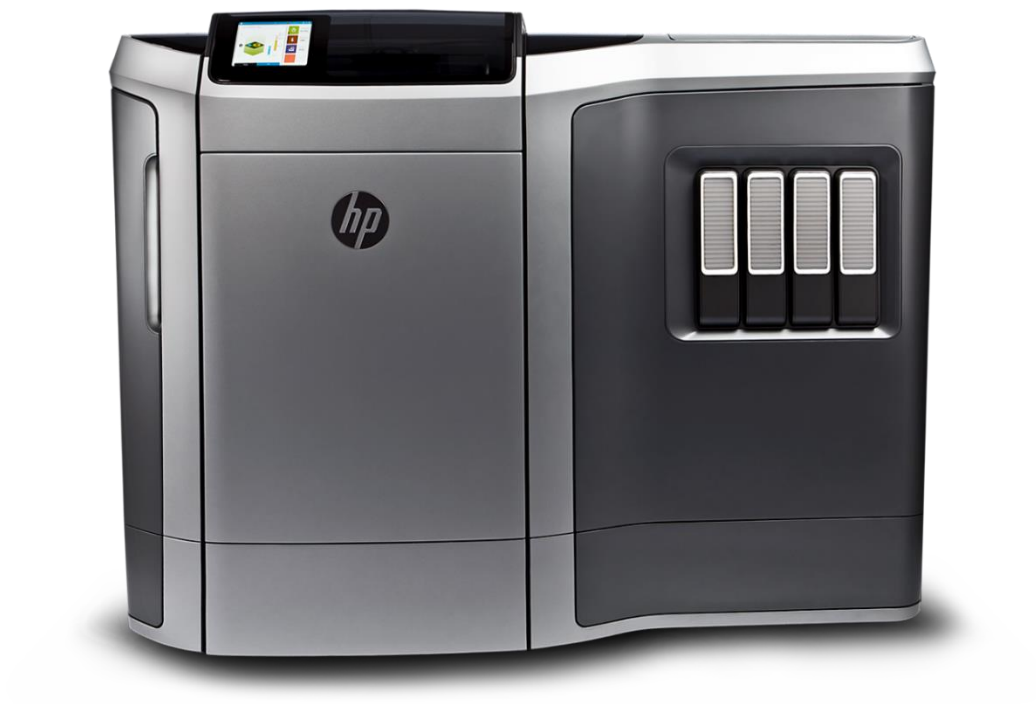
Technical white paper

HP Multi Jet Fusion™ technology

A disruptive 3D printing technology for a new era of manufacturing

The three-dimensional printing of objects and highly functional parts is becoming a reality. 3D printing offers the ability to produce—both rapidly and inexpensively—short runs or one-of-a-kind parts. In addition, 3D printing will revolutionize part manufacturing and the part distribution supply chain by offering local, on-demand production.



Conceptual industrial design for HP's first Multi Jet Fusion™ printer

Introduction

For more than 30 years, HP technologies have disrupted and led printing technologies in a wide range of markets. HP can soon change the way on-demand, high-value, complex parts and assemblies are manufactured with a new HP Multi Jet Fusion™ technology developed by HP and leveraging HP's deep assets in imaging and printing solutions.

HP's Multi Jet Fusion™ technology can offer new levels of part quality, 10 times faster[1] and at breakthrough economics[2] relative to similar systems in the marketplace today. These breakthroughs can power the widespread adoption of 3D design and hardware innovation, creating the opportunity for a digital transformation of manufacturing as widespread and profound as the way HP's Thermal Inkjet solutions changed traditional printing.

A conceptual design of HP's first Multi Jet Fusion™ product is shown above. As with other HP printing products, reliability, ease of use, versatility, and an end-to-end digital workflow are targeted as key performance attributes and customer benefits.

This technical white paper provides you with details on HP's Multi Jet Fusion™ process and HP's strategies to introduce a new era of digital manufacturing.

3D printing

In additive manufacturing technology—commonly called "3D printing"—objects are built from selective addition of material rather than by molding or by traditional methods of subtractive machining, where material is removed by cutting and grinding. Candidates for 3D printing include the functional and aesthetic components of machines, consumer and industrial products that are produced in short runs—typically less than 1000 units, and, in particular, highly customized and high-value products that may be one-of-a-kind.

Because 3D printing builds objects from cross-sections, complex parts—previously requiring multiple elements that were welded or assembled together—can now be built either as a monolithic structure or from fewer subcomponents. For example, some types of 3D printing can produce parts with hollow internal structures and complex 3D internal passages (for air or other fluids) that once required several sections to be fitted together with sealing surfaces between them.

HP's vision for 3D printing is the revolution of part manufacturing (how parts are made) and the part distribution supply chain (where and when parts are made). In the near term, affecting the creative process by making far more useful parts available to a much broader audience. And in the longer term, disrupting supply chains with 3D printing technology. In order for that disruption to occur, there must be significant changes in the economics of 3D printing and in the standards for maintaining quality.

3D printing technologies

Current 3D printing machines could be categorized in two groups, machines that produce smooth parts with good detail, and machines that produce parts with good strength.

Because of the materials that are currently used to produce smooth parts with good detail, this group of machines does not make parts with good strength. In contrast, because of point energy needed to produce parts with good strength, this group of machines does not produce smooth parts with detail.

Further, many existing processes fuse or cure the materials together at a focused point, for example using a focused laser beam to fuse, or using a single nozzle to extrude. This point processing limits the build speed of these technologies.

In the end, adoption of current technologies may be limited by imperfect parts, and slow productivity.

[1] Based on internal HP testing of part build time, for a set of representative parts in batch process comparing HP Thermal Inkjet based Multi Jet Fusion™ technology to the leading 3D printing technologies in the U.S.—selective laser sintering (SLS) and fused deposition modeling—as of October, 2014.
[2] HP Multi Jet Fusion™ technology leverages proprietary HP Thermal Inkjet technology, enabling lower cost systems that output similar quality to more expensive devices—such as selective laser sintering (SLS)—and speed.

HP Multi Jet Fusion™ technology

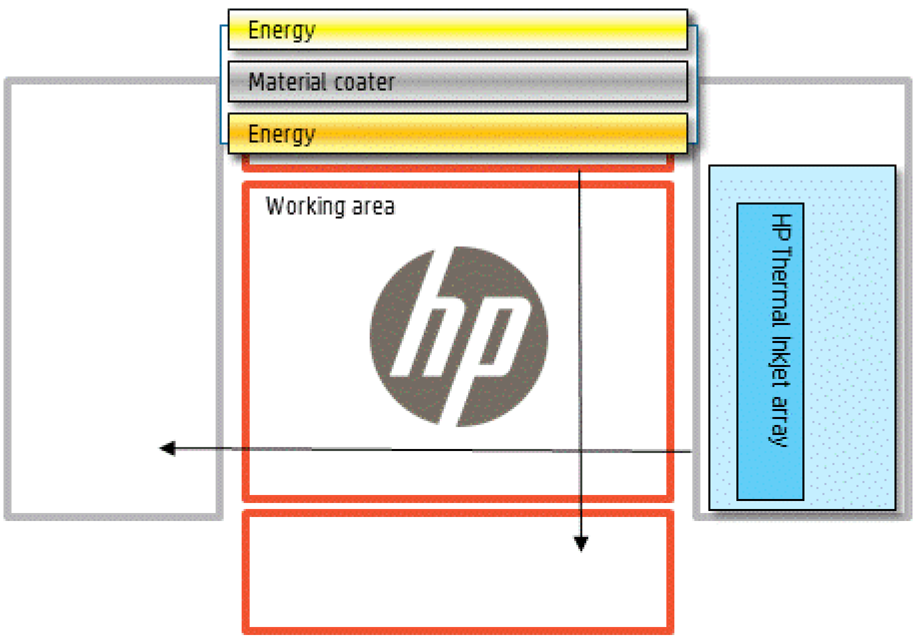
HP Multi Jet Fusion™ is a new technology built on decades of investment in HP's assets in inkjet printing, inks and jettable agents, precision low-cost mechanics, and material science. HP Multi Jet Fusion™ technology offers speed advantages as well as control over part and material properties beyond those found in other 3D printing processes.

HP Multi Jet Fusion™ technology—productivity through synchronous architecture

A number of designs for material and liquid delivery systems have been considered and evaluated during the investigation and development of the first HP Multi Jet Fusion™ technology products. Taking advantage of wide HP Thermal Inkjet arrays, an HP proprietary synchronous architecture was developed.

Figure 1 presents a schematic of the proprietary architecture used in HP Multi Jet Fusion™ technology. The dual-carriage system separates functions of writing and coating/fusing allowing each to be optimized for performance and productivity.

Figure 1 —Top view of HP's proprietary synchronous architecture



How it works

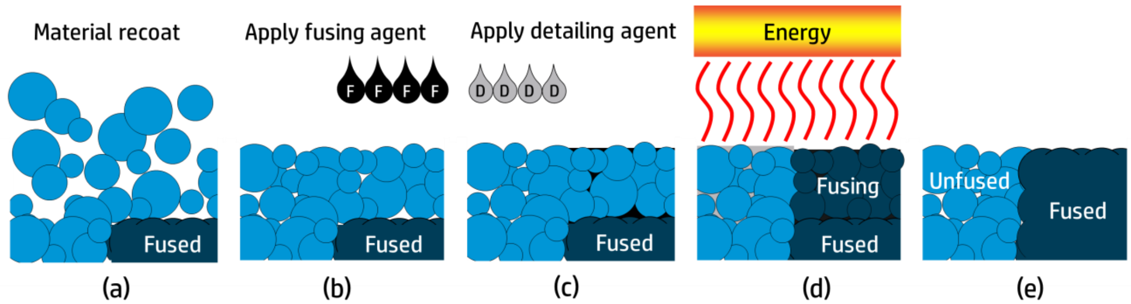
As with many 3D printing processes, HP Multi Jet Fusion™ technology starts by laying down a thin layer of material in the working area. Next, the carriage containing an HP Thermal Inkjet array passes from left-to-right, printing chemical agents across the full working area. The layering and energy processes are combined in a continuous pass of the second carriage from top-to-bottom. The process continues, layer-by-layer, until a complete part is formed. At each layer, the carriages change direction for optimum productivity.

Using HP Thermal Inkjet arrays with their high number of nozzles per inch, HP's proprietary synchronous architecture is capable of printing over 30 million drops per second across each inch of the working area.

HP Multi Jet Fusion™ technology—fusing and detailing agents

Of course, high productivity can lead to challenges in making quality parts. For parts to work, it's important to ensure that the material has been properly fused and that part edges are smooth and well-defined. To achieve quality at speed, HP invented a proprietary multi-agent printing process where the agents are applied by HP Thermal Inkjet arrays. The general process for HP's multi-agent printing process is described in detail in Figure 2.

Figure 2—Schematic of HP multi-agent printing process (cross-section views)



The material is recoated across the work area as shown schematically in Figure 2a.

In Figure 2b, a **fusing agent** ("F") is selectively applied where the particles are to fuse together, and in Figure 2c a **detailing agent** ("D") is selectively applied where the fusing action needs to be reduced or amplified. In this example, the detailing agent reduces fusing at the boundary to produce a part with sharp and smooth edges.

In Figure 2d, the work area is exposed to fusing energy, and Figure 2e shows the fused and unfused areas of the edge of a part in the work area.

The process is then repeated until a complete part has been formed.

Note that Figure 2 presents a general sequence of the steps in HP Multi Jet Fusion™ technology. In specific hardware implementations, the order of steps may be rearranged.

HP Multi Jet Fusion™ technology—transforming agents

HP Multi Jet Fusion™ technology can enable the full potential of 3D printing through the production of highly functional parts. Using HP Thermal Inkjet arrays, HP Multi Jet Fusion™ technology is built on HP's technical core competency of rapidly and accurately placing precise (and minute) quantities of multiple types of fluids. This gives HP Multi Jet Fusion™ technology a versatility and potential not found in other 3D printing technologies.

In addition to fusing and detailing agents, HP Multi Jet Fusion™ technology can employ additional agents to transform properties at each volumetric pixel (or voxel). These agents, **transforming agents**, deposited point-by-point across each cross-section, allow HP Multi Jet Fusion™ technology to produce parts that cannot be made by other methods.

For example, taking advantage of HP's in-depth knowledge of color science, HP Multi Jet Fusion™ printers could selectively print a different color at each voxel with agents containing cyan, magenta, yellow, or black (CMYK) colorants. Figure 3 shows parts produced in July 2014 by laboratory prototype HP Multi Jet Fusion™ technology machines. An example of some of the possibilities enabled by HP Multi Jet Fusion™ technology is the raised buttons of contrasting color to the base shown on the left in Figure 3. These features cannot be easily produced by conventional injection molding. In the future, millions of colors could be available to the user.

Figure 3—Color parts produced by HP Multi Jet Fusion™ technology with HP CMYK pigment inks

The long-term vision for HP Multi Jet Fusion™ technology is to create parts with controllably variable—even quite different—mechanical and physical properties within a single part or among separate parts processed simultaneously in the working area. This is accomplished by controlling the interaction of the fusing and detailing agents with each other, with the material to be fused, and with additional transforming agents.

Examples of controllably variable properties that are potentially achievable[3] with HP Multi Jet Fusion™ technology include:

- Accuracy and detail
- Surface roughness, textures, and friction
- Strength, elasticity, and other material characteristics
- Opacity or translucency (for plastics)
- Color (surface and embedded)
- Electrical and thermal conductivity

HP Multi Jet Fusion™ technology could enable design and manufacturing possibilities that surpass the limits of our imagination. That's what technology breakthroughs do.

HP Multi Jet Fusion™ technology—materials collaboration

HP's first commercial product using HP Multi Jet Fusion™ technology plans to build parts using production thermoplastic materials. Ultimately, ceramics and metals may be processed by HP Multi Jet Fusion™ technology, and these materials are under investigation by HP research engineers and scientists.

And because our technology uses HP's Thermal Inkjet arrays, HP Multi Jet Fusion™ technology has all the advantages that come with discretion of drops. By controlling the properties of each individual volumetric pixel (or voxel) through chemical agents and their interaction with build materials, HP's Multi Jet Fusion™ technology can enable parts production of designs that can't be made by other methods.

To realize this full potential of 3D printing, HP's vision is to develop a 3D printing platform designed to become an industry standard, and HP is inviting creative collaboration in materials for 3D printing.

These breakthroughs in materials and agent-material interactions can power the widespread adoption of 3D design and hardware innovation resulting in a digital transformation of manufacturing as widespread and profound as the way HP's Thermal Inkjet solutions changed traditional printing.

[3] These properties represent some of the potential of HP Multi Jet Fusion™ technology. As of the end of 2014, some of these properties have not been targeted for product development as they will not be included in the first generation of HP Multi Jet Fusion™ technology product(s).

3D design and 3D printing ecosystem collaboration

The STL file format, first developed in 1989, is still the de-facto data exchange standard for 3D printing processes in 2014. Most, if not all, of the major 3D CAD software packages provide tools for STL file conversion.

Shortcomings of the STL format in terms of processing time and object dimensional precision are a barrier for the production of complex, high-precision parts by new technologies such as HP Multi Jet Fusion™ technology. Furthermore, this format only allows geometric representation, so it does not allow voxel-by-voxel information to be carried from the CAD software to the printer. To realize the full potential of 3D printing, the roadmaps of 3D printers and 3D CAD software must be aligned, and the roadmaps must be accompanied by a change to a more information-rich file format.

HP is also inviting collaboration in software solutions that can help the world realize the full potential of 3D printing, designing and controlling a part's properties at each volumetric pixel (voxel).

By engaging the innovation potential of others, HP looks to lead the proliferation of full system solutions that can allow inventors to design and build assemblies that have form and function surpassing what can be imagined and manufactured today.

Future potential

Just as HP's traditional printing solutions evolved from inkjet-based desktop printers in the 1980s to HP's high-speed commercial and industrial printing solutions of today, HP has a roadmap for the development and implementation of Multi Jet Fusion™ technology beyond the first implementations. HP is investing in long-term R&D to enable scalable, modular 3D printing solutions with advanced materials and optimized 3D printing workflows.

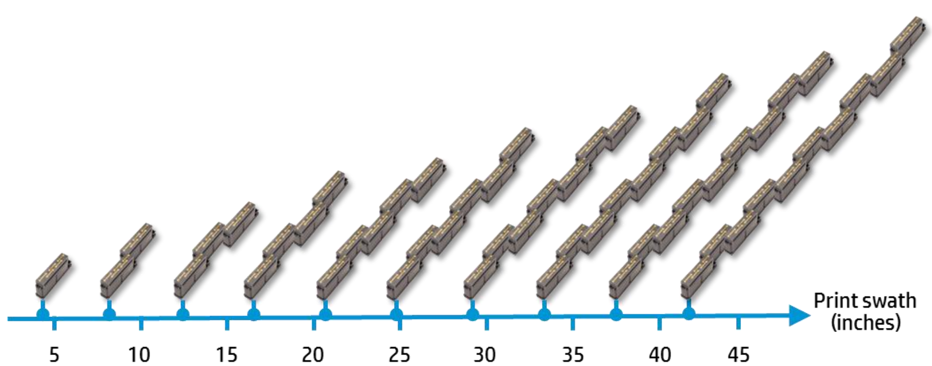
Scalable solutions

HP inkjet traditional printing solutions use modular and scalable HP Thermal Inkjet arrays. The modular design allows HP to build printers in various formats by stacking arrays—with their ink agent delivery systems and image-processing electronics—across the print swath. For example, the 4.25-inch HP Thermal Inkjet array used in HP Color Inkjet Web Presses supports presses for 22-, 26-, 30-, and 40-inch web formats using 5-, 6-, 7-, and 10-array modules, respectively. This is shown schematically in Figure 4.

Stacking HP Thermal Inkjet arrays *across the width of the scan axis* allows HP to build 3D printing solutions with working areas ranging from 4.25- to more than 40-inches wide.

Stacking HP Thermal Inkjet arrays *along the scan direction* provides more nozzles for increased writing speed and/or additional functionality from adding different types of liquid agents.

Figure 4—Scalable printing using HP Thermal Inkjet arrays



Summary

Based on HP's core competencies in precision, low-cost mechanics, precision metering and placement of liquid agents, high-volume manufacturing, and material science, HP is poised to introduce a disruptive 3D printing technology, HP's Multi Jet Fusion™ technology.

Comparison to commercially available 3D printing technologies has demonstrated clear advantages to HP Multi Jet Fusion™ technology and its material set to define new levels of part quality, high part functionality, at 10 times the build speed,[4] and at breakthrough economics.[5]

A key feature of HP Multi Jet Fusion™ technology is the potential to modify material properties to produce controlled-variability in mechanical and physical characteristics within a part. This can enable a host of new possibilities in the design and performance of parts built by 3D printing.

HP's entry into 3D printing includes realizing HP's vision of a 3D printing ecosystem with advanced user interfaces, software for 3D part creation and production, and 3D printers optimized to deliver an end-to-end experience with the potential to drive the digital transformation of manufacturing.

[4] Based on internal HP testing of part build time, for a set of representative parts in batch process comparing HP Thermal Inkjet based Multi Jet Fusion™ technology to the leading 3D printing technologies in the U.S.—selective laser sintering (SLS) and fused deposition modeling—as of October, 2014.
[5] HP Multi Jet Fusion™ technology leverages proprietary HP Thermal Inkjet technology, enabling lower cost systems that output similar quality to more expensive devices—such as selective laser sintering (SLS)—and speed.

implementing the separation transaction and restructuring plans; the resolution of pending investigations, claims and disputes; and other risks that are described in HP's Annual Report on Form 10-K for the fiscal year ended October 31, 2013, and HP's other filings with the Securities and Exchange Commission, including HP's Quarterly Report on Form 10-Q for the fiscal quarter ended July 31, 2014. HP assumes no obligation and does not intend to update these forward-looking statements.

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