## Description

This invention relates to a multitone ink jet printing apparatus as set forth in the preamble of claim 1.

A known device of this kind (DE-A-30 09 333) comprises piezoelectric transducers which concentrically enclose the ink channels leading to an orifice, respectively. By applying electrical pulses to said transducers shock waves are generated which cause ejection of the ink droplets.

Thermal ink jet printing has been described in many recent technical articles, such as an article by Kuhn & Myers in Scientific American, 1985, at pages 162 through 178, and also in an article by J. B. Angell et al. also in Scientific American April 1983 at pages 44 through 55, both incorporated herein by reference.

In the art of multitone ink jet printing, one approach to printing a dot with one of eight grey scale levels is to employ a single ink jet drop generator and fire it from one (1) to seven (7) times at a given pixel in order to provide the pixel from one to seven levels of ink drop volume. However, this approach suffers at least two distinct disadvantages when used in a thermal ink-jet printer. The first of these disadvantages is that the substantial repeated use of a single drop generator and its associated heater resistor increases the wear and failure rate (decreased lifetime) of the thermal ink jet print head. As used herein, the term "wear" is defined as the accumulation of drop ejection cycles in a drop generator with finite lifetimes. Such lifetimes are typically measured in tens of millions of cycles. Secondly, when ink is ejected in a drop sequence from a single drop generator, there is a certain recovery time related to the bubble collapse associated with each ink drop ejection from the drop generator. This recovery time obviously imposes a limitation on the maximum achievable rate at which pixels are printed using this method of thermal ink jet printing.

In DE-A-30 09 333 two other approachs to multitone ink jet printing are disclosed. One involves the use of multiple ink jet drop generators and firing these drop generators simultaneously in different numbers to achieve different corresponding ink jet drop volumes. To some extent, the use of these multiple drop generators as contrasted to a single drop generator can increase the lifetime of the thermal ink jet printer.

Such an approach is also disclosed by T. Kawanabe in U. S. Patent 4,353,079 issued October 5, 1982. However, the thermal ink jet recorder apparatus of the Kawanabe patent identified above is possessed with certain other disadvantages related to the requirement for simultaneous firing of the multiple drop generators therein.

In particular, since these drop generators of the prior art are simultaneously fired at a single location, the nozzles must be critically aligned with respect to each other so that the ink drops will properly register within the pixel on the recording medium (paper). Furthermore, this alignment is predicated upon a particular spacing between the nozzles and paper, and maintaining this distance is critical to achieving a simultaneous combination of these drop volumes on the pixel. In addition, since each drop generator in the Kawanabe recorder of U. S. Patent 4,353,079 produces only one unit volume of ink, then anywhere up to seven drop generators must be fired simultaneously to achieve the variation of one to seven levels on the grey scale. This requirement significantly increases the complexity,cost and unreliability of printhead design, and it also increases the total drop generator-use time for the print head and, again, imposes a limitation on the useful print head lifetime.

The second approach to multitone ink jet printing disclosed in DE-A-30 09 333 involves the use of a plurality of generators for ejecting ink drops into pixels in a predetermined binary sequence of drop volumes. The generators are arranged side-by-side in the direction of relative motion between the printhead and an ink receiving paper such that they can be operated sequentially to fire ink drops into the same pixel. This printing method requires precisely determined ink drop jets, as ink drops fired from different generators have to meet in one pixel on the ink receiving paper. Thus, in a device according to DE-A-30 09 333 the ink channels being concentrically enclosed by piezoelectric transducers and leading to orifices have to be precisely aligned with respect to each other. This is difficult to achieve in small dimensions.

In JP-A-59 224 352 a method for increasing the printing quality by removing the grainylike characteristic of adjacent pixels is disclosed. According to this method drops of colorless ink are to be ejected into pixels in order to wash out the sharp edges of each pixel.

In JP-A-59 207 262 a printing head having a complex multilayered structure with a plurality of heat resistors facing the center of a nozzle for increasing the efficiency of each drop generator is disclosed.

The general purpose of this invention is to provide a new and improved multitone thermal ink jet printer having the features of the classifying part of claim 1, which overcomes the aforedescribed disadvantages of the prior art and consequently provides a print head of decreased drop generator design complexity and of an extended lifetime.

To accomplish this purpose, a multitone ink printing apparatus according to the invention characterized by the features of the characteri-

part of claim 1. The drop generators which are each assigned a binary number corresponding to a specific ink drop volume are sequentially fired at a chosen pixel as they come into alignment with the pixel as the printhead moves with respect to the paper or vice versa. Thus, firing one to three binary-weighted drop generators produces 1 to 7 volume units of ink within the pixel. This process produces 1-8 levels of grey scale. The total number of drop generators required in the print head and the total drop generator use time is minimized to thereby maximize print head lifetime with a minimum of associated drop generator design complexity.

Figure 1A-1D are sequential isometric views looking up through the paper at the bottom of a scanning printhead having the "1", "2" and "4" binary volumes for ejecting ink onto a given pixel.

Figure 2 is a graph of optical dot density versus print volume for the binary drop generator depicted in Figures 1A-1D.

Figures 3A and 3B illustrate isometrically, and in cross-section respectively, a print head structure constituting a preferred embodiment of the invention.

Figures 4A-4E illustrate schematically an embodiment of the invention wherein untoned ink vehicle is combined with an ink drop of fixed dye loading. This process is carried out in order to obtain a mixture of ink vehicle and ink on paper to produce a reduction in optical density of the fixed dye loading to thereby eliminate grainyness of small dots.

Figures 5A and 5B illustrate isometrically and in plan view, respectively, a three-color, eight-level halftone printer in accordance with the present invention.

Referring now to Figures 1A-1D, there is shown in sequence the firing of the binary-weighted "4", "2" and "1" volume ink drops at the pixel p. The direction of scan for a printhead 10 is from left to right, and the "4" volume ink drop "a" has printed into the pixel at displacement $x_1$. As indicated in Figure 1B, the "2" volume drop "b" is on its way toward the pixel where it subsequently combines with the "4" volume drop to provide a "4" + "2" combined volume spot on the pixel at displacement $x_2$ as indicated in Figure 1C. Also shown in Figure 1C is the firing of the "1" volume ink "c" which combines with the already deposited "4" + "2" volumes of ink to give a seven volume ink spot or level eight on the grey scale and completely covering the pixel as indicated in Figure 1D at displacement $x_3$.

There is much less critical alignment with the drop generator scheme of the present invention than with the approach of firing drop generators simultaneously. Furthermore, since there are only three drop generators for the eight grey levels rather than the five drop generator scheme of the prior art, this feature results in a simpler electrical interconnect requirement for the printhead heater resistors, less complex driver electronics, a less complex plumbing scheme for feeding ink to the three drop generators, and a more compact and reliable printhead.

Referring to Figure 2, the scheme whereby combined ink drops with total volumes "1" through "7" produce eight grey levels is described. This figure shows how optical density of a pixel is increased from the reflectivity of the untoned paper ("white") to the reflectivity of ink covering the paper ("black") as successively larger volumes of ink are applied to the region of a single pixel. The curve in the figure obeys a typical relation between spot area and drop volume on a coated paper, and the total optical density of the pixel is computed from the reflectivities and areas of the toned and untoned regions within a pixel boundary. Next to each print volume derived from the "1", "2", and "4" binary-weighted dot printers is shown schematically the combination of drops producing this volume.

Referring now to Figures 3A and 3B, the partially cut-away isometric view of a printhead employing the three drop generator scheme of the present invention includes a silicon thin film resistor substrate 30 which is fabricated using silicon planar processing and thin film deposition techniques which are well known to those skilled in the art. The silicon substrate 30 includes a common ink feed-hole 32 in the form of a cylinder or slot through substrate 30 and configured using diamond saw blade or laser drilling techniques. As is also well known, the thin film resistor silicon substrate 30 is constructed to have a plurality of heater resistors 34, 36 and 38 thereon, and these resistors are configured to correspond to the different "1", "2" and "4" volume ink channels 40, 42 and 44 in the barrier layer 46. This barrier layer 46 isolates individual drop generators to reduce crosstalk and is important to obtaining long operating life for the thermal ink jet resistors. Typically the barrier layer 46 is fabricated from a well known commercial polymer material with the trade name "VACREL", nickel, glass, or some other material impervious to attack by the liquid ink contained therein.

The printhead in Figure 3A further includes a drop generator orifice plate 48 typically constructed of nickel and includes the plurality of orifices 50, 52 and 54 for ejecting the "1", "2" and "4" binary ink volumes, respectively. These orifices 50, 52 and 54 will emit the "1", "2" and "4" volumes of ink when their corresponding thin-film resistors 34, 36 and 38 respectively are heated by the application thereto of current pulses. The means by which the ink

bubble forms on the heater resistor and provides the energy to eject a droplet of ink is well known to those skilled in the thermal ink jet printing art, and is described, for example, in the Hewlett Packard Journal, Volume 36, Number 5, May 1985 which is incorporated herein by reference. These current pulses are applied by way of conventional surface metallization patterns (not shown), but typically consisting of very thin conductive traces of aluminum or gold on the upper surface of the silicon substrate 30 and deposited using standard evaporation processes well known in the art.

Although the substrate member 30 is referred to herein as a "silicon substrate", it will be understood by those skilled in the art that the substrate 30 will typically by a thin film composite or layered structure wherein a first layer of silicon dioxide $S_1O_2$, will be grown or deposited on a silicon substrate surface to provide surface passivation thereof, and then a resistive layer such as tantalum-aluminum will be deposited on the $S_1O_2$ layer. Next the conductive trace material will be evaporated on the tantalum-aluminum layer and lithographically defined so that openings in this trace material define the boundaries of the heater resistors. Finally, a inert outer passivation or barrier layer material such as silicon carbide, $S_1C_1$, or silicon nitride, $Si_3N_4$, or tantalum pentoxide, $Ta_2O_5$, or combination thereof in successive layers is formed on the surface of the aluminum trace material and the exposed heater resistors in order to provide a good isolation barrier layer between the heater resistors and the ink in the reservoirs above these heater resistors. This inert barrier layer is necessary due to the highly corrosive nature of the ink and also because of ther cavitation-produced wear during ink ejection from the drop generators. Therefore, as used herein, "silicon substrate" is intended to mean a thin film resistor silicon substrate of the above type of layered structure.

Referring now to Figures 4A through 4E, there is illustrated an embodiment of my invention which includes an additional drop generator which is indicated as drop generator 60 in Figure 4A. This generator 60 produces untoned droplets of fluid which is the ink without toning dyes. This liquid is known in the art as the ink vehicle. The volume of the untoned drop will be between the "1" and "4" volume. When a single drop 64 is ejected from the printhead onto the paper 65 as indicated in Figure 4B, it will typically exhibit an optical density profile in the form indicated in Figure 4C. In this Figure, reference number 66 indicates the optical density profile across the diameter of printed dot 67. As a result of the sharp steep profile 66 of optical density at the edge, the dot 67 in Figure 4C, when seen at a normal viewing distance, will produce a grainylike characteristic as perceived by the eye and will consequently result in undesirable shading or grainyness for certain image printing and background applications - particulary in the reproduction of highlights in continuous-tone images. Thus, it is frequently desirable to remove this grainylike characteristic and this may be accomplished by the utilization of an untoned liquid vehicle drop 68 as indicated in Figure 4D. This vehicle drop 68 is ejected onto the same pixel area as the toned ink drop 64 and this produces a certain quantity of vehicle volume plus "1" toned ink volume in area 69 as indicated in 4E and having an optical density profile 70 which has a maximum value in the center portion 72 thereof and then decreases out to the edges of the toned area 69.

Referring now to Figures 5A and 5B, there is shown, in isometric and plan views respectively, a three-color, eight-level halftone printhead 73 including three foam filled reservoirs 74, 76 & 78 of the type disclosed and claimed in U.S. Patent No. 4,771,295 of Jeffrey Baker, assigned to the present assignee and issued in September, 1988.

These foam filled reservoirs 74, 76 and 78 are filled with inks having dye colors of cyan, magenta and yellow, respectively for subtractive color printing. These reservoirs 74, 76 and 78 are connected using known fluid interconnect techniques to an outer orifice plate 82 with the cyan, magenta and yellow orifice patterns 84, 86 and 88, respectively. The orifice patterns 84, 86 and 88 are shown in an enlarged plan view in Figure 5B and include n-rows of the "4", "2", "1" binary drop generators in each of the cyan, magenta and yellow columns as indicated. Thus, each of the cyan, magenta and yellow columns may have as many n-rows of "4", "2", "1" binary drop generators as may be necessary to provide a desired quantity of these side by side ink dispensers for an eight-level three-color halftoning printing operation. Additionally, each of the n-rows may be modified to include a single clear fluid or ink vehicle drop generator (not shown) if it becomes desirable for some reason to diffuse one or more of the colors produced in order to reduce edge sharpness of isolated, color printed dots. This may be desirable for example when printing color dots (in the manner described previously to provide a more uniform coverage of a colored region within a pixel).

Various modifications may be made in the above-described embodiments without departing from the scope of the claims. For example, the present invention is not limited specifically to the "4", "2", "1" binary sequence indicated, and instead may employ variations of this binary sequence in accordance with the particular type of grey level imaging operation being performed. In addition, multicolor printing may be produced by individual color pens (cyan, yellow, magenta, black)

registered and aligned with respect to one another so as to print successively within the boundary of a single pixel to produce mixing of drops of various volumes and colors. Furthermore, the present invention is not limited to the particular 3-color printhead of Figure 5 wherein the different colors are all located in adjacent columns in an integrated ink storage and orifice plate structure. Instead, the cyan, magenta, yellow and black inks may be spaced apart by a chosen distance compatible with a particular color printing application.

## Claims

1. A multitone ink jet printing apparatus comprising drop generators for firing ink drops in a predetermined binary sequence (1, 2, 4) through one or more orifices (50, 52, 54) having different diameters representative of said predetermined binary sequence of drop volumes, while relative motion between the printing apparatus and paper receiving the ink drops is provided such that said drop generators are sequentially operative to fire at a chosen pixel as they come into alignment with said pixel,
**characterized** by
(a) a thin film resistor substrate (30) having a plurality of thin-film heater resistors (34, 36, 38) thereon for generating vapor bubbles in the ink to effect the generation of ink-droplets,
(b) a barrier layer (46) disposed on said thin film resistor substrate (30) and having a plurality of barrier channels (40, 42, 44) defining respectively a plurality of different binary drop volumes and forming respectively a plurality of drop generators, and
(c) a drop generator orifice plate (48) disposed on said barrier member (46) and having said orifices (50, 52, 54) which are disposed respectively over said plurality of heater resistors (34. 36, 38) and barrier channels (40, 42, 44).

2. The apparatus defined in claim 1, **characterized** in that the volumes produced by said drop generators are weighted in an approximate "1", "2", "4" binary sequence.

3. The apparatus defined in claim 2, **characterized** in that it is provided with an additional clear untoned ink vehicle drop generator (V) comprising a further orifice (60) positioned in the same row as said binary sequence (1,2,4) of orifices (50,52,54) for imparting to said print head an additonal grey scale toning capability sufficient to remove grainyness in images formed from small high-contrast dots deposited on a print media.

## Patentansprüche

1. Grauton-Tintenstrahldruckvorrichtung mit Tropfenerzeugern zum Abfeuern von Tintentropfen in einer vorbestimmten binären Sequenz (1, 2, 4) über eine oder mehrere Düsenöffnungen (50, 52, 54) mit unterschiedlichen Durchmessern, die representativ für die vorbestimmte binäre Sequenz von Tropfenvolumina sind, während eine relative Bewegung zwischen der Druckvorrichtung und dem die Tintentropfen aufnehmenden Papier vorgesehen ist, so daß die Tropfenerzeuger sequentiell wirksam werden, um ein gewähltes Pixel abzufeuern, wenn sie in Ausrichtung mit diesem Pixel gelangen,
**gekennzeichnet** durch
(a) ein Dünnfilm-Widerstandsubstrat (30) mit mehreren Dünnfilm-Heizwiderständen (34, 36, 38) zum Erzeugen von Dampfblasen in der Tinte zum Generieren von Tintentröpfchen,
(b) eine Barriereschicht (46) auf dem Dünnfilm-Widerstandsubstrat (30) mit mehreren Barrierekanälen (40, 42, 44), welche jeweils eine Mehrzahl von unterschiedlichen binären Tropfenvolumina definieren und entsprechend eine Vielzahl von Tropfenerzeugern bilden, und
(c) eine Tropfenerzeuger-Düsenplatte (48), die auf der Barriere-Schicht (46) angeordnet sind, wobei die Düsenöffnungen (50, 52, 54) jeweils über den Heizwiderständen (34, 36, 38) und den Barrierekanälen (40, 42, 44) angeordnet sind.

2. Vorrichtung nach Anspruch 1, dadurch **gekennzeichnet**, daß die von Tropfenerzeugern produzierten Volumina etwa in einer binären Sequenz "1", "2", "4" gewichtet sind.

3. Vorrichtung nach Anspruch 2, dadurch **gekennzeichnet**, daß sie mit einem zusätzlichen klaren, ungetonten Tintentropfenerzeuger (V) mit einer weiteren Düsenöffnung (60) verbunden ist, welche in derselben Reihe wie die binäre Sequenz (1, 2, 4) der Öffnungen (50, 52. 54) angeordnet ist, um dem Druckkopf eine zusätzliche Grauton-Fähigkeit zu erteilen, die dazu ausreicht, die Körnigkeit von Bildern aus kleinen Hoch-Kontrastpünkten auf einem Druckmedium zu beseitigen.

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## Revendications

1. Dispositif d'impression à jet d'encre multitonalité comprenant des générateurs de gouttes destinés à tirer des gouttes d'encre dans une séquence binaire prédéterminée (1, 2, 4) à travers un ou plusieurs orifices (50, 52, 54) ayant différents diamètres représentatifs de ladite séquence binaire prédéterminée de volumes de gouttes, cependant qu'un mouvement relatif entre le dispositif d'impression et le papier recevant les gouttes d'encre est réalisé de telle manière que lesdits générateurs de gouttes puissent tirer sur un pixel choisi au moment où elles parviennent dans l'alignement dudit pixel.

   caractérisé par

   (a) un substrat (30) de résistances en film mince portant une pluralité de résistances chauffantes en film mince (34, 36, 38) destinées à engendrer des bulles de vapeur dans l'encre pour effectuer la production de gouttelettes d'encre,

   (b) une couche barrière (46) disposée sur ledit substrat (30) de résistances en film mince et ayant une pluralité de canaux (40, 42, 44) de barrière définissant respectivement une pluralité de différents volumes binaires de gouttes et formant respectivement une pluralité de générateurs de gouttes et,

   (c) une plaque à orifices (48) de générateur de gouttes, disposée sur ladite couche barrière (46) et possédant lesdits orifices (50, 52, 54) qui sont disposés respectivement sur ladite pluralité des résistances chauffantes (34, 36, 38) et de canaux (40, 42. 44) de barrière.

2. Dispositif selon la revendication 1, caractérisé en ce que les volumes produits par lesdits générateurs de gouttes sont pondérés dans une séquence binaire approximative "1", "2", "4".

3. Dispositif selon la revendication 2, caractérisé en ce qu'il est muni d'un générateur additionnel (V) degouttes de véhicule d'encre transparent, non pigmenté comprenant un orifice supplémentaire (60) positionné dans la même rangée que ladite séquence binaire (1, 2, 4) d'orifices (50, 52, 54) pour conférer à ladite tête d'impression une capacité additionnelle de pigmentation de l'échelle de gris pour supprimer l'aspect grenu des images formées de petits points à fort contrast déposés sur un milieu d'impression.



* C L M S *