

"INK JET PRINTING HEAD"

This invention relates to ink jet printing heads of the ink-on-demand type.

Ink jet printing heads of the ink-on-demand type having
5 a pressurization chamber whose volume can be reduced by mechanical distortion upon energisation of a piezoelectric element thereby to eject liquid ink through a nozzle communicating with the pressurization chamber, are drawing attention since the energy required for printing is small and they can be provided with a
10 plurality of nozzles. Although the structure for injecting ink is quite simple, ink jet printing heads have not been completely analyzed theoretically as the ink is ejected under transient conditions and the pressure, rate of flow, etc. are difficult to measure due to the small size of the printing head.

15 With very compact ink jet printing heads having 24 or more nozzles for printing Chinese characters, an individual pressurization chamber and piezoelectric element is associated with each nozzle and should preferably be of small size. However, it has not been clear as to how the pressurization chamber
20 can be reduced in size because of the incomplete theoretical analysis, and conventionally piezoelectric elements have been used which have a thickness t_p approximately equal to 0.3 mm and a diameter D approximately equal to 5 mm or more. Furthermore, piezoelements which are of small size generate a small driving
25 force and require an increased drive voltage, and hence have

been considered impractical. For example, Stemme et al. propose in IEEE, Transaction on Electron Devices, ED-20 No. 1, 14 (1973) an arrangement wherein $t_p = 0.3$ mm and $D = 5$ mm. Matsuda et al in preprint No. 6 in a preprint collection for the 8th National
5 Conference, 1980 of the Picture Image Electronics Society suggest that a rectangular piezoelectric element having $t_p = 0.3$ mm has the best ratio of mechanical distortion. The size of this piezoelectric element is assumed to be about 2 mm x 15 mm and hence such a piezo-
electric element is not satisfactory from the standpoint of
10 reduction of size. The larger the area of a piezoelectric element, the higher the cost. It is difficult to make a highly compact printing head with a plurality of nozzles since a corresponding number of piezoelectric elements must be provided. Moreover a large number of nozzles results in an increase in the size of the
15 piezoelectric elements and thus a greater distance between the distal end of the nozzles and the respective pressurization chambers and hence in an increased resistance to flow of ink. Such an increased flow resistance in turn necessitates an increase in the area of the piezoelectric element to obtain a greater
20 driving power from the latter. This is a vicious circle.

The present invention seeks to provide an ink jet printing head of small size without requiring an increased drive voltage in operation.

According to one aspect of the present invention there is
25 provided an ink jet printing head including a pressurization chamber, a

(24)

passageway extending between the pressurization chamber and a nozzle through which, in operation, droplets of liquid ink are ejected, a vibratory plate constituting at least a portion of the wall of the pressurization chamber, and a piezoelectric element cooperating with the vibratory plate for changing the volume of said pressurization chamber, the acoustic capacitance of the piezoelectric element and said vibratory plate being $9 \times 10^{-17.5} \text{ m}^5/\text{N}$ or less.

Preferably the arrangement is such that a drive voltage V is expressed by the equation:

$$V = \sqrt{\frac{2\psi^2 C_{10}}{K^2 C_p}}$$

where ψ is the pressure

C_{10} is the acoustic capacitance of the piezoelectric element and the vibratory plate taken together,

C_p is the capacitance of the piezoelectric element, and

K is a constant

is a minimum.

Preferably, said piezoelectric element has a thickness of 0.2 mm or less and an area of $1.5 \times 10^{-5} \text{ m}^2$ or less.

The piezoelectric element may be in the form of a disc or square plate. In the former case, preferably, $0.1 \text{ mm} \leq t_p \leq 0.15 \text{ mm}$

where t_p is the thickness of the piezoelectric element, and $a \leq 1.5 \text{ mm}$ where a is the radius of the piezoelectric element.

In one embodiment a plurality of piezoelectric elements are mounted on the same vibratory plate.

According to a further aspect of the present invention there is provided an ink jet printing head including a pressurization chamber, a passageway extending between the pressurization chamber and a nozzle through which, in operation, droplets of liquid ink are ejected, a vibratory plate constituting at least a portion of the wall of the pressurization chamber, and a piezoelectric element cooperating with the vibratory plate for changing the volume of said pressurization chamber, said piezoelectric element having a thickness of 50 μm or less and being made by vapour

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deposition or sputtering.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-

Figure 1(a) is an equivalent electrical circuit diagram of

an ink jet printing head;

Figure 1(b) is a schematic illustration of the printing head;

Figure 2 is a simplification of the equivalent electrical circuit diagram of Figure 1(a);

5 Figures 3(a), 3(b), 4(a) and 4(b) are views indicating parameters used in a theoretical analysis of the ink jet printing head of Figure 1(b);

10 Figures 5(a) and 5(b) are graphs showing a comparison between calculated and measured values of oscillation of a piezoelectric element of the ink jet printing head;

Figure 6 is a graph of calculated drive voltages of the piezoelectric element;

15 Figure 7 is a graph of optimum acoustic capacitance calculated in accordance with the theoretical analysis of an ink jet printing head;

Figure 8 is a graph of diameters of ink droplets calculated in accordance with the theoretical analysis;

Figure 9 is a graph of electric field intensity calculated in accordance with the theoretical analysis; and

20 Figure 10 illustrates an ink jet printing head according to the present invention.

Figure 1(a) is an equivalent electrical circuit of an ink jet printing head, where the letter m indicates inertance or inertial resistance, the letter C indicates acoustic capacitance, 25 and the letter r indicates acoustic resistance. Figure 1(b)

schematically illustrates the printing head. The printing head has a vibratory system 10 comprising a piezoelectric element 11 and a vibratory plate 12, a pressurization chamber 1, a supply section 2, and a nozzle section 3. Suffixes in Figure 1(a) indicate parts denoted by corresponding numbers in Figure 1(b). Thus C_2 represents acoustic capacitance of the supply system 2 and ink storage chamber 4, and C_3 represents surface tension for the nozzle 3 as regarded as an acoustic capacitance. In the following discussion the units used are as follows: pressure; ψ [N/m²], volume velocity: u [m²/s], inertance: m [Kg/m⁴], acoustic capacitance: C [m⁵/N], acoustic resistance: r [Ns/m⁵]. Actual calculation indicates that the parameters of m_{10} , r_{10} , C_2 , C_3 are negligible, resulting in a simpler equivalent circuit as illustrated in Figure 2. Assuming that $m_2 = km_3$, $r_2 = kr_3$, and pressure is regarded as a step function, the damping coefficient:

$$D=r_3/2m_3 \dots\dots (1)$$

and the angular frequency:

$$E=\sqrt{\frac{(1+1/k)}{m_3C}} - D^2 \dots\dots (2)$$

a damped oscillation can be expressed by:

$$u_3 = \frac{\psi C_{10}}{m_3 C E} \exp(-Dt) \sin Et \dots\dots (3)$$

and $C=C_{10} + C_1 \dots\dots (4)$

From equation (3), a required pressure is as follows:

$$\psi = \frac{V_m A m_3 C \sqrt{E^2 + D^2}}{C_{10} \exp[-D \arctan(E/D)/E]} \dots\dots (5)$$

where V_m is a necessary velocity and A is the cross-sectional

area of the nozzle.

The volume of an ink droplet can be expressed by:

$$q = \frac{\psi C_{10}}{(1+1/k)} \left[1 + \exp(-Dt_m) \right] \dots\dots (6)$$

5 and $t_m = \frac{\pi}{E} \dots\dots (7)$

A drive voltage V can be expressed by the following equation:

$$V = \sqrt{\frac{2\psi^2 C_{10}}{K^2 C_p}} \dots\dots (8)$$

10 where C_p is the capacitance of a piezoelectric element and K is a constant between 0.1 to 0.3 and is found from experiment.

The capacitance C_p is given by:

$$C_p = \epsilon S_p / t_p \dots\dots (9)$$

15 where ϵ is a dielectric constant, S_p is the area of the piezoelectric element, and t_p is the thickness of the piezoelectric element.

The constants for a piezoelectric element in the form of a disc can be given as follows:

20 $C_{10} = \frac{\pi a^6}{K_1 E_p t_p^3 + K_2 E_v t_v^3} \dots\dots (10)$

$$C_1 = \frac{\pi a^2 d'}{v_s^2 \rho} \dots\dots (11)$$

$$r = \frac{32\eta l}{s d^2} \dots\dots (12)$$

25 $m = \frac{\ell \rho}{s} \dots\dots (13)$

where E_p is the modulus of longitudinal elasticity of the piezoelectric element, E_v is the modulus of the vibratory plate, K_1 , K_2 are constants, K_1 being about 5 and K_2 being in the range of about 10 to 20 from experiment, a is the radius of the piezoelectric element, t_p is the thickness of the piezoelectric element, t_v is the thickness of the vibratory plate, d' is the depth of the pressurization chamber, v_s is the speed of sound in the ink, ρ is the density of the ink, η is the viscosity of ink, l is the length of a flow passageway between the pressurization chamber and the nozzle, S is the cross-sectional area of the flow passageway, d is the diameter of the flow passageway, which should be an equivalent diameter ($d = 2S/(b+c)$) for a rectangular cross section, b , c are sides of the cross section of the flow passageway. The foregoing constants are indicated in Figures 3(a) and 3(b).

Examples are given below which are obtained by using the above equations. Figures 4(a) and 4(b) show a nozzle section of an ink jet printing head made by etching a glass plate. An actual flow passageway indicated by the broken lines 30 extends from a pressurization chamber 31 to a nozzle 32 and is approximated by a flow passageway indicated by the solid line, and from equations (12) and (13):

$$b_1 = 80\mu\text{m}, c_1 = 30\mu\text{m}, l_1 = 250\mu\text{m},$$

$$b_2 = 300\mu\text{m}, c_2 = 100\mu\text{m}, l_1 = 2\text{mm}$$

when $\eta = 1.8\text{CP}$, $\rho = 1,000\text{Kg/m}^3$,

$$m_3 = 1.8 \times 10^8 \text{ Kg/m}^4,$$

$$r_3 = 3.3 \times 10^{12} \text{ Ns/m}^5$$

Integration should be effected along the flow passageway for greater accuracy, or $\underline{m}$ and $\underline{r}$ of minute portions generated by smaller divisions should be added.

Figure 5(a) shows a measured oscillatory waveform of a piezoelectric element of an actual ink jet printing head with PZT used, and Figure 5(b) shows a calculated oscillatory waveform. The constants are as follows: $a = 1.25 \text{ mm}$, $k = 1.3$, $r_3 = 4 \times 10^{12} \text{ Ns/m}^5$, $m_3 = 2.5 \times 10^8 \text{ Kg/m}^4$, $t_p = t_v = 0.15 \text{ mm}$, $C_1 = 0.22 \times 10^{-18} \text{ m}^5/\text{N}$, $C_{10} = 3.45 \times 10^{-18} \text{ m}^5/\text{N}$. It should be appreciated that actual movement can be determined to a great degree from calculation, although there are inconsistencies between measurement and calculation. For example, the measured oscillatory period is about $140 \mu\text{s}$ whereas the calculated oscillatory period is about $146 \mu\text{s}$. In the measured oscillatory waveform, displacement for periods below $100 \mu\text{s}$ is not measured for the reason that the method of measurement was incomplete.

An embodiment of the present invention will be described in which the size of the piezoelectric element is reduced using the foregoing equations.

Assuming that $m_3 = 2 \times 10^8 \text{ Kg/m}^4$, $r_3 = 3 \times 10^{12} \text{ Ns/m}^5$, $V_m = 5 \text{ m/s}$, $A = 2.4 \times 10^{-9} \text{ m}^2$, $K = 0.2$, $\epsilon = 2070 \times 8.854 \times 10^{-12} \text{ F/m}$, $E_p = 5.9 \times 10^{10} \text{ N/m}^2$, $E_v = 7 \times 10^{10} \text{ N/m}^2$, $K_1 = 4.4$, $K_2 = 11$, $d' = 0.1 \text{ mm}$, $V_s = 1460 \text{ m/s}$, $k = 1$, from calculation for the necessary voltages V as the thickness t_p and radius $\underline{a}$ of the

piezoelectric element vary with $t_p = t_v$ are shown in the graph of Figure 6.

It will be seen that there is an optimum radius a for the thickness t_p of the piezoelectric element with m and r for a given flow passageway so as to effect printing at a lowest voltage, and the lowest voltage is constant under such conditions.

The above will be described from a different point of view. With fixed C_{10} under constant conditions for m and r of the flow passageway, $C_1 \ll C_{10}$ and hence $C \doteq C_{10}$ in equation (4), and E is substantially constant with C_{10} being fixed in equation (2). Therefore, ψ is constant from equation (5). For a disk-shaped piezoelectric element:

$$C_p = \epsilon \pi a^2 / t_p \quad \dots\dots (9')$$

which is derived from equation (9). When $t_p = t_v$ in equation (10), a^6 / t_p^3 is constant because C_{10} is fixed, and C_p is also constant from equation (9'). Thus, when C_{10} is fixed in equation (8) and the constants for the flow passageway are fixed, the other constants are substantially fixed and the drive voltage V does not vary.

The foregoing indicates that with a^2 / t_p within a given range, the piezoelectric element can be reduced in size with no accompanying voltage increase. From equation (6), the volume q of an ink droplet is substantially constant when C_{10} is fixed.

Values of C_{10} which minimize the drive voltage V in equation (8) under the same condition as for the graph of Figure 6

and which are frequently used with ordinary flow passages are shown in Figure 7 with m_3 varied from $1 \times 10^8 \text{ kg/m}^4$ to $3 \times 10^8 \text{ kg/m}^4$ and r_3 varied from $1 \times 10^{12} \text{ Ns/m}^5$ to $12 \times 10^{12} \text{ Ns/m}^5$. The drive voltage V can thus be held at a minimum by selecting such a vibratory system as has a value of C_{10} shown in Figure 7.

Diameters D_1 of ink droplets at this time are shown in Figure 8, and they should preferably range from $50 \mu\text{m}$ to $150 \mu\text{m}$. For high-density printing with twenty-four nozzles, too large diameters of ink droplets are not preferable as they lower the quality of printing. Therefore, under the condition of $D_1 \leq 150 \mu\text{m}$ in Figure 8, $r \geq 2 \times 10^{12} \text{ Ns/m}^5$ for $m_3 = 2 \times 10^8 \text{ kg/m}^4$ and $r \geq 3 \times 10^{12} \text{ Ns/m}^5$ for $m_3 = 3 \times 10^8 \text{ kg/m}^4$, the range indicated by the solid lines in Figure 7 hence being preferable.

For flow passages within the range indicated in Figure 7, the value of C_{10} which minimizes the drive voltage is, based on the graph, in the range of

$$1 \times 10^{-18} \text{ m}^5/\text{N} \leq C_{10} \leq 9 \times 10^{-17} \text{ m}^5/\text{N} \dots (14)$$

A printing head having a smaller C_{10} for smaller diameters of ink droplets is preferable for printing of a higher density.

There is an optimum relationship between t_v and t_p , for example, so that the stress of adhesive between the piezoelectric element and the vibratory plate is a minimum and the durability of adhesion is maximum. To this end the relationship between t_v and t_p is as follows:

$$t_v \div \sqrt[3]{\frac{K_1 E_p}{K_2 E_v}} \cdot t_p \dots (15).$$

By substituting equation (15) in equation (10)

$$a = \left\{ \frac{2C_{10}K_1E_pt_p^3}{\pi} \right\}^{1/6} \dots\dots (16)$$

Equation (16) is substituted for C_{10} in equation (14) with
5 $K_1=4.4$, $E_p=5.9 \times 10^{10} \text{ N/m}^2$ to obtain:

$$0.074 \sqrt{t_p} \leq a \leq 0.16 \sqrt{t_p} \dots\dots (17)$$

If $t_p=0.2\text{mm}$, then $1\text{mm} \leq a \leq 2.2\text{mm}$, if $t_p=0.15\text{mm}$, then
0.9mm $\leq a \leq 2.0\text{mm}$, and if $t_p=0.1\text{mm}$, then $0.7\text{mm} \leq a \leq 1.6\text{mm}$.

It will be appreciated from these results that with a given
10 flow passageway, the drive voltage V can be minimized by selecting
an optimum C_{10} therefor which is given by a^6/t_p^3 and hence a^2/t_p .
The optimum radius a of a piezoelectric element is in the range
expressed by equation (17) for a general flow passageway defined
in Figure 7.

15 To reduce the radius a of a piezoelectric element, the
thickness t_p thereof may be reduced.

It is known that the thickness t_p of piezoelectric material
PZT, for example, should not be smaller than about 0.1mm for a
required strength during machining and should not be smaller
20 than about 0.15mm for a required strength during assembly.

Under these conditions of $m_3=2 \times 10^8 \text{ Kg/m}^4$, $r_3=3 \times 10^{12} \text{ Ns/m}^5$ in Figure 6,
Figure 7 indicates that $C_{10} \doteq 2.1 \times 10^{-17} \text{ m}^5/\text{N}$ for minimizing the drive
voltage, and $a=0.123\sqrt{t_p}$ from equation (16). The radius of a
piezoelectric element for minimizing the drive voltage is:

25 $a=1.5\text{mm}$ for $t_p=0.15\text{mm}$, and
 $a=1.2\text{mm}$ for $t_p=0.1\text{mm}$.

The foregoing values are different from the radius a in Figure 6 for minimizing the drive voltage because while $t_v = t_p$ in Figure 6, $t_v = 0.7t_p$ in the above calculation by substituting $K_1 = 4.4$, $E_p = 5.9 \times 10^{10}$, $K_2 = 11$, $E_v = 7 \times 10^{10}$ for those in equation (15).

5 From equation 10, it should be noted that the radius a can be smaller if $t_v = 0$. Practically, however, t_v is optimised when its value is given by equation (15). When $t_v \ll t_p$, equation (8) is no longer applicable and an increase in the drive voltage results, since mechanical distortions of the piezoelectric element become
10 ineffective for causing deflection of the vibratory plate.

The acoustic capacitance C_{10} can be expressed by a ratio between a change of the volume of the pressurization chamber and a pressure applied to the chamber, but can have a value different from that given by equation (10) depending on the configuration of
15 the ink jet printing head, the manner in which the piezoelectric element is bonded, the manner in which the vibratory plate is bonded, the material of the vibratory plate etc. For example, the value given by

$$C_{10} = \frac{\pi a^6}{K_1 E_p (t_p + K_2 t_v)^3} \dots\dots (10')$$

20 may match experiment in some instances. The experiments were conducted with $K_1 \div 3$, $K_2 \div 0.4$ or 1.

Where equation (10') is employed, the same reasoning can be used as with equation (10) if $t_v \div t_p$.

25 As seen from Figure 6, no sharp rise of the drive voltage V

will occur with the radius a being about the value necessary for minimising the drive voltage for the thickness t_p of a piezoelectric element, and hence smaller radiuses a can be selected. For example, in Figure 6, while the optimum radius a for $t_p=0.15$ mm is about 1.75mm, $a=1.2$ mm when the drive voltage is allowed to increase from about 80V to 100V. Likewise, $a=0.9$ mm for $t_p=0.1$ mm. Further the radius a may be smaller than the value indicated above if $t_v=0.7t_p$ as with the arrangement of Figure 7.

Another study of the thickness t_p of a piezoelectric element for its lowest value for withstanding the drive voltage should be considered in addition to the reduced thickness considered from the standpoint of strength. Figure 9 indicates results of calculating the intensity V/t_p of an electric field under the same condition as for Figure 6. Generally, the dielectric breakdown voltage for PZT is known to be from about 3KV/mm to 4KV/mm, and it can be used with $t_p=25\mu\text{m}$ or $t_p=50\mu\text{m}$ as seen from Figure 9. Therefore, the radius a can be made smaller if and when piezoelectric elements having a thickness of $25\mu\text{m}$ or $50\mu\text{m}$ can be produced as the manufacturing process improves.

Ink jet printing heads of a reduced radius a can be manufactured with thin layers of PZT piezoelectric material produced by vapour deposition or sputtering. Since the voltage that a piezoelectric element can withstand is generally lowered as ambient humidity increases, however, ink jet printing heads should be used in an electric field of 1KV/mm or below for safe

ink injection under the condition of high humidity. Under such a condition, the thickness of $t_p = 50\mu\text{m}$ cannot be employed, and the radius should be as follows as seen from Figure 9:

$$0.9\text{mm} \leq a \leq 1.7\text{mm} \text{ for } t_p = 0.1\text{mm},$$

5 $0.8\text{mm} \leq a \leq 2.2\text{mm} \text{ for } t_p = 0.15\text{mm}, \text{ and}$

$$0.8\text{mm} \leq a \leq 2.6\text{mm} \text{ for } t_p = 0.2\text{mm}.$$

The foregoing will be summarised:

1. For a given flow passageway, a value of C_{10} exists which minimizes the drive voltage.
- 10 2. C_{10} is determined by a^2/t_p . Therefore, t_p may be made smaller with reduction of a .
3. From the standpoint of withstanding voltages, t_p should be $25\mu\text{m}$ or greater. However, $t_p \geq 0.1\text{mm}$ is preferable allowing for detrimental effects caused by humidity.
- 15 4. For a required strength during machining and handling, t_p should be 0.1mm or 0.15mm , or greater, and to be on the safe side, t_p should be 0.2mm or greater.
5. Optimum values of a are as follows:
 $1\text{mm} \leq a \leq 2.2\text{mm}$ for $t_p = 0.2\text{mm}$, $0.9\text{mm} \leq a \leq 2.0\text{mm}$ for $t_p = 0.15\text{mm}$,
20 and $0.7\text{mm} \leq a \leq 1.6\text{mm}$ for $t_p = 0.1\text{mm}$.
6. The value of a can be selected which is smaller than those indicated at 5 above if a small increase in the drive voltage is allowed.

While in the above description, it is assumed that the
25 piezoelectric element and pressurization chamber are circular,

they may be elliptic, polygonal etc. although equation (10) and other equations need to be changed accordingly. Where the piezoelectric element is in the form of a narrow rectangle, its rigidity is increased with a resulting reduced C_{10} , and hence
5 the piezoelectric element should be thinner or greater in area than a disk-shaped or a piezoelectric element in the form of a square plate: an arrangement which is less advantageous as to size. It is preferable for a rectangular piezoelectric element to have a ratio between width and length not to exceed 1:2.

10 Figure 10 illustrates an ink jet printing head according to the present invention. In the arrangement shown, a piezoelectric element 100 of PZT has a radius $a=1.25\text{mm}$ and a thickness $t_p=0.15\text{mm}$. The ink jet printing head is made of small size by a combination of alternating disk-shaped pressurization chambers 101 as
15 illustrated. The dimensions of the ink jet printing head are $22\text{mm} \times 18\text{mm} \times 2\text{mm}$ and it has twenty-four nozzles with twelve nozzles on each side. The inertance $\underline{m}$ and acoustic resistance $\underline{r}$ of supply passageways 102 and outlet passages 103 which communicate with the pressurization chambers are substantially of the same
20 length and width to equalize the speeds of injection of ink and the diameters of ink droplets, between the respective nozzles. A filter 104 prevents dust from entering the ink jet printing head, and lands 105 make the flow of ink through the pressurization chambers uniform. The lands 105 are produced simultaneously with
25 the flow passages by etching a glass substrate.

It will be appreciated from the above discussion of the present invention that an ink jet printing head can be provided with a piezoelectric element having a reduced thickness t_p and reduced area with no accompanying increase in the drive voltage.

5 While in the foregoing description PZT has been described as a preferred piezoelectric material, other piezoelectric materials can be used.

The vibratory system has been shown to comprise a single piezoelectric element and a single vibratory plate. However, it
10 appears possible to reduce the size of an ink jet printing head by employing a vibratory system consisting of a plurality of piezoelectric elements such as a bimorph cell or by two vibratory systems disposed on opposite sides of the pressurization chamber.

Although in the above embodiment printing is effected upon
15 reduction of the volume of the pressurization chamber, a proposal has been made for increasing the volume of the pressurization chamber upon application of a printing signal and then carrying out printing upon restoration of the volume of the pressurization chamber utilizing motion of the vibratory system. With such an
20 arrangement, it is possible to reduce the drive voltage to less than that required for ink ejection effected directly on the volume reduction of the pressurization chamber. This application results in a value of a which is smaller than the aforementioned optimum value due to a reduction in the drive voltage.

25 As described above, according to the present invention, a

vibratory system, is selected which is suitable for a flow passage to lower the drive voltage, thereby allowing a piezoelectric element to be made thinner and hence of reduced area so that the overall area of an ink jet printing head can be reduced, and the distance from the nozzles to pressurization chambers can be reduced to lower the impedance of the flow passages, thereby further lowering the drive voltage. The above described embodiments of the present invention are also advantageous in that the piezoelectric elements and hence the ink jet printing heads are small in size, the head can be manufacture at less cost, and a motor for moving the ink jet printing head in a printer can be of small size and less costly to manufacture. An ink jet printing head according to the present invention finds a wide variety of applications such as in a serial printer with compact multiple heads, a plotter, a facsimile machine, and other types of printer.



CLAIMS

1. An ink jet printing head including a pressurization chamber,
a passageway extending between the pressurization chamber and a
nozzle through which, in operation, droplets of liquid ink are
ejected, a vibratory plate constituting at least a portion of
5 the wall of the pressurization chamber, and a piezoelectric element
cooperating with the vibratory plate for changing the volume
of said pressurization chamber, the acoustic capacitance of the
piezoelectric element and said vibratory plate being $9 \times 10^{-17.5} \text{ m}^5/\text{N}$
or less.

10 2. An ink jet printing head as claimed in claim 1 in which the
arrangement is such that a drive voltage V is expressed by the
equation:

$$V = \sqrt{\frac{2\psi^2 C_{10}}{K^2 C_p}}$$

15 where ψ is the pressure

C_{10} is the acoustic capacitance of the piezoelectric
element and the vibratory plate taken together,

~~C_{10} is the acoustic capacitance~~

C_p is the capacitance of the piezoelectric element, and

K is a constant

20 is a minimum.

3. A printing head as claimed in claim 1 or 2 in which said
piezoelectric element has a thickness of 0.2 mm or less and an
area of $1.5 \times 10^{-5} \text{ m}^2$ or less.

4. A printing head as claimed in any preceding claim in which
25 the piezoelectric element is in the form of a disk.

5. A printing head as claimed in any of claims 1 to 3 in which the



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piezoelectric element is in the form of a square plate.

6. A printing head as claimed in claim 4 in which $0.1 \text{ mm} < t_p$
< 1.5 mm where t_p is the thickness of the piezoelectric element,
and $a < 1.5 \text{ mm}$ where a is the radius of the piezoelectric element.

5 7. A printing head as claimed in any preceding claim in which
a plurality of piezoelectric elements are mounted on the same
vibratory plate.

8. An ink jet printing head including a pressurization chamber,
a passageway extending between the pressurization chamber and a
10 nozzle through which, in operation, droplets of liquid ink are ejected,
a vibratory plate constituting at least a portion of the wall of
the pressurization chamber, and a piezoelectric element cooperating
with the vibratory plate for changing the volume of said pressurization
chamber, said piezoelectric element having a thickness of $50 \text{ }\mu\text{m}$
15 or less and being made by vapour deposition or sputtering.

9. An ink jet printing head substantially as herein described
with reference to and as shown in the accompanying drawings.