In 1899, C.H. Duell, the head of the U.S. Patent Office, surveyed the many and great technological advances of the 19th century and declared, “Everything that can be invented has been invented.”

One hundred years later, at the beginning of the 21st century, the same could have been said about inkjet printing technology; innovations that propelled inkjet to the forefront of graphics printing were known, and users could look forward only to refinements. Needless to say, that prediction would have been wildly off the mark. Although inkjet technology was developed in the 1970s, its potential for commercial and industrial printing applications is exponentially greater than initially conceived. (Figure 1)

Inkjet printers can deposit fluids without contacting the material being printed, making them both substrate and application independent. Inkjets are also driven digitally, under computer control, enabling both precision and versatility. And as a digital technology, startup costs for inkjet production are comparatively low compared to other deposition methods.

Figure 1 Shown here is ANP Silverjet DGP on 152-µm Teslin at 5x (A), 10x (B), and 50x (C).
Of the three types of inkjet technologies—thermal, continuous, and piezoelectric—piezoelectric drop-on-demand (piezo DOD) is the most precise and versatile for industrial applications and is able to jet a wider variety of fluids at greater distances with accuracy and precision.

These characteristics make piezo DOD particularly suited to decorate, coat, treat and enhance existing materials. It is uniquely qualified for the precision deposition in manufacturing needed to create advanced products that have moved away from traditional graphics printing in R&D and full-scale industrial production (see the sidebar, Applications for Piezo DOD Inkjet Technologies).

Improvements to piezo DOD print- head precision, throughput, and versatility continue today, including important breakthroughs in printhead fabrication using advanced Silicon Microelectromechanical Systems (S-MEMS) technologies to produce printheads on a chip (Figure 2). These advances position piezo DOD to dominate industrial applications far beyond the scope of two- and three-dimensional graphics production, to diverse realms ranging from printed electronics (Figure 3), photovoltaics, and optics to 3-D mechanics, chemistry, and biomaterials.

NEW MARKETS AND OPPORTUNITIES

Applications for piezo DOD printheads fall into two broad categories: those used for macroprinting and those used for microprinting. 

Macroprinting entails jetting 35- to 200-pl fluid droplets (1 pl = 10 trillionths of a liter). Conventional ink applications include wide-format printing, addressing, and bar coding. This category also covers newer and faster growing applications for product decoration and large-feature fluid deposition such as precision jetting scratch-resistant coatings on eyeglass lenses or cell-phone displays, applying thin layers of adhesives, and depositing conductive and non-conductive patterns.

Microprinting involves jetting functional fluids with droplets smaller than 35 pl onto all types of surfaces. Microprinting fluids are limited only by the user’s imagination, ranging from silver and copper nanoparticle inks used in the fabrication of flexible electronic circuits, to organic inks used to produce organic electronics, DNA arrays, and biologically sensitive papers and sensors. Expansion of opportunities exists in both realms.

MACROPRINTING: A TRANSFORMING TECHNOLOGY

On the macroprinting front, new printhead products with higher nozzle densities, multiple head arrays, and composite material designs offer increasingly higher throughput while handling a wider range of fluids such as UV-curable, solvent, and aqueous inks.

Although the potential for piezo DOD inkjet in conventional wide-format printing, addressing, and bar coding hasn’t been fully realized, the greatest opportunity for piezo DOD lies in its potential as a transforming technology for decorating products and jetting functional fluids.

Piezo DOD inkjet can make clear pine panels look like an exotic wood, or make ordinary leather look like alligator or crocodile hide. It can add a corporate logo or marketing message to objects in unique ways. It can even print conductive inks on a circuit board.

The print media can be hot, cold, wet, dry, rough, smooth, delicate, sturdy, porous, non-porous, rigid, or flexible. Such inkjet systems are already used to print on chocolate and other foods while they are still warm, as well as on frozen treats decorated while semi-solid prior to chilling. Other substrates include many types of plastics; durable goods like wood, ceramics, and metals; and clothes and synthetic fabrics.

Just as there are differences in substrates and manufacturing environments, fluids jetted also run the gamut. These include adhesives and conductive and dielectric inks; aqueous, solvent, UV-curable, and hot-melt inks; photoresists, etch resists, and anti-scratch and anti-glare compounds; enzymes, edible colorants, and many other functional fluids—in addition to the full spectrum of graphics inks used in the printing industry.

This diversity is distinctly different from commercial print production, where paper products and two or three types of vinyl make up the lion’s share of target media and where inks are well characterized and closely matched to the printheads used for deposition and the target substrates.

The challenge for manufacturers often lies in understanding how to integrate new technologies to operate seamlessly within unique applications and environments. Owing to its versatility, inkjet can be integrated into most multistep manufacturing processes, often at the most appropriate place in a production line to decorate or pattern materials as they are formed.
Fluid development is pivotal

Starting with legend print

piezo DOD is the industry stan-

dard technology for wide-format printing and display graphics, industrial marking and coding; and decorating products from fabrics and tools to foods.

Electronics Starting with legend print-

ning on printed circuit boards, piezo DOD printheads are used to create functional electrical traces using conductive fluids on both rigid and flexible substrates.

Displays Printhead productivity, reliability and uniformity are critical at-

ttributes required for the precise deposi-
tion of materials such as light emitting polymers used in manufacturing flat panel displays (FPDs).

Life sciences The application of ad-

vanced inkjet technologies to the life sci-

cences in fields such as genetics research is limited only by the imagination.

Chemistry Fluid development is pivotal to successful implementation of many new digital micro-production applications under consideration.

3D mechanics piezoelectric inkjet tech-

nology is an ideal solution for jetting the binder fluids used within digital three-di-
mensional mechanical applications.

Optics Precision jetting of UV-curable optical polymers will be a key technology used in the cost-effective production of microlenses.

Photovoltaics Non-contact functional fluid deposition is growing in importance as a critical production process for high-

value, cost-effective manufacturing.

Applications for Piezo DOD Inkjet Technologies

Graphics piezo DOD is the industry stan-

dard technology for wide-format printing and display graphics; industrial marking and coding; and decorating products from fabrics and tools to foods.

Materials deposition: the microprinting frontier

The great potential of piezo DOD for mac-

roprinting applications pales in comparison to the possibilities presented by materials-

deposition microprinting.

Imagine a precision specialty printing method that operates at the microscopic level to produce flexible printed electronic,

ics, photovoltaics, flat panel displays, back-

planes, RFIDs, smart tags, sequences of genetic material, and chemical and bio-

logical sensors. This new frontier in high-technology manufacturing is where the materials deposited can range from light-emitting polymers and conductive fluids to organic ink and DNA, and where the deposited thickness often must be con-

rolled to within a few ten-millionths of a meter. It’s also where piezo DOD inkjet is quickly finding acceptance as a valuable manufacturing method.

Unlike deposition methods that flood a surface with functional fluids, piezo DOD inkjet is precise and additive, able to deposit the exact amount of fluid at the exact locations where it is needed without waste. This precision makes it unnecessary to image and pattern, etch, and recover waste material, thereby en-

hancing its appeal for use with expensive materials like nanoparticle silver and DNA or aggressive conductive and reactive

fluids and coatings that must be deposited at specific locations in precisely controlled amounts.

The printhead on a chip

Materials deposition demands droplet size tolerances exceeding those used for print production by an order of magnitude. Instead of jetting ink at the 30- to 80-pl droplet sizes common to print produc-

tion, high-technology materials deposition routinely requires fluid drop sizes of 1-10 pl or less. It also requires inkjet printheads to handle a wide variety of fluid chem-

istries for a virtually unlimited range of applications and an even broader range of substrates at closely controlled processing temperatures (see the sidebar, Materials Deposition vs. Macroprinting).

S-MEMS fabrication technology has proven to be a critical event in moving high-tech materials deposition forward. S-MEMS manufacturing methods create ultra-miniature inkjet structures in silicon, enabling an entire printhead assembly to be produced on a chip. By spawning a new generation of printheads capable of jetting fluids from traditional inks to nanoparticle-

based materials, silicon MEMS have trans-

formed piezo DOD from a method primar-

ily suited for industrial print production to one that also offers unique possibilities and advantages for materials deposition and nanotechnology manufacturing.

Building in new directions

Piezo DOD inkjet printheads designed for high-tech materials deposition, sustainably jet picroliter-sized droplets of organic inks and many other fluids at high frequen-

cies with exceptional precision onto all types of surfaces—all without sacrificing drop-placement accuracy. They also do it with high duty cycles and long life—traits that enable manufacturers and systems integrators to design advanced systems for industrial production that are fast, reliable, and economical.

Unlike macroprinting applications such as product decoration, where the inkjet system can often be inserted at the optimal point within an existing production line, developing a new process for mass-producing printed electronics, photovoltaics, or new biological materials comes with ad-

ditional requirements. Applying materials deposition to industrial production typically requires new facilities and new methods, as well as a great deal of planning, testing, and proving materials and processes. The first phase in product development often takes place in the research lab—develop-

ing and testing manufacturing processes and product prototypes. For low-volume manufacturing applications, researchers commonly use benchtop-format materi-

als-deposition systems designed to print features as small as 20 μm.

This type of system uses single-use silicon MEMS cartridge printheads that minimize waste of expensive fluid materi-

als and reduce the cost and complexity associated with traditional product develop-

ment and prototyping. The applications can also demand such unusual features as temperature-controlled platens, systems.
affording the ability to visualize droplets as they are formed, and the ability to calibrate individual nozzles to compensate for channel-to-channel variability. Once the basic manufacturing process is verified, the manufacturer or specialty printer can methodically scale it up with the large-format systems needed for volume manufacturing.

Thousands of these new products and processes are in development today. Many of them are developed under a cloak of secrecy for the sake of competitive advantage. The few examples known publicly comprise a diverse set, ranging from Procter & Gamble’s use of edible food colorants to decorate Pringles chips, to microprinting applications such as the development of Agilent’s SurePrint inkjet technology, which allows life scientists to target and analyze sequences of genetic material efficiently. Other examples include:

- The pioneering fabrication by photovoltaics innovator Konarka Technologies of a new breed of highly efficient solar cells based on Power Plastic, a material that converts light to energy;
- A novel method developed by researchers at the Department of Chemistry at Colorado State University for producing, testing, and optimizing new materials that hold promise for efficiently producing hydrogen from water and sunlight;
- The creation by a research team at McMaster University in Hamilton, Ontario, working with Canada’s SENTINEL Bioactive Paper Network, of inexpensive, portable biopaper sensors able to detect harmful substances that can cause food poisoning or be used for bioterrorism. The broader application for bioactive paper ranges from neuroscience and drug assessment to surgical masks, food packaging, and water purification.

Each of these applications of piezo DOD materials deposition technology holds huge potential and equally far reaching ramifications, ranging from their potential for current manufacturing processes to opening new markets for products and processes that don’t currently exist.

Owing to the many advantages piezo DOD inkjet technology offers for macroprinting and microprinting, new and exciting products and applications—limited only by human imagination—will be conceived, developed, and manufactured for many years to come. This technology provides unparalleled opportunities to entrepreneurial manufacturers and specialty printers.