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**Baker et al.**

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(54) **ELECTRONIC DEVICE WITH INTERLEAVED PORTIONS FOR USE IN INTEGRATED CIRCUITS**

(58) **Field of Search** ..... 438/396, 210, 438/239, 241, 255, 381, 382, 398, 253, 238, 237; 257/296, 306-309

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(\* ) **Notice:** Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(22) **Filed:** **Aug. 27, 2001**

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US 2002/0155677 A1 Oct. 24, 2002

**Related U.S. Application Data**

(62) Division of application No. 09/838,526, filed on Apr. 19, 2001, now Pat. No. 6,410,955.

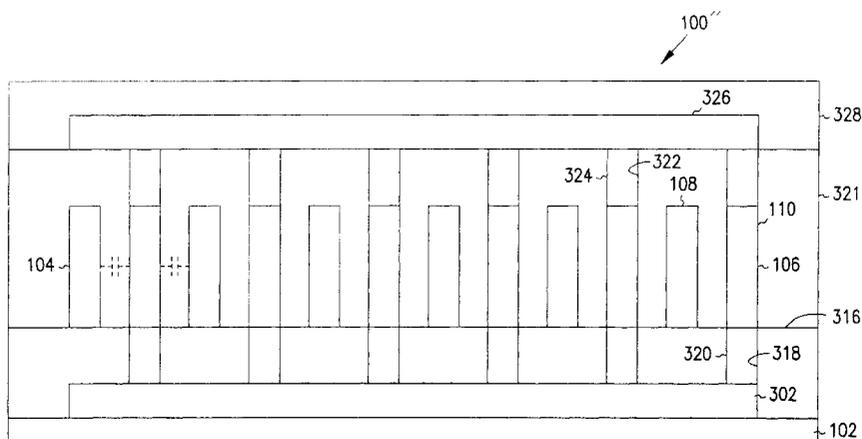
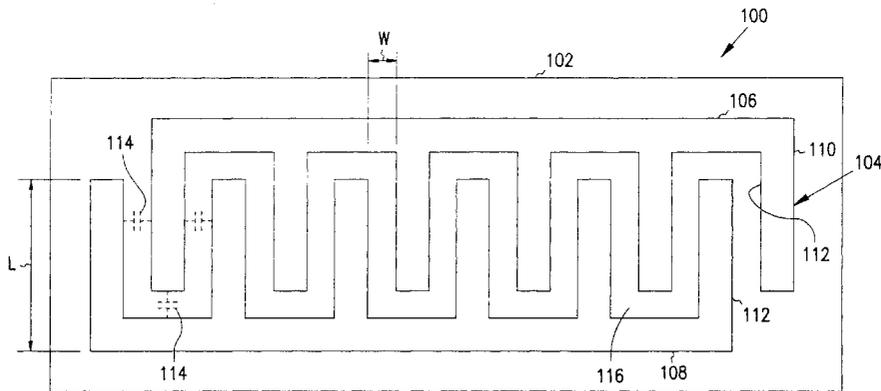
(51) **Int. Cl.<sup>7</sup>** ..... **H01L 21/20**

(52) **U.S. Cl.** ..... **438/396; 438/253; 438/241; 438/398**

(57) **ABSTRACT**

A capacitor for use in integrated circuits comprises a layer of conductive material. The layer of conductive material including at least a first portion and a second portion, wherein the first portion and the second portion are arranged in a predetermined pattern relative to one another to provide a maximum amount of capacitance per semiconductor die area.

**25 Claims, 9 Drawing Sheets**



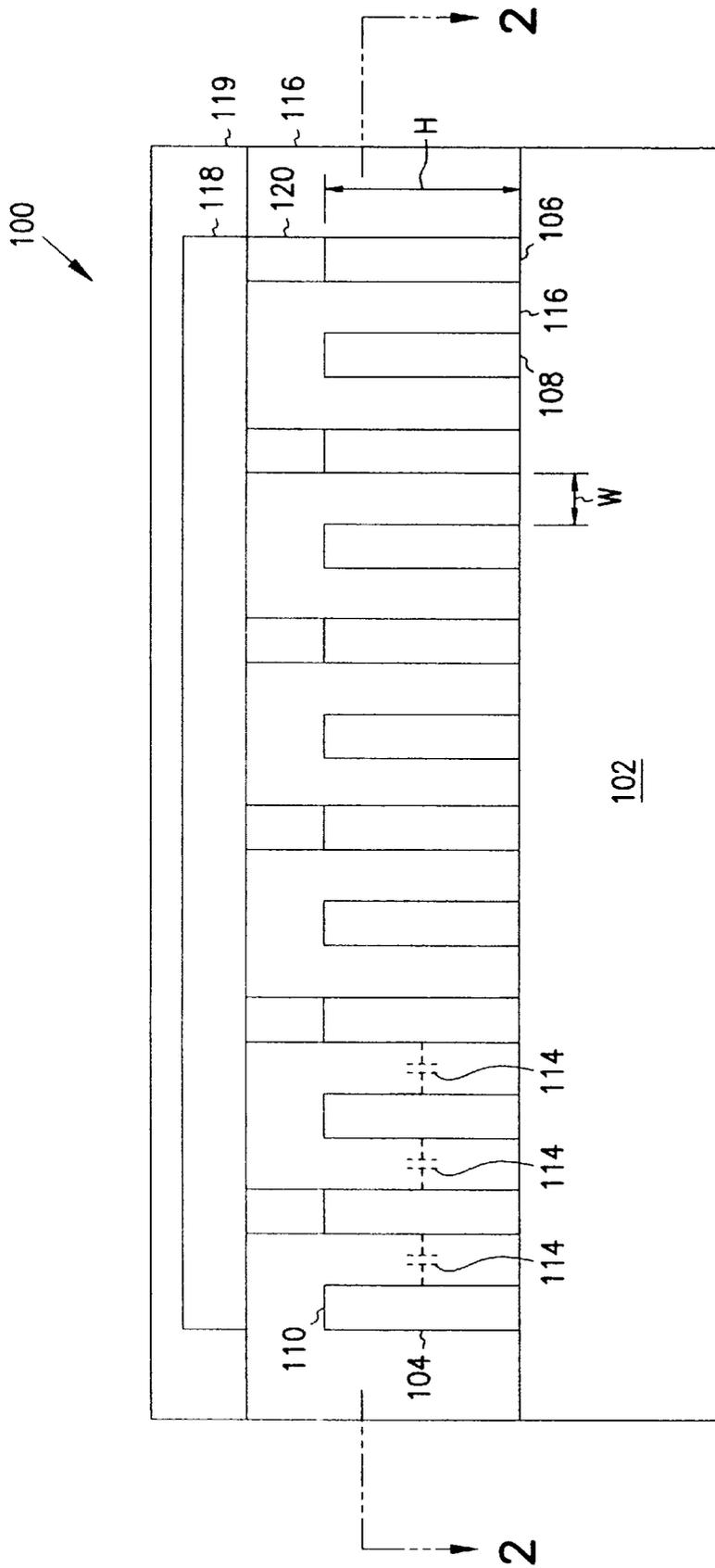


FIG. 1



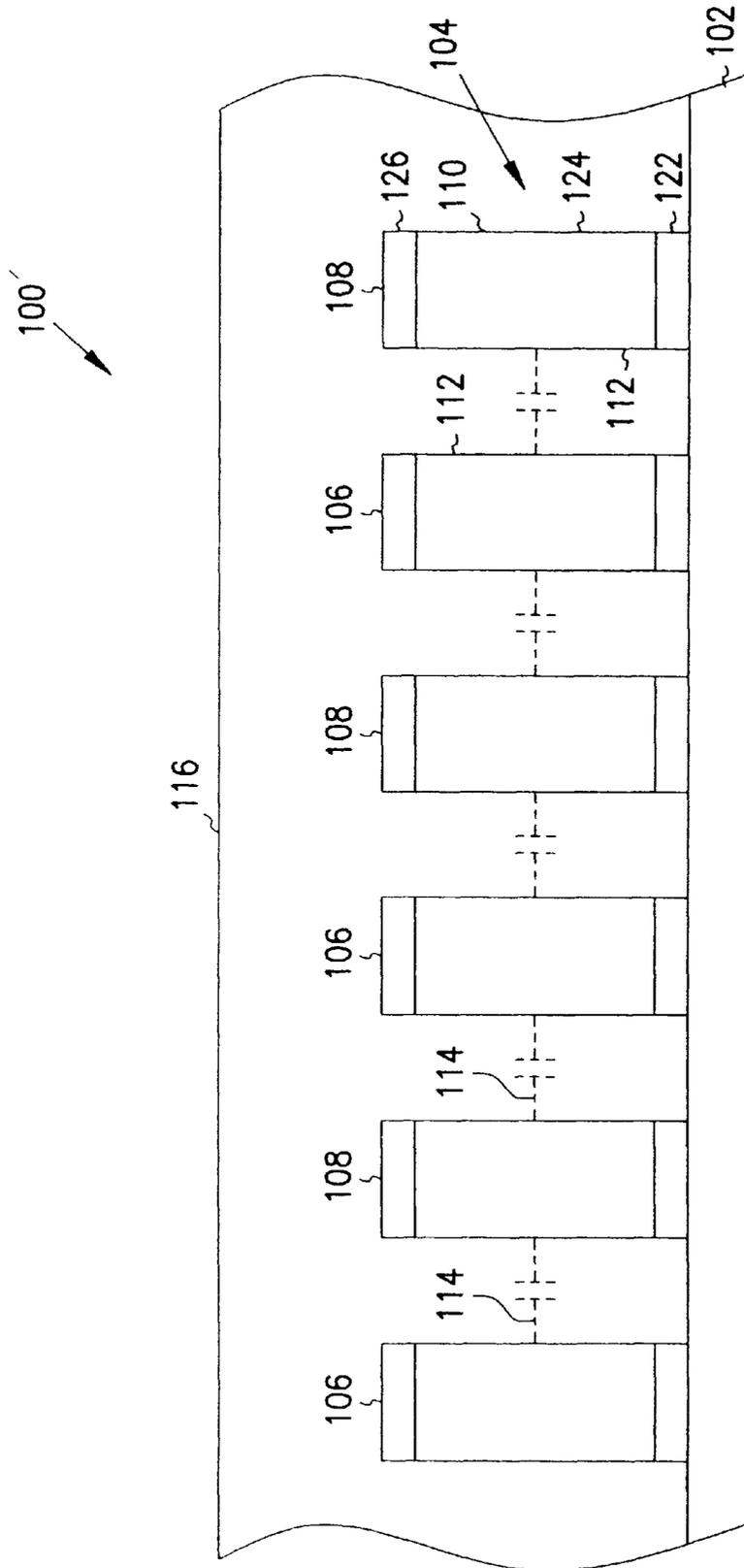


FIG. 3

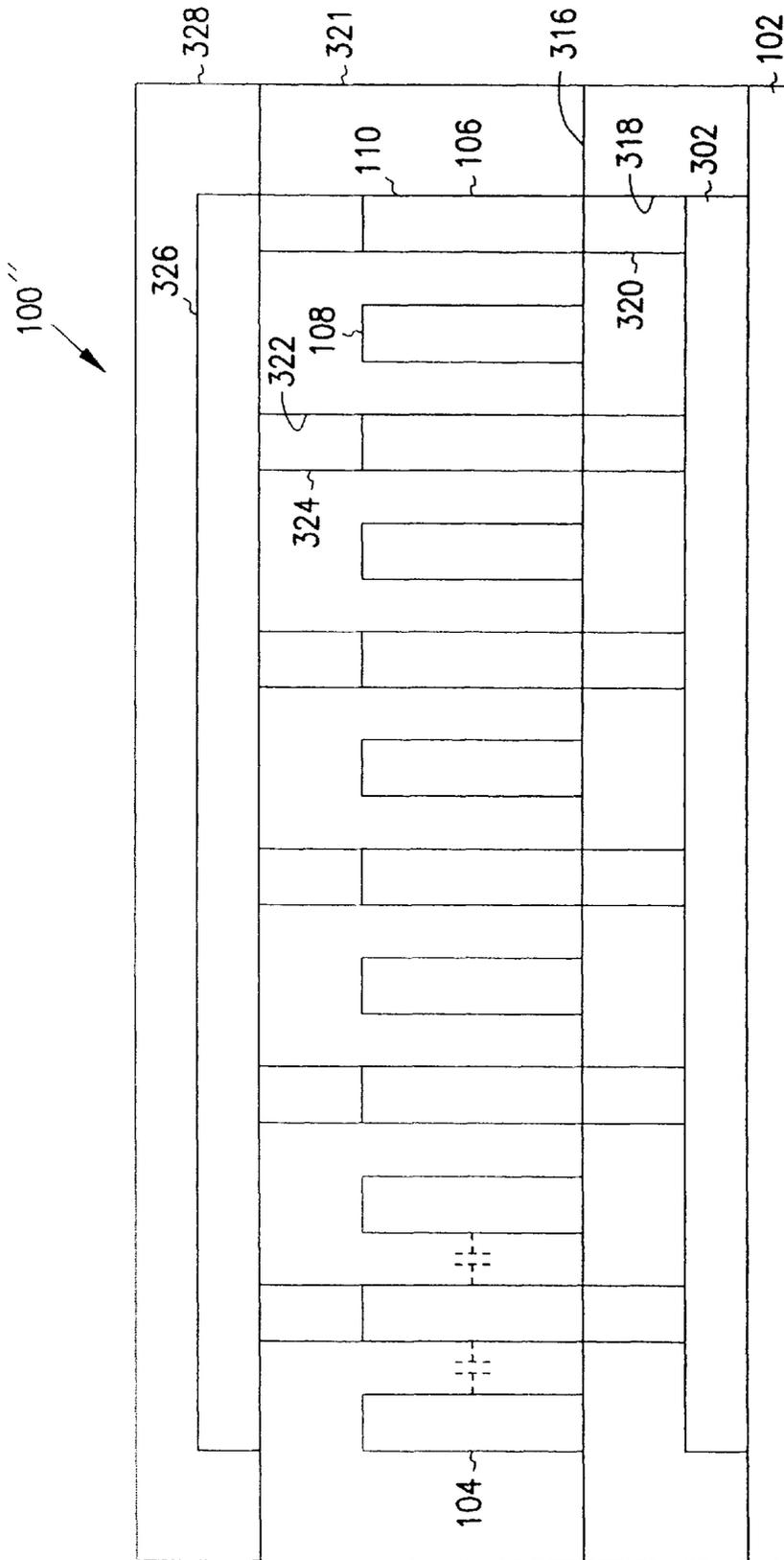


FIG. 4

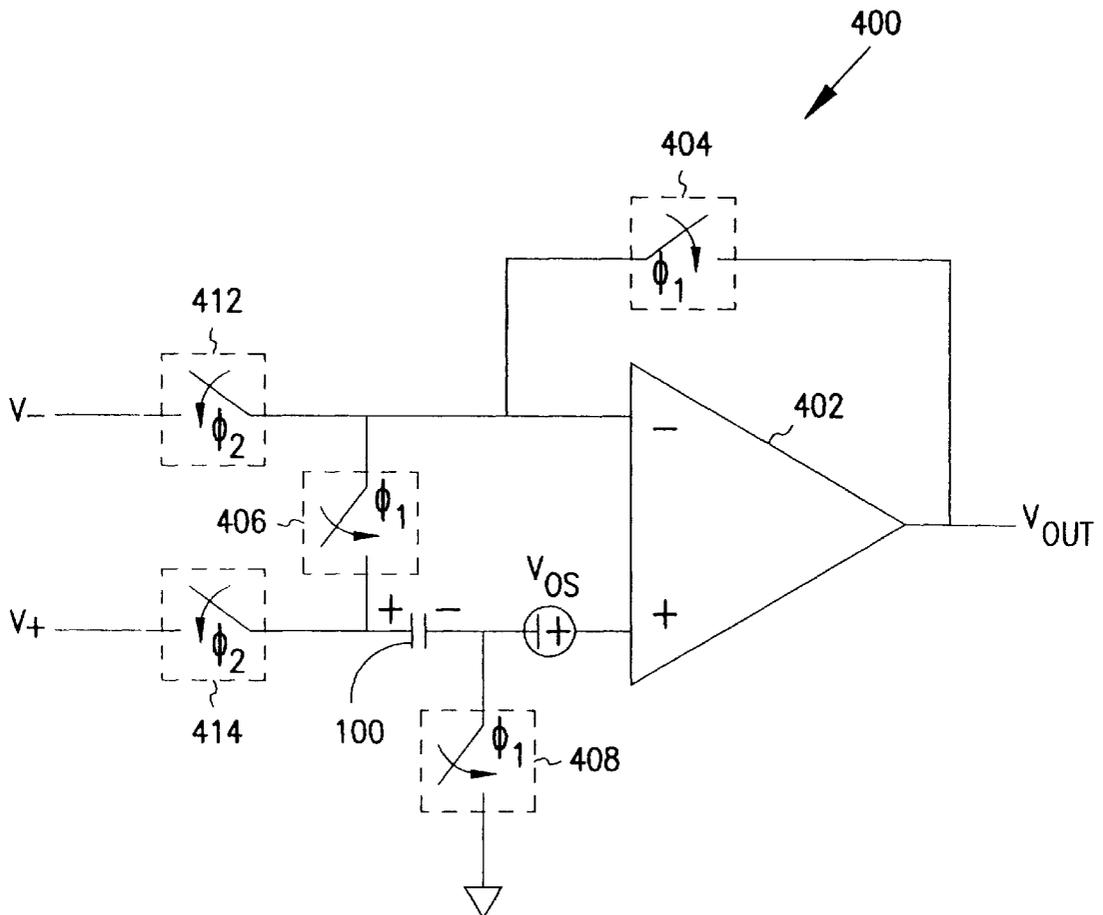


FIG. 5

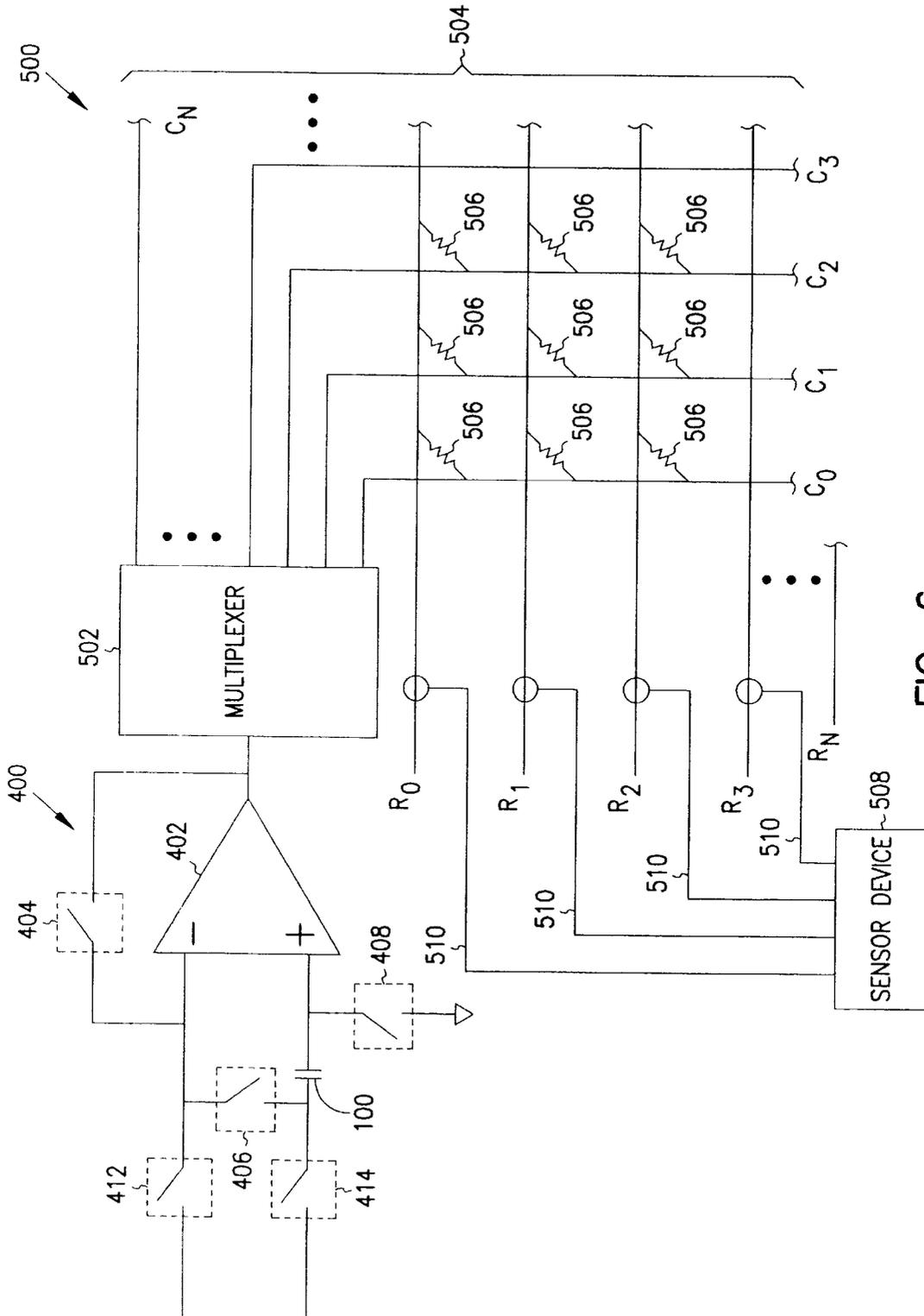


FIG. 6

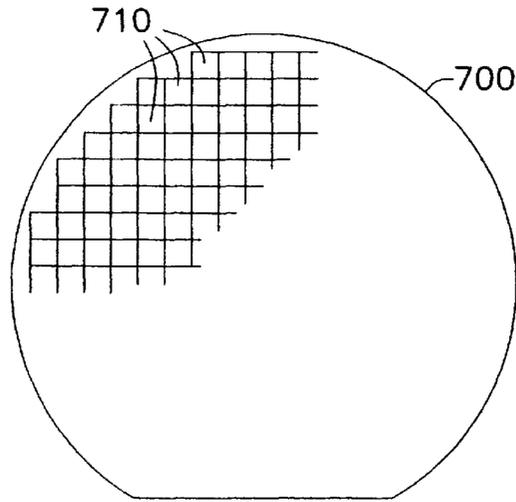


FIG. 7

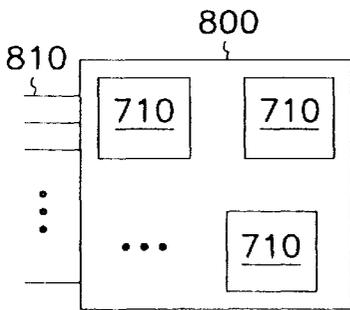


FIG. 8

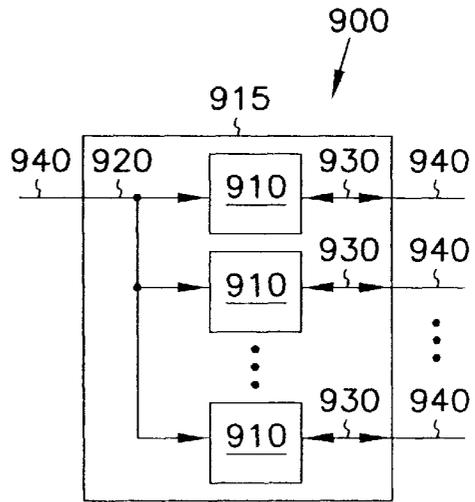


FIG. 9

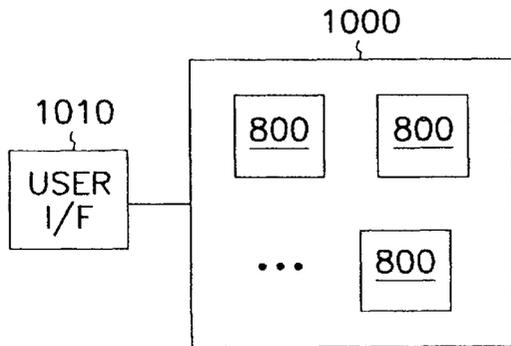


FIG. 10

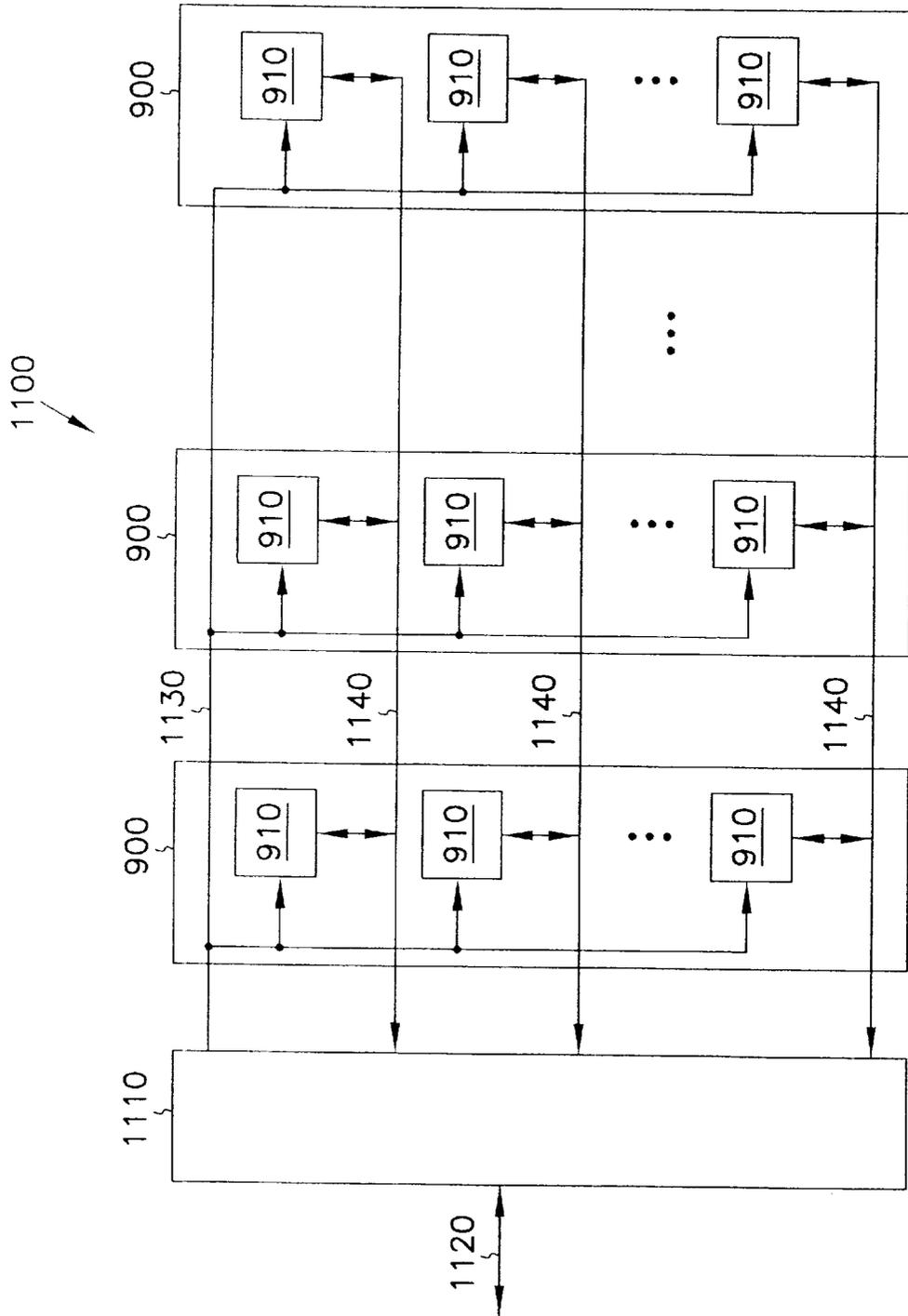


FIG. 11

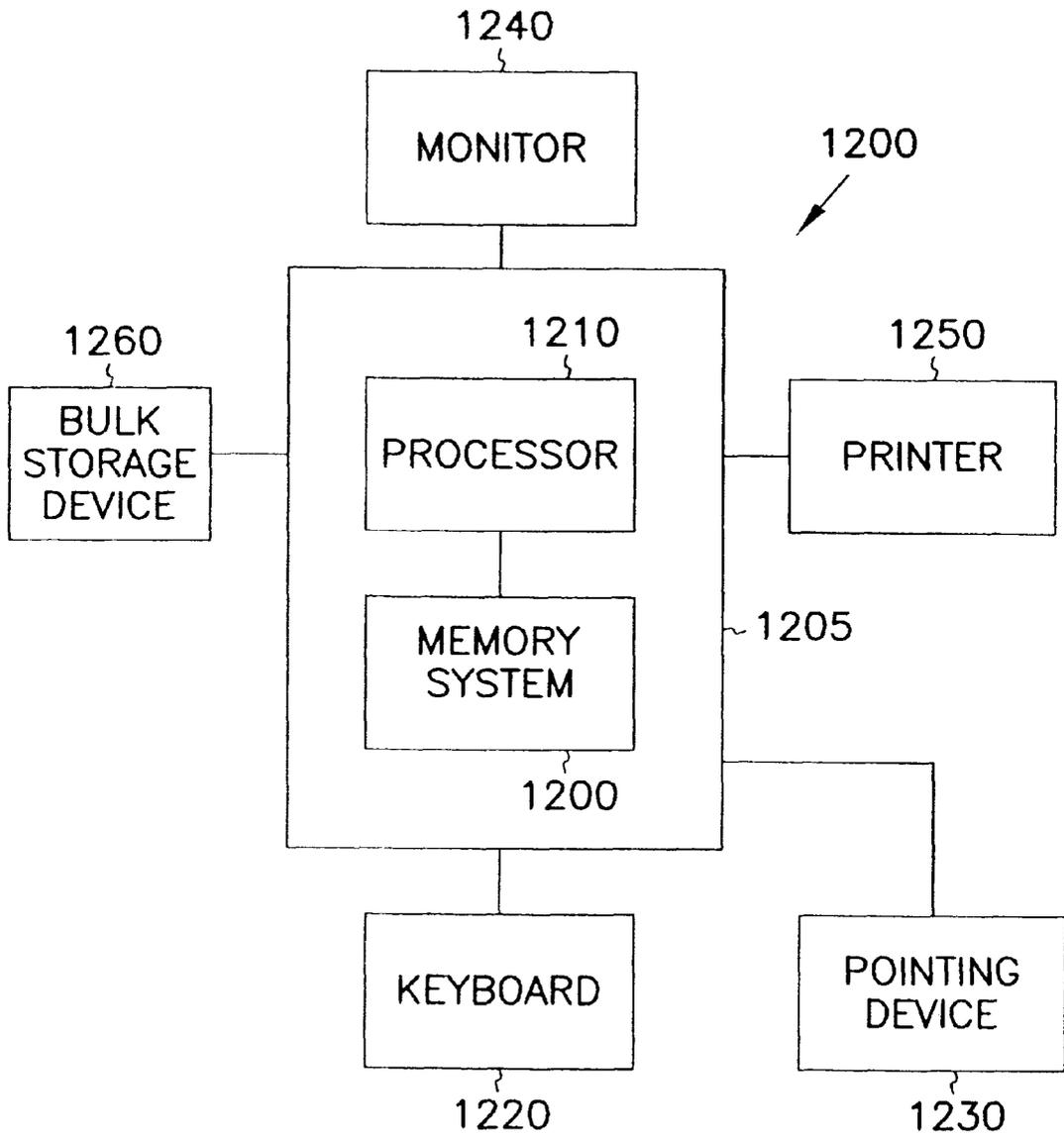


FIG. 12

## ELECTRONIC DEVICE WITH INTERLEAVED PORTIONS FOR USE IN INTEGRATED CIRCUITS

This application is a Divisional of U.S. application Ser. No. 09/838,526, now U.S. Pat. No. 6,410,955 filed Apr. 19, 2001.

### FIELD OF THE INVENTION

The present invention relates generally to electronic circuits, and more particularly to a capacitor for use in integrated circuits.

### BACKGROUND INFORMATION

There is a continuing demand for integrated circuits to perform more functions or operations in shorter periods of time. This typically requires additional components to perform the additional functions, store more data and operate more efficiently. At the same time packaging requirements are decreasing. Consumers want smaller, lighter weight products that do more and are more mobile or portable. Accordingly, circuit designers are challenged to provide more components or greater capacity per unit of area on a semiconductor die. Most electronic circuits include basic electrical components such as transistors, resistors, inductors, capacitors and the like. Capacitors are one component that can occupy a lot of area on a semiconductor die depending upon the size of the capacitor. Capacitors are typically made by depositing a first metal plate, depositing a layer of insulation material over the first metal plate and then depositing a second metal plate over the layer of insulation material and parallel to the first metal plate. The size of the capacitance will be a function of the surface area of the two facing parallel plates and other parameters such as the dielectric constant of the insulation material and the spacing between the plates. Accordingly, one primary means of increasing the capacitance, is to increase the size of each of the parallel plates but this will consume more area on the semiconductor die.

Additionally, in some circuits it may be desirable for the capacitor to be independent of voltage and frequency applied across the capacitor once it is charged to a predetermined level. For example, a capacitor may be connected to the non-inverting input of an operational amplifier to reduce or cancel the offset voltage inherent in the operational amplifier. The capacitor may be pre-charged to the opposite polarity of the offset voltage of the amplifier so that the offset voltage is canceled during normal operation of the amplifier. When an input voltage signal is applied to the input of the operational amplifier, the output voltage signal will be stable and uninfluenced by the offset voltage if the capacitor is voltage and frequency independent.

Accordingly, for the reason stated above, and for other reasons that will become apparent upon reading and understanding the present specification, there is a need for a capacitor that maximizes the amount of capacitance per unit of area of a semiconductor die and that is independent of voltage and frequency.

### SUMMARY OF THE INVENTION

In accordance with the present invention, a capacitor includes a layer of conductive material formed on a substrate or semiconductor die. The layer of conductive material includes a first portion and a second portion. The first and second portions are arranged in a predetermined pattern

relative to one another to provide a maximum amount of capacitance per unit of area on the substrate or semiconductor die.

In accordance with one embodiment of the present invention, the first portion and the second portion of the layer of conductive material each have a substantially comb-like structure with a plurality of teeth. The teeth of the first portion and the teeth of the second portion are interleaved and each tooth includes a pair of sidewalls. Each sidewall, except an outside sidewall of an end tooth, faces a sidewall of a tooth of the other portion to provide a maximum of juxtaposed surface area.

In accordance with another embodiment of the present invention, an integrated circuit includes an amplifier formed on a substrate or semiconductor die and a capacitor formed on the substrate and connected to an input of the amplifier. The capacitor includes a first substantially comb-like structure of conductive material with a plurality of teeth and a second substantially comb-like structure of conductive material also with a plurality of teeth. The teeth of the second substantially comb-like structure are interleaved with the teeth of the first substantially comb-like structure and each tooth of the first and second comb-like structures have a pair of sidewalls. Each sidewall has a selected surface area and each of the teeth of the first and second comb-like structures are separated by a gap of a chosen width to provide a predetermined capacitance.

In accordance with another embodiment of the present invention, a memory system includes an array of memory elements. Each memory element is connected by one of plurality of row lines and by one of a plurality of column lines. An amplifier is connected to at least one of each of the plurality of column lines or each of the plurality of row lines. A capacitor is connected to an input of each amplifier to cancel the offset voltage of the amplifier. The capacitor includes a layer of conductive material having a first portion and a second portion. The first portion and the second portion are arranged in a predetermined pattern relative to one another to provide a maximum amount of capacitance per given area of the substrate or semiconductor die.

In accordance with a further embodiment of the present invention, an electronic system includes a processor and a memory device coupled to the processor. The memory device includes an array of memory elements and each memory element is connected by one of a plurality of row lines and by one of a plurality of column lines. An amplifier is connected to at least one of each of the plurality of row lines or to each of the plurality of column lines. A capacitor is connected to an input of each amplifier to cancel the offset voltage. Each capacitor includes a layer of conductive material divided into a first portion and a second portion. The first and second portions are arranged in a predetermined pattern relative to one another to provide a maximum amount of capacitance per given area of a substrate or semiconductor die.

In accordance with a further embodiment of the present invention, a method for making a capacitor includes depositing at least one layer of conductive material on a substrate; removing material from the layer of conductive material to form a first and second portion arranged in a predetermined pattern relative to one another to provide a maximum amount of capacitance per area of the substrate or wafer.

In accordance with another embodiment of the present invention, a method for correcting for offset voltage in an amplifier includes: connecting an output of the amplifier to an inverting input of the amplifier; connecting a capacitor

between the inverting input and a positive or non-inverting input of the amplifier, wherein the capacitor comprises a layer of conductive material including at least a first portion and a second portion and wherein the first portion and the second portion are arranged in a predetermined pattern relative to one another to provide a maximum capacitance per area; and connecting the positive input of the amplifier to ground to cause the capacitor to charge to the offset voltage.

In accordance with a further embodiment of the present invention, a method for applying a stable voltage to a column or a row line of a memory device includes forming an amplifier and connecting an output of the amplifier to one of the row line or the column line; forming a capacitor connected to an input of the amplifier, wherein the capacitor is formed by depositing at least one layer of conductive material and removing material from the at least one layer of conductive material to form a first portion and a second portion that are arranged in a predetermined pattern relative to one another to provide a maximum capacitance per area of a semiconductor wafer or die; and forming circuitry to charge the capacitor to an opposite polarity of the offset voltage to nullify the offset voltage of the amplifier.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings like reference numerals describe substantially similar components throughout the several views. Like numerals having different letter suffixes represent different instances of substantially similar components.

FIG. 1 is a side elevation view of a capacitor in accordance with one embodiment of the present invention.

FIG. 2 is a cross-section view of the capacitor of FIG. 1 taken along lines 2—2.

FIG. 3 is a partial-side elevation view of a capacitor in accordance with another embodiment of the present invention.

FIG. 4 is a side elevation view of a capacitor in accordance with a further embodiment of the present invention.

FIG. 5 is a schematic diagram of an offset or operational amplifier and offset capacitor in accordance with an embodiment of the present invention.

FIG. 6 is schematic diagram of a portion of a memory device or system including an operational amplifier and offset capacitor in accordance with an embodiment of the present invention.

FIG. 7 is a top view of a wafer or substrate containing semiconductor dies in accordance with an embodiment of the present invention.

FIG. 8 is a block diagram of an exemplary circuit module in accordance with an embodiment of the present invention.

FIG. 9 is a block diagram of an exemplary memory module in accordance with an embodiment of the present invention.

FIG. 10 is a block diagram of an exemplary electronic system in accordance with the present invention.

FIG. 11 is a block diagram of an exemplary memory system in accordance with the present invention.

FIG. 12 is a block diagram of an exemplary computer system in accordance with the present invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following detailed description of the preferred embodiments, reference is made to the accompanying draw-

ings which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that process or mechanical changes may be made without departing from the scope of the present invention. The terms wafer and substrate used in the following description include any base semiconductor structure. Both are to be understood as including silicon-on-sapphire (SOS) technology, silicon-on-insulator (SOI) technology, thin film transistor (TFT) technology, doped and undoped semiconductors, epitaxial layers of a silicon supported by a base semiconductor, as well as other semiconductor support structures well known to one skilled in the art. Furthermore, when reference is made to a wafer or substrate in the following description, previous process steps may have been utilized to form regions/junctions in the base semiconductor structure. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims.

Referring to FIGS. 1 and 2, FIG. 1 is a side elevation of a capacitor 100 in accordance with the present invention. The capacitor 100 may be formed on a substrate 102 or semiconductor wafer. A layer 104 of conductive material is deposited on the substrate 102 by chemical vapor deposition (CVD) or similar techniques to a selected height "H." The conductive layer 104 may be tungsten. The conductive layer 104 is then etched by photo resistive techniques, mechanical etching or the like to form a first portion 106 and a second portion 108 arranged in a predetermined pattern relative to one another to provide a maximum amount of juxtaposed surface area between the first and second portions 106 and 108 and accordingly a maximum amount of capacitance per unit of area of the substrate 102 or semiconductor wafer on which the capacitor 100 is formed. In accordance with one embodiment of the invention, the predetermined pattern of the first portion 106 and the second portion 108 may be substantially comb-like structures as shown in FIG. 2. Each of the first and second portions 106 and 108 include a plurality of teeth 110. Each tooth 110 has a sidewall 112 with a selected height "H" corresponding to the height of the conductive layer 104 and length "L" to provide a selected surface area facing a juxtaposed surface area of the other portion 106 or 108. The capacitor 100 is then formed by the juxtaposed sidewalls 112 of the teeth 110 of the first and second portions 106 and 108 corresponding to parallel plates of a capacitor as illustrated by the standard capacitor symbols 114 shown by broken lines between the sidewalls 112 in FIGS. 1 and 2. The interleaved teeth 110 of the comb-like structures of first and second portions 106 and 108 provide a maximum amount of capacitance per unit of area of the substrate 102.

In the predetermined pattern, the first and second portions 106 and 108 are separated by a substantially serpentine-shaped gap of a selected width "W." A layer of insulation material 116 is deposited over and between the first and second portions 106 and 108. The value or amount of the capacitance formed by the first and second portions 106 and 108 will be a function of the surface area of the juxtaposed sidewalls 112, the width W of the gap between the first and second portions 106 and 108 and the dielectric constant of the insulation layer 116. Accordingly, the value or amount of the capacitance may be predetermined by selecting the length L and height H of the juxtaposed sidewalls 112 to provide a selected surface area, choosing the width of the gap W and selecting the dielectric constant of the insulation layer 116.

While the predetermined pattern of the first and second portions **106** and **108** have been described as a substantially comb-like structure, it should be noted that other patterns may be used as well to provide a predetermined or desired capacitance. Interconnected strips of material of a selected height and width that are interleaved with other interconnected strips of material may be used to provide the desired capacitance value.

In accordance with one embodiment of the present invention shown in FIG. 1, a reference plate **118** of conductive or semiconductor material may be disposed on the insulation layer **116** and over the first and second portions **106** and **108**. The reference plate **118** is electrically connected to one of the first or second portions **106** or **108** by at least one contact or plug **120**. The plugs may be formed by creating vias or holes through the insulation layer **116** and then depositing a conductive material in the via in contact with the first portion **106** or the second portion **108**. The plugs **120** may be formed from tungsten, copper, aluminum or the like. The reference plate **118** will provide further capacitance between itself and the one of the first or second portions **106** or **108** that is not electrically connected to the reference plate **118**. The reference plate **118** is then preferably covered by another insulation layer **119**. While the reference plate **118** is shown in FIG. 1 and being disposed over the first and second portions **106** and **108**, the reference plate **118** could have also been formed on the substrate **102** first and then the first and second portions **106** and **108** could have been formed over the reference plate **118**.

In another embodiment of the present invention shown in FIG. 3, the layer of conductive material **104** may include a first layer of metalization, semiconductor material or polysilicon **122**, a second layer of tungsten **124** disposed over the first layer of metalization **122** and a third layer of metalization, semiconductor material or polysilicon **126** or polysilicon disposed over the second layer of tungsten **124**. All three layers **122**, **124** and **126** are then etched to form the teeth **110** of the first and second portions **106** and **108**. The capacitance **100'** is therefore created between the sidewalls **112** as illustrated by the capacitor symbols **114** in broken lines and between the metalization layers **122** and **126**. The metalizations layers **122** and **126** may be much thinner than the tungsten layer **124**.

In another embodiment of the present invention shown in FIG. 4, a capacitor **100"** is similar to the capacitor **100** in FIGS. 1 and 2 and includes a first reference plate or layer **302** of conductive or semiconductor material formed on the substrate **102** or silicon wafer. A layer of insulation material **316** is disposed over the first reference plate **302**. At least one hole or via **318** is formed in the insulation layer **316** and contacts or plugs **320** are formed in the vias **318** to electrically connect the first reference plate **302** to the teeth **110** of one of the first or second portions **106** or **108**. A layer of conductive material **104** is deposited on the insulation layer **316** and is etched to form the first portion **106** and the second portion **108**. The first and second portions **106** and **108** will preferably be formed in a predetermined pattern to provide the maximum amount of juxtaposed surface area and therefore the maximum amount of capacitance per unit of area of the substrate **102** similar to that described with respect to the capacitor **100** in FIGS. 1 and 2. Accordingly, the first and second portions **106** and **108** may also be comb-like structures similar to those in FIGS. 1 and 2; although other patterns may be used as well to provide a predetermined capacitance value. A further layer of insulation material **321** is deposited over the first and second portions **106** and **108**. At least one hole or via **322** is formed through the insulation

material **321** exposing whichever of the first or second portions **106** or **108** that is contacted by the first reference plate **302**. A plug or contact **324** of conductive material is deposited in the hole **322** in contact with the first or second portion **106** or **108**. A second reference plate **326** of conductive or semiconductor material is then deposited on the insulation material layer **321** and in contact with the at least one plug **324**. Accordingly, the reference plates **302** and **326** form additional capacitance with whichever of the first and second portions **106** or **108** that is not connected by the plugs **320** and **324** to the first and second reference plates **302** and **326**. The plugs **320** and **324** may be made from tungsten. The first portion **106** and the second portion **108** may also be made from tungsten or may be two metalization layers separated by a thicker layer of tungsten similar to the teeth **110** shown in FIG. 3.

One application of the capacitor **100** is as an offset capacitor **100** in an operational amplifier circuit **400** to reduce or cancel the offset voltage ( $V_{os}$ ) of an operational amplifier **402** as shown in FIG. 5. The offset capacitor **100** may be connected to the non-inverting or positive input of the operational amplifier **402**. A first switch **404** is connected between an output ( $V_{out}$ ) of the amplifier **402** and an inverting or negative input of the amplifier **400**. A second switch **406** is connected between the inverting input of the amplifier **402** and one side of the capacitor **100**. The other side of the capacitor **100** is connected to the non-inverting input of the amplifier **402**, and a third switch **408** is connected between the other side of the capacitor **100** at a node **410** and ground. Another pair of switches **412** and **414** respectively connect or disconnect any input signals  $V^-$  or  $V^+$  from the inverting and non-inverting inputs of the amplifier **402**.

In operation, a timing signal  $\phi_1$  may be generated by a controller or processor (not shown in FIG. 5) to close switches **404**, **406** and **408**. The capacitor **100** will then be charged to the level of the offset voltage  $V_{os}$  but with the opposite polarity of the offset voltage to nullify or cancel the offset voltage during normal operation of the amplifier **402**. After a predetermined time delay to fully charge the capacitor **100** to the offset voltage, switches **404**, **406** and **408** are opened or another signal may be generated to open switches **404**, **406** and **408**, and a timing signal  $\phi_2$  is generated to connect any input signals to the operational amplifier **402**. The offset capacitor **100** will then cancel the offset voltage  $V_{os}$  to provide a stable output voltage  $V_{out}$  that is independent of the input voltage and frequency.

Referring to FIG. 6, one application of the operational amplifier circuit **400** of FIG. 5 is to drive the column lines of a magnetic random access memory (MRAM) device or system **500**. A simplified schematic diagram of a portion of an MRAM system **500** is shown in FIG. 6. The amplifier **402** is preferably connected to a multiplexer **502** and the multiplexer **502** is connected to a plurality of column lines  $C_0-C_n$ . A plurality of amplifier circuits **400** could be used rather than the multiplexer **502** with an amplifier circuit **400** being connected to each column line; however, the plurality of amplifier circuits **400** would occupy much more area on a substrate or semiconductor die (not shown in FIG. 6) that is better used for other components such a memory array **504** or matrix. The memory array **504** includes a plurality of resistive elements or memory elements **506**. Each memory element **506** is connected between each column line  $C_0-C_n$  and row line  $R_0-R_n$ . A sensor device **508** is connected by leads **510** to each of the row lines to sense the current when a row line is active to retrieve or read information from the MRAM system **500**. The current in an active row line should

be precise for sensing to function correctly. Accordingly, to provide an accurate current level and proper sensing, the associated column lines must be held at a stable, constant reference voltage level. A variation of one or two millivolts could provide erroneous sensing of the row lines. Accordingly, the reference output voltage  $V_{out}$  from the amplifier circuit **400** that is applied to the column lines must be very stable and not influenced by the offset voltage of the operational amplifier **402**. The capacitor **100** must therefore accurately nullify the offset voltage and not be influenced or vary as a result of voltage or frequency changes associated with the input signals; in other words, the capacitor **100** should be independent of voltage and frequency.

The present invention provides a relatively large bipolar capacitor in terms of the number of microfarads per unit of die area compared to other uses of capacitors in memory circuits which have capacitances on the order of nanofarads or femtofarads per unit of area. As described above, the large capacitance values are required in the MRAM amplifier circuit to provide the very stable line voltage for sensing and reading of the row lines for proper operation of the MRAM system. The three dimensional capacitor structures of the present invention pack the largest surface area between capacitor plates in the smallest footprint or die area (IC real estate) to provide additional die area for memory elements.

While the memory device **500** has been described with respect to the amplifier circuit **400** being connected to the column lines, the memory array **504** is substantially symmetrical and the row and column lines could be interchanged such that the amplifier circuit **400** could just as well be connected to the row lines and the column lines could be read or sensed by the sensor device **508**.

With reference to FIG. 7, in one embodiment, a semiconductor die **710** is produced from a silicon wafer **700**. The die **710** is an individual pattern, typically rectangular, on a substrate that contains circuitry to perform a specific function. A semiconductor wafer **700** will typically contain a repeated pattern of such dies **710** containing the same functionality. Die **710** may contain circuitry for the capacitor **100**, operational amplifier circuit **400** and memory device **500** or other device with which the capacitor **100** may be utilized, as discussed above. Die **710** may further contain additional circuitry to extend to such complex devices as a monolithic processor with multiple functionality. Die **710** is typically packaged in a protective casing (not shown) with leads extending therefrom (not shown) providing access to the circuitry of the die **710** for unilateral or bilateral communication and control.

As shown in FIG. 8, two or more dies **710** may be combined, with or without protective casing, into a circuit module **800** to enhance or extend the functionality of an individual die **710**. Circuit module **800** may be a combination of dies **710** representing a variety of functions, or a combination of dies **710** containing the same functionality. Some examples of a circuit module include memory modules, device drivers, power modules, communication modems, processor modules and application-specific modules, multiple voltage supply switches **100** and control circuits **200** and may include multi-layer, multi-chip modules. Circuit module **800** may be a sub-component of a variety of electronic systems, such as a clock, a television, a cell phone, a personal computer, an automobile, an industrial control system, an aircraft and others. Circuit module **800** will have a variety of leads **810** extending therefrom providing unilateral or bilateral communication and control.

FIG. 9 shows one embodiment of a circuit module as a memory module **900**. Memory module **900** generally depicts

a Single In-line Memory Module (SIMM) or Dual In-line Memory Module (DIAM). A SIMM or DIAM is generally a printed circuit board (PCB) or other support containing a series of memory devices. While a SIMM will have a single in-line set of contacts or leads, a DIAM will have a set of leads on each side of the support with each set representing separate I/O signals. Memory module **900** contains multiple memory devices **910** contained on support **915**, the number depending upon the desired bus width and the desire for parity. Memory module **900** may contain memory devices **910** on both sides of support **915**. Memory module **900** accepts a command signal from an external controller (not shown) on a command link **920** and provides for data input and data output on data links **930**. The command link **920** and data links **930** are connected to leads **940** extending from the support **915**. Leads **940** are shown for conceptual purposes and are not limited to the positions shown in FIG. 9. The memory module **900** or memory devices **910** may also include the multiple voltage switch **100** and control circuit **200** to provide application of different voltages to the memory devices **910** to enable the memory devices to perform different functions or operations or to place the memory devices **910** in different modes as previously described.

FIG. 10 shows an electronic system **1000** containing one or more circuit modules **800**. Electronic system **1000** generally contains a user interface **1010**. User interface **1010** provides a user of the electronic system **1000** with some form of control or observation of the results of the electronic system **1000**. Some examples of user interface **1010** include the keyboard, pointing device, monitor and printer of a personal computer; the tuning dial, display and speakers of a radio; the ignition switch and gas pedal of an automobile; and the card reader, keypad, display and currency dispenser of an automated teller machine. User interface **1010** may further describe access ports provided to electronic system **1000**. Access ports are used to connect an electronic system to the more tangible user interface components previously exemplified. One or more of the circuit modules **800** may be a processor providing some form of manipulation, control or direction of inputs from or outputs to user interface **1010**, or of other information either preprogrammed into, or otherwise provided to, electronic system **1000**. One or more of the circuit modules **800** may also include a multiple voltage switch **100** and control circuit **200** to facilitate the application of different voltage levels to other components in the circuit module **800** or to other circuit modules **800** in the electronic system **1000**. As will be apparent from the lists of examples previously given, electronic system **1000** will often contain certain mechanical components (not shown) in addition to circuit modules **800** and user interface **1010**. It will be appreciated that the one or more circuit modules **800** in electronic system **1000** can be replaced by a single integrated circuit. Furthermore, electronic system **1000** may be a sub-component of a larger electronic system.

FIG. 11 shows one embodiment of an electronic system as a memory system **1100**. Memory system **1100** contains one or more memory modules **900** and a memory controller **1110**. Memory controller **1110** provides and controls a bidirectional interface between memory system **1100** and an external system bus **1120**. Memory system **1100** accepts a command signal from the external bus **1120** and relays it to the one or more memory modules **900** on a command link **1130**. Memory system **1100** provides for data input and data output between the one or more memory modules **900** and external system bus **1120** on data links **1140**. Memory system **1100** may include memory devices such as the MRAM device **500** of FIG. 6.

FIG. 12 shows a further embodiment of an electronic system as a computer system 1200. Computer system 1200 contains a processor 1210 and a memory system 1100 housed in a computer unit 1205. Computer system 1200 is but one example of an electronic system containing another electronic system, i.e. memory system 1100, as a sub-component. Computer system 1200 optionally contains user interface components. Depicted in FIG. 12 are a keyboard 1220, a pointing device 1230, a monitor 1240, a printer 1250 and a bulk storage device 1260. It will be appreciated that other components are often associated with computer system 1200 such as modems, device driver cards, additional storage devices, etc. It will further be appreciated that the processor 1210 and memory system 1100 of computer system 1200 can be incorporated on a single integrated circuit. Such single package processing units reduce the communication time between the processor 1210 and the memory system 1100.

While the three dimensional capacitor structures of the present invention have been described with respect to use in an amplifier circuit and memory circuits, it should be noted that the three dimensional capacitor structures may be used in any circuit where a relatively large capacitance value is needed but design constraints or available die area necessitate that the capacitor occupies the smallest possible footprint on the die or wafer. The present invention packs the largest surface area between capacitor plates into the smallest footprint on a semiconductor die or wafer.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A method of making an electronic device, comprising: forming at least one layer of conductive material on a substrate; and removing material from the at least one layer of conductive material to simultaneously form a first portion and a second portion arranged in a predetermined pattern relative to one another to provide a maximum amount of juxtaposed surface area between the first and second portions.
2. The method of claim 1, wherein forming at least one layer of conductive material comprises forming a layer including at least tungsten.
3. The method of claim 1, wherein forming at least one layer of conductive material comprises: forming a first layer of metalization or polysilicon; forming a layer of tungsten on the first layer of metalization or polysilicon; and forming a second layer of metalization or polysilicon.
4. A method of making an electronic device, comprising: forming at least one layer of conductive material on a substrate; removing a portion of the at least one layer of conductive material to form a first substantially comb-like structure including a plurality of teeth, wherein the plurality of teeth extend in a plane substantially parallel to the substrate; and removing another portion of the at least one layer of conductive material to form a second substantially

comb-like structure including a plurality of teeth, wherein the teeth of the second substantially comb-like structure extend in the plane of the teeth of the first substantially comb-like structure and are interleaved with the teeth of the first substantially comb-like structure, and wherein each tooth of the first and second comb-like structures have a pair of sidewalls, each sidewall having a selected surface area and each of the teeth of the first comb-like structure and the second comb-like structure being separated by a gap of a chosen width to provide a predetermined capacitance.

5. The method of claim 4, wherein forming at least one layer of conductive material comprises forming a layer including at least tungsten.

6. A method of making an electronic device, comprising forming at least one layer of conductive material on a substrate;

removing a portion of the at least one layer of conductive material to form a first substantially comb-like structure including a plurality of teeth; and

removing another portion of the at least one layer of conductive material to form a second substantially comb-like structure including a plurality of teeth, wherein each tooth of the first and second comb-like structures have a pair of sidewalls with a selected surface area and wherein the teeth of the first comb-like structure and the second comb-like structure are formed in a plane substantially parallel to the substrate and are interleaved to provide a maximum amount of juxtaposed sidewall surface area between the teeth of the first and second comb-like structures.

7. A method of making an electronic device, comprising: forming at least one layer of conductive material on a substrate;

removing material from the layer of conductive material to simultaneously form a first portion and second portion arranged in a predetermined pattern relative to one another to provide a maximum amount of capacitance per area of the substrate; and

depositing a layer of insulation material at least between the first and second portions.

8. The method of claim 7, wherein forming at least one layer of conductive material comprises forming a layer including at least tungsten.

9. A method of making an electronic device, comprising: forming an array of memory elements with each memory element being connected by one of a plurality of row lines and by one of a plurality of column lines;

forming an amplifier connected to at least one of each of the plurality of column lines or to at least one each of the plurality of row lines;

forming a capacitor connected to an input of each amplifier, forming the capacitor comprising: depositing at least one layer of conductive material on a substrate; and

removing material from the at least one layer of conductive material to form a first portion and second portion arranged in a predetermined pattern relative to one another to provide a maximum amount of juxtaposed surface area between the first and second portions.

10. A method of making an electronic device, comprising: forming an array of memory elements with each memory element being connected by one of a plurality of row lines and by one of a plurality of column lines;

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forming an amplifier connected to at least one of each of the plurality of column lines or to at least one each of the plurality of row lines;  
 forming a capacitor connected to an input of each amplifier, forming the capacitor comprising:  
 depositing at least one layer of conductive material;  
 removing a portion of the at least one layer of conductive material to form a first substantially comb-like structure including a plurality of teeth; and  
 removing another portion of the at least one layer of conductive material to form a second substantially comb-like structure including a plurality of teeth, wherein the teeth of the second substantially comb-like structure are interleaved with the teeth of the first substantially comb-like structure, and wherein each tooth of the first and second comb-like structures have a pair of sidewalls, each sidewall having a selected surface area and each of the teeth of the first comb-like structure and the second comb-like structure being separated by a gap of a chosen width to provide a predetermined capacitance.

**11.** A method of making an electronic device, comprising:  
 forming an array of memory elements with each memory element being connected by one of a plurality of row lines and by one of a plurality of column lines;  
 forming an amplifier connected to at least one of each of the plurality of column lines or to at least one each of the plurality of row lines;  
 forming a capacitor connected to an input of each amplifier, forming the capacitor comprising:  
 depositing at least one layer of conductive material;  
 removing a portion of the at least one layer of conductive material to form a first substantially comb-like structure including a plurality of teeth; and  
 removing another portion of the at least one layer of conductive material to form a second substantially comb-like structure including a plurality of teeth, wherein each tooth of the first and second comb-like structures have a pair of sidewalls with a selected surface area and wherein the first comb-like structure and the second comb-like structure are interleaved to provide a maximum amount of juxtaposed sidewall surface area between the teeth of the first and second comb-like structures.

**12.** A method of making an electronic device, comprising:  
 forming an array of memory elements with each memory element being connected by one of a plurality of row lines and by one of a plurality of column lines;  
 forming an amplifier connected to at least one of each of the plurality of column lines or to at least one each of the plurality of row lines;  
 forming a capacitor connected to an input of each amplifier, forming the capacitor comprising:  
 depositing at least one layer of conductive material on a substrate;  
 removing material from the layer of conductive material to form a first portion and second portion arranged in a predetermined pattern relative to one another to provide a maximum amount of capacitance per area of the substrate; and  
 depositing a layer of insulation material at least between the first and second portions.

**13.** A method of making an electronic device, comprising:  
 forming an array of memory elements with each memory element being connected by one of a plurality of row lines and by one of a plurality of column lines;

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forming at least one multiplexer connected to each of the plurality of column lines or to each of the plurality of row lines;  
 forming at least one amplifier connected to the at least one multiplexer;  
 forming a capacitor connected to an input of each amplifier, forming the capacitor comprising:  
 depositing at least one layer of conductive material on a substrate;  
 removing material from the layer of conductive material to form a first portion and second portion arranged in a predetermined pattern relative to one another to provide a maximum amount of capacitance per area per area of the substrate; and  
 depositing a layer of insulation material at least between the first and second portions.

**14.** A method of making an electronic device, comprising:  
 forming a processor;  
 forming a memory device coupled to the processor, the memory device comprising an array of memory elements, each memory element being connected by one of a plurality of row lines and by one of a plurality of column lines;  
 forming an amplifier connected to at least one of each of the plurality of row lines or to each of the plurality of column lines; and  
 forming a capacitor connected to an input of each amplifier, wherein forming the capacitor comprises:  
 forming at least one layer of conductive material on a substrate; and  
 removing material from the layer of conductive material to form a first portion and second portion arranged in a predetermined pattern relative to one another to provide a maximum amount of juxtaposed surface area between the first and second portions.

**15.** A method of making an electronic device, comprising:  
 forming a processor;  
 forming a memory device coupled to the processor, the memory device comprising an array of memory elements, each memory element being connected by one of a plurality of row lines and by one of a plurality of column lines;  
 forming an amplifier connected to at least one of each of the plurality of row lines or to each of the plurality of column lines; and  
 forming a capacitor connected to an input of each amplifier, wherein forming the capacitor comprises:  
 forming at least one layer of conductive material;  
 removing a portion of the at least one layer of conductive material to form a first substantially comb-like structure including a plurality of teeth; and  
 removing another portion of the at least one layer of conductive material to form a second substantially comb-like structure including a plurality of teeth, wherein the teeth of the second substantially comb-like structure are interleaved with the teeth of the first substantially comb-like structure, and wherein each tooth of the first and second comb-like structures have a pair of sidewalls, each sidewall having a selected surface area and each of the teeth of the first comb-like structure and the second comb-like structure being separated by a gap of a chosen width to provide a predetermined capacitance.

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16. A method of making an electronic device, comprising:  
forming a processor;  
forming a memory device coupled to the processor, the  
memory device comprising an array of memory  
elements, each memory element being connected by  
one of a plurality of row lines and by one of a plurality  
of column lines; 5  
forming an amplifier connected to at least one of each of  
the plurality of row lines or to each of the plurality of  
column lines; and 10  
forming a capacitor connected to an input of each  
amplifier, wherein forming the capacitor comprises:  
forming at least one layer of conductive material;  
removing a portion of the at least one layer of conduc-  
tive material to form a first substantially comb-like  
structure including a plurality of teeth; and 15  
removing another portion of the at least one layer of  
conductive material to form a second substantially  
comb-like structure including a plurality of teeth,  
wherein each tooth of the first and second comb-like  
structures have a pair of sidewalls with a selected  
surface area and wherein the first comb-like structure  
and the second comb-like structure are interleaved to  
provide a maximum amount of juxtaposed sidewall  
surface area between the teeth of the first and second  
comb-like structures. 25

17. A method of making an electronic device, comprising:  
forming a processor;  
forming a memory device coupled to the processor, the  
memory device comprising an array of memory  
elements, each memory element being connected by  
one of a plurality of row lines and by one of a plurality  
of column lines; 30  
forming an amplifier connected to at least one of each of  
the plurality of row lines or to each of the plurality of  
column lines; and 35  
forming a capacitor connected to an input of each  
amplifier, wherein forming the capacitor comprises:  
forming at least one layer of conductive material on a  
substrate; 40  
removing material from the layer of conductive material  
to form a first portion and second portion  
arranged in a predetermined pattern relative to one  
another to provide a maximum amount of capacita-  
nce per area of the substrate; and 45  
forming a layer of insulation material at least between  
the first and second portions.

18. A method of making an electronic device, comprising:  
forming at least one layer of conductive material on a  
substrate; 50  
removing material from the at least one layer of conduc-  
tive material to form a first portion and a second portion  
arranged in a predetermined pattern relative to one  
another to provide a maximum amount of juxtaposed  
surface area between the first and second portions; 55  
forming an array of memory elements with each memory  
element being connected by one of a plurality of row  
lines and by one of a plurality of column lines;  
forming an amplifier connected to at least one of each of  
the plurality of column lines or to at least one each of  
the plurality of row lines; and 60  
configuring the first and second portions to form a capaci-  
tor coupled to an input of the amplifier.

19. A method of making an electronic device, comprising: 65  
forming at least one layer of conductive material on a  
substrate;

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removing material from the at least one layer of conduc-  
tive material to form a first portion and a second portion  
arranged in a predetermined pattern relative to one  
another to provide a maximum amount of juxtaposed  
surface area between the first and second portions;  
forming a processor;  
forming a memory device coupled to the processor, the  
memory device comprising an array of memory  
elements, each memory element being connected by  
one of a plurality of row lines and by one of a plurality  
of column lines;  
forming an amplifier connected to at least one of each of  
the plurality of row lines or to each of the plurality of  
column lines; and  
configuring the first and second portions to form a capaci-  
tor coupled to an input of the amplifier.

20. A method of making an electronic device, comprising:  
forming at least one layer of conductive material;  
removing a portion of the at least one layer of conductive  
material to form a first substantially comb-like structure  
including a plurality of teeth;  
removing another portion of the at least one layer of  
conductive material to form a second substantially  
comb-like structure including a plurality of teeth,  
wherein the teeth of the second substantially comb-like  
structure are interleaved with the teeth of the first  
substantially comb-like structure, and wherein each  
tooth of the first and second comb-like structures have  
a pair of sidewalls, each sidewall having a selected  
surface area and each of the teeth of the first comb-like  
structure and the second comb-like structure being  
separated by a gap of a chosen width to provide a  
predetermined capacitance;  
forming an array of memory elements with each memory  
element being connected by one of a plurality of row  
lines and by one of a plurality of column lines;  
forming an amplifier connected to at least one of the  
plurality of column lines or to at least one each of the  
plurality of row lines; and  
configuring the first substantially comb-like structure and  
the second substantially comb-like structure to form a  
capacitor coupled to an input of the amplifier.

21. A method of making an electronic device, comprising:  
forming at least one layer of conductive material;  
removing a portion of the least one layer of conductive  
material to form a first substantially comb-like structure  
including a plurality of teeth;  
removing another portion of the least one layer of conduc-  
tive material to form a second substantially comb-  
like structure including a plurality of teeth, wherein the  
teeth of the second substantially comb-like structure are  
interleaved with the teeth of the first substantially  
comb-like structure, and wherein each tooth of the first  
and second comb-like structures have a pair of  
sidewalls, each sidewall having a selected surface area  
and each of the teeth of the first comb-like structure and  
the second comb-like structure by a gap of a chosen  
width to provide a predetermined capacitance;  
forming a processor;  
forming a memory elements, each memory element being  
connected by one of a plurality of row lines and by on  
of column lines; and  
configuring the first substantially comb-like structure and  
the second substantially cob-like structure to form a  
capacitor coupled to an input of the amplifier.

22. A method of making an electronic device, comprising:  
forming at least one layer of conductive material;  
removing a portion of the at least one layer of conductive  
material to form a first substantially comb-like structure  
including a plurality of teeth; and 5  
removing another portion of the at least one layer of  
conductive material to form a second substantially  
comb-like structure including a plurality of teeth,  
wherein each tooth of the first and second comb-like 10  
structures have a pair of sidewalls with a selected  
surface area and wherein the first comb-like structure  
and the second comb-like structure are interleaved to  
provide a maximum amount of juxtaposed sidewall  
surface area between the teeth of the first and second 15  
comb-like structures;  
forming an array of memory elements with each memory  
element being connected by one of a plurality of row  
lines and by one of a plurality of column lines;  
forming an amplifier connected to at least one of each of 20  
the plurality of column lines or to at least one each of  
the plurality of row lines; and  
configuring the first substantially comb-like structure and  
the second substantially comb-like structure to form a  
capacitor coupled to an input of the amplifier. 25  
23. A method of making an electronic device, comprising:  
forming at least one layer of conductive material;  
removing a portion of the at least one layer of conductive  
material to form a first substantially comb-like structure  
including a plurality of teeth; and 30  
removing another portion of the at least one layer of  
conductive material to form a second substantially  
comb-like structure including a plurality of teeth,  
wherein each tooth of the first and second comb-like 35  
structures have a pair of sidewalls with a selected  
surface area and wherein the first comb-like structure  
and the second comb-like structure are interleaved to  
provide a maximum amount of juxtaposed sidewall  
surface area between the teeth of the first and second 40  
comb-like structures;  
forming a processor;  
forming a memory device coupled to the processor, the  
memory device comprising an array of memory  
elements, each memory element being connected by 45  
one of a plurality of row lines and by one of a plurality  
of column lines;

forming an amplifier connected to at least one of each of  
the plurality of row lines or to each of the plurality of  
column lines; and  
configuring the first substantially comb-like structure and  
the second substantially comb-like structure to form a  
capacitor coupled to an input of the amplifier.  
24. A method of making an electronic device, comprising:  
forming at least one layer of conductive material on a  
substrate;  
removing material from the layer of conductive material  
to form a first portion and second portion arranged in a  
predetermined pattern relative to one another to provide  
a maximum amount of capacitance per area of the  
substrate;  
depositing a layer of insulation material at least between  
the first and second portions;  
forming an array of memory elements with each memory  
element being connected by one of a plurality of row  
lines and by one of a plurality of column lines;  
forming an amplifier connected to at least one of each of  
the plurality of column lines or to at least one each of  
the plurality of row lines; and  
configuring the first portion and the second portion to  
form a capacitor coupled to an input of the amplifier.  
25. A method of making an electronic device, comprising:  
forming at least one layer of conductive material on a  
substrate;  
removing material from the layer of conductive material  
to form a first portion and second portion arranged in a  
predetermined relative to one another to provide a  
maximum amount of capacitance per area of the sub-  
strate;  
forming a layer of insulation material at least between the  
first and second portions;  
forming a processor;  
forming a memory device coupled to the processor, the  
memory device comprising an array of memory  
elements, each memory element being connected by  
one of a plurality of row lines and by one of a plurality  
of column lines;  
forming an amplifier connected to at least one of each of  
the plurality of row lines or to each of the plurality of  
column lines; and  
configuring the first portion and the second portion to  
form a capacitor coupled to an input of the amplifier.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 6,509,245 B2  
DATED : January 21, 2003  
INVENTOR(S) : R. J. Baker, Ph.D. and Kurt D. Beigel

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 5,

Line 2, delete "an" after "described".

Line 42, delete "metalizations" and insert -- metalization -- therefor.

Column 6,

Line 40, delete "filly" and insert -- fully --, therefor.

Column 12,

Line 15, delete "per area" before "of".

Column 13,

Line 13, delete "." after "one".

Column 14,

Line 57, delete "sidwalls" and insert -- sidewalls -- therefor.

Line 59, insert -- being separated -- after "structure".

Line 62, insert -- device coupled to the processor, the memory device comprising an array of memory -- before "elements".

Line 64, insert -- forming an amplifier connected to at least one of each of the plurality of row lines or to each of the plurality of column lines; -- before "and".

Column 16,

Line 30, insert -- pattern -- after "predetermined".

Signed and Sealed this

Nineteenth Day of August, 2003



JAMES E. ROGAN  
*Director of the United States Patent and Trademark Office*