Super Inkjet Printer Technology and Its Properties

***Dr. Kazuhiro Murata, **Dr. Kazuyuki Masuda**
***National Institute of Advanced Industrial Science and Technology,**
**** SIJ Technology , Inc.**

1. Introduction

Expectations are rapidly increasing on the field of printable electronics, or printed electronics, which applies printing systems to the creation of electronic elements. The majority of printers in use today, however, use inkjet technology. As shown in Figure 1, the smallest droplet size produced through the piezoelectric method or thermal method adopted in standard inkjet printers is on the scale of several pL, resulting in droplets of roughly 13μm in diameter. While this droplet size is sufficient for tonal control of photographic image quality, it is insufficient for the precision required of printable electronics applications. In other words, more precise dot sizes are desirable. While super inkjet (SIJ) technology is a form of inkjet technology, it allows for ultraprecision printing on the sub-micrometer order by producing ultra-microscopic droplets that are 1/1000th the size of conventional droplets.[1]

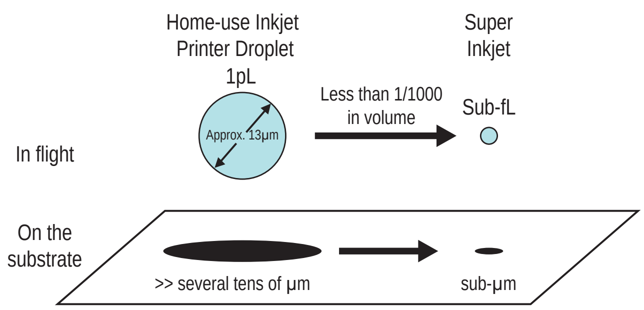

Figure 1 Standard Inkjet Droplet (left) and Super Inkjet Droplet (right) Size Comparison

2. Technological Development History

SIJ technology was developed by Dr. Kazuhiro Murata, one of the authors of this article, while at the National Institute of Advanced Industrial Science and Technology (AIST, originally the Electrotechnical Laboratory). The trigger for the development was that Dr. Murata wanted to produce a nanotechnology research and development tool for his own use. At the time, research into nanotechnology was still in the early stages, and even molecular wiring was simply made by spreading nanotubes randomly over fine electrode wiring; the resistivity of the sections that the nanotubes happened to fall on would then be measured. Even self-assembly was just electron microscope images of locations that happened to be well organized; these would then be shown in famous science journals. At the time, most research was simply nanoscience, but to turn this science into nanotechnology, Dr. Murata strongly felt that a method of connecting functions on the micro level with the macro level was necessary.

Nanotechnology can be called an extreme application technology for material substances. The materials in the world of the nanometer display clearer individual material characteristics than do atoms. At the same time, this is a size at which a range of diversity arises and a size which expresses many properties that are different from those at the macro scale. Moreover, materials referred to as nano-materials have functionality in and of themselves. In other words, these materials are the smallest units with functionality. Therefore, to integrate functions and link the nano-level functions to functions at the macro scale, it is necessary to artificially arrange the necessary functions at the necessary location at either the nanometer or micrometer scale.

Conventional microfabrication technology is represented by silicone technology. As this technology primarily evolved based on inorganic semiconductors, it is well suited to dealing with silicone and works as a methodology for producing functionality. On the other hand, from the perspective of nanotechnology, there are various materials subject to the methodology including organic, inorganic, and bio-materials. Nanotechnology does not produce functionality, though. Instead, it is a technology that takes advantage of the functions these materials already possess to the greatest extent possible by precisely arranging the required volume of material at the required location. In short, the research and development tool for nanotechnology discussed here came into being as SIJ. While the SIJ technology was developed in this way, there were also naturally many demands for applications other than use in the nanotechnology field. Currently, through SIJTechnology Inc., a venture company established by AIST to relay its technology, super inkjet technology is moving towards commercial viability.[2]

3. Technological Summary and Properties

Standard inkjet technology was originally designed for printing characters and figures. For this reason, the concept of printing with fine dot sizes that the human eye could not see was ignored. With the emergence of digital cameras, however, the need for high-precision printing if photographic quality images increased; along with this advent droplet sizes were increasingly reduced. Moreover, with the emerging trend of applying inkjet technology to commercial processes such as printable electronics, the need for fine, precise patterning applications has also grown. Figure 2 shows the changes over the past twenty years in the smallest ink discharge volume of commercially available inkjet printers.[3] Over the years, the inkjet droplet size has been reduced, but progress seems to have slowed at about a size of 1pL. The reasons for this slow down are that (i) with mechanical pressure, firing of fine droplets becomes difficult in principle because of problems such as pressure loss; and (ii) even if the liquid were able to be fired, air resistance causes the speed of the droplet to drop, which results in a significant reduction in the impact precision and in some cases impact itself becomes precarious. In contrast, the SIJ technology AIST developed allows for the firing of minute liquid volumes that are more than three degrees smaller than those fired by conventional inkjet technology. This small size is made possible by using an original electrostatic firing mechanism.

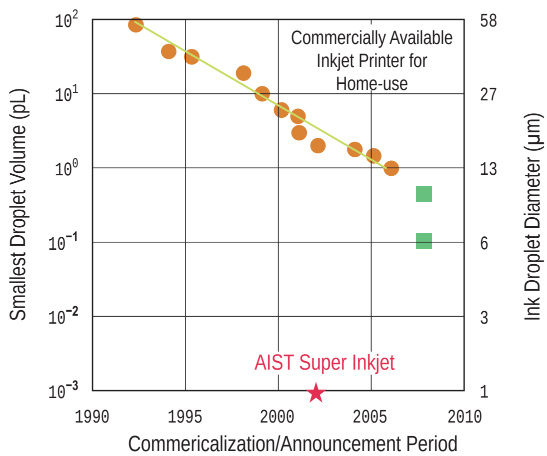

Figure 2 Inkjet Droplet Size Change by Year

The technology behind the electrostatic-based firing mechanism itself actually has a long history. The conventional technology for this approach prints onto a facing substrate by applying a high voltage of several thousand volts between the nozzles to produce liquid columns called Taylor Cones. SIJ technology, however, uses a low driving voltage of 150-400V, a degree less than the conventional technology; this technology can also print on substrates having insulation properties. As can be seen from the observation of the flying droplet in Photo 1, SIJ technology, which individually fires droplets, achieves a printing result with quite different aspects than piezoelectric inkjet or conventional electrostatic inkjet technology. This point will be elaborated on later.

Figure 3 shows a plot which maps the different printing technologies in terms of ink viscosity and printing resolution.[3] Standard inkjet technology is able to produce a minimum printing resolution of several tens of micrometers with an ink viscosity of under 10cps. On the other hand, the dispenser is a technology that can handle high-viscosity inks of several tens of thousands of cps to produce resolutions of several hundred micrometers to several millimeters. In contrast to these, SIJ technology can produce resolutions ranging from the sub-micrometer level to several tens of micrometers with ink viscosities of several tens of thousands of cps. AIST has also confirmed that the types of liquids SIJ technology can handle cover a wide range of solvents, including water-based and oil-based inks.

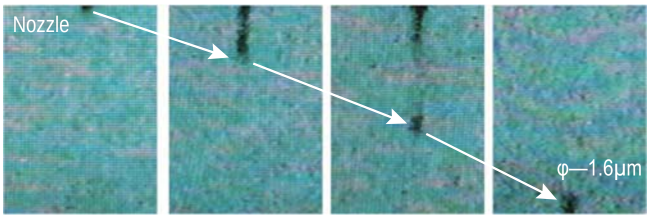

Photo 1 Observation of SIJ Droplet in Flight
(For photography purposes, the droplet size was set larger than the standard size fired)

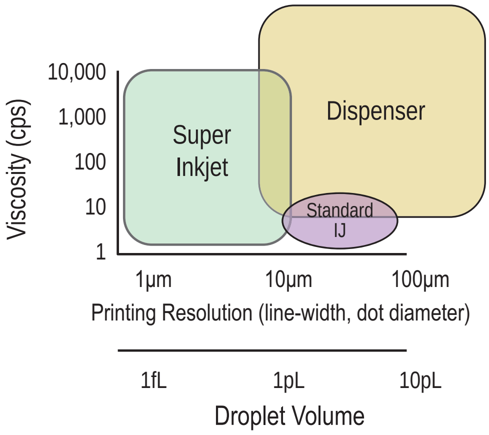

Figure 3 Printing Resolution, Viscosity, and Droplet Volume Comparison of Different Printing Technologies

4. SIJ Precision Printing

Photo 2 is an example of fine wiring patterns printed by an SIJ machine. These fine patterns on the micrometer order use various ink materials that are primarily composed of gold, silver, copper, and ITO. By using an SIJ machine, such precise drawing is possible with these inks. When using an inkjet printer to produce precise patterning on industrial substrates the greatest areas of concern are pattern deformation and wet spreading caused by surface tension. Thus, when using standard inkjet technology, it is common to treat the surface with a hydrophilic or liquid repellent prepattern through photolithography. With SIJ patterning, however, such pretreatment is unnecessary. This is because after impact, the fine droplets dry rapidly, increaseing their viscosity; as a result, there is extremely little pattern distortion on the substrate. This drying at the moment of impact is a result of the droplet size, not a result of substrate heating. Heating of the substrate invites the drying of the head and clogging; partial heating also complicates phenomena such as those which lower the viscosity of the ink on the substrate.

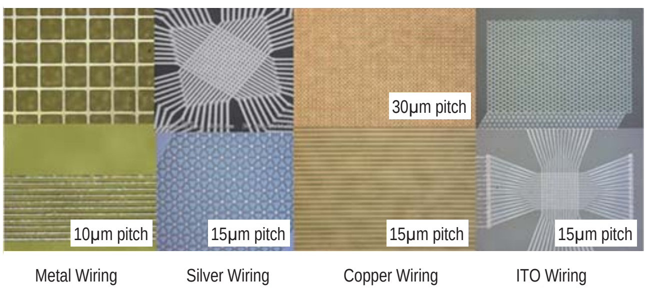

Photo 2 Wiring Examples Printed with SIJ and Various Microparticle Inks

Using SIJ technology allows one to form electronic circuit patterns and sub-micrometer wiring, such as that shown in Photo 3. In this way we anticipate that SIJ will also be applied to source-drain electrodes for organic transistors.

Using inkjet technology to form a solid film is typically difficult. As shown in Photo 4 (left), with standard inkjet droplet sizes, when patterning is conducted over a given area, the liquid on the substrate merges to form a single puddle, so surface tensions causes the corners to become rounded and the thickness distribution to be nonuniform. In contrast, Photo 4 (right) is an image of a solid film printed with SIJ technology; the edges of the pattern are sharp and the thickness is uniform. Through these properties, SIJ technology is able to form patterns without disarray regardless of the pattern size, as with the solid sections of the pad and fine electrode wires shown in the upper left hand image in Photo 3.

An example that further expands on the use of the rapid drying ability of microscopic droplets is using SIJ to form three-dimensional structures. SIJ is able to fire droplets on the same spot and by controlling the discharge volume of the SIJ, the fine droplets dry on impact. This rapid drying allows the SIJ to fire droplets one on top of another, making it possible to form three-dimensional forms as desired. Photo 5 (left) is an image of silver micro pumps that have been continuously

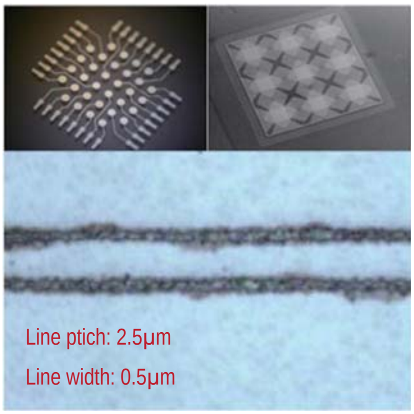

Photo 3 Examples of Electronic Circuit Wiring Printed with SIJ (top) and Ultra-fine Wiring Example (bottom) (Plate width: 0.5µm)

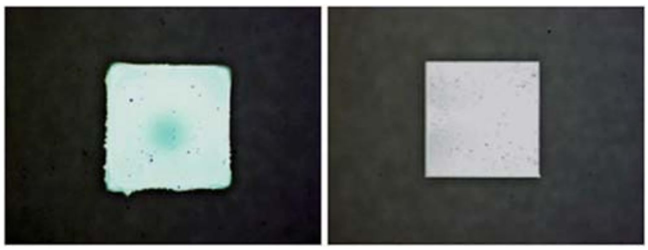

Photo 4 Comparison of Solid Film Formed with Picoliter Size Droplets (left) and Solid Film Formed with SIJ (right)

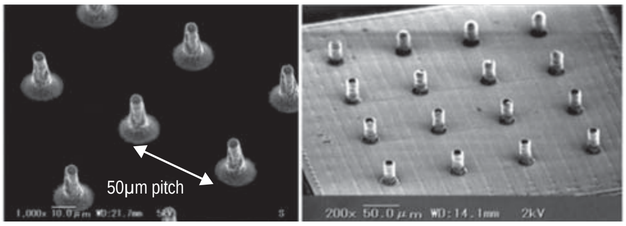

Photo 5 Micro Pump Array Formed with SIJ and Silver Nanoparticles (left) 3-dimensional Cylinder Structure Array (right)

formed in this way. The column forms that can be seen in Photo 5 (right) are cylinders with diameters of about 20μm, and were formed by rotating the nozzles as they were fired. In this way it is possible to form these types of simple three-dimensional structures at will by controlling the movement of the nozzle.

Typically, these types of three-dimensional structures require the process used to form MEMS and uses ion-etching to carve out the entire form to finally produce the desired three-dimensional structure. In contrast, SIJ can form these types of structures in normal environments without the need for special facilities, such as clean rooms, and can add on to the structures where necessary at a later time.

5. Commercially Available SIJ: "Sub Femt Ink Jet"

The "Sub Femt Ink Jet" is a commercially available version of the SIJ technology for research and development and is sold by SIJTechnology, Inc. Photo 6 is an image of this device, and the Table lists its main specs and properties. One of the properties other than fine, precision coating that must be mentioned here is the large number of inks which it can fire. With standard inkjet printers, the conditions for the types

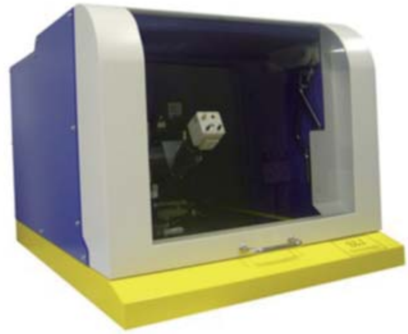

Photo 6 Commercially Available SIJ Printer for Research and Development (Sub Femt Ink Jet Printer)

of solvents, the required surface tensions, and ink viscosities are severe, so it is necessary to go through a process called "ink formulation." This process improves the ink so that the user will be able to fire the materials he or she wants to work with using standard inkjet technology. As a result of adjusting the ink and the given materials in various ways to make them useable with the inkjet printer, the materials lose their original properties. This approach is like putting the cart before the horse, so it is important that the materials initially have the physical ability to work with inkjet printing. In addition with the characteristics of small volume firing, it is possible to use these kinds of valuable inks effectively. Moreover, while microfabrication at the photolithographic level is possible in reduced space, this device is also specialized for research and development as it allows for immediate verification of an idea. SIJTechnology is furthering development on multi-nozzle devices and high-frequency so that after the user determines their idea's appropriateness to the inkjet process using this device, SIJTechnology will be able to support the shift to production facilities using specialized equipment.

Table Sub Femt Ink Jet Printer Specifications and Properties

Main Specifications	• Size: W610 X D800 X H545mm • Power Source: AC100V • Standard Printing Area: 50 X 50mm (larger area available by option)
Properties	• Firing Volume: 0.1fL (femtoliter)—10pL (picoliter), line width: 0.5μm—100μm • Applicable Viscosity Range: 0.5—10,000cps (unheated), unheated firing of high-viscosity fluids is possible • 3-dimensional structure (pillar) forming, high-precision impact positioning • Can fire a wide variety of fluids: conductive, insulative, resist, adhesive, protein, solvent-based, UV types, etc.
Usability	• Replaceable head and cartridge types, no need to clean complicated heads or supply systems • Usable with a small amount of fluid of 10μL for an extended period. Allows for effective use of rare and expensive materials • Ink refilling is simple, heads can be replaced in three minutes • Through numerical input using proprietary software, firing volumes (line width, dot size) can be quickly adjusted • 0.1μm resolution, repeated positioning of ±0.2μm for high-precision sample stage mounting • Real-time observation of video during coating • Good reproduction of position alignment using a CCD camera (θ correction function software)
Options	• Laser length measurement function (topographical data generation and feedback control)

6. Closing

This article introduced an inkjet technology which makes the smallest firing volumes in the world possible. Using this ground breaking inkjet technology which fires droplets having particle diameters on the sub-micrometer level, microfabrication on a level that conventionally requires a cleanroom becomes possible using an easy-to-use desktop device. Moreover, it allows for maskless and on-demand fabrication. While printable electronics is just the start, this printer is finding its way into biotech applications and various research laboratories. By using a minimal amount of resources and energy, this technology increases value and is a technology we hope will be used in Japan and around the world.

References

1. AIST Press Release: Developing "Microscopic Inkjet Technology" that Fires Fine Droplets 1/1000th the Size of Conventional Droplets
www.aist.go.jp/aist_j/press_release/pr2002/pr20020401/pr20020401.html

2. SIJTechnology, Inc. Homepage: www.sijtechnology.com

3. Fujiii, M. (2008): J. Image Soc. Jpn., Vol. 47, 241