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DRAWINGS ATTACHED.

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511, 520, 530, 552, 563, 581, 615, 618, 619, 650).

Int. Cl.:—B 41 j 3/10.

COMPLETE SPECIFICATION.

Thermal Print Head.

We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organised according to the laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention pertains to thermal printing, and more particularly to a novel form of thermal print head.

In the printing art there is a continuing search for new and better printing methods and apparatus. One of the more recent improvements has been the development of a process which uses heat rather than impact for the printing energy. According to this process, a matrix of heating elements is selectively energized to heat a specially treated paper sensitive to changes in temperature, the paper being in physical contact with the heating elements at the time the printing takes place. For example, if the letter "A" is desired to be printed, the heating matrix will be energized in a pattern corresponding to this letter, the letter "A" thereby being defined, or "printed", upon the heat sensitive paper.

The advantages of thermal printing over impact printing include a minimum of mechanical motion (the primary mechanism being only that required to advance the heat sensitive paper); a reduction in the problems associated with any change of information representation from one form of representation to another (the information up to the time of printing appearing as an electrical

signal); and a substantial increase in printing speed.

The heart of the thermal printer is the thermal print head which contains the matrix of heating elements. These thermal print heads are generally fabricated by several different processes. By one process, for example, resistors composed of a conductive compound, for example, tin oxide, are selectively deposited by evaporation or the like upon a ceramic substrate, the resistors forming the heating elements. By another process, the fabrication of the print head involves planar techniques, whereby resistors are formed by diffusion into one face of a flat semiconductor wafer, the heat sensitive paper passing in contact with this face.

There are problems associated with these techniques, however, which result in thermal print heads that are unsatisfactory for various reasons. First, the heating elements of the print head are subject to degradation due to the abrasive action of the paper when passing over the print head. Second, in the planar approach, leads to and between the resistor heating elements are ordinarily exposed, providing unreliable connections. Also, where the diffused resistors are formed in a monolithic semiconductor planar substrate, a large amount of power is required to heat the elements to the proper printing temperature, and a substantial amount of "spillover" heat occurs from one element to another, due to the lack of thermal isolation between elements, thereby reducing the ability to achieve a sharp print-out.

With these difficulties in mind, it is an object of the present invention to provide an improved print head for a thermal printer.

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be accomplished by any conventional technique, as, for example, by flow solder fillets. An epoxy may then be placed under the overhanging portions of the silicon slice to provide added mechanical support.

The actual operation of the thermal printer may be accomplished by various techniques and is not restricted to any one method of excitation of the appropriate heating elements. For example, a short high power pulse may be applied to selected external leads, such as 30—32, the pulse causing current to flow through resistors of selected printing elements, the selected printing elements heating up to say 300°C in a pattern corresponding to the letters or numbers to be printed. The selection of the proper leads to be energized may be accomplished manually or by a separate diode digital decoder, for example. Accordingly, as shown in Figure 1, selected elements of the "characters" 11—15 may be heated to define the numbers "1", "2", "3", "4", and "5", respectively, which then are printed on heat sensitive paper which has been indexed over the face of the thermal print head 1. (The selected elements which have been heated are represented on Figure 1 by a double cross-hatching, and may be best seen by holding the drawing at arms length from the eye.) Depending upon the interconnection scheme used, the printing may be accomplished, for example, by simultaneously heating selected elements of "characters" 11—15, thereby printing a whole line at a time, or by heating the selected elements of the characters in a manner so as to sequentially print out the numbers "1" through "5".

Referring now to Figure 2, there is depicted an underside plan view of a portion of one of the "characters" 11, showing some of its heating elements 40, 41, 42, and 43 and a typical, but not restrictive, pattern of interconnections. Each of the heating elements comprises a raised mesa of semiconductor material (as observed in the cross-section view of Figures 3—6), a diode and resistor pair such as D_{40} and R_{40} being formed by conventional masking and diffusion techniques, for example, in the base of the mesa, the pair being interconnected with each other and with the rest of the system. The function of the resistors R_{41} , R_{42} , R_{43} , and R_{44} is to provide the source of heat for each printing element, and the function of the diodes D_{41} , D_{42} , and D_{43} is to direct the current flow through only those resistors which are to be heated. First level interconnectors such as 50 and 51 ohmically connect the P-type regions of the diodes D_{41} and D_{42} and the P-type regions of diodes D_{42} and D_{43} to the second level interconnector 75 respectively, and first level interconnectors 52, 53, and 54 connect the ends of the resistor R_{41} and other resistors of the

other mesas (not shown in Figure 2) to the second level interconnectors 30a, 31a, and 32a, respectively.

The function of the diodes may be further understood by reference to the schematic representation shown in Figure 9. The diode-resistor pairs within the elements 40, 41, 46 and 47 are interconnected as shown. Assume that the element 40 is to be heated (i.e., a current made to flow through the resistor R_{40} of element 40), but the elements 41, 47, and 46 are to remain "cool"; i.e., no current is to flow through the resistors R_{41} , R_{47} and R_{46} . A source of positive potential is applied to the terminal 90 while a source of negative or ground potential is applied to terminal 91. Due to the blocking effect of the diode D_{47} , the only current path between the positive and negative terminals is the one through the diode D_{41} and resistor R_{40} . Consequently, only the element 40 heats up. Similarly, utilizing the same principle and arrangement, the remaining diodes and resistors of the other elements may be wired in like manner or in any other conventional manner, to selectively heat desired elements, the diodes functioning as current blocks. It is to be pointed out that the use of the diodes allows one to limit the number of external leads; if a pair of leads is applied to each element of each character, there is no need for the diodes.

With reference to the cross-section views of Figures 3—6 there is now described the fabrication of the print head of this invention, particularly the formation of the silicon mesa thermal printing elements. Single crystal semiconductor material, such as silicon, is used as the starting material for a slice 10. A portion of this slice is shown in Figure 3. The top surface of the slice is first masked and etched to form a pattern of raised mesas such as 40, 41 and 45. The masking may be by a material such as wax or preferably by photoresist techniques which permit excellent geometry control. The height of the mesas 40, 41 and 45, for example, or in other words, the depth of the etching may be approximately 1.5 to 2 mils. After the mesas are formed, the top surface of the slice is covered with a coating 60 of silicon carbide which may be formed by any technique to a thickness of perhaps 0.3 to 0.8 mil.

One method of depositing the silicon carbide is described with reference to Figure 7. Apparatus for depositing the silicon carbide in accordance with this process comprises a reactor in the form of a furnace tube 70 having heating coils 71. The furnace may be of a horizontal or vertical type, may be suited for single or multiple slices, and may be either resistively or inductively heated. Silicon slices, including the slice 10, with the mesas formed therein, are

disposed within the furnace in such a position as to expose the slices to gases directed into the tube through a conduit 73. Toluene (C_7H_8) and silicon tetrachloride ($SiCl_4$) vapors are respectively introduced into the conduit 73 from cylinders containing liquid toluene and liquid silicon tetrachloride, through which hydrogen gas is bubbled. Purified dried hydrogen enters end 72 of the conduit. The flow of the gases into the tube furnace 70 is regulated by conventional valves.

The rate of deposition is determined largely by the temperature at which the reactor is maintained, the flow rate through the conduit 73, and the percentage composition of the constituents. For example, when the flow rate was kept at approximately 10 liters per minute, the temperature at approximately $1080^\circ C$, and the reactive mixture consisted of 0.87 mol percent of $SiCl_4$, 0.18 mol percent C_7H_8 , and the remaining mol percent H_2 , a layer of silicon carbide was deposited upon slice 10 as seen in Figure 3 at a rate of approximately 1 micron per minute.

A layer 61 of material, for example polycrystalline semiconductor material, is now deposited over the top surface of the slice 10 adjacent the silicon carbide layer 60, as seen in Figure 3. The most common method of deposition is by the hydrogen reduction of silicon tetrachloride, a technique well known in the art and requiring no elaboration here. The conductivity type of the layer 61 is not critical; the crystalline structure may also be either single crystalline or amorphous, and should be, perhaps, six or eight mils or more to facilitate handling.

As the next step in the fabrication of the thermal printing head of this invention, the structure of Figure 3 is subjected to a lapping and polishing treatment on its lower face to remove all the original silicon material except that portion remaining within the mesas 40, 41 and 45, as illustrated in Figure 4. It is to be noted at this point, and as a particular feature of the invention, that the silicon carbide coating 60 functions as a substantially continuous "stop" to the lapping and polishing operation, enabling precision control to be maintained over the amount of semiconductor material left within the mesa regions. This is important for a variety of reasons. First, as a consequence of the various steps preceding the lapping operation, the silicon slice will bow, presenting a somewhat convex or concave surface to the lapping apparatus. Hence when the lapping and polishing operations are carried out to remove the substrate material from below the mesa regions, a considerable number of the mesas will be cut through and destroyed. The silicon carbide layer 60 tends to halt the lapping operation at the

lower face 62 so that none of the mesas will be cut through. Second, because of the precision control that can be maintained, the actual thickness of the semiconductor material within the mesa regions may be controlled to a precise degree. This is important since the thickness of each of the mesas influences their rate of heating and cooling (in other words, the thermal response) which, in turn, determines the speed of the printing.

Inverting the structure and looking at what was the bottom face 62 of Figure 4, but what will now be considered the top face of the unit, the structure appears as in Figure 5. The mesa regions 40 and 41 now serve as regions into which subsequent diffusions, or upon which epitaxial depositions, may be made in order to fabricate the diode-resistor pair of each printing element. In this particular embodiment the diode-resistor pair D_{40} and R_{40} and D_{41} and R_{41} are formed by conventional oxide masking and diffusion operations in the N type material of mesa elements 40 and 41, respectively.

P-type diffused regions 63a and 63b provide the respective anodes of the diodes D_{40} and D_{41} , while elongated P-type regions 64a and 64b, formed simultaneously with the anode regions, provide the resistors R_{40} and R_{41} . The N-type material of the mesas 40 and 41 provide the cathodes of the diodes D_{40} and D_{41} . Contact to the N region is made through low resistivity N+ regions as shown. The diffusion operations utilize silicon oxide masking as mentioned so that an oxide layer 65 is formed which acquires a stepped configuration in the final device. Openings are made in the oxide where contact is necessary, then metal film is deposited over the oxide and selectively removed to provide the desired contacts and interconnections.

It is to be observed that the silicon mesa 45 is masked with the silicon oxide layer 65 during the formation of the dioxides and resistors in the various printing elements. This region provides the spacing between the individual characters as also observed in Figures 1 and 2. The second level interconnections 30a, 31a, and 32a, for example, are formed over these regions between the characters rather than over the printing elements in order to prevent exposure of the insulation between these leads to the high temperature thermal transients associated with the thermal printing elements. An insulating layer 66 capable of withstanding high temperatures is formed by conventional techniques intermediate the first level interconnections and the second level interconnections 30a and 30b, as shown in Figure 5.

As the final steps in the fabrication of the thermal print head of the present invention, the composite structure with the individual

printing elements dual wafers ceramic substrate 68, Figure 6. The elements is interconnected, ample, engaged pattern shown in Figure 6 being according to the next step in the semiconductor moved, resulting in Figure 6, with printing elements isolated from silicon carbide (air, for example, by a mixture of volume), and acetic top surface line material semiconductor mesas is provided by layer 60 or barrier.

As a result, a process, a method such as a complete structure. As for pair of from the sensitive within the coating (6) component out the able wear self afford abrasive paper. The layer 60, protection for overlying the interconnection from the tested, printed.

The material between gaps between thermal insulation elements, including the quenching each element.

In addition, described schemes is shown in the drawings, with silicon carbide

the mesas will cause of the maintained, the semiconductor elements may be. This is important each of the heating and thermal refinements the speed of looking at Figure 4, but the top face appears as in 80 and 41 now subsequent differential depositions, state the diode element. In this diode-resistor R_{41} are masking and type material respectively. 90 and 63b provide the diodes D_{40} in regions 64a closely with the resistors R_{40} and the mesas 40 of the diodes N region is N+ regions utilize 100 tioned so that each acquires a final device. where contact film is selectively re-contacts and

silicon mesa oxide layer 65 oxides and resist elements. This between the in- observed in d level inter- 115 for example, between the printing exposure of the s to the high 120 its associated ents. An in- withstanding conventional st level inter- 121 level intercon- in Figure 5. lication of the tent invention, the individual 130

printing elements is sawed into the individual wafers and inverted and mounted upon ceramic substrate 20 with a suitable adhesive 68, such as epoxy, as shown in Figure 6. The wafer with the mesa printing elements is aligned so that the second level interconnections 30a, 31a, and 32a, for example, engage the appropriate metallized lead pattern on the ceramic substrate, as shown in Figure 1, the joining of the metal being accomplished by soldering. As the next step in the process, the polycrystalline semiconductor layer 61 is completely removed, resulting in a structure shown in Figure 6, whereby each of the mesa thermal printing elements 40 and 41, for example, are isolated from each other by the layer 60 of silicon carbide and the surrounding ambient (air, for example). This removal is accomplished by applying an etchant such as a mixture of hydrofluoric acid (2 parts per volume), nitric acid (15 parts per volume) and acetic acid (5 parts per volume) to the top surface, whereby all of the polycrystalline material 61 is etched away, while the semiconductor material within the individual mesas is protected from the etchant by the layer 60 of silicon carbide acting as an etch barrier.

As a result of the above described process, a matrix of mesa printing elements, such as 40 and 41, is produced, the complete structure providing numerous advantages. As seen in Figure 6, the diode-resistor pair of each element is positioned away from the surface over which the thermal sensitive paper passes, the silicon material within the mesas and the silicon carbide coating 60 providing the protection for these components. The final structure, even without the silicon carbide, will offer considerable wear resistance, the silicon material itself affording substantial protection from the abrasive action of the thermal sensitive paper. The presence of the silicon carbide layer 60, however, affords much greater protection for both the components and the overlying silicon material. In addition, since the interconnections are also formed away from the upper surface, they will be protected, providing greater reliability.

The removal of the polycrystalline material between each mesa, resulting in the gaps between each printing element, provides thermal isolation between each of the printing elements, thereby reducing heat "spillovers" into the adjacent elements and keeping the quantity of powder required to heat each element at a minimum.

In addition to the interconnection scheme described above, alternate interconnection schemes may be utilized. One such scheme is shown in Figure 6. The mesa printing elements, with the diode-resistor pairs and the silicon carbide layer are fabricated as pre-

viously described with reference to Figures 3—7, and the first level interconnection pattern deposited as before. The ceramic substrate 20 with the slot 80, for example, has the second level interconnection pattern, for example second level interconnection 69, formed on its lower face, as shown in Figure 8. The silicon wafer with the mesa printing elements is then mounted face down upon the ceramic, the mesa 45, for example, containing no diode-resistor pairs located over the slot 80. The first and second level interconnections are then selectively joined by way of individual wires such as 81, which are ball bonded at the appropriate points. The polycrystalline material is then removed as before. The ceramic substrate 20 and the slot 80 then provide the necessary insulation between the two levels of leads.

Various modifications may also be made in the material used for the insulating substrate 20. Since the substrate 20 physically connects the individual mesas, it should be fabricated of a material that provides adequate thermal isolation between the mesas while at the same time having sufficient thermal conductivity to provide a cooling path for the mesas after the print. An example of one material which may be used is alumina.

Although a 5×5 array has been described, any matrix or array of printing elements is deemed to be within the scope of the present invention. In addition, the thermal print head may be used to print many forms of information as letters, figures, symbols, etc. The starting material of the semiconductor slice may be either P-type or N-type.

Various other modifications of the disclosed embodiments, as well as other embodiments of the invention, may become apparent to persons skilled in the art without departing from the invention as defined by the appended claims.

WHAT WE CLAIM IS:—

1. A thermal print head comprising:—
 - (a) a substrate,
 - (b) an array of semiconductor mesas upon one surface of said substrate, said mesas being so arranged in said array that various ones of said mesas can be selected to define a form of information representation,
 - (c) a resistor within each of said mesas, and
 - (d) means for producing current in the resistors of selected ones of said mesas, thereby to heat said selected ones of said mesas.
2. A thermal print head as claimed in claim 1 wherein the said form of information representation is a letter of an alphabet.
3. A thermal print head as claimed in



mesas will use of the obtained, the semiconductor may be this is im- ch of the heating and thermal res- the speed

looking at Figure 4, but the top face appears as in and 41 now sequent dif- lepositions, the diode- ent. In this diode-resistor R_{41} are asking and pe material pectively. d 63b pro- diodes D_{40} regions 64a y with the ors R_{40} and e mesas 40 the diodes + region is + regions tions utilize ned so that h acquires a nal device. where con- film is de- lectively re- contacts and

silicon mesa ide layer 65 des and res- ements. This een the in- bserved in level inter- for example, between the the printing osure of the to the high s associated ents. An in- withstanding conventional st level inter- vel intercon- in Figure 5. ication of the ent invention, he individual

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Various other modifications of the disclosed embodiments, as well as other embodiments of the invention, may become apparent to persons skilled in the art without departing from the invention as defined by the appended claims.

WHAT WE CLAIM IS:—

1. A thermal print head comprising:—
 - (a) a substrate,
 - (b) an array of semiconductor mesas upon one surface of said substrate, said mesas being so arranged in said array that various ones of said mesas can be selected to define a form of information representation,
 - (c) a resistor within each of said mesas, and
 - (d) means for producing current in the resistors of selected ones of said mesas, thereby to heat said selected ones of said mesas.
2. A thermal print head as claimed in claim 1 wherein the said form of information representation is a letter of an alphabet.
3. A thermal print head as claimed in

- claim 1 wherein the said form of information representation is a number.
4. A thermal print head as claimed in claim 1 wherein said form of information presentation consists of a plurality of characters laterally spaced from one another.
5. A thermal print head as claimed in any of the preceding claims wherein the resistors are spaced from the top surfaces of the respective mesas.
- 10 6. A thermal print head as claimed in any of the preceding claims, wherein each of said semiconductor means includes a diode interconnected with the resistor therein.
- 15 7. A thermal print head as claimed in claim 6 wherein said resistor and diode are formed by diffusion into the semiconductor material of said mesa.
- 20 8. A thermal print head as claimed in either claim 6 or claim 7 wherein the resistors and diodes of the respective mesas are vertically spaced from the top surfaces of the respective mesas.
- 25 9. A thermal print head as claimed in any of the preceding claims, wherein the substrate has a slot opening to an opposite surface of the substrate from said one surface having said semiconductor mesas thereon, and including a first interconnection between the resistors of two of said mesas, said first interconnection extending across the bottom of said slot, a second interconnection on said opposite surface of said substrate, and a wire having a portion within said slot, said wire electrically connecting said first and second interconnections.
10. A thermal print head as claimed in claim 9, wherein said wire is ball-bonded to said first and second interconnections.
- 40 11. A thermal print head as claimed in any of the preceding claims, including a layer of wear-resistant material overlying said semiconductor mesas.
12. A thermal print head as claimed in claim 11 wherein the layer of wear-resistant material is silicon carbide.
- 45 13. A thermal print head substantially as described herein with reference to Figures 1 to 6, 8 and 9 of the drawings.
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