High Speed High Image Quality Printing on Plain Paper Using Symmetrically Arranged Color Bubble Jet Print Head

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Abstract

To date, printer manufacturers have faced an ongoing dilemma: How to increase printing speed without sacrificing image quality, and vice versa. The new bi-directional printing system that utilizes the New "MicroFine Droplet Technology" has proposed to overcome the problem.

In conventional color printing, simple bi-direction printing leads to inconsistency in color produced between forward printing and backward printing due to the difference of color placement order within each printing direction. With the new bi-directional printing system, however, two groups of ink nozzle rows with cyan, magenta and yellow are arranged symmetrically to eliminate the inconsistency of color produced between different printing directions. The result of this work is Canon's S750 and i850 bubble jet printer. The key technologies that enabled this new nozzle arrangement without sacrificing the cost and the size of the print head will be described in this paper.

Introduction

Print quality of printouts from ink jet printer has been rapidly improved since 1990's. Today people can enjoy photo quality printing with the aid of popularization of the Internet and digital camera. However high quality printing requires smaller droplet and higher resolution, thus making more droplets to be needed to fill the same area. That leads to slower print time, which was the major problem left unsolved when people want to print in high quality.

The keys to high speed printing with serial scanning type printer are higher print frequency and wider print width. Print frequency is limited by the fluidic resistance inside the nozzle, especially when the nozzle is small. On the other hand, the manufacturing cost and precision requirement limits the number of the nozzles, the print width.

Another key to achieve high speed printing is to reduce the number of print scan. Most printer uses multi pass printing process to smooth the fluctuation of the drop size and the drop placement. In addition, higher nozzle resolution is needed to print in a single pass using small droplet. In 1999 Canon has introduced MicroFine Droplet Technology (MFDT) that is suitable for high accuracy printing with very small droplets from precisely fabricated nozzles.

Further improvement of the print speed can be realized by bi-directional printing. In bi-directional printing, printing is made during both in forward pass and return pass, so the non-printing time become minimum. But in case of multi color printing the color banding occurs by the difference of color lay down order between forward-pass and return-pass. In the case of the large format printer where printing speed is the critical issue, two sets of print heads are installed in one printer to eliminate the color difference in bi-directional printing. But it cannot be applied to the consumer products because of the reason such as the high cost of the system or the difficulty of precise alignment between two print heads.

New bi-directional Printing

The inconsistency in color produced between forward-pass and return-pass is explained in Fig. 1. When two inks of different colors are placed on the paper, the mixed color becomes tinged with the first color that is placed on the paper. For instance, when blue (magenta + cyan) is produced, the final color will differ slightly depending on which color is placed first. If magenta is first, it will tend to dominate the resulting blue. The same applies if cyan is first.

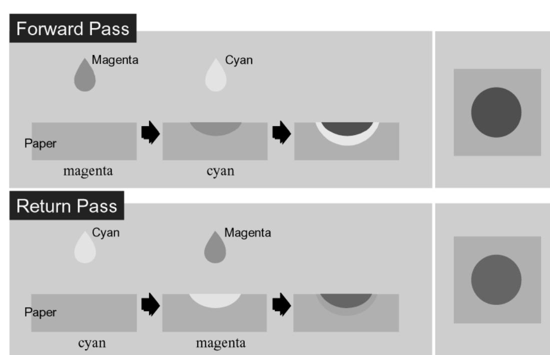

Figure 1. The Color Difference in Forward pass and Return pass

This behavior can be explained as follows. Surface of the paper is tinted by first color before the second color is placed. Since the surface fiber is already tinted by the first color, second color goes through the surface to deeper part of the paper, and the result color is dominated by the first color.

This problem can be solved by laying down the colors in same order in forward-pass printing and in return-pass printing. For example, to produce blue, place cyan, magenta, cyan, in that order. To bring this printing system into diffusive product, three major problems left to be solved.

They are:

1. Precise alignment between different color nozzles.
2. Low cost and minimum size print head
3. Color stability

To meet the first condition, all nozzles of three colors must be located on single silicon print chip. If they are placed on separate chips, they have to be aligned on the printer and that requires complicated system.

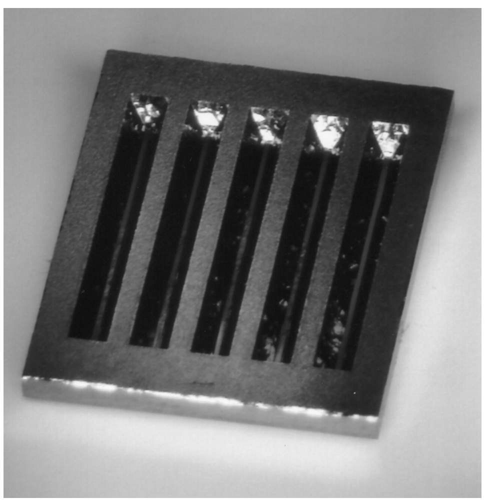

Figure 2. Back side of the print chip with five ink feed slots

To meet the second condition, several nozzle configurations have been examined, and the ideal configuration was found. On one side of the print chip surface, three sets of nozzles/heaters, driving circuits, ink feed slot, each for cyan, magenta, yellow, are placed. On the other side of the print chip surface, same sets are placed as the mirror image of the before mentioned sets. At the center of the print chip, two nozzle rows are located along the two long sides of the ink feed slot, which provides the yellow ink. The nozzle rows and ink feed slots for magenta ink is located on both sides of the central slot and the same applies to cyan nozzles. With this configuration, the increase of the print chip size only comes from the increase of ink slot number which become five, compared to three in conventional system. The width of the ink slot opening is minimized utilizing anisotropic etching (AE) of the silicon substrate. The shape of the slot is tapered and that allows lower fluidic resistance with narrow opening. The accuracy of the opening is very high.

In single-pass bi-directional printing, printing duty becomes higher and excess heat from heater and drive circuit tend to raise the print head temperature. With MFDT the variance of the droplet volume caused by temperature change can be reduced. Besides, the excess heat will be released through the ceramic base holding plate, which holds the multi-chip in high precision alignment. These improvements lead to stable color.

MicroFine Droplet Technology

Microfine Droplet Technology consists of ink ejection mechanism and nozzle manufacturing process

Ink Ejection Mechanism

To improve the print quality, the droplet volume must be reduced while keeping the droplet velocity high. Smaller the droplet becomes, effect from the resistance of the air grow bigger and tend to affect on accuracy of the drop placement.

In common ink jet printer, ink must be pushed out quickly and drew back quickly to eject small droplet with high velocity. The droplet volume is very sensitive to the parameters such as pushing pressure, pushing period, ink viscosity. So, when the droplet becomes smaller, it becomes difficult to keep the droplet volume stable.

To solve this problem, our ink ejection mechanism shown in Figure 3 separates the ink by the boiling bubble into the portion near the ejection opening and into the portion near the feeding channel. The ink portion near the ejection opening is ejected nearly completely so that the droplet volume is defined by geometric factor and will not be affected by the fluctuation of the bubble pressure nor by change in ink viscosity.

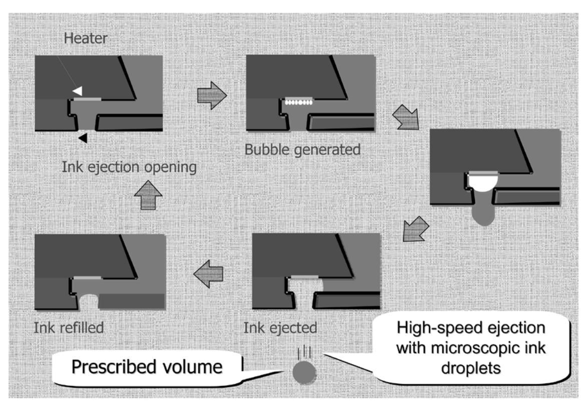

Figure 3. Ink ejection mechanism in MFDT

New Nozzle Manufacturing Process

In conventional nozzle manufacturing process, the nozzles are fabricated by attaching and adhering the heater substrate and the nozzle component. But there are intrinsic problems concerning the attaching process such as alignment accuracy and deformation during the attaching process and difference in thermal expanding coefficient. These problems could limit the print head size.

In the new manufacturing process, the nozzle is fabricated on the silicon wafer using photolithographic process without any attaching process. Full process is shown in Figure 4. First, the photosensitive resin a is coated and patterned on the silicon wafer. A heater and a driver is patterned onto the silicon wafer beforehand. Then the photosensitive resin b is coated both on the wafer and resin a. Then the ejection opening is patterned in resin b, the ink feed slot is etched through silicon wafer, and finally the resin a is removed to form the ink channel. The wafer is cut into each print chip and assembled in print head combined with other print chips as shown in Figure 5. Because the nozzle is made by photolithographic process, there is no need to change manufacturing apparatus when producing the different product.

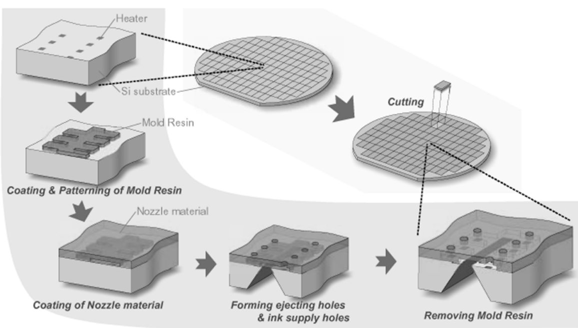

Figure 4. nozzle manufacturing process in MFDT

Permanent Type Print head

High speed printing helps people to get information more easily consuming more ink. There are two types in ink jet consumables; one is the disposable print head that includes the ink container, and the other is the ink container that can be detached from the print head. The latter one is preferred in running cost and environmental aspect, but it requires higher print head reliability. The major problem concerning the reliability is the durability of the heater. The mechanical stress caused by repetition of cavitation damage, the thermal stress and the chemical attack from the ink component, breaks the protection layer to help the ink reaches the heater element and leads to breakdown. In MFDT system, the negative pressure inside the bubble is released when the bubble communicates the air, so that no cavitation occurs. Besides, to minimize the thermal stress, the driving pulse is controlled according to the printing condition. The chemical attack, which is accelerated by higher temperature, can be reduced also.

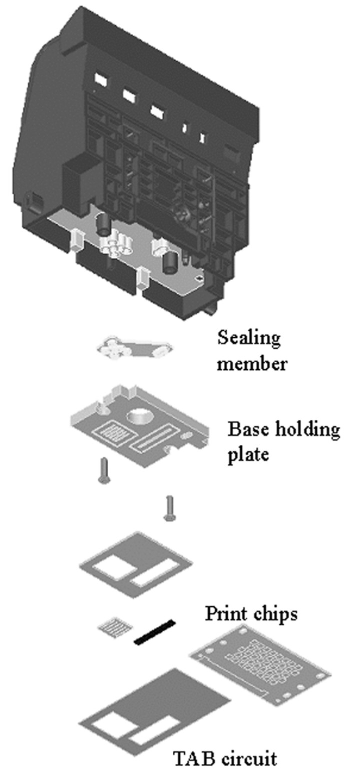

Figure 5. Print head assembly

Results

Symmetrically Arranged Color Bubble Jet Print Head (1st Generation)

The enlarged image of the color bubble jet chip used in S750 bubble jet printer is shown in Figure 8. There are five equally spaced elongated ink feed slots that leads the ink of three different colors from the back of the bubble jet chip. The nozzles for yellow ink are located along both long sides of the center slot. These nozzles are spaced 600dpi in each row with the total number of 128 nozzles in one row. The nozzles for magenta ink are located along the two slots next to the center slot, but along only on the outer long sides of the slots. Along the outer long sides of the two outermost slots, 256 nozzles for cyan ink are allocated in two rows. That makes the group of three nozzle rows for cyan, magenta, yellow, respectively, on the half area of the chip, and the group of three rows for yellow, magenta, cyan, respectively, on the other half of the chip. The nozzles in two groups are staggered to make the total nozzle resolution of 1200dpi. Every nozzle produces 5 pl droplet which is suitable for high quality printing both on the plain paper and the photo paper.

The spacing between two slots is 1.2mm and the dimension of the chip across the slots is 7.1mm, while the dimension along the slot is 8.7mm. Total number of the nozzles in one chip is 768 and the nozzle density is 12.4 nozzles/mm^2.

The electric circuit to provide driving pulse to the heater is located between two slots. To minimize the print chip size, the shift register for receiving print data from the printer cannot be prepared for all heaters. Instead, small set of shift registers just enough to receive print data for the heaters, which are activated at the same time, are prepared near the end of the nozzle row.

Besides the color print chip, another print chip that is used for black pigment printing is located on the same print head, as shown in Figure 10. The black chip is displaced from the color chip along the direction parallel to the nozzle rows so that some time elapses between when the black and other color inks hit the paper. Because less wettable ink property is preferred for the black ink to print sharp text, this time interval allows fixing of the black ink to prevent breeding between color ink and black ink.

The color measurement of the printouts from bi-directional printing system has been carried out and the results are shown in Figure 6. Printouts from new bi-directional printing system shows slight color difference between forward pass printing and return pass printing, and the amount of delta E is under 0.5, which is indistinguishable to human eye. On the other hand, printouts from conventional bi-directional printing system shows large amount of delta E especially in high print duty region.

The SEM image of the heater after print cycle of $1x10^9$ pulses is shown in Figure 7. No serious damage was found on the heater and the durability of this printing system has been proved.

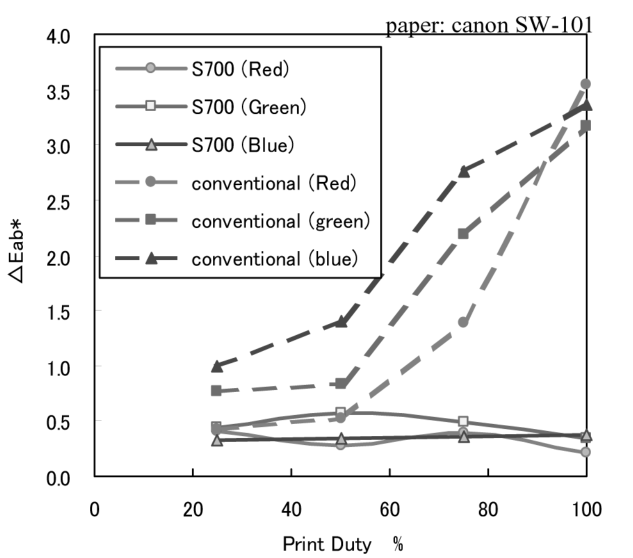

Figure 6. Color inconsistence in bi-directional printing

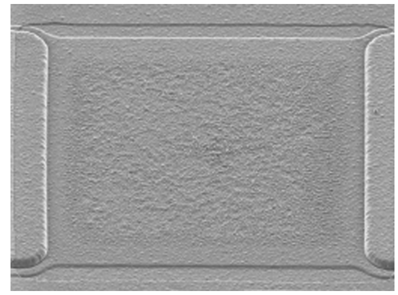

Figure 7. SEM image of the heater after the duration test

Symmetrically Arranged Color Bubble Jet Print Head (2nd Generation)

To improve the print quality further, the four rows of nozzles are added to each side of the four slots, where no nozzles were located before. These nozzles produce 2pl tiny droplets, and with the preexisting 5pl nozzles, higher quality printouts with less granularity and rich gradation have been achieved without sacrificing the print speed. Although the number of the nozzles has increased to 1280, the size of the print chip remains the same. The shape of the heater, formerly a square, has been changed to two parallel rectangles, which are connected in series. The resistance of the connected heaters has become four times larger compared to the single square heater and driving current has become half. Then the size of the driving transistor is reduced to make room for the new nozzle row. The resulting nozzle packing density is 20.7 nozzles/mm^2, the highest packing density at present. This print chip is used in the i850 bubble jet printer.

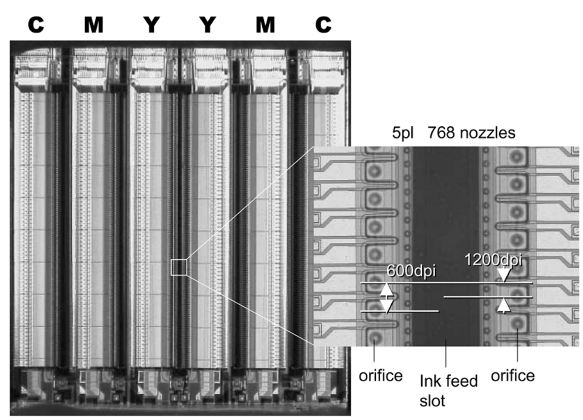

Figure 8. Symmetrically arranged color chip (1st generation)

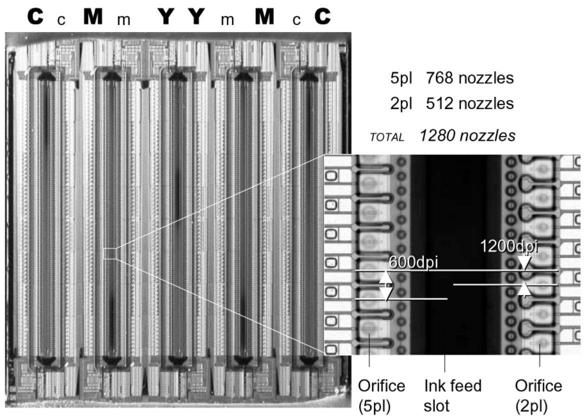

Figure 9. Symmetrically arranged color chip (2nd generation)

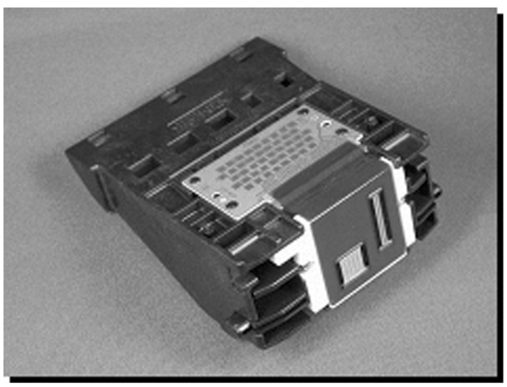

Figure 10. Print head for bi-directional printing (1st generation)

Figure 11. i850 Bubble Jet printer

Conclusion

The key factors to achieve single pass bi-directional printing in consumer product have been surveyed. MicroFine Droplet Technology enables symmetrical arrangement of the nozzle rows in single print chip without sacrificing the print chip size or print quality. Photographic color printing and sharp text and high speed color plain paper printing are all achieved in single i850 printer.

References

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Biographies

Mineo Kaneko received his B.S. and M.S.degree in Physics from Waseda University, Tokyo, Japan in 1982 and 1984. Subsequently he joined Canon and has been working on development of bubble jet head.

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