The Top 10 Breakthroughs in Thermal Ink Jet Technology

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Introduction

1997 represents the 13th selling year for commercialized thermal ink jet products. The first embodiment of this technology to reach market was HP’s ThinkJet, released in 1984. The “decade plus” has seen many technical advances and the growth of a multi-billion dollar industry that now exceeds unit sales of any other technology for printing, including, the previous ubiquitous dot matrix impact printers.

My purpose today is to highlight the key technical breakthrough that enabled the growth of the technology and thus the industry. To begin with, thermal ink jet has two common embodiments, the top shooter pioneered by HewlettPackard, and the side shooter pioneered by Canon.

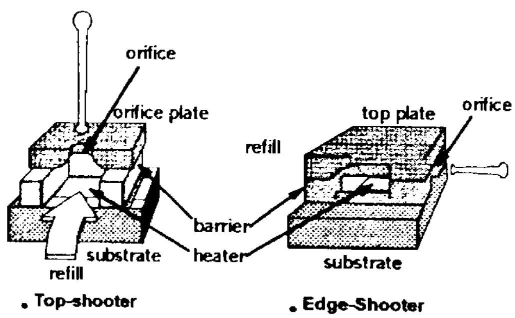

Illustration 1: Architecture

As you can see from illustrations 2 and 3, both architectures have many parts in common; the silicon thin film substrates, the formation of ink channels called barriers and a top layer to close off the channels.

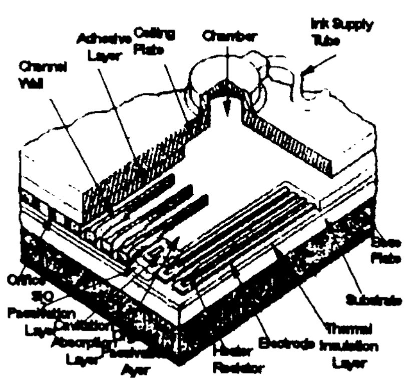

Illustration 2. Canon Printhead

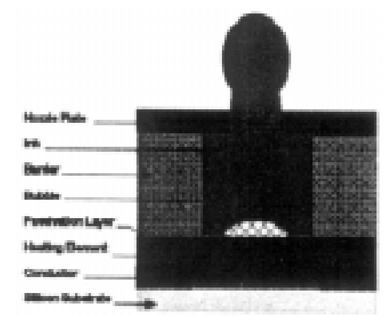

Illustration 3: Hewlett-Packard Printhead.

Both technological approaches needed many of the same types of breakthroughs and the parts taken in early research was common to both companies.

Here's how it unfolded.

Breakthrough 1: Vaporization Principle

The vaporization principle of fluid ejection is the fundamental breakthrough that enables any discussion of thermal ink jet. Without this, there would be no ink jet industry, as illustration 4 shows, the principle involves superheating a fluid to the point of bubble formation. This rapidly expanding bubble drives a drop of ink out of an exposed area (a nozzle) and onto the media to be printed. All of this happens on a rapid time scale (< 200 microseconds). Although a lot of work had to be done to develop a stable system, this fundamental invention that can be traced to experiments conducted by Lord Kelvin in 1867, made an industry possible. Although in concurrent development by HP and Canon, the original impulse, thermal patent was issued to Endo of Canon in 1978.

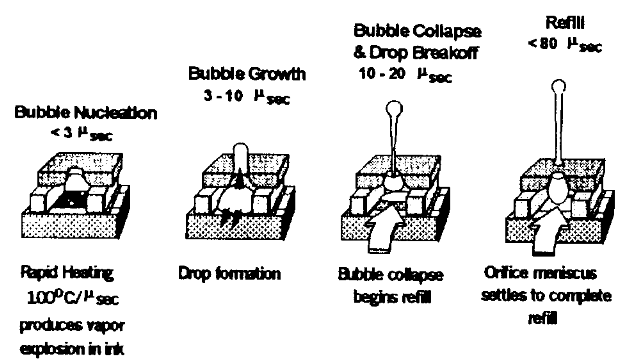

Illustration 4: Vaporization Principle of Drop Ejection: No moving parts except the ink itself

Breakthrough 2: Disposable Printheads Concept

This innovation was brought to market in 1984 by Hewlett-Packard. Inkjet technology implementations before this had a poor reputation for reliability and were considered "specialty" printers. The disposable head changed user perceptions and allowed TIJ to become a mainstream printing technology. By offering low cost, ($10) disposable heads with built-in ink supplies, HP enables a degree of customer acceptance that allowed the market to develop. This self-contained, printing unit also enabled low cost printers and this allowed the TIJ technology to rapidly replace dot matrix printers.

Several embodiments of disposable heads made their way to market: bladders (ThinkJet, 1985), foam (DeskJet, 1987, Spring Bags (DeskJet, 1993) and “snap on” supplies (Bubblejet~ 1992).

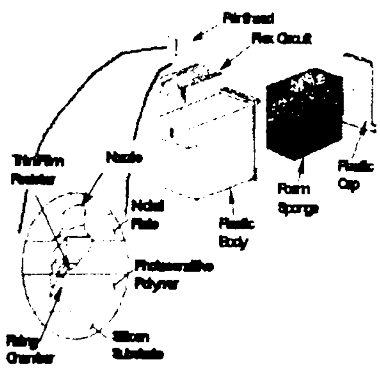

Illustration 5: Inside the Early Cartridge

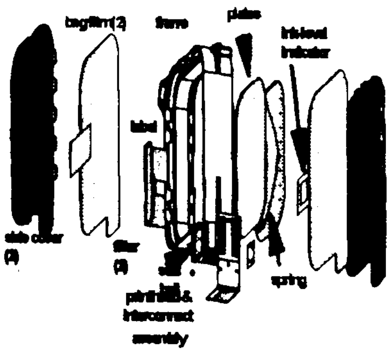

Illustration 6: Inside the Current Cartridge

Breakthrough 3: Simple Square Pulse Drives

Canon patented the use of simple square pulses to drive TIJ heads. This breakthrough produced extremely stable drop ejection and relatively easy energy control to the resistor. Early work involved using pre-curser and trigger pulses with the pre-curser being a long nonnucleating heat pulse to store energy and the trigger being a short high pulse to start the nucleation. This yielded inconsistent drop ejection and secondary jetting. The simple square pulse is an advantage over more complex pulse shapes required by piezo ink jet.

Today, a warming pulse is often used to preheat the ink to remove viscosity fluctuations that result from temperature changes.

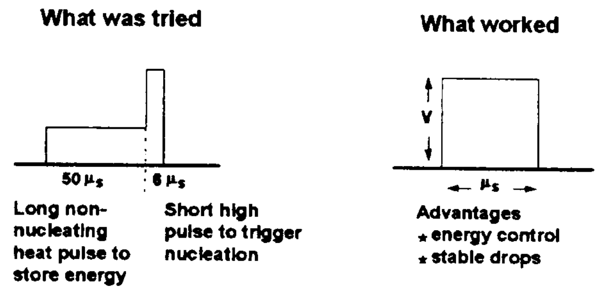

Illustration 7: Simple Square Pulse Drive

Breakthrough 4: Plain Paper Inks

Early TIJ embodiments required special papers to absorb the inks used in ThinkJet, PaintJet, BubbleJet. For TIJ to reach mainstream printing markets, it was vital to invent inks that maintained enough surface tension on ordinary office papers to form crisp, round dots.

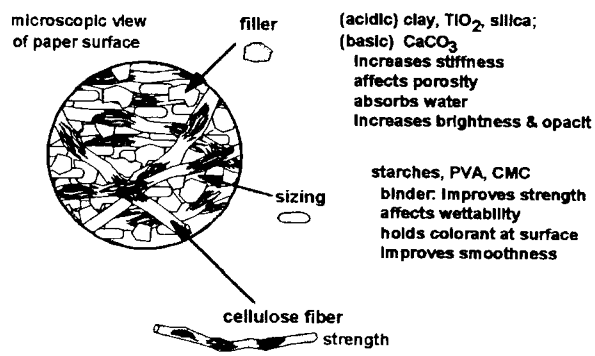

Illustration 8: Paper is a Complex Chemical System

High surface tension inks usually consist of water as the main ingredient, thus, an effect known as cockle occurs.

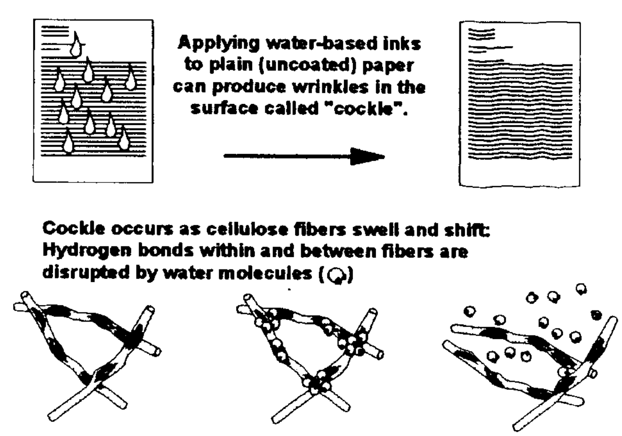

Illustration 9: Plain Paper Inks - Cockle

Ink systems must be engineered to overcome this cockle, especially for high density color systems. In addition, TIJ inks must be robust to high temperature and achieve many other characteristics as it interacts with paper.

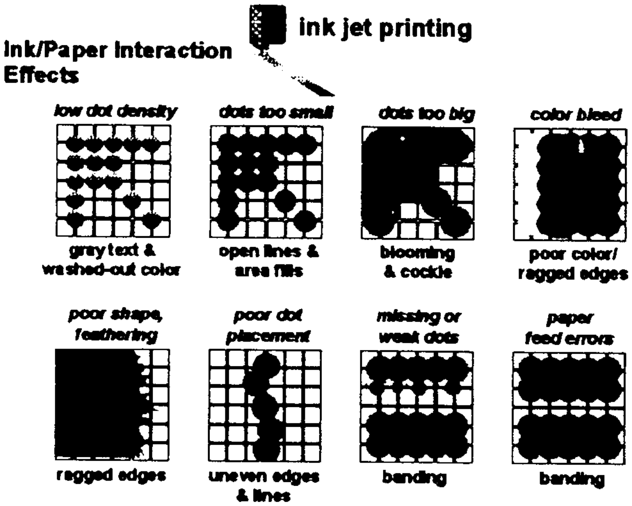

Illustration 10 : Ink/Media Effects

Although this area has lots of room for continued innovation, inks used in the HP DeskJet (1987) produced respectable text quality and allowed applications in the office.

Breakthrough 5: Multiplexed Addressing

Multiplexed addressing allowed printheads with "many" nozzles to be built with fewer electrical connections, thus, offering throughput advances at low cost. Today's best example is the DeskJet 1600 black pen that has 300 nozzles multiplexed to 64 pads that connect to the printer carriage. The breakthrough involved using standard tab circuit technology and forming a tab finger that is bonded to the silicon substrate of the printhead. This required a bonding pad be exposed on the reverse side of the tab and involved process innovation in tab circuit manufacturing.

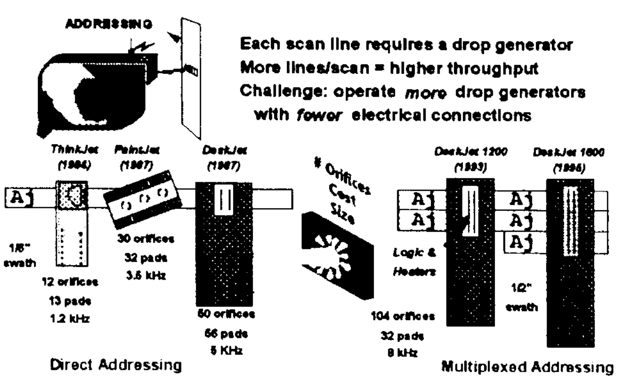

Illustration 11: Multiplexed Addressing A Key Challenge to Throughput and Cost

Breakthrough 6: Photo Imageable Barriers

Even though the architectures are very different, both Canon and HP used photo definable films to define ink channels on the surface of the printhead substrate. "Vacrel" (trademark of Dupont Co.) was the magic material that provided reasonable stable spacing with good adhesion characteristics. The amazing thing is that the imaging resolution required and delivered was far beyond the manufacturers specification for the intended application as a solder mask.

This breakthrough enables mass production using standard silicon wafer processing equipment for the disposable head concept.

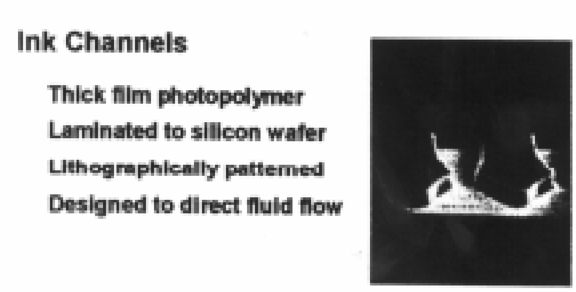

Illustration 12: Photo Imageable Barriers

Breakthrough 7: Nickel Orifice Plate

There were two major things enabled by the electroformed nickel orifice plate: mass production and high density head arrays. The advantage to a top shooter became evident when HP introduced the DeskJet printhead which contained a 2 row array containing 50 orifices. This continues to be a significant advantage over other layouts and over piezo.

In addition, the ability to electroform complete sheets of orifice plates, i.e., millions of holes, enabled mass production. Electroforming was also a developed technology with good process control, thus enabling HP to beat Canon to market since there were many process control problems in the edge shooter design.

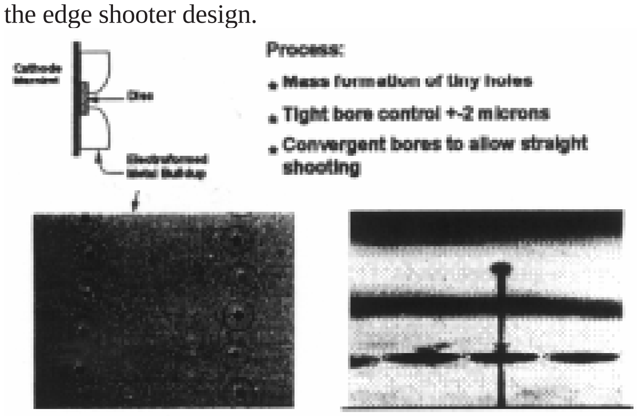

Illustration 12: Electroformed Orifice Plates.

Breakthrough 8: Logic Integration

The combination of TIJ thin films and an NMOS logic layer done in HP's DeskJet 1200 & 1600 series, allowed even larger head arrays to be built economically. The new circuitry allowed the use of standard FET's to direct the current to the nozzle to be fired, thus reducing the number of lines in both the head and the tab circuit.

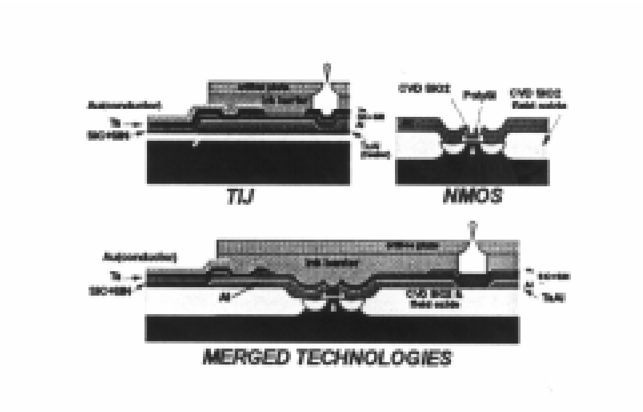

Illustration 13: Logic Integration Merging TIJ with Logic on Silicon

Breakthrough 9: The Use of Computer Simulation

I doubt that this technology could have come this far, this fast, without the use of computer modeling to develop and verify the fundamental concepts of TIJ printing to save countless prototype runs during development.

As a perusal through the IS&T proceeding will show, there are always one or two papers each conference on the discoveries made using computer simulation.

Within HP's many laboratories we use computer modeling to understand fluidic flow, to simulate ink/media interactions, and to understand thermal dissipation.

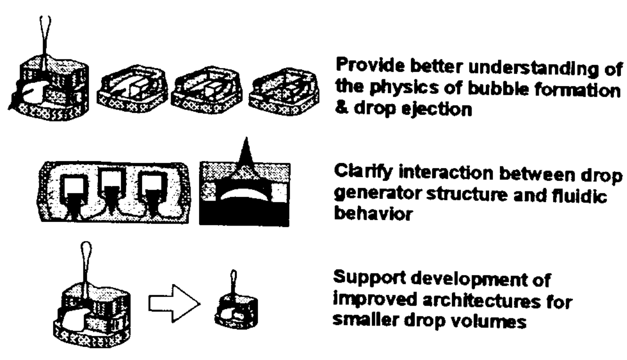

Illustration 14: Computer Simulation

Breakthrough 10: Photo Imaging Using Dilute Inks

1996 and 1997 will be known as the year of the photo printer. This has been made possible through the use of diluted inks to create a gray scale or "tone levels" to allow photo realistic printing. Dilute inks allow printing with fairly large volume drops to appear much less grainy than if the inks had not been diluted. The addition of the two extra inks also allowed many more colors to be printed, i.e., binary 4 color ink jet printers can produce 16 spot colors without halftoning, whereas 6 colors can give you 2500 spot colors using no more than 4 drops of any one ink and no more than 8 total. Dilute inks can, thus render more colors and can produce smoother gradients of these colors to mimic the effects of photos.

The technological implementations available today are all 6 ink systems because "tri-chamber" pens have been developed for normal 3 color binary printing. There is no technological reason why 9 or even 12 inks could not be used to produce even less granular output.

In addition, to careful selection of the dilution levels, rendering to eliminate common printing artifacts must be considered to obtain true "photo" quality. HP's newly announced PhotoSmart(!) printer has state-of-the-art media advance as well as many innovations in print masks and error diffusion. HP also developed a true photo stock print media for this printer. This system approach of optimizing printer, ink and media has yielded truly outstanding results and photos made from PhotoSmart using high quality input signals have been mistaken for silver halide output by representatives of film companies.

Future Breakthroughs

As we approach the 21st Century, there arise many more breakthroughs in TIJ technology that will yield even more business opportunity.

I can foresee the day when we totally displace the "print and distribute" paradigm and each of us will own ink jet printers that produce a customized morning paper, complete with photo images to match the best that magazines of today can deliver.

The 3 most important breakthroughs of the next decade are as follows:

1. Page wide arrays to enable very high speed output

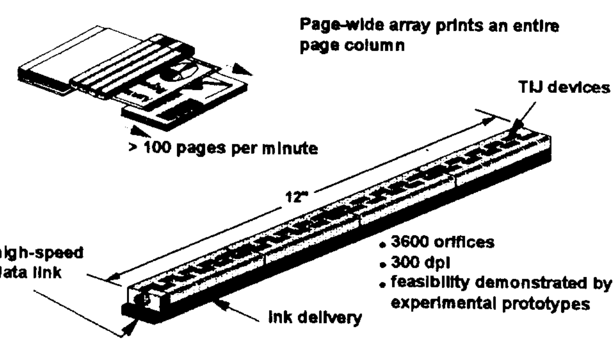

Illustration 15: Page Wide Arrays. High Throughput from a Large Array of Orifices.

2. Variable Dot size printing from a single nozzle. This will yield image quality with fewer nozzles and will put less ink on a page thus enabling faster dry times.

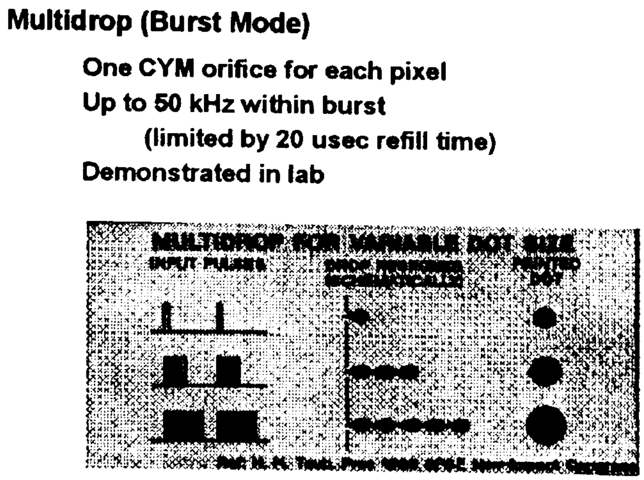

Illustration 16: Variable Drop Size

This technique requires very small drops that yield spot sizes just below the visual threshold (<40 um).

3. The third area of breakthrough is in inks. The world will surely benefit from an instant dry, permanent, jettable, non-cockling, safe, cheap and nonpatentable ink breakthrough. This area will require slow, steady, development. I work with many chemists and chemical companies and for every breakthrough on the key frontiers, there always seems to be new problems to solve. Inks can be said to be the “Achilles Heel” of thermal ink jet as opposed to piezo technology that doesn’t expose the ink to thermal degradation or viscosity changes as a function of heating. Breakthroughs on this frontier are severely needed, but the current set of printable medias illustrates the inherent flexibility of this technology. Thermal ink jet can print on paper, plastic films, CD’s, photo stock, vellums, and fabrics. If you can feed it in, you can print on it. Such flexible, fast-moving technology will continue to find applications and will continue to grow. I hope to be doing a “Top 20” in the early 2000’s.