



Europäisches Patentamt
European Patent Office
Office européen des brevets



(11) Publication number:

0 433 556 A2

(12)

EUROPEAN PATENT APPLICATION

(21) Application number: **90116669.4**

(51) Int. Cl.⁵: **B41J 2/21**

(22) Date of filing: **30.08.90**

The title of the invention has been amended
(Guidelines for Examination in the EPO, A-III,
7.3).

(30) Priority: **21.12.89 US 454792**

(43) Date of publication of application:
26.06.91 Bulletin 91/26

(84) Designated Contracting States:
DE FR GB IT

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(54) **Process and apparatus for multi-color ink jet printing.**

(57) A process for multi-color ink jet printing and a color pen (10) and nozzle plate (12) for use therewith wherein nozzles are provided in adjacent spaced apart and vertically offset columns (30, 32, 34, 36) in the nozzle plate (12). Each column (30, 32, 34, 36) of nozzles (C, M, Y, K) is dedicated to a particular color of ink to be printed, and these columns (30, 32, 34, 36) of nozzles are passed in multiple, back and

forth passes across a print medium during an ink jet printing process. Using this process, the rate of ink deposition per printhead (10) pass across a print media will be minimized, and this enhances color uniformity and absorption by the print media, particularly in applications requiring large amounts of solid color area fill.

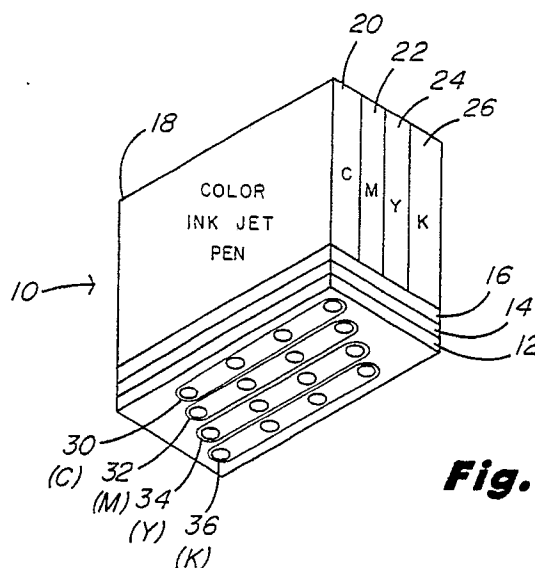


Fig. 1

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MULTI-COLOR INK JET PRINTING PROCESS AND COLOR PEN FOR MINIMIZING BANDING AND COLOR BLEED AND INK JET NOZZLE PLATE FOR USE THEREWITH

Technical Field

This invention relates generally to ink jet printing and more particularly to an improved multi-color dot-next-to-dot (DND) ink jet printing process for reducing banding and color bleed on printed media. This process serves to improve the overall ink jet print quality on the printed media.

Background Art

Substantial advances have been made in recent years in the field of color ink jet printing, and many of these advances relate to improving the print quality of the printed media, which include plain paper, special papers and various types of transparencies. Typical of these advancements in this art and technology are the various improvements and developments embodied in the Hewlett Packard "PAINTJET" printer first marketed in August 1987. These are described in some detail in the Hewlett Packard Journal, Volume 39, No. 4, August 1988, incorporated herein by reference.

In the field of multi-color ink jet printing, it is known to construct ink jet pens (also referred to as printheads) having nozzle or orifice groups of primary colors which are spaced adjacent to one another along a length dimension of the printhead and usually perpendicular to printhead motion. When the printhead is moved from side-to-side relative to an adjacent print medium, each color-dedicated nozzle group is fired simultaneously to produce a combined swath width having a total number of adjacent dot rows equal to the sum of the total number of nozzles in all of the nozzle groups. For example, in the three color thermal ink jet pen disclosed in U. S. Patent No. 4,812,859 issued to C. S. Chan et al, the three primary color nozzle groups of cyan, yellow, and magenta have sixteen nozzles in each group. Thus, three separate adjacent color bands totalling forty eight vertical dot rows may be produced when the pen is scanned from side-to-side across a print medium moving relative thereto. U. S. Patent No. 4,812,859 issued to C. S. Chan et al is assigned to the present assignee and is incorporated herein by reference.

Whereas the above identified thermal ink jet color pen disclosed in U. S. Patent No. 4,812,859 performs quite satisfactorily in most respects, there are nevertheless certain ink jet printing applications where the above Chan et al patented approach to multi-color printing may produce either banding or an undesirable color bleed or color mixing. All of

these undesirable characteristics in print quality may result from an insufficient drying of ink printed over a given surface area of print media. Thus, this insufficient drying of ink may produce banding in areas of solid color fill where the excessive printed ink volume deposited per unit area per unit of time produces an uneven drying of ink across the width of a printed swath. The ink will bead up at a small angle and in a smoothly rounded curvature across the width of the printed swath, and as a result of this phenomenon the ink at the swath edges will dry faster than the ink in the interior regions of the swath. This produces a lighter color at the swath edges, and this lighter color may be visible as a narrow lighter band extending horizontally across the swath. Hence, the term "banding" has been used in the ink jet printing arts to describe this undesirable characteristic in print quality.

In yet other printing applications, this same excess of ink volume per unit of printed area per unit of time may produce an undesirable color bleed or color mixing where different colors are printed in direct side-by-side contact to establish a two-color interface. If these two colors are printed either simultaneously or in sufficiently rapid succession, the wet ink at the two-color interface boundary will bleed laterally across this boundary and mix with the other different colored ink which may not be completely dried. This interaction will in turn produce an undesirable visual blurring at the two color interface boundary.

Both of the above problems of banding and color bleed are caused by the side-by-side swath printing over adjacent printed areas of print media with more ink volume per unit area per unit of time than will permit a sufficient and uniform drying of the ink. The print media, such as untreated plain paper, simply cannot sufficiently absorb the ink printed above a given printing speed in the swath area whose width is defined by a number of simultaneously printed adjacent dot rows, such as the sixteen (16) dot rows per swath arranged in the nozzle geometry of the adjacent color printheads in U. S. Patent No. 4,812,859 identified above.

Disclosure of Invention

A general object of this invention is to provide a novel alternative approach to multi-color ink jet printing and one operable in contrast to the simultaneous printing of adjacent swaths of different colors as described above. This novel approach is useful to either minimize or eliminate the above undesirable print characteristics of banding, color

mixing and color bleed. This is accomplished in accordance with the present invention by printing selected dot rows of ink horizontally across a predefined print area and in succession by ink ejected from separate, vertically offset nozzle columns in an ink jet pen or printhead. These selected dot rows may be printed either simultaneously or in rapid succession, or both, until all of the nozzles necessary to print a desired image or a solid area fill in the predefined area have been fired. The above nozzle firing sequence is such that never more than two adjacent dot rows are printed within the time it takes the nozzle plate to make one traverse or pass across one dimension of the predefined print area of the printed media.

In a preferred embodiment of the invention, the above process employs a novel nozzle plate geometry wherein a plurality of color-dedicated nozzle columns extend vertically along one dimension of the nozzle plate and perpendicular to the direction of nozzle plate horizontal motion described above. Each nozzle column is dedicated only to one color of ink such as the primary ink colors of cyan, yellow, magenta or black, and the nozzles in each column are offset or staggered vertically with respect to nozzles in each adjacent column by a distance equal to one dot row. Thus, the selective firing of these nozzles during a horizontal traverse or pass across a print medium is always such that never more than two vertically spaced adjacent dot rows are deposited either simultaneously or in rapid succession. This operation continues as the nozzle plate completes all of its multiple passes over a single print area necessary to print a desired image or solid area fill over the above predefined area. The vertical dimension of this predefined area is substantially coextensive with the vertical dimension of the nozzle plate.

Another object of this invention is to provide a new and improved color printing process of the type described which minimizes banding and color bleed without any sacrifice in printing speed.

Another object of this invention is to provide a new and improved process for ink jet color printing which improves ink drying uniformity over a given printed area and thereby improves the overall print quality of color images which are printed within that area.

Another object is to provide a new and improved process of the type described which is particularly useful for improving color print quality on less-absorbent types of print media having a low drying factor, such as certain grades of office papers and transparencies.

A feature of this invention is the provision of a multi-color ink jet printing process of the type described wherein full speed, multiple pass printing is utilized to achieve an increased average drying

time between different color dots printed adjacent to one another on a print medium.

Another feature of this invention is the provision of a novel nozzle plate geometry for use in a multi-color ink jet pen, including spaced apart columns of color-dedicated nozzles therein. The nozzles in each column are vertically offset with respect to nozzles in adjacent columns by a predetermined distance equal to one dot row, and means are provided for fluidically coupling separate colors of ink to each of the columns of nozzles, respectively.

Another feature of this invention is the provision of a new and improved process of the type described which produces a horizontal ink drying boundary between only two solid filled printed rows, so that the total drying area never exceeds an allowable maximum of two dot rows in total width.

Another feature of this invention is the provision of a color ink jet pen for generating graphic color pixels which are interlaced at the dot row level. This minimizes the visible effects of scan line errors on the printed medium.

Another feature of this invention is the provision of an improved nozzle plate geometry which is operative in combination with currently available print algorithms for the purpose of reducing color bleed.

The above objects, features and various related advantages of this invention will become better understood with reference to the following description of the accompanying drawings.

Brief Description of the Drawings

Figure 1 is an isometric view of a multi-color ink jet pen having an ink ejection orifice plate whose nozzle arrangement is configured in accordance with the present invention.

Figure 2 is an enlarged plan view of the orifice plate of Figure 1.

Figures 3A through 3D are schematic plan views illustrating the nozzle firing sequence used on four successive passes of the orifice plate over a given print area. These successive passes are used to form adjacent upper and lower solid fill areas of cyan, C, and magenta, M, and these solid fill areas define a single horizontal cyan/magenta interface boundary.

Figures 4A through 4D are schematic plan views illustrating the nozzle firing sequence used on four successive passes of the orifice plate over a given print area to form solid fill areas of cyan, C, magenta, M, yellow, Y, and black, K, as shown in Figure 4D. These C, M, Y, and K solid fill areas are separated in Figure 4D by both vertical and horizontal interface boundaries located between the

solid fill areas as shown.

Description of the Preferred Embodiment

Referring now to Figure 1, there is shown a three-color and black ink jet pen which is generally designated as 10 and includes an orifice or nozzle plate 12 which is secured to an adjacent barrier layer 14. The barrier layer 14 is typically formed of a polymer material such as the well-known insulator VACREL and is secured to a thin film resistor (TFR) substrate 16 whose general construction and architecture are well-known in the art. In the field of thermal ink jet printing, these thin film resistor substrates 16 may be constructed to have photolithographically defined heater resistors (not shown) which are aligned with ink ejection openings in the orifice plate 12, and such construction is described in more detail in the above identified Hewlett Packard Journal, Volume 39, No. 4, August 1988; in the Hewlett Packard Journal, Volume 36, No. 5, May 1985, and also in the above identified U. S. Patent No. 4,812,859 issued to C. S. Chan et al. These ink ejection openings are referred to alternatively in this field of ink jet printing as either "orifices" or "nozzles".

The TFR substrate 16 is in turn mounted on one surface of a pen body housing 18 having separate ink storage compartments 20, 22, 24, and 26 therein containing, respectively, the primary ink colors of cyan, magenta, yellow, and black. This ink storage may be accomplished using a polyurethane foam material in the compartments 20, 22, 24, and 26, and processes used for foam storage in this type of pen body housing construction are disclosed, for example, in U. S. Patent No. 4,771,295 issued to Jeffrey P. Baker et al, assigned to the present assignee and incorporated herein by reference.

The orifice plate 12 of Figure 1, also shown in the enlarged plan view of Figure 2, includes four columns of nozzles 30, 32, 34, and 36 which are fluidically isolated one from another and fed, respectively, with the four primary ink colors of cyan, magenta, yellow, and black as indicated in these figures. Each of these nozzle columns is separated from an adjacent column by a width dimension W as indicated in Figure 2 and is offset vertically from an adjacent nozzle position by a length dimension D. Thus, the center-to-center spacing between adjacent nozzles of like color in any of the nozzle columns 30, 32, 34, and 36 is a dimension of four (4) times the number of nozzle columns, or 4D as indicated in Figure 2. Using a print density of 300 dots per inch (DPI), the dimension D will be approximately 0.0033 inches (1/300"), and W will range typically from 25D to 32D.

Referring now in succession to Figures 3A

through 3D, the orifice plate or nozzle plate 12 is first moved as shown in Figure 3A from a first or starting position 40 on the right hand side of the figure to a second position 42 and in the direction of the arrow shown to form a dot pattern 44. The nozzles 46, 48, 50, 52, and 54 in the nozzle plate 12 are fired simultaneously to form, respectively, the two upper cyan dot rows 56 and 58 and the three lower magenta dot rows 60, 62, and 64 as indicated.

In preparation for making a second left-to-right pass as shown in Figure 3B, the nozzle plate 12 is first moved vertically down by a distance of one dot row with respect to the print media, D, and then the nozzles 46, 50, 52, and 54 are fired simultaneously to add the dot rows 66, 68, 70, and 72, respectively, in the resulting dot pattern 74.

Referring now to Figure 3C, the cyan nozzle 46 has been moved down one dot row in this next scan to form the added row 76 of cyan dots; a magenta nozzle 50 adds the lower magenta dot row 78; the magenta nozzle 52 also adds the magenta dot row 80, and the magenta nozzle 54 adds the lowermost magenta dot row 82 in the resulting dot pattern 84.

Finally, in the fourth and final left-to-right pass shown in Figure 3D, these same cyan and magenta nozzles 46, 50, 52, and 54 are simultaneously fired on the left-to-right movement of the nozzle plate 12 indicated by the direction of the arrow to add the cyan dot row 86 and the three magenta dot rows 88, 90, and 92. This pass completes the solid color area fill pattern indicated generally at 94 in Figure 3D and defining a single cyan/magenta interface boundary 96. Thus, it can be seen that the entire solid color area fill pattern 94 in Figure 3D was printed by the ink jet pen of Figures 1 and 2 above without ever printing more than two adjacent and touching dot rows either simultaneously or in rapid succession.

Referring now to Figures 4A through 4D, these figures illustrate an ink jet printing process operative in accordance with the present invention wherein four solid fill areas of cyan, magenta, yellow, and black are formed adjacent to one another and define both vertical and horizontal interface boundaries of separation therebetween. In Figure 4A, an orifice plate 12' is moved from the right hand position 98 in the direction of the arrow to the left hand position 100. During this pass, the nozzles 102, 104, 106, 108, 110, 112, 114, 116, and 118 on the nozzle plate 12' are fired to form, respectively, the cyan row 120, the yellow row 122, the cyan row 124, the yellow row 126, the black row 128, the magenta row 130, the black row 132, the magenta row 134, and the black row 136.

On the next pass of the orifice plate 12' from the left hand position to the right hand position

shown in Figure 4B, the cyan row 138 is formed using the cyan nozzle 102 simultaneously with the formation of the black row 140, the cyan row 142, the yellow row 144, the magenta row 146, the black row 148, the magenta row 150, and the black row 152. These latter seven rows are formed, respectively, with the firing of nozzles 104, 106, 110, 112, 114, 116, and 118 in the nozzle plate 12'.

In the next right-to-left pass shown in Figure 4C, the cyan, yellow, magenta, and black rows 154, 156, 158, 160, 162, 164, 166, and 168 are added as the nozzle plate 12' is first moved one dot row lower than the position shown in Figure 4B and then across the scan area between nozzle positions 98 and 100.

In the final horizontal pass of this embodiment, the solid area color fill pattern 170 shown in Figure 4D is completed with the left-to-right printhead motion shown therein to add the completing rows 172, 174, 176, 178, 180, and 182 of the pattern 170. During this fourth right-to-left pass shown in Figure 4D, the nozzles 102, 104, 107, 110, 112, 114, 116 and 118 are fired to form the two upper solid fill areas of cyan and yellow and the two lower solid fill areas of magenta and black. As seen in this pattern 170, the upper blocks of cyan and yellow are separated from the lower blocks of magenta and black by a continuous horizontal C/M and Y/K color boundary and by a continuous vertical C/Y and M/K color boundary. The formation of these solid area color fill patterns and their associated C/M and Y/K horizontal color boundaries never requires the deposition of more than two adjacent rows of dots either simultaneously or in rapid succession on a single pass of an ink jet pen. Also, it will be appreciated from the above description of Figures 4A-4D that in forming the continuous C/Y and M/K vertical color boundary, two horizontal adjacent dots of different colors are never deposited either simultaneously or in rapid succession during a single printing pass.

Using this process for forming solid primary color fill areas, the volume of ink deposited per unit area per unit of time is approximately one fourth of the ink drop volume deposited per unit area per unit of time of any known prior art processes. In general, it can be seen that in accordance with the present invention, the deposited ink density is inversely proportional to the number of unique color nozzle columns used.

Various modifications may be made in the above described embodiments without departing from the scope of this invention. For example, the number of nozzles in each nozzle column can be increased substantially, and the size, shape, dimensions and spacing of these nozzles may be widely varied depending upon the particular ink jet printing application in which this ink jet pen is

used. In addition, this pen may be modified for use with ink ejection transducers (e.g. piezoelectric types) other than thermal ink jet heater resistors and for use with ink storage methods other than foam storage. An example of another suitable ink storage method and pen body construction is the capillary ink feed system disclosed in U. S. Patent No. 4,791,438 issued to Gary E. Hanson et al, assigned to the present assignee and incorporated herein by reference.

It should also be understood that the present invention is not limited to the use of a single nozzle plate and a corresponding single ink jet pen, but instead may employ, for example, two or more side-by-side pens which have the same adjacent nozzle column relationship as is described above. In such an alternative construction, it may be preferred to use a three color pen together with a separate black pen in a side-by-side arrangement on a common pen carriage member. In this alternative application, two or more separate pens may be replaced independently of each other, and this is particularly desirable where disposable ink jet pens are used in printing applications with a large disparity in ink color demands.

It should further be understood that the present invention is both compatible and useful with super pixelling printing processes where dot-next-to-dot (DND) printing is used for the mixing of colors in a matrix of pixels which themselves constitute super pixels. These matrices may for example be equally sectioned two-by-two or three-by-three super pixels where the divided sections of the super pixel matrix are selectively printed with different colors of ink to form a secondary color fill. For example, the quadrants of a two-by-two super pixel may be selectively printed with the primary ink colors of magenta/yellow, cyan/yellow, and cyan/magenta to form the secondary colors of red, green and blue, respectively. Such super pixelling processes are described, for example, in copending application Serial No. 278,881 of C. S. Chan et al and also in copending application Serial No. (PD 189070) of Jeffrey L. Trask, both assigned to the present assignee and incorporated herein by reference.

Therefore, while the present invention teaches a novel approach to both time and spatial separation of ink drop (dot) deposition on the printed media, it may be further combined with super pixelling techniques such as those described in the above-identified Trask and Chan et al copending and coassigned applications to add even a further dimension of time and spatial separation to the ink dot deposition process. This combination serves to even further enhance the ink drying uniformity and print quality of the printed media.

Finally, it will also be understood and appreciated that the present invention is also compatible

and useful with dot-on-dot (DOD) printing processes, since many of these types of DOD processes require that a first-deposited drop in a given printed area be dry or substantially dry before a second drop is deposited directly thereon. Since single pass drops deposited in accordance with the present invention have a large spatial distribution, the overall drying time is maximized and color bleed is minimized. This feature makes it possible to decrease the time between the first pass drops to the second pass of overlay drops, thereby permitting an increased DOD printing speed.

Claims

1. A process for ink jet color printing which includes the steps of:
 - a. printing dot rows (58, 60) of ink across a predefined area of media to be printed, and
 - b. completing a dot row scan (Figures 3A - 3D and 4A - 4D) of said predefined area without printing in excess of two dot rows either simultaneously or successively across said predefined area.
2. The process defined in claim 1 which includes providing an ink jet nozzle plate (12) having a plurality of color-dedicated columns (30, 32, 34, 36) of nozzles (C, M, Y, K) therein, with each nozzle column being vertically offset with respect to each adjacent column by a distance (D) equal to the width dimension of one dot row.
3. A process for color ink jet printing which includes ejecting ink to print a plurality of dot rows from a plurality of vertically offset color-dedicated nozzle columns (30, 32, 34, 36) in a nozzle plate (12) which defines one dimension of a first color printed area, and then moving said nozzle plate (12) relative to print media by a predetermined distance, and printing a second area of media adjacent to said first area.
4. The process defined in claim 3 which includes offsetting each nozzle column with respect to each adjacent column by an amount equal to a width dimension (D) of one of said dot rows.
5. A process for scanning and printing a predefined area of print media with an ink jet printhead (10), which includes the steps of:
 - a. arranging color-dedicated nozzles in a printhead nozzle plate (12) in adjacent columns (30, 32, 34, 36) of nozzles (C, M, Y, K) which are offset along a length dimension of said nozzle plate by the width (D) of one row of dots to be printed horizontally

across said predefined area, and
 b. selectively firing said nozzles (C, M, Y, K) to thereby print a plurality of dot rows without depositing in excess of two adjacent dot rows (58, 60) either simultaneously or in succession.

6. A multi-color ink jet printing process which comprises the steps of:
 - a. providing ink ejection nozzles (C, M, Y, K) in adjacent spaced apart columns (30, 32, 34, 36) for receiving, respectively, different colors of ink in each column,
 - b. offsetting said nozzles vertically in each column (30, 32, 34, 36) by a predetermined distance (D),
 - c. moving said columns (30, 32, 34, 36) of nozzles a predetermined number of passes with respect to an adjacent print medium, and
 - d. firing a percentage of the nozzles in each column (30, 32, 34, 36) in a sequence that deposits a maximum of two adjacent dot rows (58, 60) either simultaneously or in succession, whereby the printed areas of ink drying on the printed media and defining a boundary between adjacent dot rows is limited to two dot rows (58, 60).
7. The process defined in claim 6 which further includes firing nozzles (C, M, Y, K) in each of said columns (30, 32, 34, 36) in a predetermined spaced vertical sequence therein.
8. A method for multi-color ink jet printing which comprises:
 - a. providing adjacent columns (30, 32, 34, 36) of ink ejection nozzles (C, M, Y, K) for each color, respectively, of a plurality of colors to be printed,
 - b. moving said ink ejection nozzles relative to an adjacent print medium (Figures 3A - 3D and 4A - 4D), and
 - c. firing only a predetermined percentage of nozzles (C, M, Y, K) within each column (30, 32, 34, 36) on each successive pass of said nozzles across a horizontal dimension of a print scan area until all nozzles required for firing have been fired upon completion of all passes necessary to print a desired color image on said scan area.
9. An ink jet pen (10) for use in multi-color ink jet printers, including:
 - a. a nozzle plate having spaced apart columns (30, 32, 34, 36) of nozzles (C, M, Y, K) therein, with nozzles in each column being offset vertically with respect to nozzles

in each adjacent column by a predetermined distance (D), and

b. means (20, 22, 24, 26) fluidically coupled to each of said columns (30, 32, 34, 36) for supplying each column of nozzles with a separate color of ink.

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10. The pen defined in claim 9 which further includes:

a. a support housing (18) having fluidically isolated ink storage compartments (20, 22, 24, 26) therein, and

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b. a thin film resistor substrate member (16) disposed between said support housing (18) and said nozzle plate (12) for providing firing energy to said nozzle columns (30, 32, 34, and 36) and propelling ink from said ink storage compartments (20, 22, 24, 26) to said nozzle columns (30, 32, 34, 36) respectively.

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11. The pen defined in claim 10 wherein said pen includes ink storage compartments (20, 22, 24, 26) of cyan, magenta, yellow, and black ink coupled, respectively, to vertically offset dedicated ink ejection nozzle columns (30, 32, 34, 36) of cyan, magenta, yellow, and black arranged along a length dimension of said nozzle plate (12).

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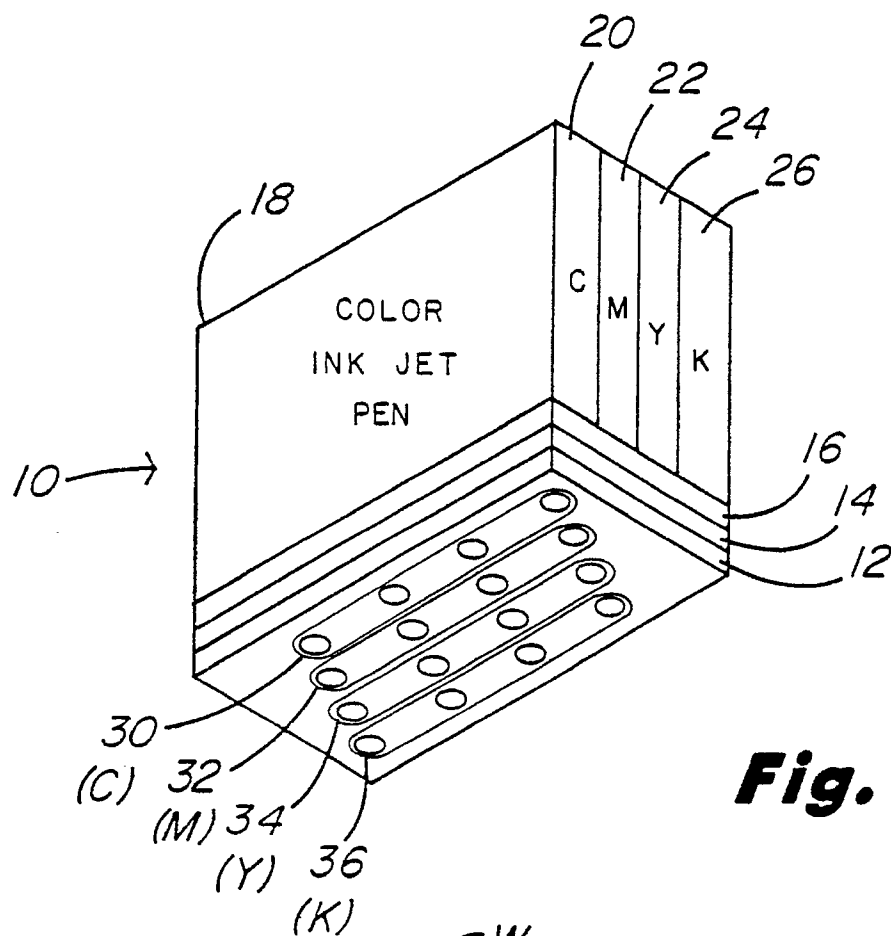


Fig. 1

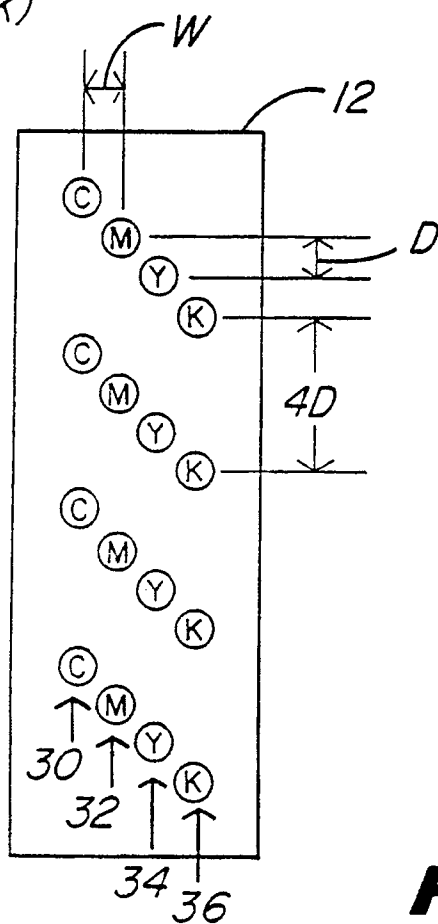


Fig. 2

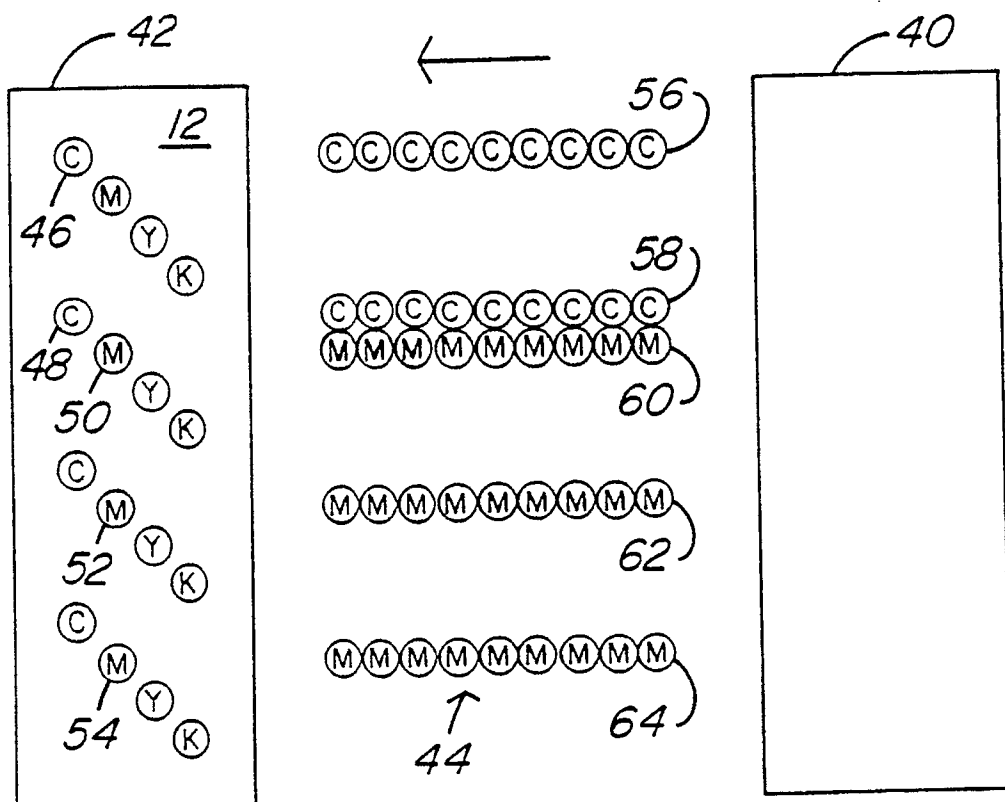


Fig. 3A

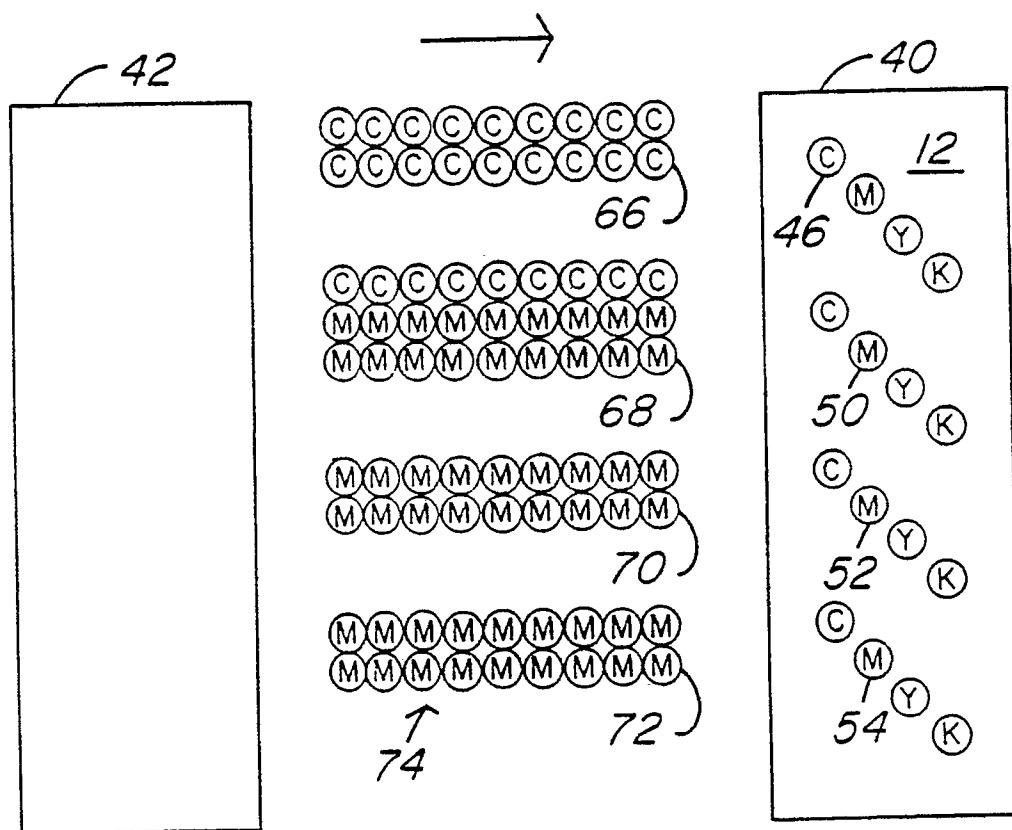


Fig. 3B

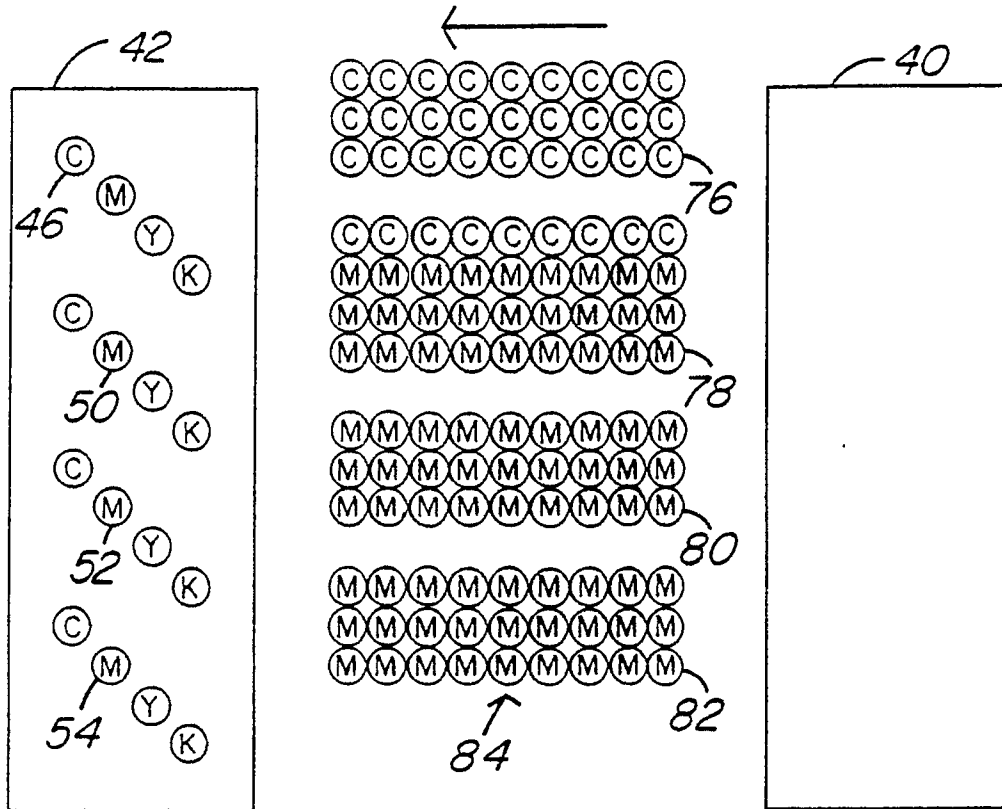


Fig. 3C

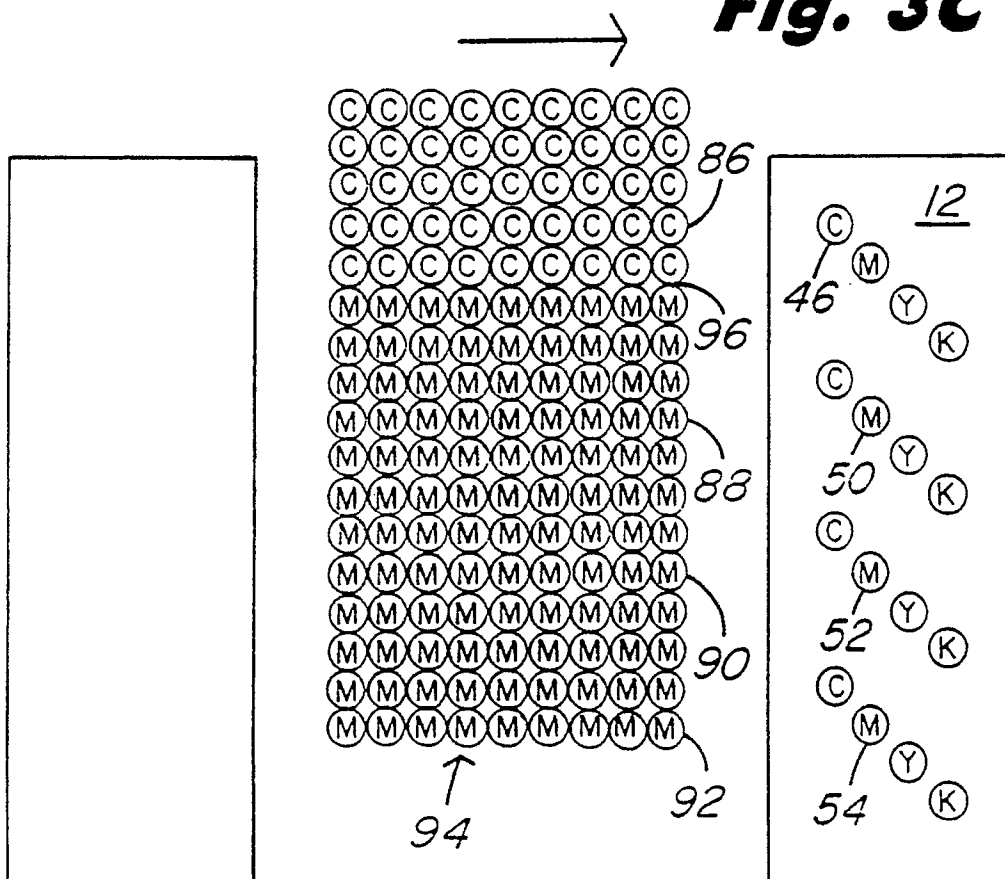


Fig. 3D

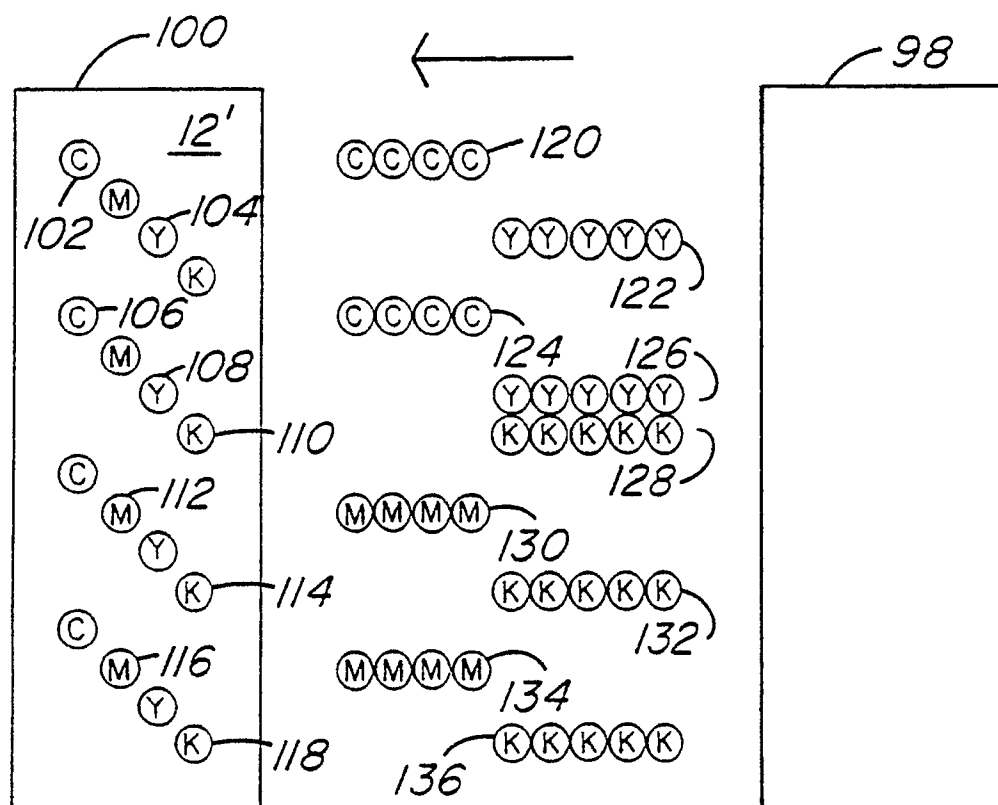


Fig. 4A

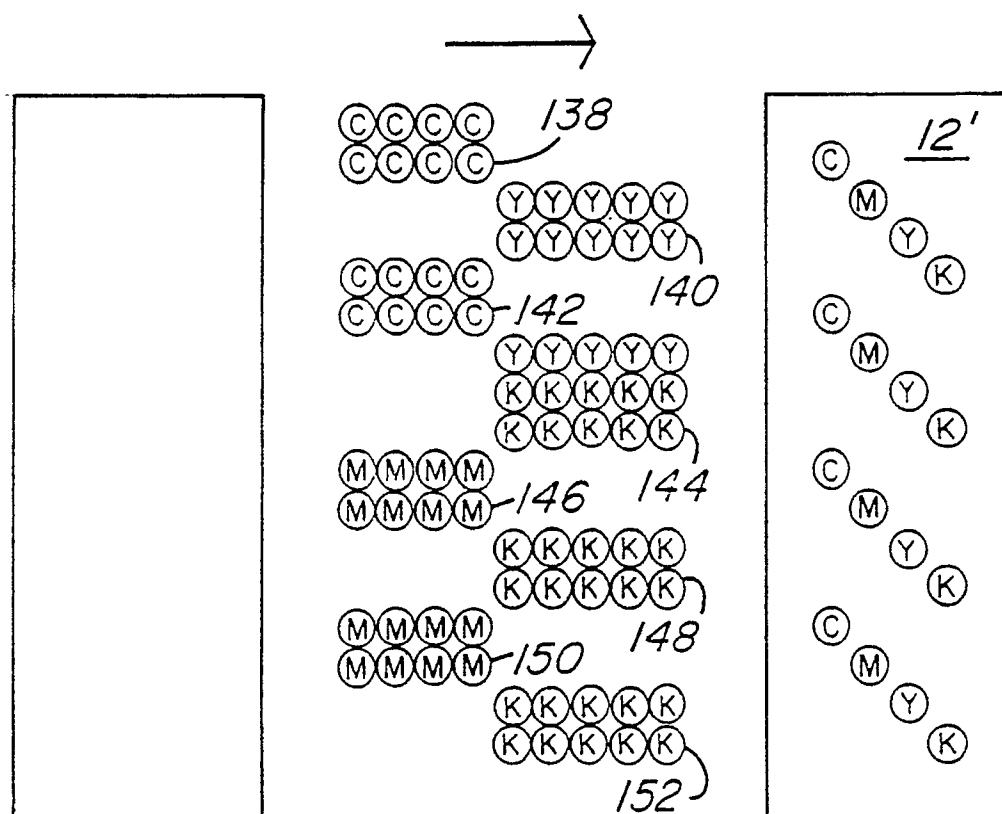


Fig. 4B

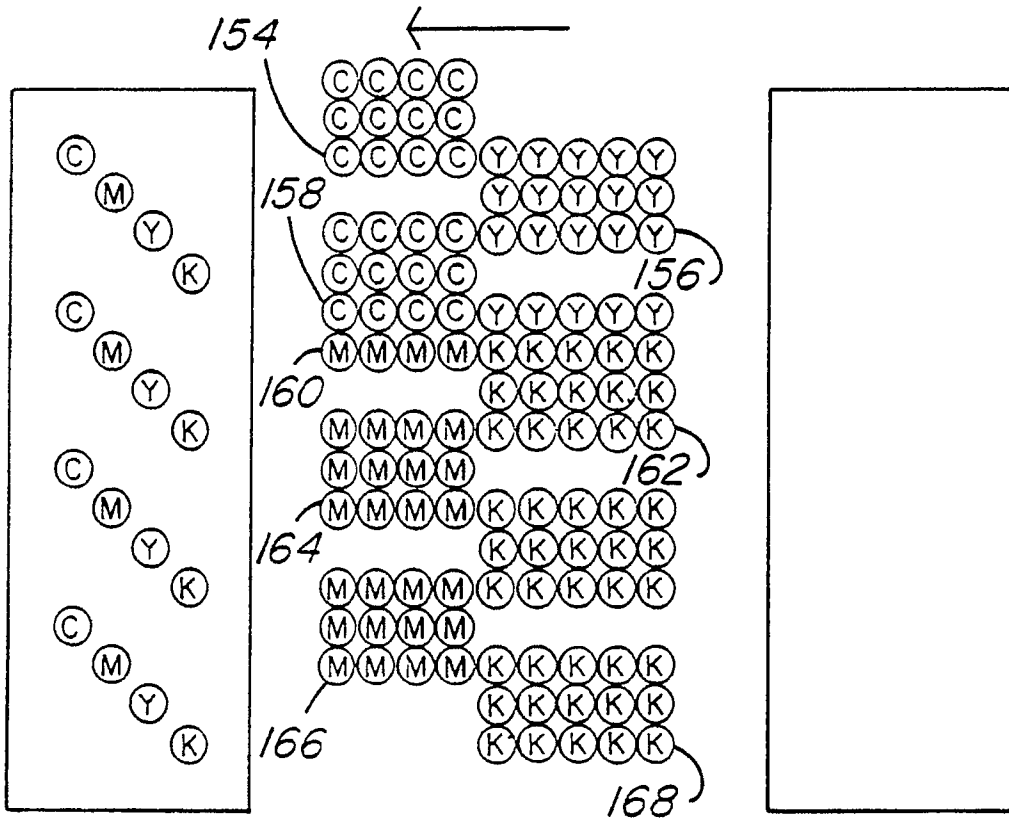


Fig. 4C

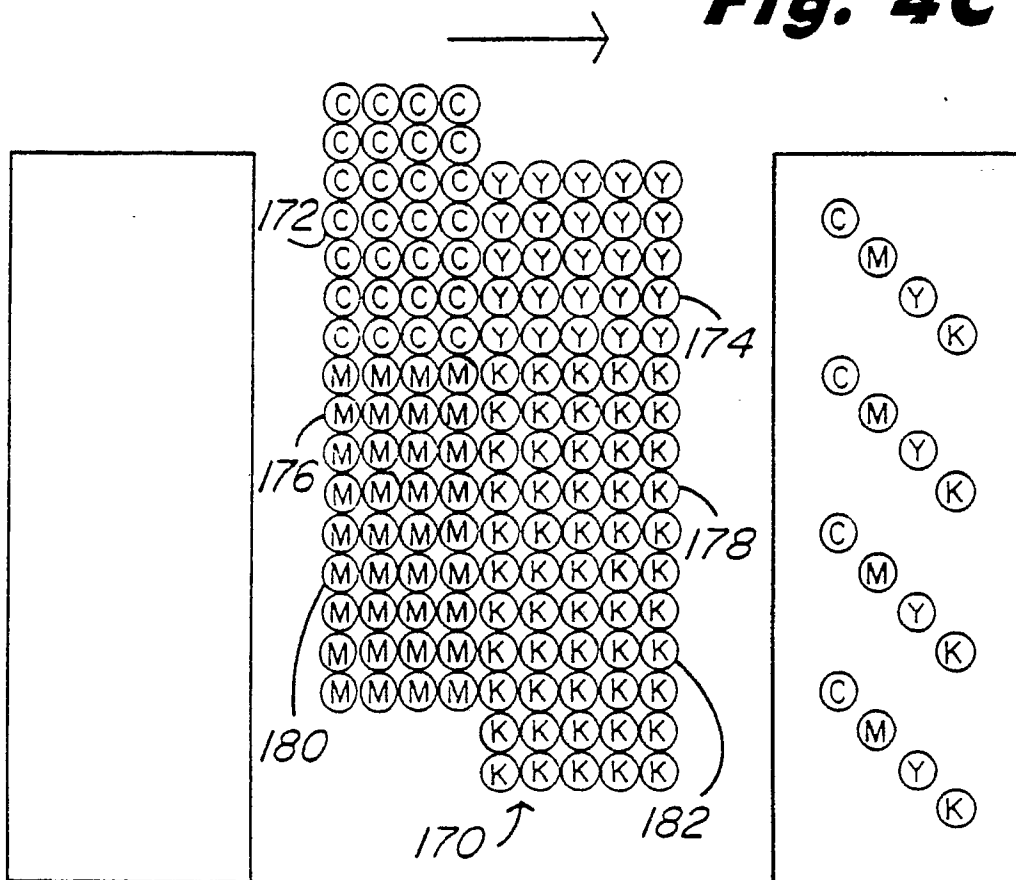


Fig. 4D