plates contain complex, close-tolerance flow channels to direct reactant gases (oxygen and hydrogen). A bipolar plate has channels on both sides, whereas a monopolar plate has a flow field on only one side, and is often thicker as it serves to close out the stack at each end. Plates may be metal, ceramic, polymer coated, or composite (with a polymeric matrix that is reinforced with graphite, glass, or other fillers). Plates are gasketed to form a seal that keeps the gases in the channels and inside the stack, and they require a high degree of flatness and structural integrity.

Goodman says bipolar plates up to 12 by 20 inches (300 by 500 mm) and less than 0.06 inch (1.5 mm) in thickness can be made at the Chaska plant, and various plate designs are applicable to all three primary fuel cell markets: portable, stationary, and mobile. "Compression molding plates with molded-in flow fields requires an

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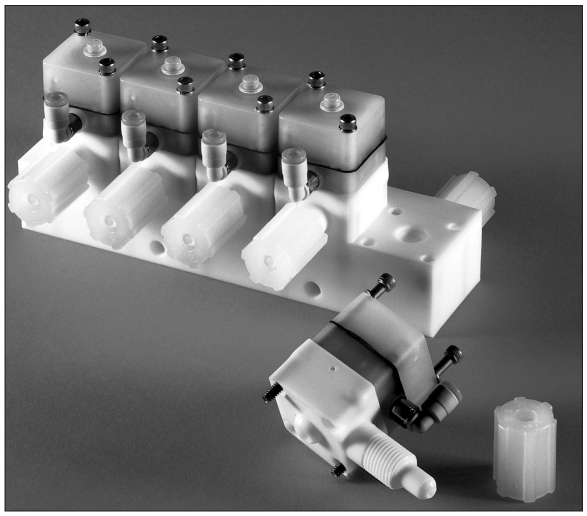
initial tooling investment," he explains, "but allows final plates to be produced at per unit cost substantially below machined plates — up to an order of magnitude lower in cost."

The type of BOP elements under development by Entegris include fluid and gas handling components, manifold assemblies, and valves. The company offers a number of off-the-shelf polymer valves under its Integra, Dymak, Reliant, and Galtek trademarks that can be used in fuel cells, and Goodman says a new air/fuel polymer valve soon to be commercialized has been specifically designed to replace large metal valves now being used in fuel cells.

The new valve is made from polyvinylidene fluoride (PVDF) and is roughly half the size and weight of the metal valve it replaces. Goodman counts OEMs designing solid oxide fuel cells (SOFCs) and molten carbonate fuel cells (MCFCs) among his customers for BOP products. "We're encountering an openness toward polymer materials in BOP components in lieu of metals in virtually all automotive applications," he notes.

Capitalization and distribution in place

Entegris has been researching fuel cells for the past five years, "although we've had a technology council for years that matches our core competencies with new industries," Goodman reports. "We were attracted by the emerging technology of fuel cells, and we see this market segment as having two key qualities for success: the technology is disruptive and has high-volume potential." He goes on to say that "we're used to handling high-performance materials. We understand the operating conditions associated with these materials, as well as their use in fragile substrates and BOP components, especially where polymers have replaced metals to reduce weight and cost."



Polymer valve manifold provides complex fluid control in a small, reliable package. (Source: Entegris)

With 16 plants around the globe, including in Japan and Germany, Entegris has developed a network of international customers. "We already have an in-country staff in Japan that is working on fuel cell products, and as you are aware, that country has some leading applications in fuel cell technology. We believe if a company has only one regional focus, they are missing the dynamics of this industry," Goodman says.

In Goodman's opinion, "there are a number of what you might call window-shoppers in the fuel cell industry, but we have made a long-term commitment. As a financially sound company with a strong cash position, we have the capital, as well as the management and brand credibility, to stay in this industry as it develops and during down cycles. In fact, in our 36 years of existence, we have never lost money on an annual basis."

Matching materials to performance

Polymeric materials are clearly an important knowledge base for Entegris to draw upon in making fuel cell componentry. In 1998, the company undertook a project for a modular electrochemical system designed by CerOx, located in Santa Maria, Calif., to injection mold polymeric end plates, bipolar plates, membrane frames, and flow channels from PVDF. Entegris engineers gained considerable experience from this project in welding leak-free stack assemblies and in bonding and sealing, as well as from working with DuPont's Nafion in the membrane electrode assemblies (MEAs). "But we don't intend to ever become an MEA supplier," Goodman states. "We have cooperative relationships with equipment manufacturers and raw material suppliers that help us achieve optimal molding conditions for our plate and BOP components."

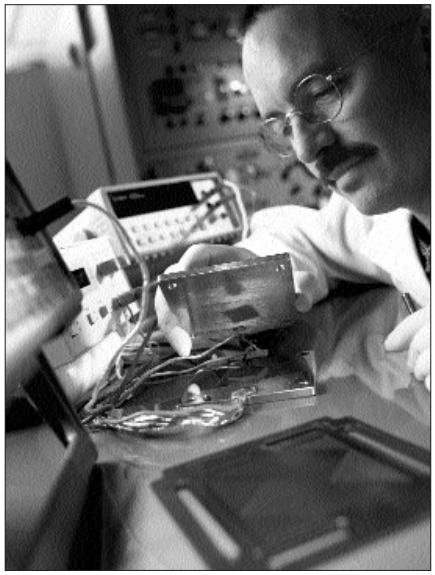
He adds that Entegris is not focused solely on producing or managing polymeric materials rather than metals or ceramics. "Use of polymers for plates really

depends upon market segment. There is bias for metal plates in some segments due to the extreme plate thinness that can be achieved, and because of perceived issues with conductivity, permeability, and porosity in polymer composite plates. By the same token, there is keen interest in other segments in furthering composite plate technology for its weight and cost benefits."

To Goodman, the expertise Entegris has in a varied palette of materials is the key to its success. "We'll use river clay if it works," he states, mentioning that the company has recently purchased a firm that manufactures stainless steel components and systems.

While Entegris has made composite plates one to four mm thick, Goodman believes it hasn't yet determined the outside envelope for thinness with polymer materials. He does state that "so far, no one has brought us a plate design we couldn't make." He adds that "our customers' expertise tends to be in electrochemistry or power generation, rather than materials science. So we can help them understand the process of analyzing the materials that will work best for their specific performance requirements. That's why we emphasize system architecture. You have to consider placement in the overall system of every component and what it is made from.

Polymer resins considered for the current compression molded plates include thermosets such as ethyl vinyl acetate (EVA) and phenolics, and selected thermoplastics like PVDF. In BOP applications, material candidates range



Conductivity testing ensures that bipolar plates will perform properly. (Source: Entegris)

from polypropylene and polyethylene to highly engineered resin systems such as polyetheretherketone (PEEK) and fluoropolymers like PVDF and perfluoroalkoxy (PFA). Goodman points out that the company also has experience molding plates with graphite, glass, and other reinforcing fillers.

"We'll use river clay if it works."

Further, he told *FCIR* that "we are one of the largest converters of PEEK, which can be molded into extremely close tolerance, intricate parts. We are also one of the leading consumers of fluoropolymers in the world; in BOP components, these materials offer a comprehensive suite of properties for varying performance requirements." When it comes to gasketing and sealing plates within a stack, Goodman points out that the company has experience with many relevant elastomeric materials, ranging from ethylene propylene diene terpolymer (EPDM) to fluoroelastomers. In BOP polymer components, Entegris can apply its patented PureBond infrared noncontact welding system to make leak-free joints and integrate quick-connect ports.

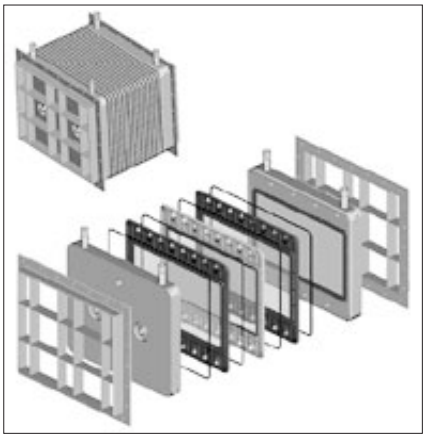
Partnerships important to success

Goodman identifies "our biggest success" so far in fuel cell products as partnerships in system development — with OEMs of both stacks and componentry. These partnerships allow the examination of the chemistry being used in a system — in particular, the reaction of polymer resins to fluids or gases in a fuel cell system, and the level and types of extractable ionics or outgassed elements from the polymer materials themselves. Many polymers have antioxidants or other stabilizers that may outgas or be released in vapor form depending upon the operating temperatures to which the polymeric components are subjected. In some cases, contaminants such as metal ions or sulfur compounds may be harmful to cell life or performance.

As part of a fundamental research and development consortium formed through the University of South Carolina, Entegris and other consortia members will be gathering data on the effects of contaminants on fuel cells, which will relate to fuel cell system elements such as plates, piping, and BOP components. In Goodman's opinion, "the consortia approach [indicative of this South Carolina group and the U.S. Fuel Cell Council, of which Entegris is a member] provides good leverage for this

industry — in terms of R&D dollars, you get so much more back than with a single-company internal project."

In one partnership effort, Entegris and a fuel cell OEM worked together to develop a complicated polymeric manifold. "The manifold creates pathways for fluid and gas within a fuel cell stack without using tubing or fitting connections" Goodman explains. "We looked at how materials get into and out of the stack, and as part of our customer's design team, helped identify cost targets, chemical compatibility, temperature ranges, and physical stresses. Each design iteration incorporates more of the BOP into the manifold, reducing the number of components and reducing system cost and weight while improving reliability. Early designs are machined with volume-based tooling to be built as the technology and commercial demand warrant."



Entegris's proprietary bonding technology results in reliable, leak-free permanent plate assembly.

Acceleration of the Energy Age

The mention of a hydrogen-powered vehicle in President Bush's State of the Union address (see Newswire this issue, p. 2) convinces Goodman "that we are on the cusp of something developing as rapidly and with as much potential to change our culture as semiconductor chips did in creating the Information Age, only this will be the Energy Age. The President could have mentioned many different technology initiatives, but the one he focused on was hydrogen power."

How fast will the Energy Age evolve? Goodman points to Moore's Law as related to the development of semiconductor chips: doubling device density at half the cost every 18 months. "This is the industry we come from," he states, intimating perhaps that this is the speed at which Entegris intends to obsolete existing materials technology and the advantages it can bring to fuel cell systems. This Editor asked him point blank about cost-per-plate targets. "Cost is dependent on volume and size of the plates," he answered. Industry estimates put automotive fuel cell plates at $1.00 to $2.00 each in high volumes, and Goodman emphasizes, "Entegris will be competitive with that target."

Again paralleling the evolution of the fuel cell industry with microelectronics, Goodman suggested that "the fuel cell industry is immature and needs to standardize a number of things ranging from bipolar plate test methods to BOP fitting connections, which will accelerate the development curve somewhat and avoid some of the same mistakes seen in the early development of the microelectronics industry."

He also thinks demonstration projects with hydrogen vehicles would be more helpful than additional research in terms of the $1.7 billion pledged by President Bush. "Actual demonstrations of hydrogen-fueled systems are more relevant to addressing the problems of making commercial products in volume, which is directly tied to cost reduction. I'd like to see the government buy 500 fuel cell cars or 300 additional stationary fuel cells and put them into operation around the world. We need such a technology push, and the U.S. government is in a unique position to provide that push."

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