FUJIFILM Value from Innovation

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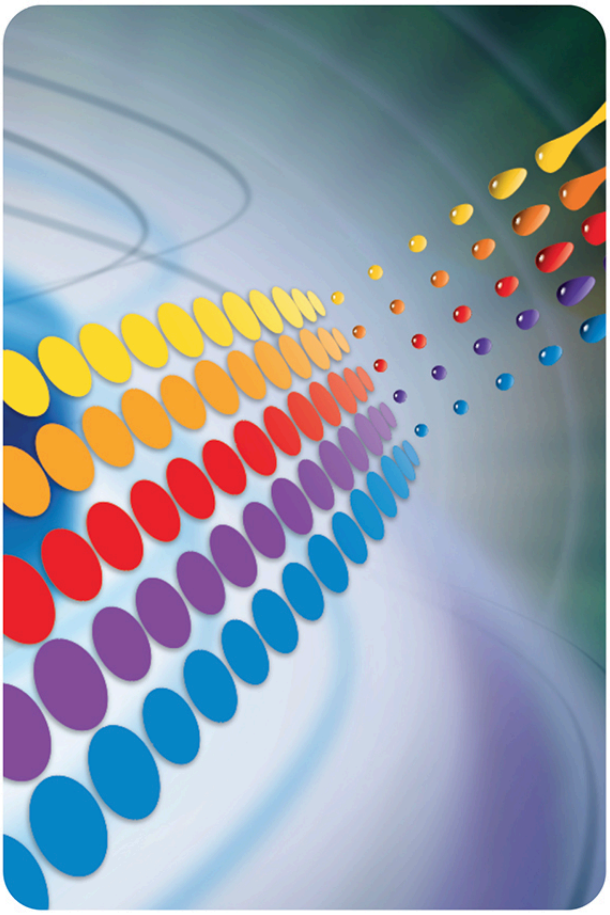
Graphics Packaging Textile Ceramics



Using Silicon MEMS Technology to Address Key Print Industry Market Needs

White Paper

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FUJIFILM Dimatix, Inc.
Industrial Inkjet Printheads

2250 Martin Avenue, Santa Clara, CA 95050
Tel: 408-565-9150 • Fax: (408) 565-9151
fdmxmarketing@fufilm.com

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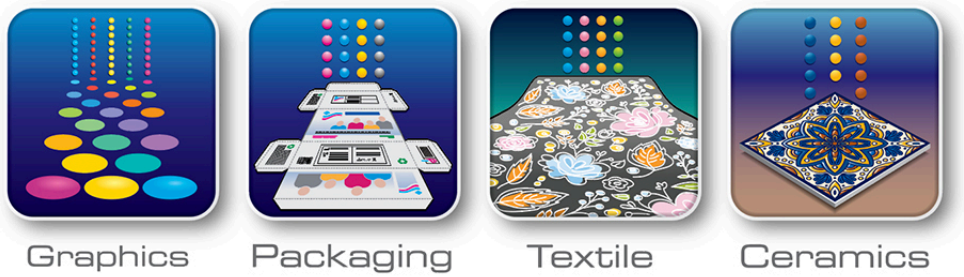
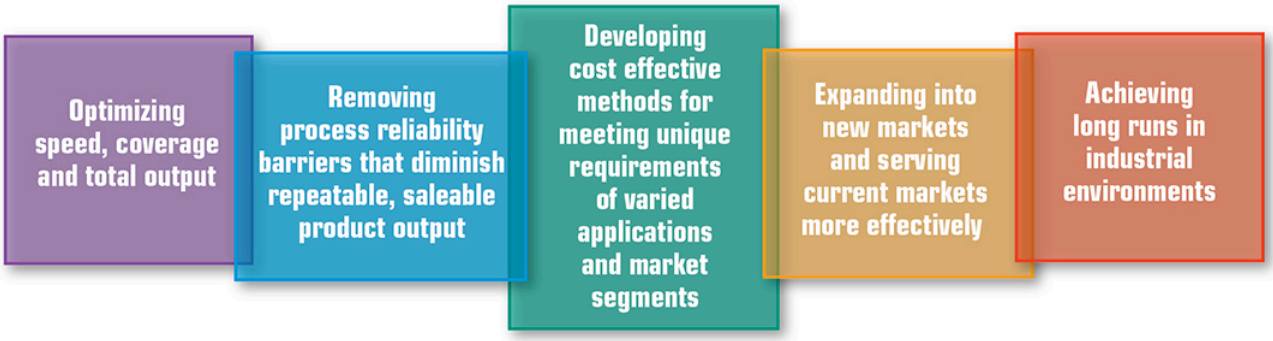


Introduction

FUJIFILM Dimatix Inc. has developed silicon MEMS technology that is becoming an important design and development tool throughout the printing industry. In this paper, we begin by identifying the top market needs of the industry's main players: product manufacturers, OEMs and component suppliers. We offer insight into how printer manufacturers, ink manufacturers and printhead designers are working together to meet those needs. Finally, we explore the critical role of Si-MEMS technology in enhancing existing technologies and enabling new printhead designs that printers, manufacturers and components suppliers throughout the industry are using to innovate solutions to meet the industry's most pressing market needs.

The Top Five Print Industry Market Needs

FUJIFILM Dimatix has been in the forefront of printing industry innovation for over 30 years. We conduct ongoing research with customers and other industry partners to keep abreast of their product and service needs, as well as the pluses and minuses of current solutions. Based on the latest results of these inquiries, these are the printing industry's top five challenges at present:



Industry Leaders Developing Technology and Solutions

Printer manufacturers, ink manufacturers and component makers including FUJIFILM Dimatix are all working in concert to provide successful product and technology design solutions for these market needs. Ink manufacturers are developing hybrid inks with higher speeds, faster curing methods and better media interaction. By opening up the design space and facilitating extremely small features, Si-MEMS enabled nozzle shapes facilitate reliable jetting of these hybrid inks, broadening ink latitude and improving quality control to increase repeatable, saleable product outputs. At the same time, printer manufacturers are developing

print-bar technologies that utilize Si-MEMS printheads and optimized inks to achieve long runs while maximizing speed, coverage and total output. These are just two examples of the groundbreaking collaborative work underway throughout the inkjet printing industry. As we will explain in the remainder of this paper, the revolutionary benefits of FUJIFILM Diamatix's patented Si-MEMS inkjet print technology often form the foundation of the most effective, efficient solutions to the most critical market needs.

Optimizing Speed, Coverage and Total Output

Silicon Micro-Machining Integrates Five Key Functionalities

The industry-leading silicon micro machining processes developed by FUJIFILM Dimatix to fabricate the SAMBA family of printheads enables integration of a number of critical functionalities in a very small footprint. This extensible "printhead on a chip technology" combines the potential packing density and cost of Thermal Ink Jet (TIJ) with the high throughput of Continuous Ink Jet (CIJ), while providing the operational flexibility associated with Piezo Ink Jet (PIJ). For printers seeking a combination of high image resolution and print speed, reduced errors and higher productivity and efficiency, the most important functionalities are:

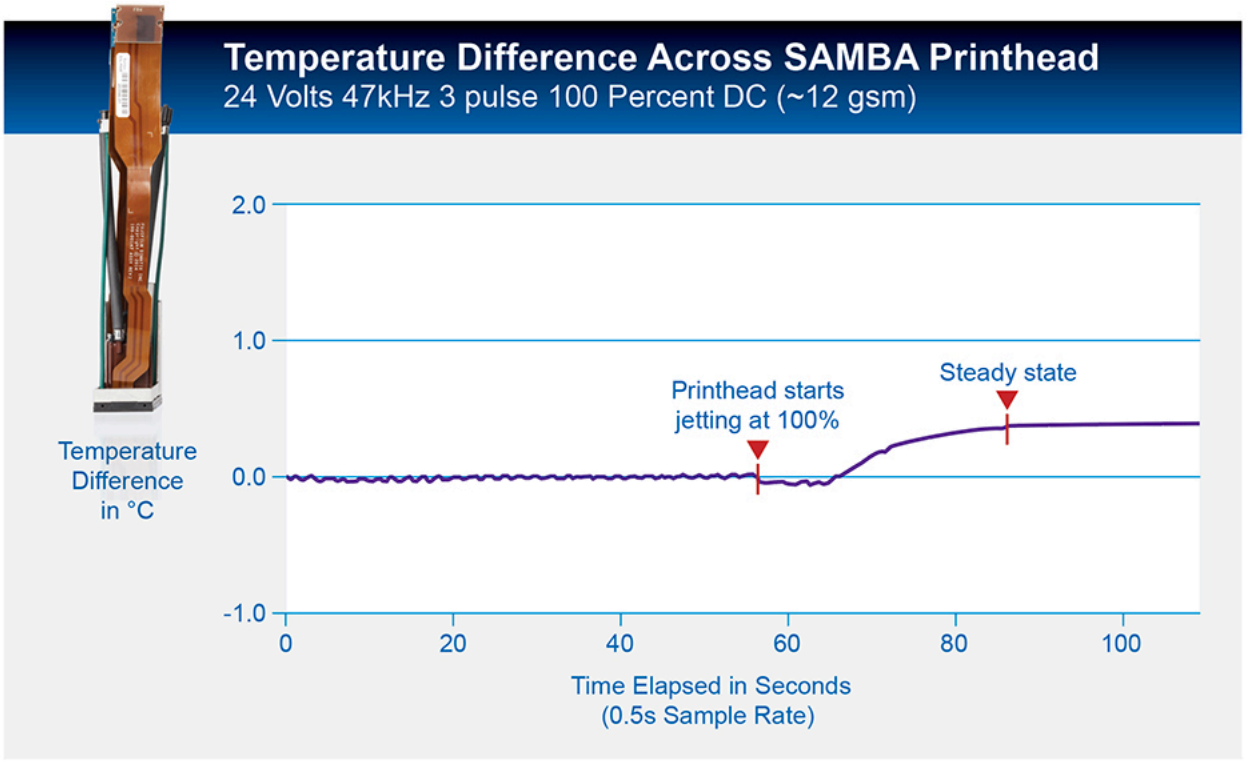
- Two-dimensional precision nozzle array etched in silicon enables high native resolution of 1200 NPI and exceptional jet straightness
- Compact network of ink channels provides continues ink recirculation around nozzles for reliable jetting and high firing frequencies
- High performance pumping chamber with sputtered PZT film actuator on thin silicon membrane offers high uniformity, wide range of drop volumes and gray scale capability
- Durable non-wetting coating for high reliability and ease of maintenance
- In combination with sputtered PZT, Si-MEMS further enhances the drop-size tuning capability and compact ink recirculation benefits of VersaDrop and RediJet technologies without compromising print rate speeds

Reducing Process Reliability Barriers to Increase Repeatable, Saleable Output

Si-MEMS Improves Industrial Reliability

While particular requirements vary widely, most industrial printing applications demand high printhead performance over time to achieve quality control, high productivity and ease of use. FUJIFILM Dimatix has conducted sustainability testing and specific studies on nozzle plate temperature changes during jetting, among other areas. The results show that Si-MEMS printheads deliver stable jetting conditions with high coverage and no sustainability issues throughout variations in printing and process variations for numerous industrial applications.

Sustainability testing is a process where testers observe printing with any percentage of active nozzles from 0% to 100%. Special printing patterns exercise the heads in ways similar to the intended application. These patterns also allow the system to observe the behavior of the printhead relative to straightness, weak or strong jets, or missing jets. In addition, testers observe productivity as a function of duty cycle. Repeated, rigorous testing determined that the Si-MEMS printheads remain robust throughout the printing process no matter what percentage of active nozzles are printing— even 100%. The temperature studies demonstrated that printhead temperatures stay stable throughout jetting duration, indicating that the heat from printhead electronics introduces negligible heat to the printhead during jetting.



This graph illustrates how Si-MEMS enabled SAMBA printheads maintain thermal stability at a very low level of heat throughout the printing process. This is a key printhead requirement for achieving long runs in industrial environments. The graph data shows that when SAMBA printheads are operated in maximum production capacity as required by textile applications, the temperature rises just 4/10 of one degree before reaching a thermal steady state after 30 seconds of jetting. The printhead maintains this thermal stability for the duration of the run.

Single Silicon Monolithic Structure Delivers Image Quality, Longer Head Life

One of the most important structural features of the MEMS-enabled jet design is how it eliminates PZT material from the path of often-aggressive jetting fluids while overcoming the source of mechanical crosstalk inherent in shared wall jet designs. The MEMS technology incorporates the PZT onto a thin barrier layer atop the ink channel to form the pumping chamber. In this way, the entire micro-array is fabricated as a single monolithic structure. This results in a highly efficient, high-resonant-frequency design with no contact between the jetted material and the PZT.

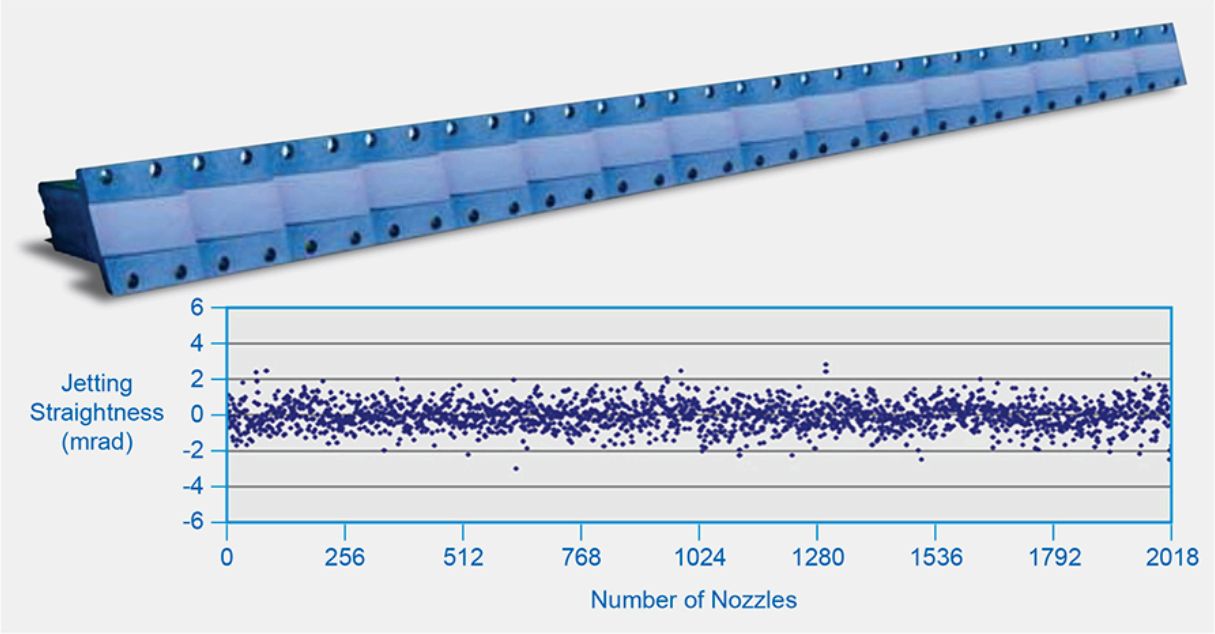
Si-MEMS technology enables fast jetting while enhancing the VersaDrop's™ waveform tuning capabilities. The high-performance

pumping chamber with sputtered PZT film actuator offers high uniformity and precision control over drop volume and velocity. By applying multiple pulses continuously to the PZT actuator, VersaDrop adjusts the individual jet drop volume. The MEMS-enabled drop ejector design further enhances VersaDrop's tunability; producing an even wider range of drop volumes, drop velocities, and fluid viscosities. The combination of Si-MEMS technology, sputtered PZT and VersaDrop delivers fast, high-accuracy, high image quality jetting and printheads with low voltage operation and longer service life.

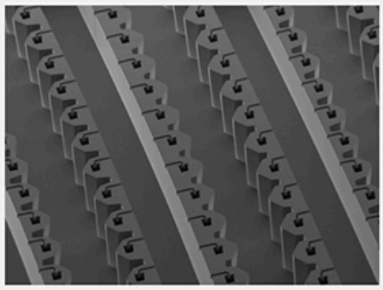
Developing Cost Effective Methods for Meeting Varied Application and Market Requirements

Si-MEMS Manufacturing Process Improves Precision, Supports Multiple Designs

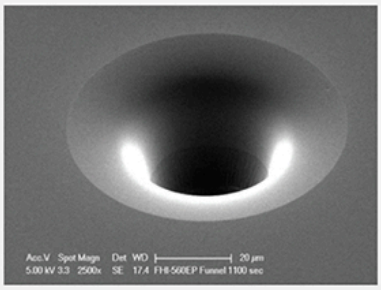
The microelectromechanical (MEMS) process used to fabricate and empower SAMBA's silicon-base ink channel in the vicinity of the nozzle is built on semiconductor lithography technology. The MEMS processing precision is extremely high, preventing variations in the fluid path properties of individual nozzles and pumping chambers while, as shown below, contributing to extremely small deviations in jet direction. Photolithographic control of MEMS features also supports a range of printhead designs from cartridges to large array heads.



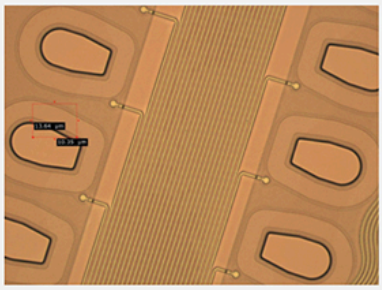
**Jet straightness @ 1200 dpi (21 µm) @ 1 mm standoff*



Deep Silicon Etch



Funnel Nozzle – Combination Etch



Plating – Electrode Traces

All Silicon Construction Enables Broader Ink Latitude

In contrast to "traditional" industrial inkjet printheads, the MEMS technology has no need for multilayer stacks of different materials connected with thin film epoxy adhesives. The Si-MEMS enabled monolithic silicon jetting structure is inert, which minimizes ink compatibility issues and makes these printheads chemically compatible with a much broader range of inks and functional fluids. The unique geometry of the Si-MEMS nozzle plate allows us to build wide bars in a single row, thus avoiding the need for stitching areas and reducing correlated adjustment efforts. The diminished need for adhesives in the all silicon construction diminishes opportunities for adhesion-related failures.

Si-MEMS also facilitates development of extremely small features for nozzle shapes and designs. These specialized shapes can aid in the control and release of ink (meniscus and drop breakoff), which is critical to creating well-formed drops and sustainable printing. By opening up the design space, Si-MEMS enabled nozzle shapes have also facilitated reliable jetting of the numerous new hybrid inks coming to market in recent years. These inks expand on current ink formulations with higher speeds, faster curing methods and better media interaction. With traditional nozzle shapes, hybrid inks have been difficult to jet.

The tables below illustrate some of the benefits of Si-MEMS enabled funnel-shaped nozzles. FUJIFILM Dimatix can produce funnel nozzles in any product line with silicon nozzle plates.

Table 1 demonstrates the benefit of a funnel-shaped nozzle compare to the standard nozzle geometry, namely, reduction of deviated jets during sustainability testing at a range of frequencies on the QS-10 product. This capability is especially helpful in opening the window for lower surface tension inks by increasing formulation latitude to meet certain application requirements. Funnel-shaped nozzles allowed jetting a 100%

duty cycle image up to 40 kHz with good reliability for all inks in the table (the maximum frequency evaluated). This was not achievable with the standard geometry for any of the inks listed in the table.

Printhead	Ink Type at 25c (cP/Dynes cm-1)	Nozzle Plate Wetting	Divergent or Crooked Jets on Print
Original Design Silicon Nozzleplate	24/22	🟢🟢🟢	🟡
	23/31	🟡	🟢🟢🟢
	19/24	🟢🟢🟢	🔴🔴
	25/35	🟡	🟢🟢🟢
Second Generation Added Funnel Nozzles	24/22	🟢🟢🟢	🟢🟢🟢
	23/31	🟡	🟢🟢🟢
	19/24	🟢🟢🟢	🟢🟢🟢
	25/35	🔴🔴	🟢🟢🟢
Latest Generation Added NWC to Funnel	24/22	🟢🟢🟢	🟢🟢🟢
	23/31	🟢🟢🟢	🟢🟢🟢
	19/24	🟢🟢🟢	🟢🟢🟢
	25/35	🟢🟢🟢	🟢🟢🟢

Score	Capability
🟢🟢🟢	Excellent
🔴🔴	Average
🟡	Minimum

This table illustrates how adding nozzle wetness coating (NWC) to a funnel-shaped printhead further increases robustness to a wide range of ink types.

Si-MEMS Enabled Products Expand Configuration Options

MEMS manufacturing provides the capability to vary printhead designs that can be integrated into different setups, from cartridges for lab systems to large width bars for production systems. The advanced silicon micro-machining process enables a level of miniaturization that integrates multiple functionalities onto a very small footprint. These

printheads are highly scalable, and may include many individual print modules aligned into a single, tightly integrated print bar. This allows print bars to accommodate industry standard press sizes serving diverse printing applications from multi-page signatures to traditionally analog applications. The ability to construct wide bars in a single row also enables construction of more compact print engines to minimize space requirements and improve color-to-color registration accuracy.

Success in single pass printing applications such as textile and corrugated sheet printing requires large print bars. For these applications, Si-MEMS enabled high nozzle packing density of 1200 nozzles per inch in combination with grayscale capabilities, has the built-in redundancy to deliver imaging models with high image resolution. At the same time, this redundancy eliminates visible artifacts such as streaks produced by transient missing or severely misdirected jets. The result is increased print quality and reduced frequency of head maintenance and replacement.

Manufacturing Excellence for a Large Product Mix

As a world leader in printhead production and design, FUJIFILM Dimatix is uniquely positioned to maximize the benefits of MEMS technology in the industrial printing arena. Already, the unparalleled performance of our piezo electric crystal and its integration with the MEMS process has produced numerous breakthroughs in production inkjet printing. Because we have our own MEMS fabrication site, we are able to develop skills, processes and techniques to optimize jet performance and regularly innovate new products. FUJIFILM Dimatix produces hundreds of thousands of printheads each year, the broadest offering in the industry. These include 75 printhead varieties spanning five product families. As the company increases the use of Si-MEMS in product development to address new and existing market needs, these product offerings will grow.

TYPICAL MONTHLY PRINTHEAD PRODUCT MIX

FUJIFILM Dimatix produces a multitude of different printheads each month. We offer different printhead configurations to meet to our customers' specific application needs, utilizing Si-MEMS technology in an increasing number of products. Printheads include variations in: native drop size, nozzle plate technology, recirculation, gray scale/binary, ink connections and frame.

Achieving Longer Runs in Industrial Environments

Si-MEMS Enhances RediJet™ Technology to Elevate Robustness and Ease of Use

All FUJIFILM Dimatix printheads feature RediJet technology, which includes several productivity-enhancing innovations. Chief among them are continuous ink recirculation directly behind the nozzle, specialized nozzle plate design and coatings, and waveforms tailored to specific fluids. RediJet allows printheads to be primed quickly and easily; this results in faster time to print and minimal ink waste. Printheads with RediJet can also jet heavier pigmented and faster drying fluids more easily and reliably than non-circulating printheads. FUJIFILM Dimatix test data demonstrates that for printheads without RediJet's recirculation capabilities drop mass can change up to 25% with highly pigmented inks over a three-month period. RediJet recirculation limits drop mass changes to within 2% over the same period. For faster drying inks, heads without recirculation show as many as 98% of jets dropping out in a three hour period; with RediJet, 0% jets were disabled over 64 hours of testing. RediJet enables longer jetting periods between maintenance, potentially lowering instances of required head replacement while extending machine uptime for better ROI.

Si-MEMS technology enhances RediJet's already impressive ink recirculation capabilities even further. The miniaturization and inert nature of the single monolithic jetting structure means more jets on a smaller footprint, plus thousands of ink passageways to facilitate the internal ink flow or recirculation. This can make it easier for printers to achieve application performance specs, especially for those using aqueous inks. Essentially, combining Si-MEMS and RediJet enables FUJIFILM Dimatix to manufacture and deliver economically viable printheads with an exceedingly rich set of features.

Conclusions

FUJIFILM Dimatix's revolutionary Si-MEMS technology allows printer manufacturers, ink developers and integrators to solve the inkjet printing industry's most pressing problems effectively, efficiently and economically. The silicon micro machining process allows fabrication of the printhead's entire microarray as a single silicon monolithic structure that integrates a number of critical functionalities in a very small footprint. Essential capabilities include productivity enhancements that enable longer runs in industrial environments; extensive image addressability options to expand each printer's current competitive capacity and market expansion potential; exceptional jetting reliability and reduced system errors for increased repeatable, saleable product output; and, enhanced RediJet and VersaDrop capabilities for cost effective methods of addressing the process requirements of varied applications and market segments.

Of course, the most complete solutions to the print industry's most compelling problems require teamwork. For its part, FUJIFILM Dimatix will continue to identify key market segments, study their unmet needs and requirements and use our research, technological capabilities, and our best in class technical support to provide robust products and solutions. We encourage customers, ink developers, OEMs and other global printer vendors to contact us at *fdmxmarketing@FUJIFILM.com* anytime with questions and ideas to further this process.