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(54) **FOOTPRINT FOR MULTI-BIT FLIP FLOP**

(71) Applicant: **TAIWAN SEMICONDUCTOR MANUFACTURING CO., LTD.**,
Hsinchu (TW)

(72) Inventors: **Po-Chun Wang**, Hsinchu (TW);
Hui-Zhong Zhuang, Kaohsiung (TW);
Chih-Liang Chen, Hsinchu (TW);
Jerry Chang-Jui Kao, Taipei (TW);
Tzu-Ying Lin, Hsinchu (TW)

(73) Assignee: **TAIWAN SEMICONDUCTOR MANUFACTURING CO., LTD.**,
Hsinchu (TW)

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H03K 3/037 (2006.01)
H10D 30/01 (2025.01)
H10D 30/62 (2025.01)
H10D 89/10 (2025.01)

(52) **U.S. Cl.**
CPC **H03K 3/037** (2013.01); **G01R 31/3187** (2013.01); **H10D 30/024** (2025.01); **H10D 30/6219** (2025.01); **H10D 89/10** (2025.01)

(58) **Field of Classification Search**

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G11C 7/1087; G11C 29/006
USPC 257/312
See application file for complete search history.

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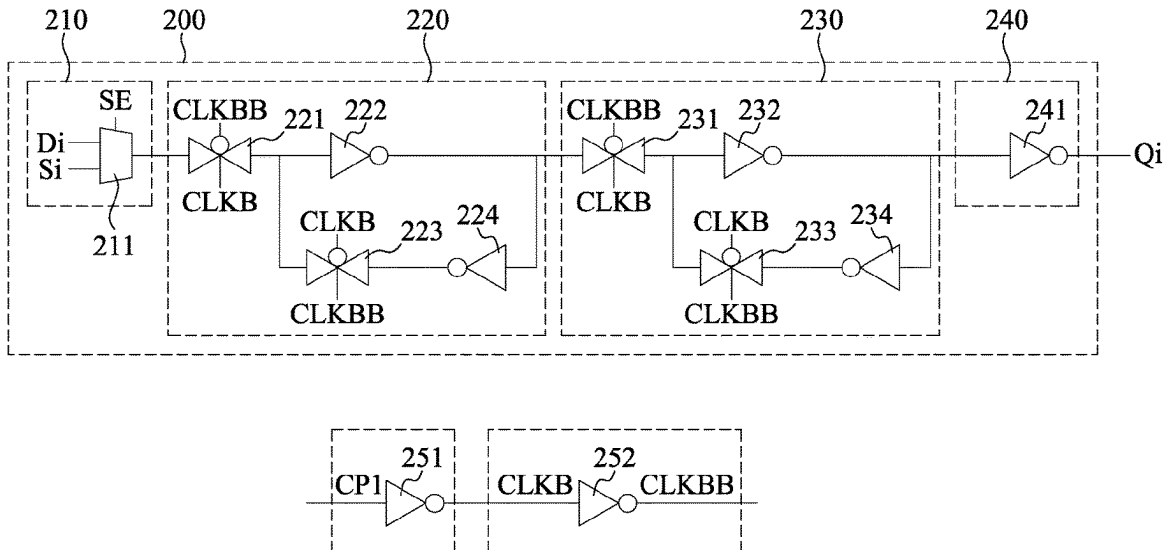
Primary Examiner — Vu A Vu

(74) *Attorney, Agent, or Firm* — Maschoff Brennan

(57) **ABSTRACT**

An integrated circuit includes first bit cells, second bit cells, and clock cells. Each of first bit cells is arranged in one of multiple first cell rows having a first row height. Each of the second bit cells is arranged in one of multiple second cells rows having a second row height different from the first row height. The second bit cells extend to pass the first bit cells in a first direction. The clock cells are arranged in peripheral regions of a multi-bit flip flop cell in the first cell rows. The first and second bit cells and the clock cells are included in the multi-bit flip flop cell.

20 Claims, 17 Drawing Sheets



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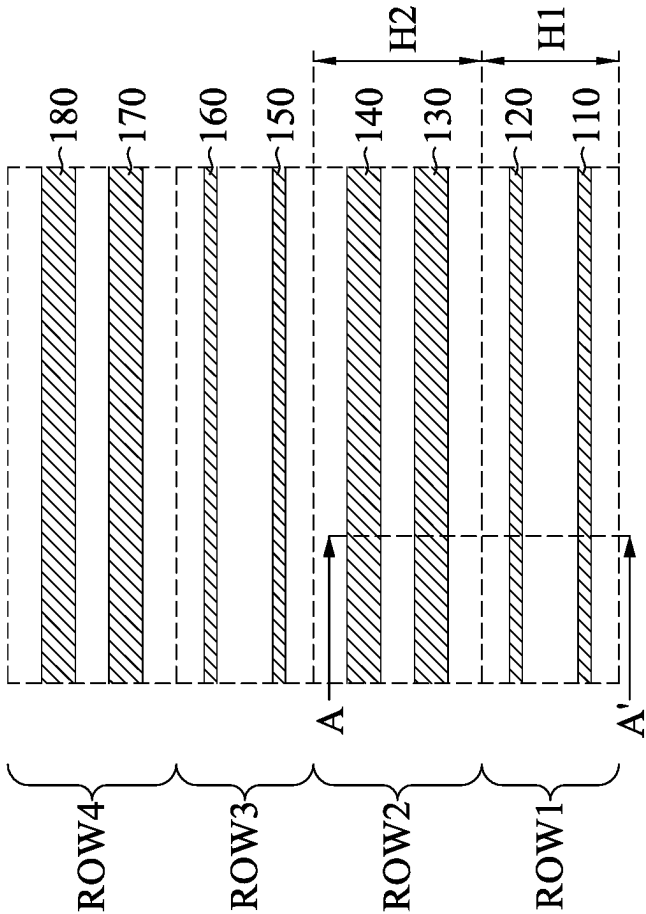


FIG. 1A

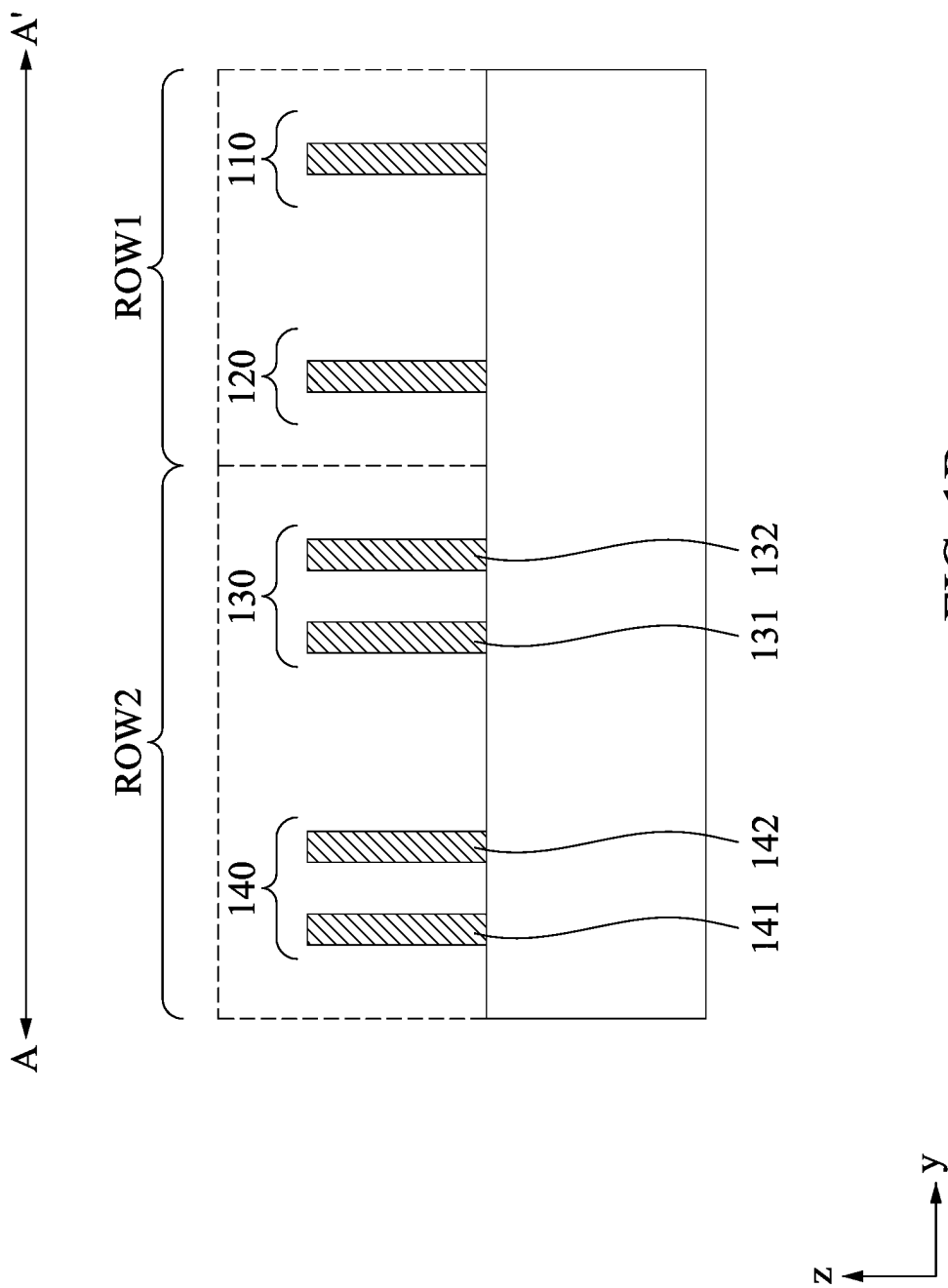


FIG. 1B

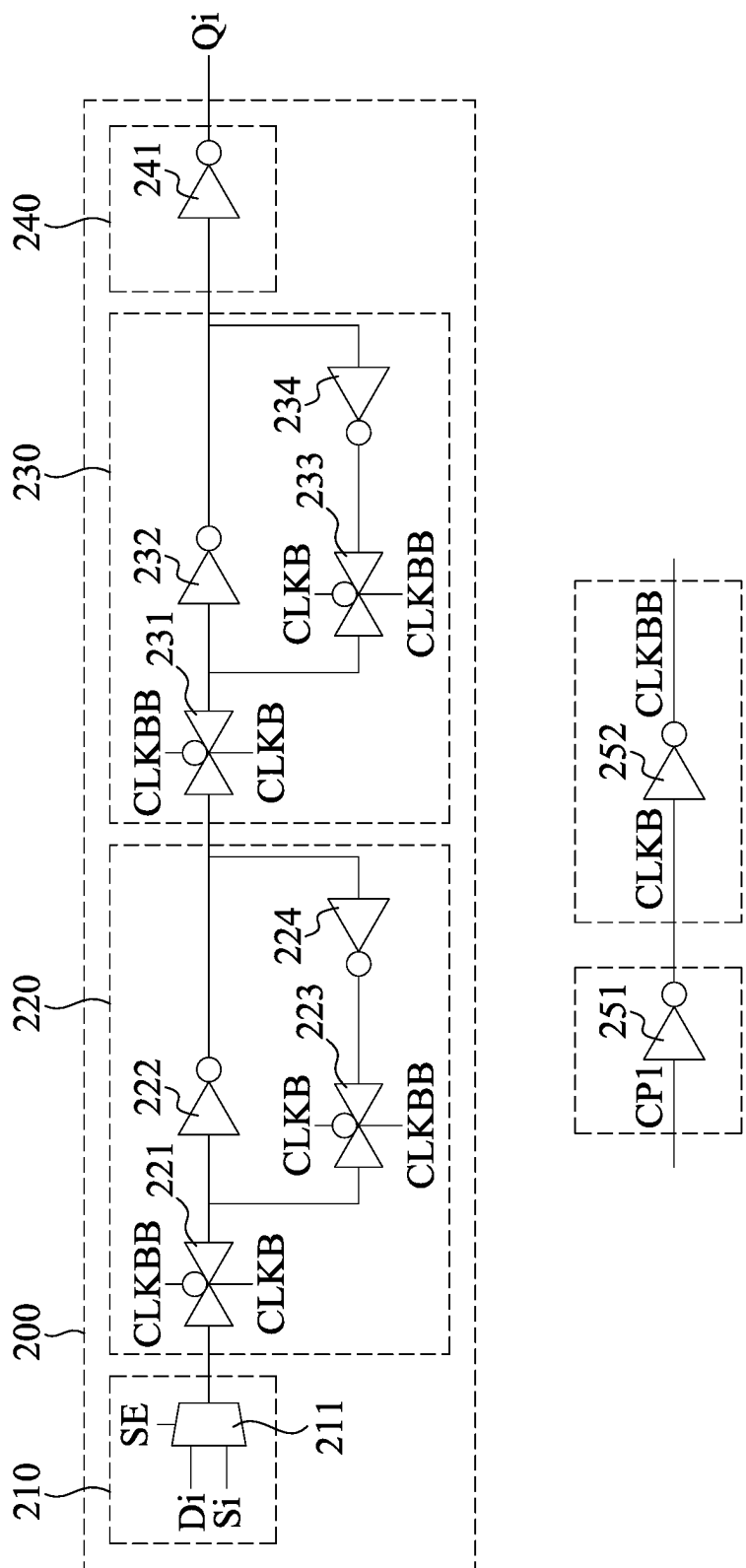


FIG. 2A

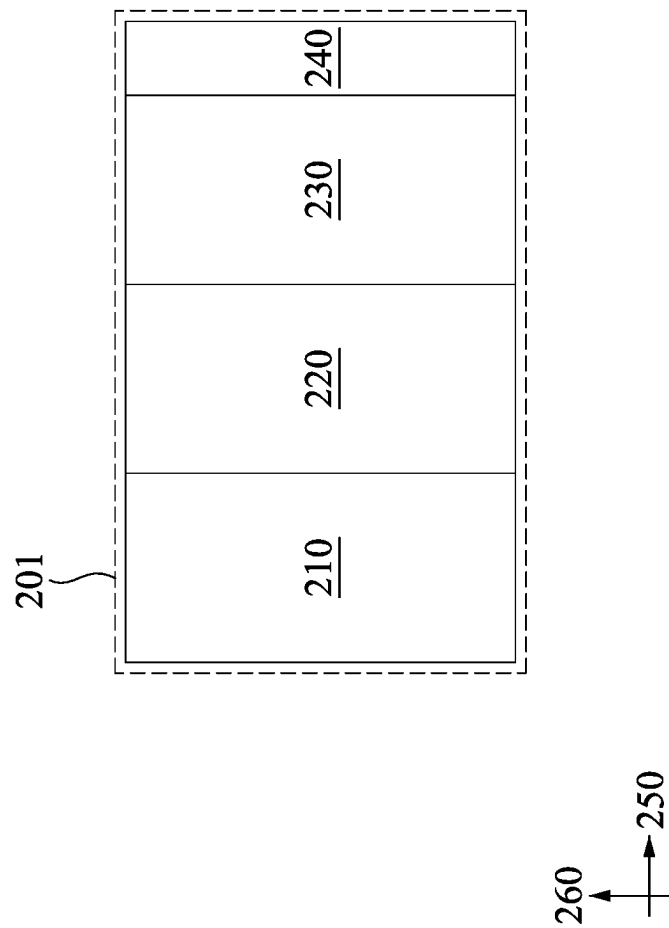


FIG. 2B

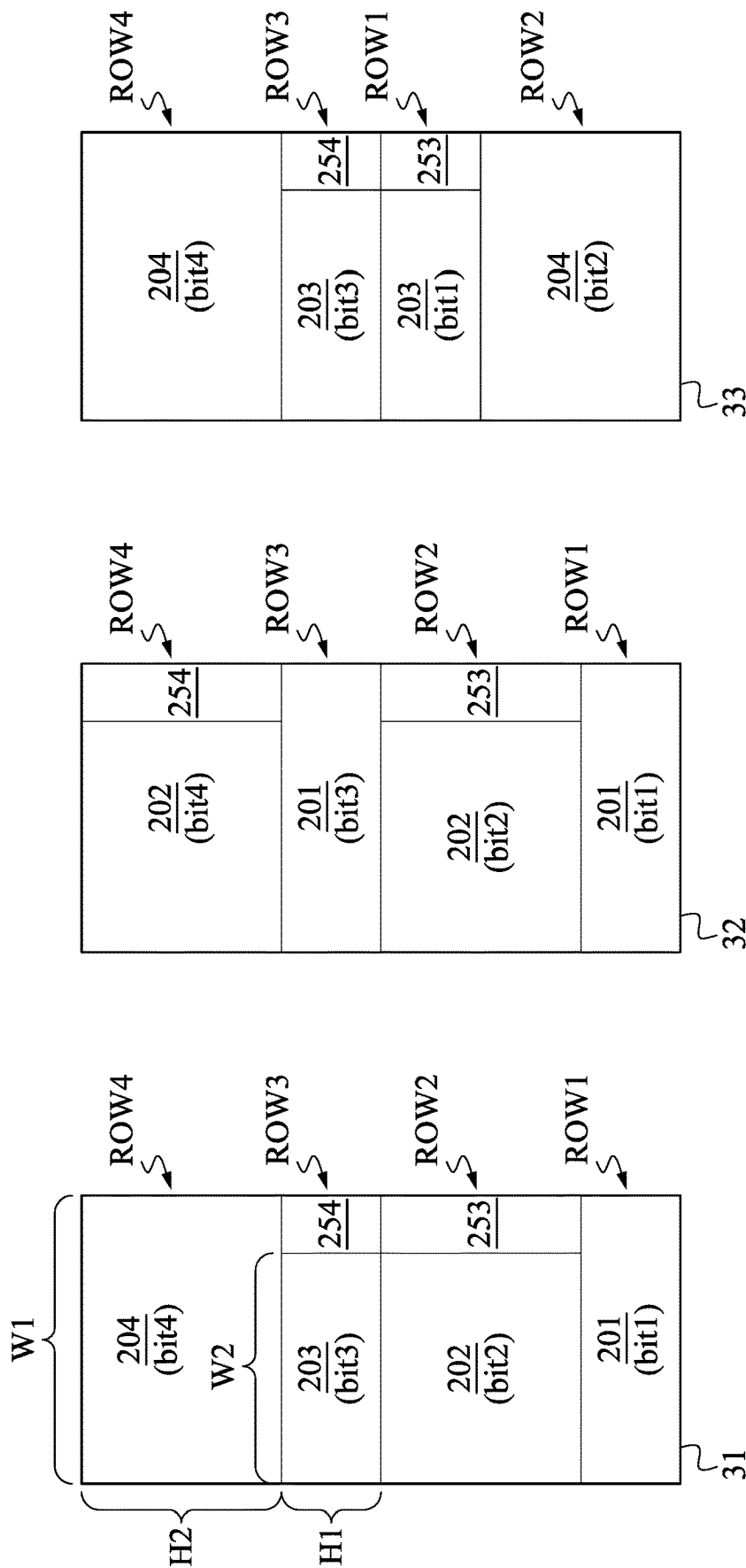


FIG. 3A

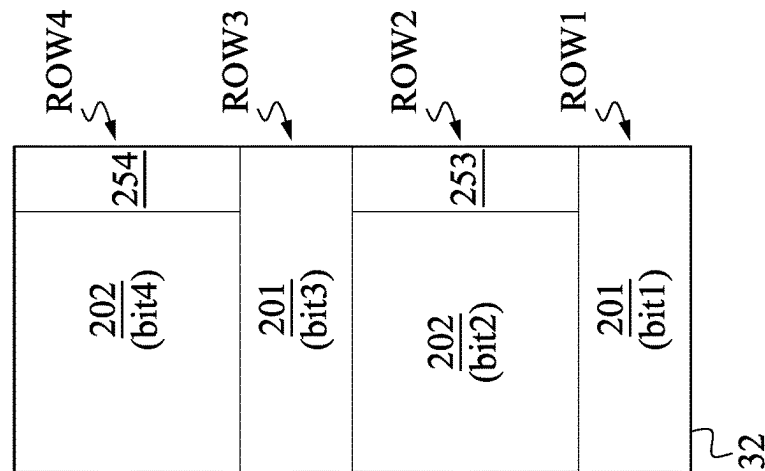


FIG. 3B

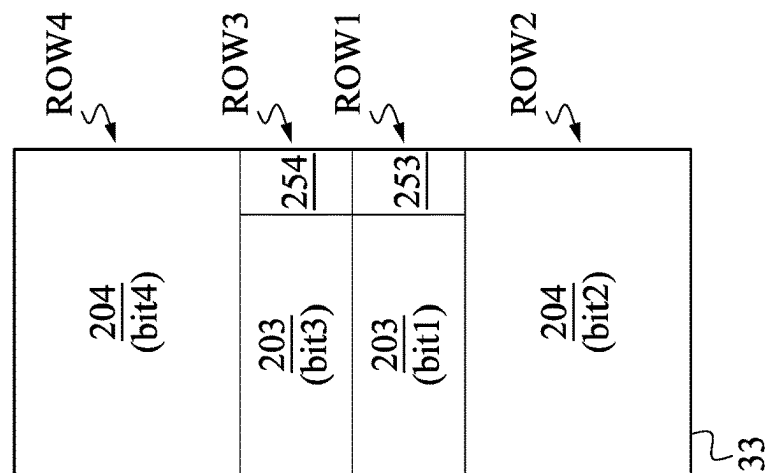
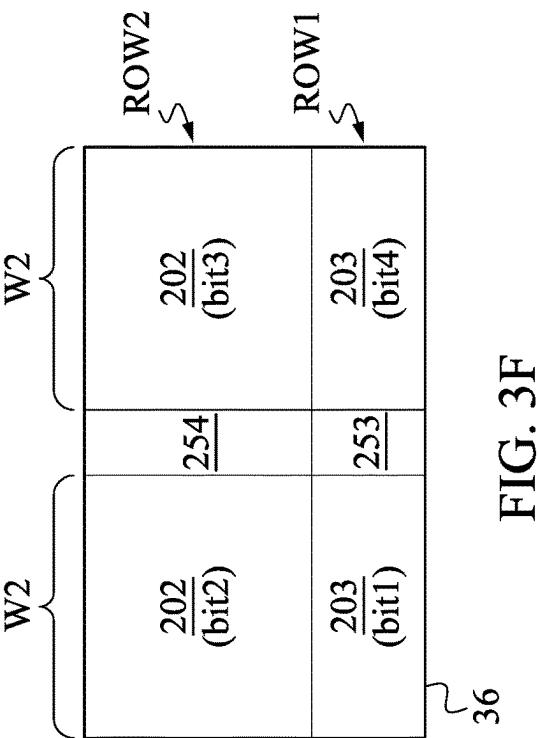
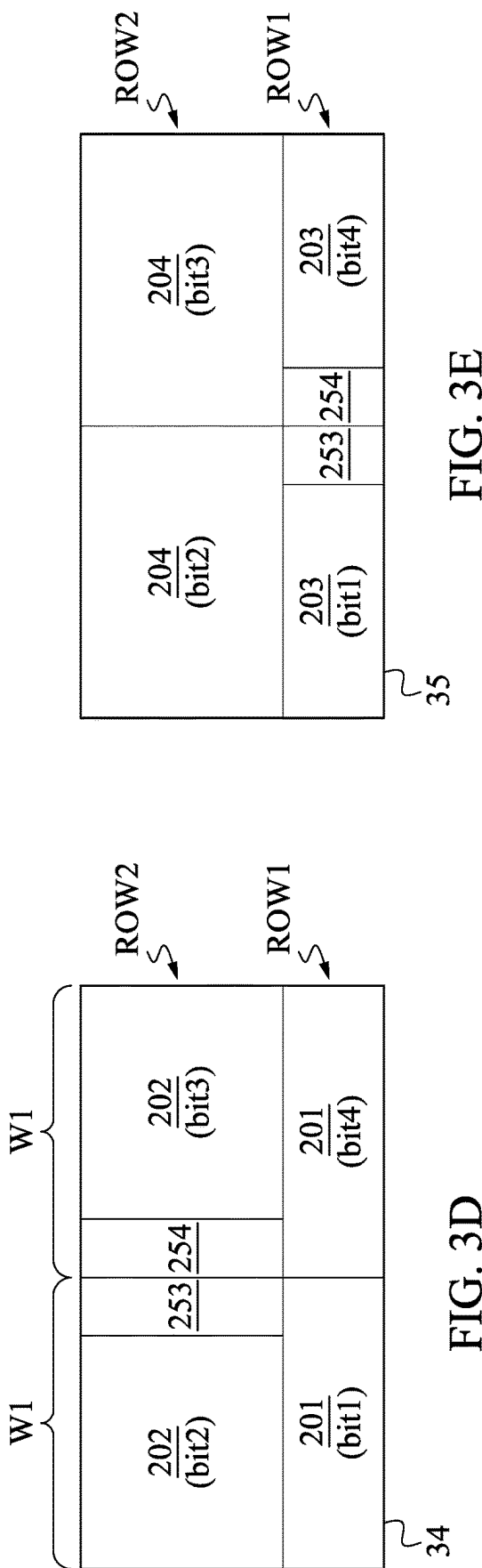


FIG. 3C



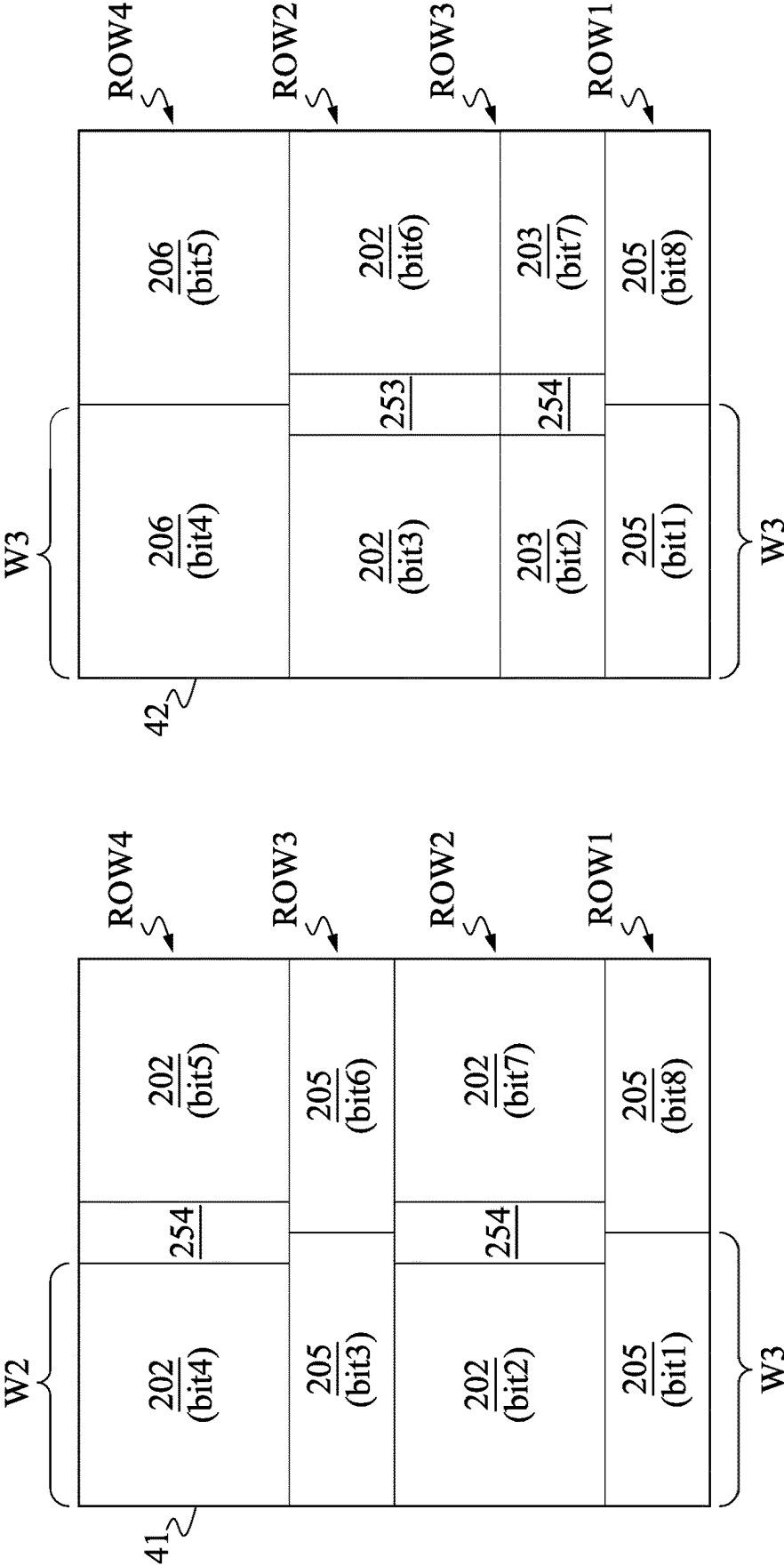


FIG. 4A

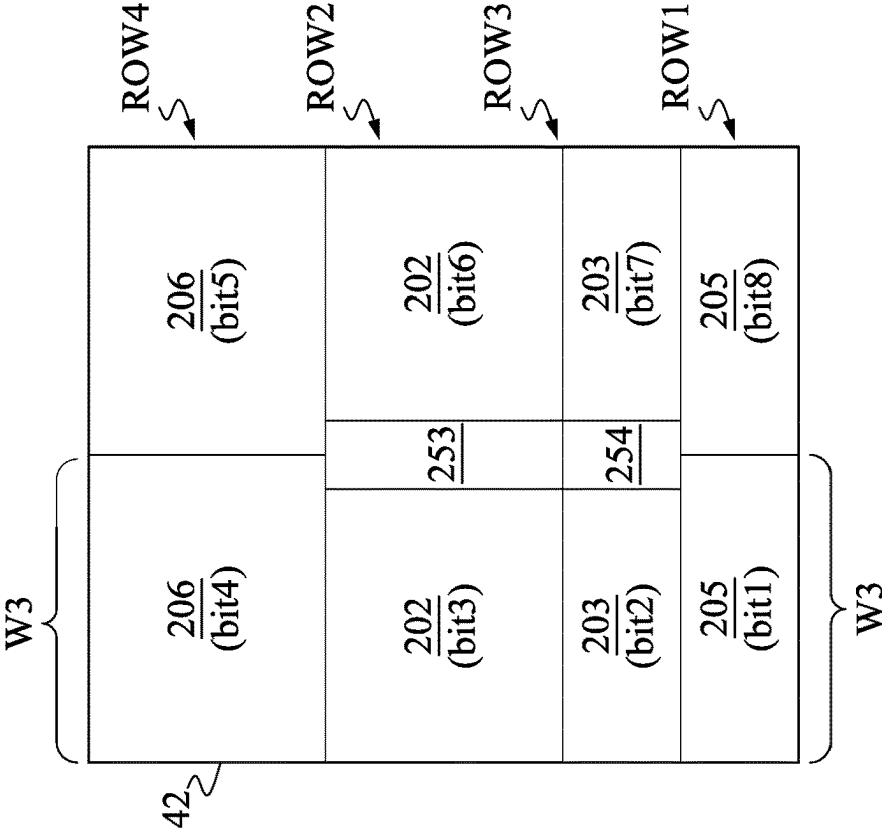


FIG. 4B

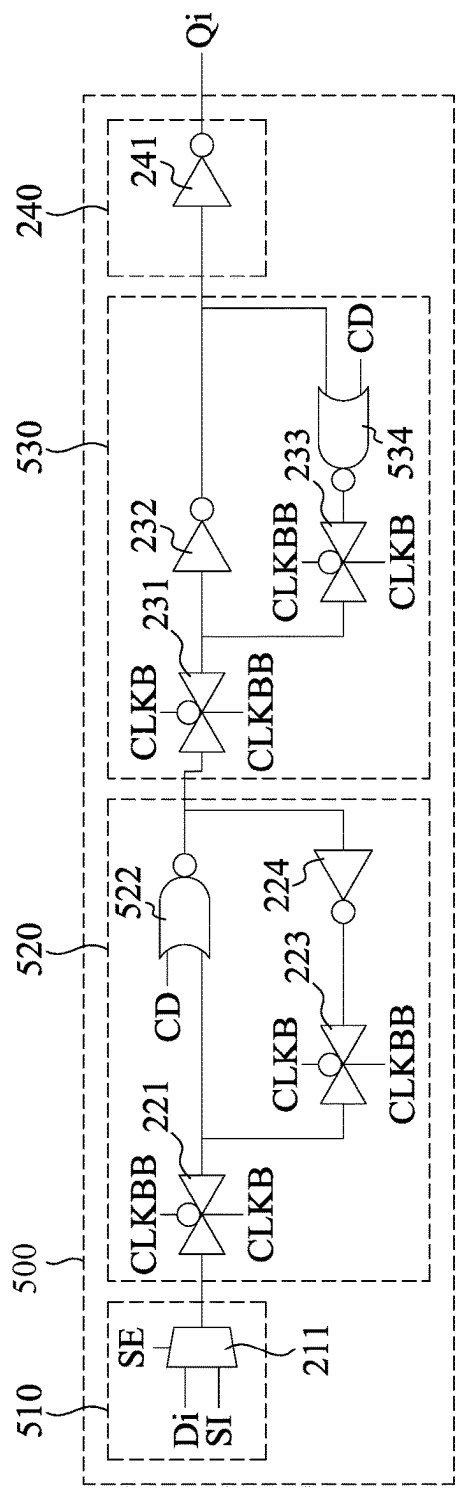


FIG. 5A

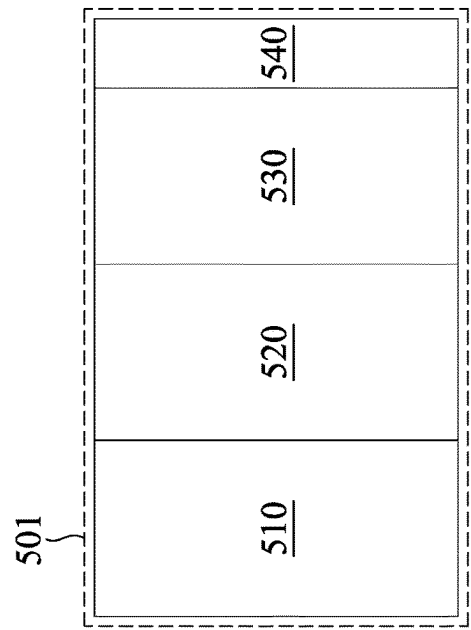
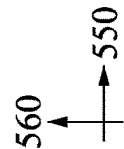


FIG. 5B



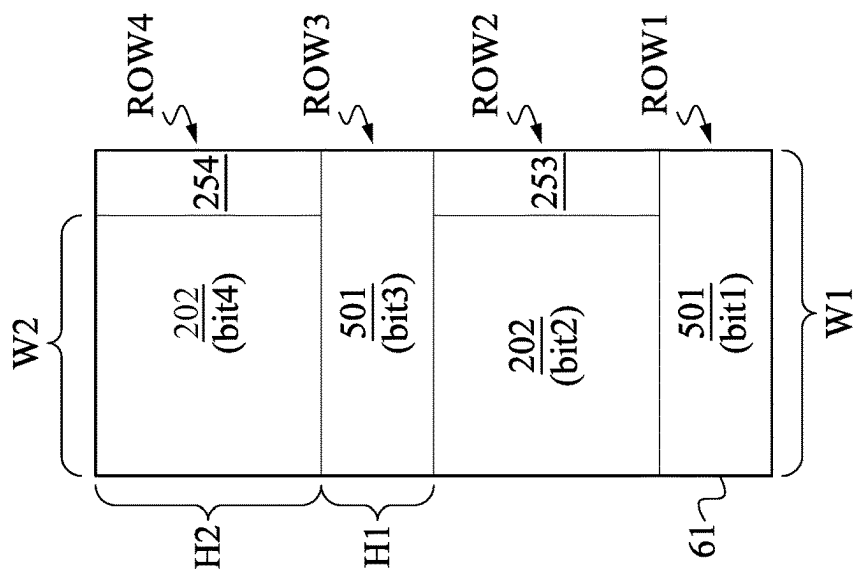


FIG. 6A

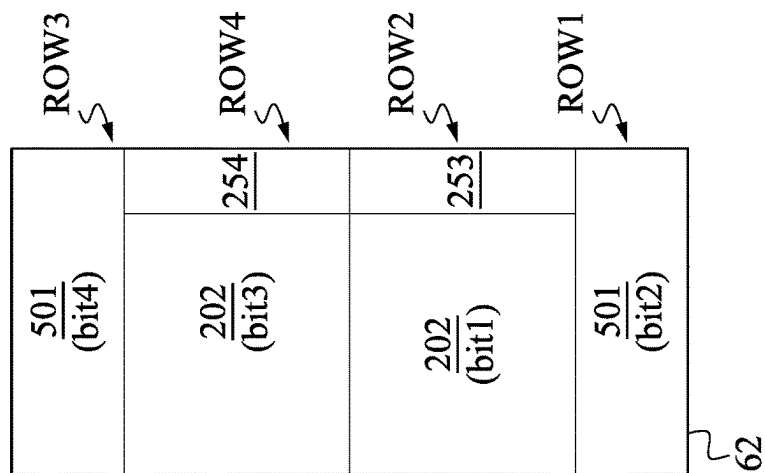


FIG. 6B

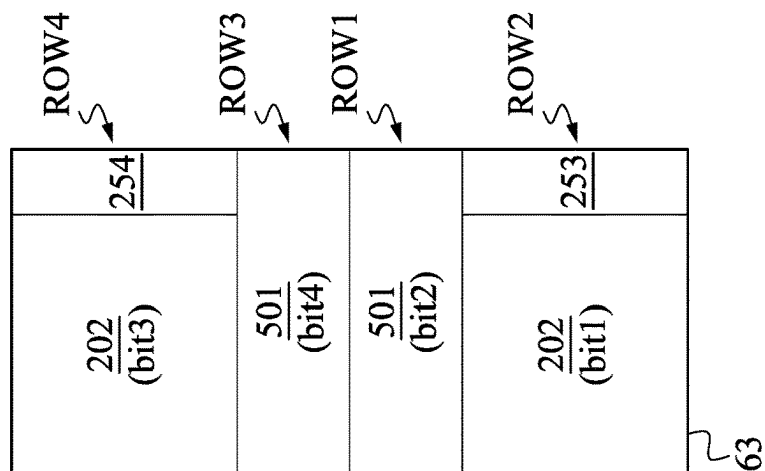


FIG. 6C

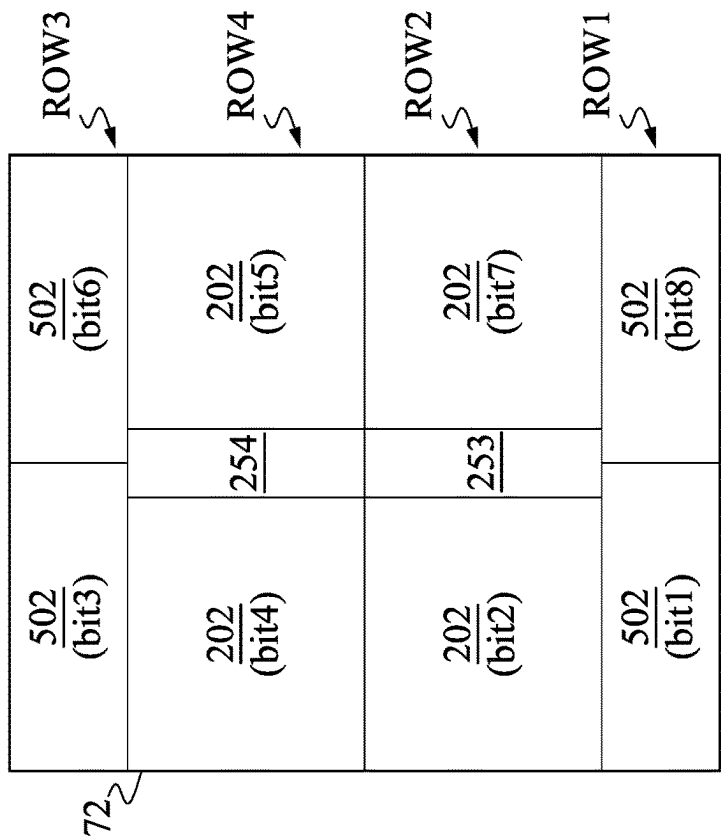


FIG. 7B

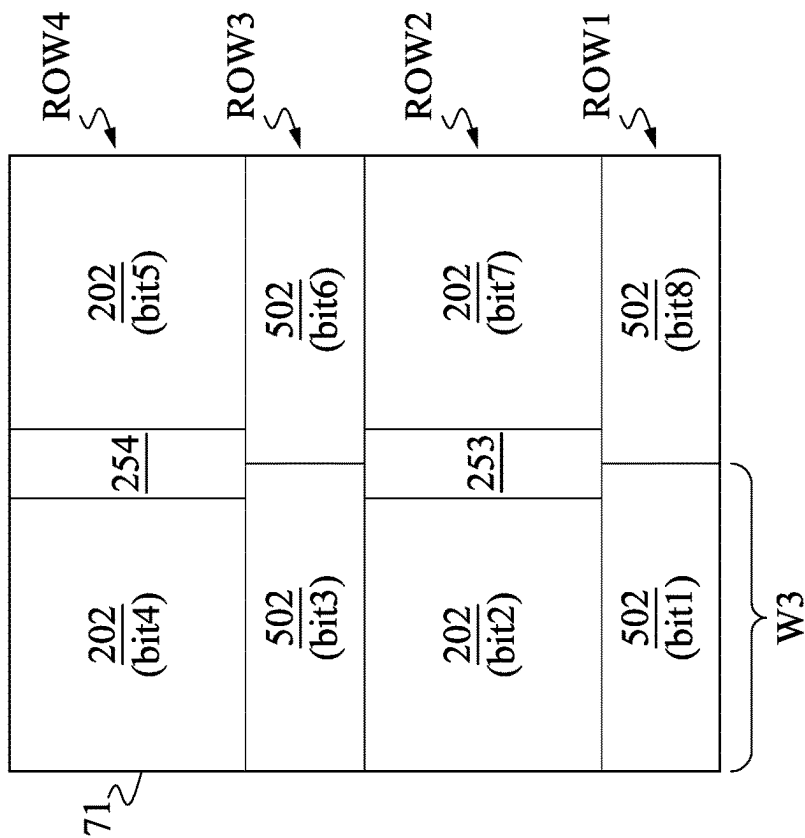


FIG. 7A

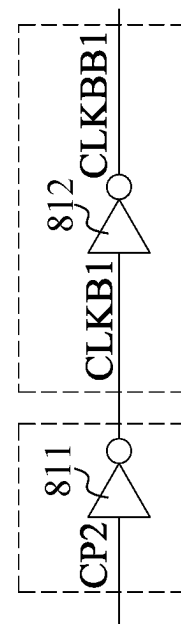
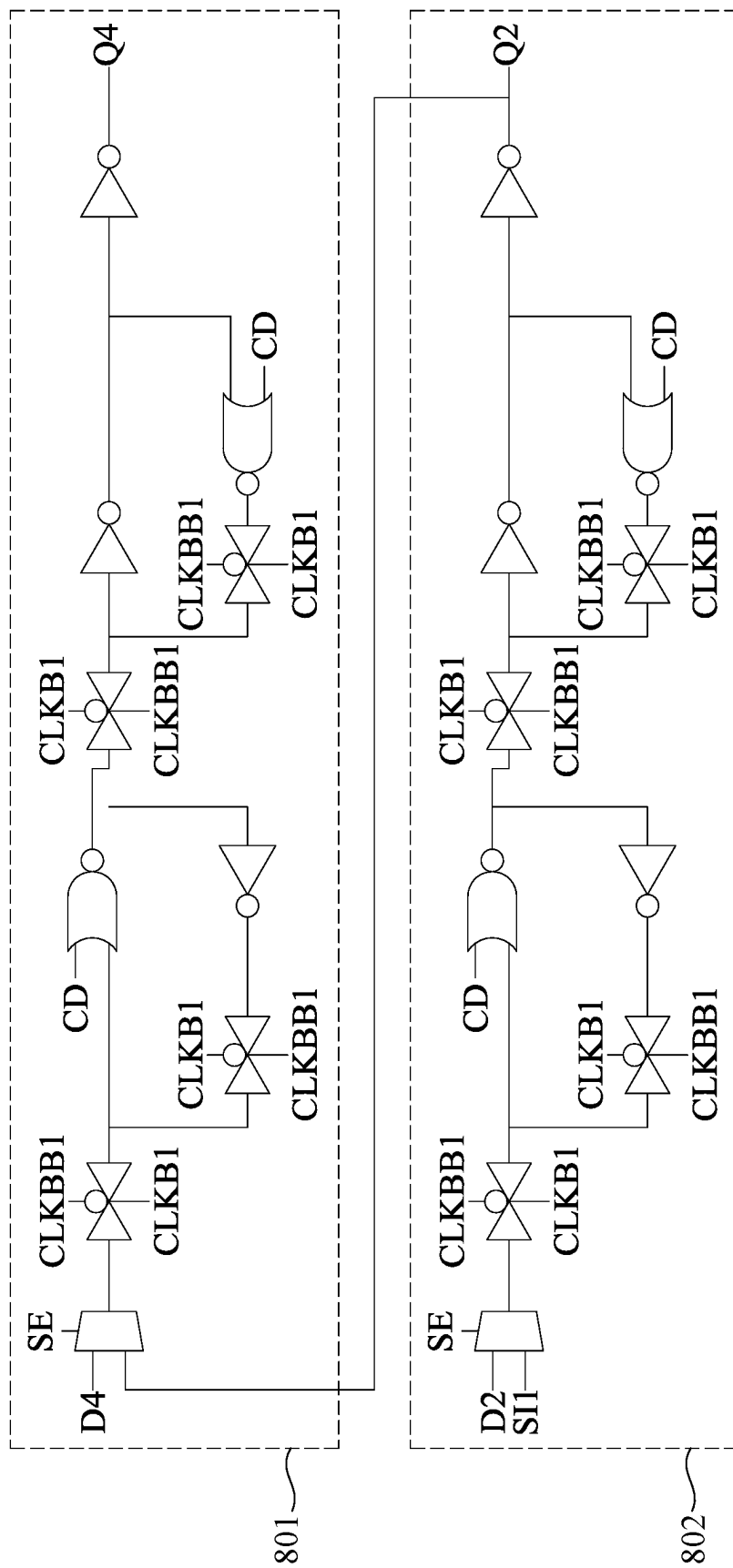


FIG. 8A

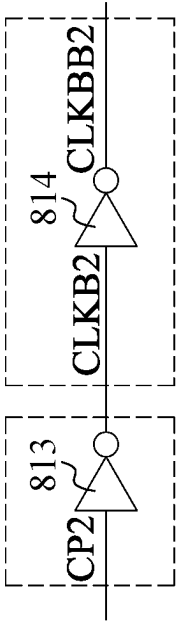
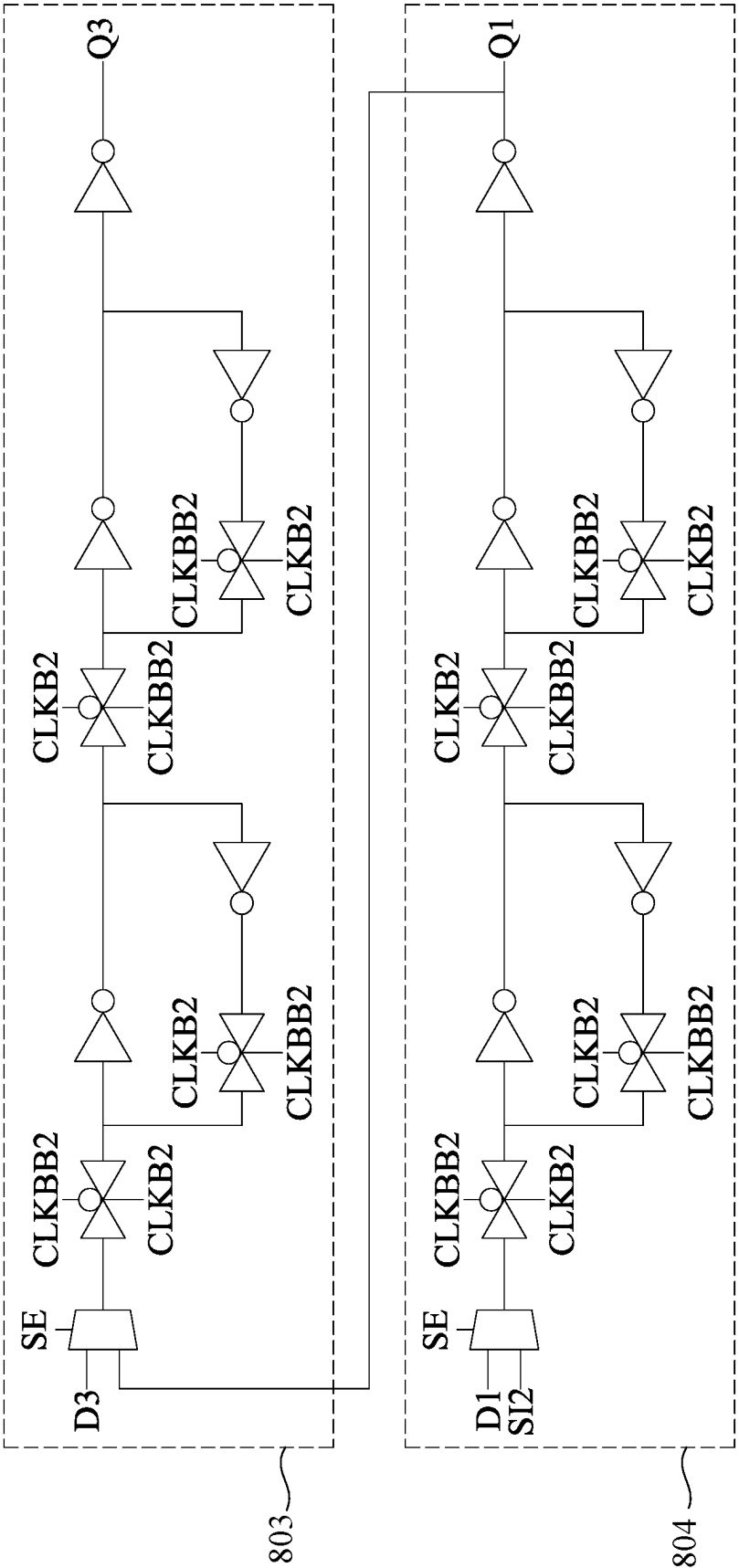


FIG. 8B

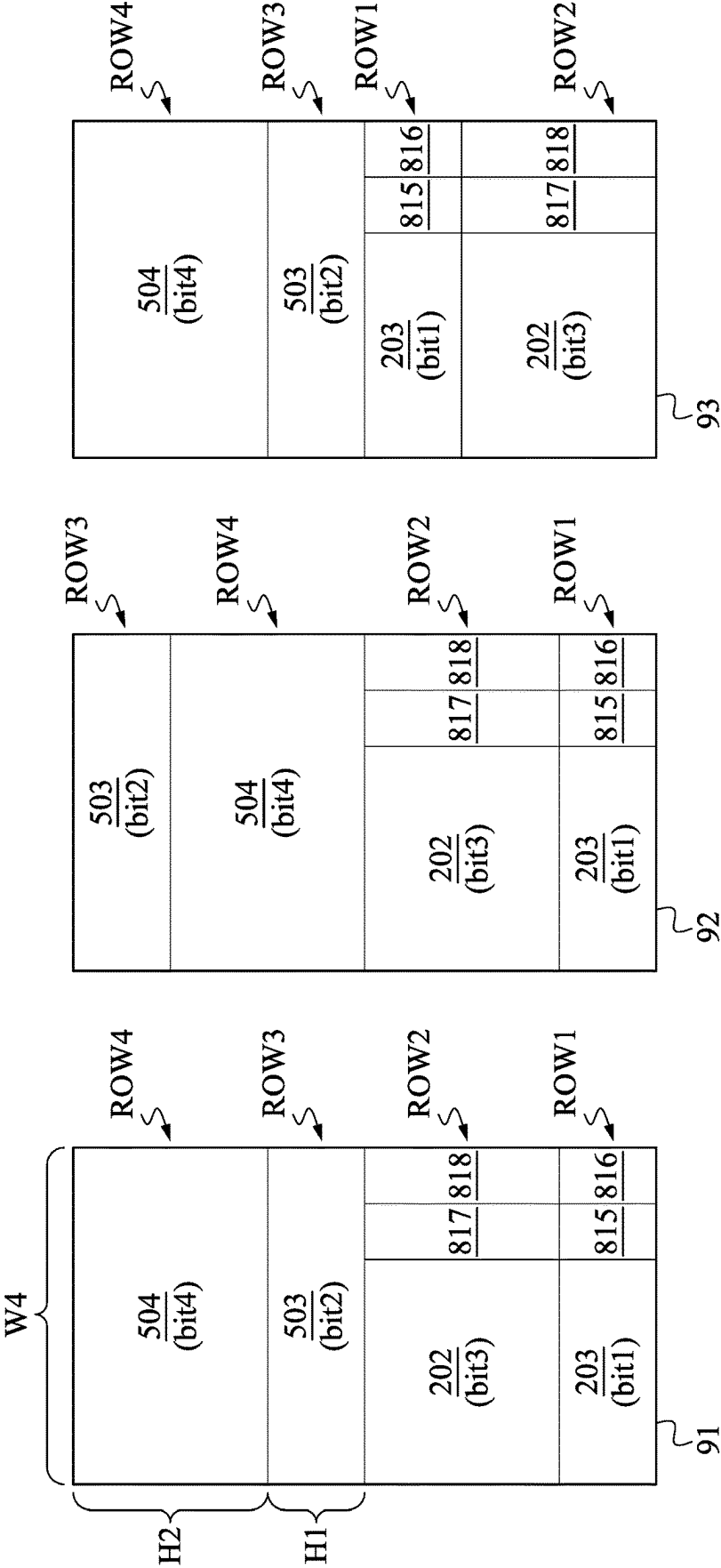


FIG. 9A

FIG. 9B

FIG. 9C

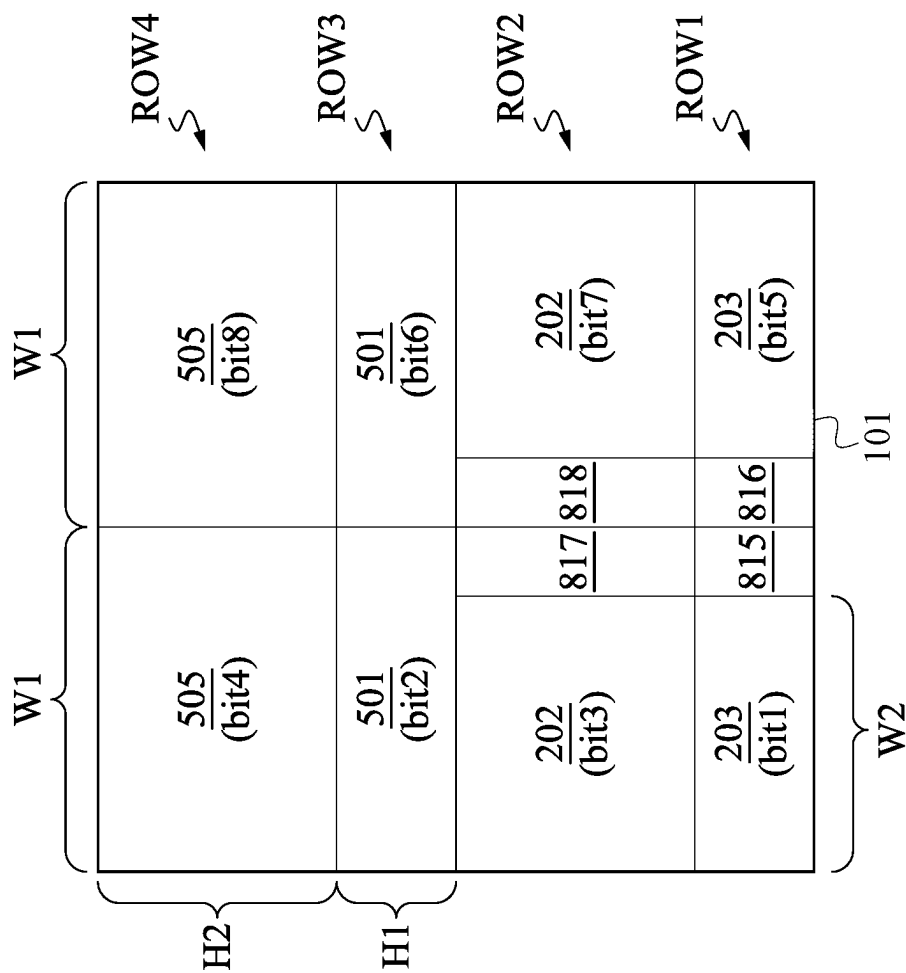


FIG. 10

1100

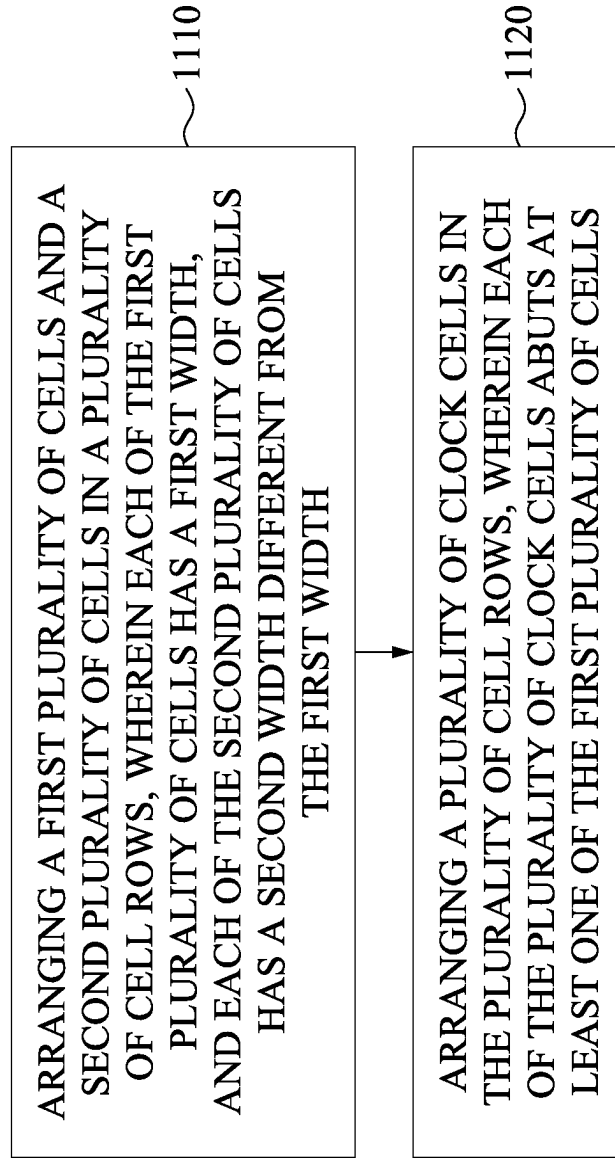


FIG. 11

1200

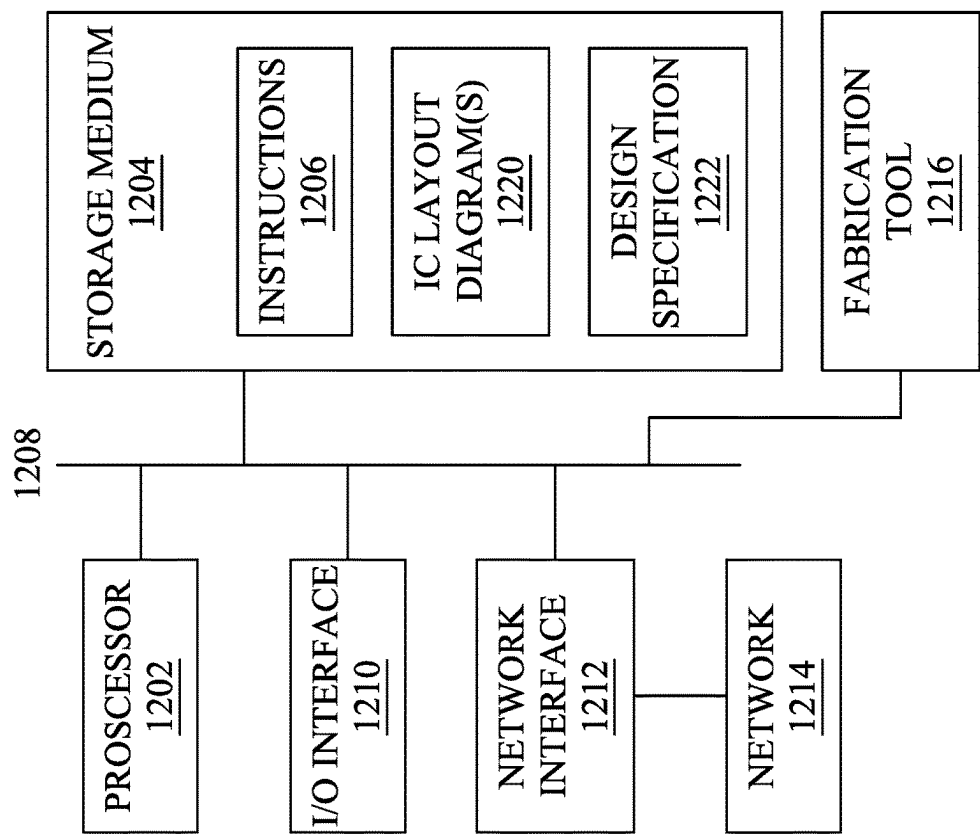


FIG. 12

1300

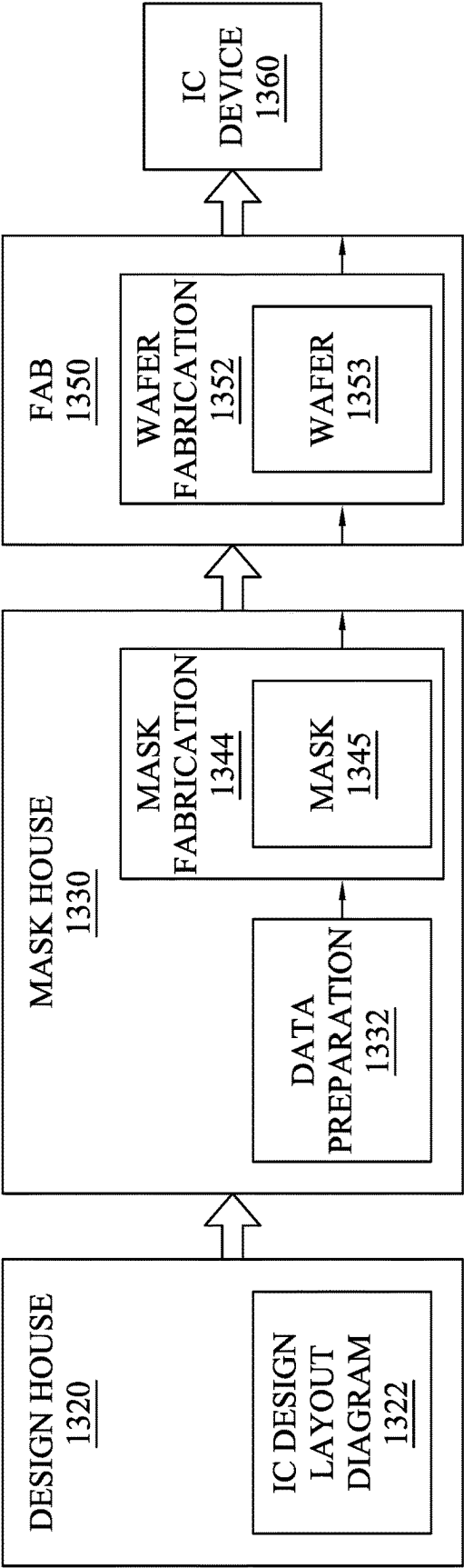


FIG. 13

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FOOTPRINT FOR MULTI-BIT FLIP FLOP**CROSS REFERENCE**

The present is a continuation application of U.S. application Ser. No. 16/900,765, filed Jun. 12, 2020, now U.S. Pat. No. 11,509,293, issued Nov. 22, 2022, which is herein incorporated by reference.

BACKGROUND

Multi-bit flip-flop circuits are utilized in electronic systems to store digital data. Scan flip-flops included in the multi-bit flip-flop operate to store many bits of data in response to clock signals. In some approaches, the multi-bit flip-flop circuits are based on circuitry with similar circuit topology and sizing.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

FIG. 1A is a top view diagram of part of a semiconductor device, in accordance with some embodiments.

FIG. 1B is a sectional view diagram illustrating a structure of some cell rows along a sectional line in FIG. 1A in accordance with some embodiments.

FIG. 2A is a schematic diagram of part of a scan flip-flop, in accordance with some embodiments.

FIG. 2B is a layout view of the scan flip-flop of FIG. 2A, in accordance with some embodiments.

FIGS. 3A-3F are floor planning or layout views of several the scan flip-flops of FIGS. 2A-2B included in 4-bit flip-flop circuits in the semiconductor device of FIG. 1A, in accordance with some embodiments.

FIGS. 4A-4B are floor planning or layout views of several the scan flip-flops of FIGS. 2A-2B included in 8-bit flip-flop circuits in the semiconductor device of FIG. 1A, in accordance with some embodiments.

FIG. 5A is a schematic diagram of part of a scan flip-flop, in accordance with some embodiments.

FIG. 5B is a layout view of the scan flip-flop of FIG. 5A, in accordance with some embodiments.

FIGS. 6A-6C are floor planning or layout views of several the scan flip-flops of FIGS. 2A-2B and several the scan flip-flops of FIGS. 5A-5B that are included in 4-bit flip-flop circuits in the semiconductor device of FIG. 1A, in accordance with some embodiments.

FIGS. 7A-7B are floor planning or layout views of several the scan flip-flops of FIGS. 2A-2B and several the scan flip-flops of FIGS. 5A-5B included in 8-bit flip-flop circuits in the semiconductor device of FIG. 1A, in accordance with some embodiments.

FIG. 8A is a schematic diagram of part of a first set of scan flip-flops corresponding to the scan flip-flop of FIG. 2A, in accordance with some embodiments.

FIG. 8B is a schematic diagram of part of a second set of scan flip-flops corresponding to the scan flip-flop of FIG. 5A, in accordance with some embodiments.

FIGS. 9A-9C are floor planning or layout views of the first set of scan flip-flops and the second set of scan flip-flops

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that are included in 4-bit flip-flop circuits in the semiconductor device of FIG. 1A, in accordance with some embodiments.

FIG. 10 is floor planning or layout views of the first set of scan flip-flops and the second set of scan flip-flops that are included in an 8-bit flip-flop circuit in the semiconductor device of FIG. 1A, in accordance with some embodiments.

FIG. 11 is a flow chart of a method of generating a layout design for fabricating the integrated circuit, in accordance with some embodiments of the present disclosure.

FIG. 12 is a block diagram of a system for designing the integrated circuit layout design, in accordance with some embodiments of the present disclosure.

FIG. 13 is a block diagram of an integrated circuit manufacturing system, and an integrated circuit manufacturing flow associated therewith, in accordance with some embodiments.

DETAILED DESCRIPTION

The following disclosure provides many different embodiments, or examples, for implementing different features of the provided subject matter. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

The terms used in this specification generally have their ordinary meanings in the art and in the specific context where each term is used. The use of examples in this specification, including examples of any terms discussed herein, is illustrative only, and in no way limits the scope and meaning of the disclosure or of any exemplified term. Likewise, the present disclosure is not limited to various embodiments given in this specification.

As used herein, the terms “comprising,” “including,” “having,” “containing,” “involving,” and the like are to be understood to be open-ended, i.e., to mean including but not limited to.

Reference throughout the specification to “one embodiment,” “an embodiment,” or “some embodiments” means that a particular feature, structure, implementation, or characteristic described in connection with the embodiment(s) is included in at least one embodiment of the present disclosure. Thus, uses of the phrases “in one embodiment” or “in an embodiment” or “in some embodiments” in various places throughout the specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, implementation, or characteristics may be combined in any suitable manner in one or more embodiments.

Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature’s relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in

use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

As used herein, “around”, “about”, “approximately” or “substantially” shall generally refer to any approximate value of a given value or range, in which it is varied depending on various arts in which it pertains, and the scope of which should be accorded with the broadest interpretation understood by the person skilled in the art to which it pertains, so as to encompass all such modifications and similar structures. In some embodiments, it shall generally mean within 20 percent, preferably within 10 percent, and more preferably within 5 percent of a given value or range. Numerical quantities given herein are approximate, meaning that the term “around”, “about”, “approximately” or “substantially” can be inferred if not expressly stated, or meaning other approximate values.

Reference is now made to FIG. 1A. FIG. 1A is a top view diagram of part of a semiconductor device 10, in accordance with some embodiments. As illustratively shown in FIG. 1A, the semiconductor device 10 includes several cell rows ROW1-ROW4. In some embodiments, there are cells, for example, cells illustrated in FIGS. 3A-3F, 4A-4B, 6A-7B, 9A-10, are implemented by integrated circuits arranged in these cell rows ROW1-ROW4. The number of the cell rows ROW1-ROW4 in the semiconductor device 10 in FIG. 1A is given for illustrative purposes. Various numbers of the cell rows ROW1-ROW4 are within the contemplated scope of the present disclosure. For example, in some embodiments, the number of the cell rows in the semiconductor device 10 is more than 4.

For illustration, the cell rows ROW1-ROW4 extend along x direction and are parallel to each other. In some embodiments, the cell rows ROW1-ROW4 are arranged along y direction, which is substantially perpendicular to the x direction.

In some embodiments, there are two groups of cell rows among the rows ROW1-ROW4 in reference with their row heights. As illustratively shown in FIG. 1A, each of the cell rows ROW1 and ROW3 is configured to have a row height H1, and each of the cell rows ROW2 and ROW4 is configured to have another row height H2, which is shorter than the row height H1. The cell rows ROW1 and ROW3 with the row height H1 are regarded as a first group “A” of the cell rows ROW1-ROW4, and the cell rows ROW2 and ROW4 are regarded as a second group “B” of the cell rows ROW1-ROW4. In some embodiments, as depicted in FIG. 1A, the first group A of the cell rows and the second group B of the cell rows are interlaced.

For illustration, the cell row ROW1 with the row height H1 in the first group “A” includes two active areas 110-120, and the cell row ROW2 with the row height H2 in the second group “B” includes two active areas 130-140. Similarly, the cell row ROW3 includes two active areas 150-160, and the cell row ROW4 includes two active areas 170-180. For illustration, the active areas 110-180 extend along x direction and are separate from each other in y direction. The configurations of the active areas 110-180 will be discussed in the following paragraphs with FIG. 1B.

In some embodiments, the active areas 110 and 140 have a conductivity of P type, while the active areas 120 and 130 have a conductivity of N type. The configurations of the active areas 150 and 180 are similar to the active areas 110 and 140, and the configurations of the active areas 160 and

170 are similar to the active areas 120 and 130. Alternatively stated, the cell rows ROW1-ROW4 are interlaced in a periodic sequence along y direction. The configurations of the active areas 110-180 are given for illustrative purposes.

Various implements of the active areas 110-180 are included in the contemplated scope of the present disclosure. For example, in some embodiments, the active areas 110, 140, 150, and 180 are N type and the active areas 120, 130, 160 and 170 are P type.

The configurations of the semiconductor device 10 of FIG. 1A are given for illustrative purposes. Various implements of the semiconductor device 10 are included in the contemplated scope of the present disclosure. For example, in some embodiments discussed in the following paragraphs, the cell rows are arranged in sequence different from the cell rows ROW1 to ROW4, such like, in sequence ROW1, ROW2, ROW4, and ROW3. Alternatively stated, the cell rows having the same height are arranged abutted each other.

Reference is now made to FIG. 1B. FIG. 1B is a sectional view diagram illustrating a structure of the cell rows ROW3-ROW4 along a sectional line AA' in FIG. 1A in accordance with some embodiments. With respect to the embodiments of FIG. 1A, like elements in FIG. 1B are designated with the same reference numbers for ease of understanding.

As illustratively shown in FIG. 1B, the cell row ROW1 with the row height H1 in the second group “A” includes two active areas 110-120 on the substrate Sub. The active area 110 of the cell row ROW1 includes a first one fin-shaped structure, and the active area 120 of the cell row ROW1 includes a second one fin-shaped structure. Alternatively stated, each one of the active areas 110-120 includes one fin-shaped structure.

As illustratively shown in FIG. 1B, the cell row ROW2 with the row height H1 in the first group “B” includes the active areas 130-140 on a substrate Sub. The active area 130 of the cell row ROW2 includes two fin-shaped structures 131 and 132, and the active area 140 of the cell row ROW2 includes another two fin-shaped structures 141 and 142. Alternatively stated, each one of the active areas 130-140 include two fin-shaped structures, such as 131 and 132, or 141 and 142.

In some embodiments, the fin-shaped structures 131 and 132 are n-type fin-shaped structures, and the fin-shaped structures 141 and 142 are p-type fin-shaped structures. In some other embodiments, the fin-shaped structures 131 and 132 are p-type fin-shaped structures, and the fin-shaped structures 141 and 142 are n-type fin-shaped structures.

The fins mentioned above may be patterned by any suitable method. For example, the fins may be patterned using one or more photolithography processes, including double-patterning or multi-patterning processes. Generally, double-patterning or multi-patterning processes combine photolithography and self-aligned processes, allowing patterns to be created that have, for example, pitches smaller than what is otherwise obtainable using a single, direct photolithography process. For example, in one embodiment, a sacrificial layer is formed over a substrate and patterned using a photolithography process. Spacers are formed alongside the patterned sacrificial layer using a self-aligned process. The sacrificial layer is then removed, and the remaining spacers may then be used to pattern the fins.

In some embodiments, such an active area may include one or more fin-shaped structures of one or more three-dimensional field-effect-transistors (e.g., FinFETs, gate-all-around (GAA) transistors), or an oxide-definition (OD) region of one or more planar metal-oxide-semiconductor

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field-effect transistors (MOSFETs). The active region may serve as a source feature or a drain feature of the respective transistor (s).

In some embodiments, the active area **130** of the cell row ROW2 includes two fin-shaped structures **131** and **132** together as an active region to form an integrated circuit component (such as a transistor), such that an equivalent width of the active region of the integrated circuit component disposed on the active area **130** will be wider than one of another integrated circuit component disposed on the active area **110**, which includes the first one fin-shaped structure. Alternatively stated, in some embodiments, integrated circuit components disposed on the cell row ROW2 have a better performance than integrated circuit components disposed on the cell row ROW1.

Reference is now made to FIG. 2A. FIG. 2A is a schematic diagram of part of a scan flip-flop **200** and corresponding inverters **251-252**, in accordance with some embodiments. In some embodiments, the scan flip-flop **200** is formed in the semiconductor device **10** of FIG. 1A. For illustration, the scan flip-flop **200** includes a mux input circuit **210**, a first latch circuit **220**, a second latch circuit **230**, and an output stage **240**. The mux input circuit **210** is coupled to the first latch circuit **220**. The first latch circuit **220** is coupled to the second latch circuit **230**. The second latch circuit **230** is coupled to the output stage **240**.

In operation, the mux input circuit **210** is configured to receive a scan data input SI, a data input Di and a scan enable signal SE and output the scan data input SI or the normal data input Di. The first and second latch circuits **220-230** are configured to receive clock signals CLKB and CLKBB and to be cross-coupled to store a data state. The clock signal CLKB is generated by the inverter **251** inverting a clock signal CP1, and the clock signal CLKBB is generated by the inverter **252** inverting the clock signal CLKB. The output stage **240** is configured to generate an output data signal Qi based on the output of the second latch circuit **230**. In some embodiments, the output signal Qi is associated with the output signal of the mux input circuit **210**, the data state stored in the first and second latch circuits **220-230** and the clock signals CLKB and CLKBB.

Specifically, the mux input circuit **210** includes a multiplexer (MUX) **211**. The MUX **211** is configured to output the scan data input SI or the data input Di in accordance of the scan enable signal SE. In some embodiments, there are several scan flip-flops, configured with respect to the scan flip-flop **200**, configured to receive a multi-bit data signal, and the data input Di corresponds to the i-th bit data of the multi-bit data signal. For example, the scan flip-flops receive a 4-bit signal, and accordingly, data inputs D1-D4 correspond to the first to fourth-bit data of the 4-bit signal.

In some embodiments, the scan enable signal SE received by the MUX **211** switches the scan flip-flop **200** between a normal operation mode and a scan test mode. For example, when the scan enable signal SE is raised to a high logic level (i.e., logic 1) and the scan flip-flop **200** operates in the scan test mode, the scan data input SI is output by the MUX **211**. When the scan enable signal SE is pulled down to a low logic level (i.e., logic 0) and the scan flip-flop **200** operates in the normal operation mode, the data input Di is output by the MUX **211**.

For illustration, the first latch circuit **220** includes transmission gates **221** and **223** and inverters **222** and **224**. The transmission gate **221** receives the clock signals CLKB and CLKBB. The inverters **222** and **224** and the and transmission gate **223** form a latch that includes the inverter **222** coupled in a forward path between the transmission gate **221**

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and an output terminal of the first latch circuit **220**, and the inverter **224** coupled in a feedback configuration and the transmission gate **223** enabled and disabled by the clock signals CLKB and CLKBB.

Similarly, the second latch circuit **230** includes transmission gates **231** and **233** and inverters **232** and **234**. The transmission gate **231** receives the clock signals CLKB and CLKBB. The inverters **232** and **234** and the and transmission gate **233** form a latch that includes the inverter **232** coupled in a forward path between the transmission gate **231** and an output terminal of the second latch circuit **230**, and the inverter **234** coupled in a feedback configuration and the transmission gate **233** enabled and disabled by the clock signals CLKB and CLKBB.

The output stage **240** includes an inverter **241**. The inverter **241** is coupled to an output of the second latch circuit **230**. The inverter **241** is configured to output the output signal of the second latch circuit **230** and generate the output data signal Qi.

As mentioned above, in some embodiments, the data input Di corresponds to the i-th bit data of the multi-bit data signal. Accordingly, the output data signal Qi corresponds to i-th bit data of the multi-bit data signal. Furthermore, in alternative embodiments, the output data signal Qi of the i-th bit flip-flop is input as the scan data input SI(i+1) along with the data input D(i+1) to the (i+1)-th bit flip-flop, and so on. In some embodiments, all the scan flip-flops in a multi-bit flip-flop circuit receive the same scan data input.

In some embodiments, the output data signal Qi “flips” and “flops” between a “1” and a “0” in a manner that depends on the output of the mux input circuit **210** and the clock signal CP1. Generally, the stored data state in the scan flip-flop **200** is output as the output data signal Qi until a logic state of the clock signal CP1 changes. When the logic state of the clock signal CP1 changes, the present state of the output signal of the mux input circuit **210** is stored and delivered as the output data signal Qi. For example, in some embodiments, the initial stored state in the scan flip-flop is “1”. When the state of the clock signal CP1 changes and the state of the output signal of the mux input circuit **210** is still “1”, state “1” is stored for another clock cycle. In contrast, when the state of the clock signal CP1 changes and the state of the output signal of the mux input circuit **210** is “0”, state “0” is stored for the ensuing clock cycle and correspondingly the output data signal Qi having a state “0” is output.

The configurations of FIG. 2A are given for illustrative purposes. Various implements of FIG. 2A are within the contemplated scope of the present disclosure. For example, in some embodiments, the transmission gate **223** of the first latch circuit **220** and the transmission gate **233** of the second latch circuit **230** are omitted.

Reference is now made to FIG. 2B. FIG. 2B is a layout view of the scan flip-flop **200** of FIG. 2A, in accordance with some embodiments. With respect to FIG. 2A, like elements in FIG. 2B are designated with the same reference numbers for ease of understanding.

In some embodiments, a cell **201** is configured in the formation of the scan flip-flop **200** of FIG. 2A. As illustratively shown in FIG. 2B, the cell **201** includes the mux input circuit **210**, the first latch circuit **220**, the second latch circuit **230**, and the output stage **240** that are arranged along a cell boundary direction **250**. The configurations of the cell **201** corresponding to the scan flip-flop **200** are given for illustrative purposes. Various implements of the cell **201** are within the contemplated scope of the present disclosure. For example, in some embodiments, the mux input circuit **210**, the first latch circuit **220**, the second latch circuit **230**, and

the output stage **240** are arranged along both two cell boundary directions **250** and **260**.

FIGS. 3A-3F are floor planning or layout views of several the scan flip-flops of FIGS. 2A-2B included in 4-bit flip-flop circuits **31-33** in the semiconductor device **10** of FIG. 1A, in accordance with some embodiments. In some embodiments, cells, included in the multi-bit flip-flop circuits **31-36**, having a cell height H1 are arranged in rows, for example, the cell rows ROW1 and ROW3 of FIG. 1A. Similarly, the cells, included in the multi-bit flip-flop circuits **31-36**, having a cell height H2 are arranged in rows, for example, the cell rows ROW2 and ROW4 of FIG. 1A. Alternatively stated, the cells having the cell height H1 are implemented in the high fin (including at least two fins in an active area) rows, and the cells having the cell height H2 are implemented in the low fin (including one fin in an active area) rows.

In some embodiments, the cell rows ROW1-ROW4 are arranged in sequences different from FIG. 1A to implement the corresponding the multi-bit flip-flop circuits **31-36**.

Reference is now made to FIG. 3A. The 4-bit flip-flop circuit **31** includes cells **201-204** and **253-254**. The cells **202-204** are configured with respect to, for example, the cell **201**. In some embodiments, the cells **201-204** have the same equivalent circuit including, for example, the scan flip-flop **200** of FIG. 2A.

The cells **201-204** correspond to bit 1 to bit 4 scan flip-flops separately (as shown in FIG. 3A). In alternative embodiments, the output data signal Qi in the cell **201** of bit 1 is input as the scan data input SI for the cell **202** of bit 2. The output data signal Qi in the cell **202** of bit 2 is input as the scan data input SI for the cell **203** of bit 3. The output data signal Qi in the cell **203** of bit 3 is input as the scan data input SI for the cell **204** of bit 4. The cells **253** and **254** correspond to the inverters **251** and **252** of FIG. 2A respectively. In some embodiments, the scan flip-flops of the cells **201-204** operate in response to the clock signal CLKB generated by the inverter **251** of the cell **253** and the clock signal CLKBB generated by the inverter **252** of the cell **254**.

For illustration, the cell **201** of bit 1 is arranged in the cell row ROW1 and has a width W1. The cells **202** of bit 2 and **253** are arranged in the cell row ROW2. The cell **202** of bit 2 has a width W2 smaller than the width W1 and abuts the cell **253**. The cells **203** of bit 3 and **254** are arranged in the cell row ROW3. The cell **203** of bit 3 has the width W2 and abuts the cell **254**. The cell **204** of bit 4 is arranged in the cell row ROW4 and has the width W1. The cells **253-254** abut one another.

In some embodiments, transistors of the cells **201-204** included in the scan multi-bit flip-flop circuit **31** shares gate structures in the layout view. For example, in various embodiments, at least one gate structure is configured to be in the formation of the inverter **222** in the cell **201** and the transmission gate **223** in the cell **202**. Alternatively stated, due to the shared gate structures, cells in the cell row having smaller cell height, such like the cell rows ROW1 and ROW3, save routing resource for connecting gates, and further, the cells are capable to include complex circuits (more circuit elements) within relatively smaller area of cells, compared with that of cells in the cell rows having larger row height. The configurations mentioned above are given for illustrative purposes. Various implements are included in the contemplated scope of the present disclosure. For example, in some embodiments, the inverters in the cells **253-254** share gate or other layout structures (i.e., conductive patterns MD configured to be drain or source terminals of transistors) with elements in the cells **201-204**.

In addition, in some approaches, each bit of a multi-bit flip-flop circuit has similar circuit topology and sizing. Accordingly, the functionality of each bit is the same, and the timing characteristics are very similar. Compared with the approaches, with the configurations of the present disclosure, bits of the multi-bit flip-flop circuit are arranged in mixed row height structures, and therefore the flexibility of topology and device sizing are provided. Moreover, because the constraint of having the same topology and sizing to bits of multi-bit flip-flop circuit has been removed, area overhead of implementing the multi-bit flip-flop circuit in mixed row cell architecture is also removed. Accordingly, the better power, performance, and area usage of the multi-bit flip-flop circuit are achieved in the present disclosure, compared with some approaches.

Reference is now made to FIG. 3B. With respect to FIG. 3A, like elements in FIG. 3B are designated with the same reference numbers for ease of understanding.

Compared with FIG. 3A, instead of arranging the cell **254** in the cell row ROW3, the cell **254** of the multi-bit flip-flop circuit **32** is arranged in the cell row ROW4 and abuts the cell **202** of bit 4.

With the configurations of FIG. 3B, because the cells **202** of bit 2 and **202** of bit 4 are arranged in the cell rows ROW2 and ROW4 that have 2-fin structure as mention in FIG. 1A, scan flip-flops operating with higher computing speed are formed within the cell rows ROW2 and ROW4, compared with scan flip-flops, formed within the cell rows ROW1 and ROW3, operating with lower computing speed. Alternatively stated, the scan flip-flops in the multi-bit flip-flop circuit operate in different speeds. In some embodiments, the speed of the multi-bit flip-flops is not dominated by the scan flip-flops operating with lower computing speed.

Reference is now made to FIG. 3C. With respect to FIGS. 3A-3B, like elements in FIG. 3C are designated with the same reference numbers for ease of understanding.

Compared with FIG. 3A, instead of having the cell **201** of bit 1 in the cell row ROW1 and the cell **202** of bit 2 in the cell row ROW2, the multi-bit flip-flop circuit **33** includes the cell **204** of bit 2 arranged in the cell row ROW2 and the cell **203** of bit 1 in the cell row ROW1. The cell **203** of bit 1 abuts the cell **253**. Alternatively stated, the cells **203** of bit 1 and **203** of bit 3 are arranged interposed between the cells **204** of bit 2 and **204** of bit 4. To explain in another way, the cell rows ROW1 and ROW3 are arranged interposed between the cell rows ROW2 and ROW4.

Reference is now made to FIG. 3D. With respect to FIGS. 3A-3C, like elements in FIG. 3D are designated with the same reference numbers for ease of understanding.

Compared with FIG. 3A, instead of arranging the cells of bit 3 and bit 4 vertically in the cell of the multi-bit flip-flop circuit **31**, the multi-bit flip-flop circuit **34** includes the cell **202** of bit 3 and the cell **254** that are arranged in the cell row ROW2. Alternatively stated, the cells **253-254** are arranged interposed between the cells **202** of bit 2 and **202** of bit 3. The multi-bit flip-flop circuit **34** further includes the cell **201** of bit 4 in the cell row ROW1. The cell **201** of bit 4 abuts the cell **201** of bit 1. In some embodiments, the cells of bit 1 to bit 4 are arranged clockwise in the cell corresponding to the multi-bit flip-flop circuit **34**.

Reference is now made to FIG. 3E. With respect to FIGS. 3A-3D, like elements in FIG. 3E are designated with the same reference numbers for ease of understanding.

Compared with FIG. 3D, instead of arranging the cells **253-254** in the cell row ROW2, the multi-bit flip-flop circuit **35** includes the cells **253-254** that are in the cell row ROW1 and arranged interposed between the cells **203** of bit 1 and

203 of bit 4. As shown in FIG. 3D, the multi-bit flip-flop circuit 35 further includes the cells 204 of bit 2 and 204 of bit 3 that are in the cell row ROW2 and abut each other.

Reference is now made to FIG. 3F. With respect to FIGS. 3A-3E, like elements in FIG. 3F are designated with the same reference numbers for ease of understanding.

Compared with FIG. 3E, instead of having the cells 253-254 in the same cell row, the multi-bit flip-flop circuit 36 includes the cell 253 in the cell row ROW1 and the cell 254 in the cell row ROW2. As shown in FIG. 3F, the multi-bit flip-flop circuit 36 includes the cells 203 of bit 1 and 203 of bit 4 in the cell row ROW1 and the cells 202 of bit 2 and 202 of bit 3 in the cell row ROW2. The cell 253 is arranged interposed between the cells 203 of bit 1 and 203 of bit 4, and the cell 254 is arranged interposed between the cells 202 of bit 2 and 202 of bit 3. The cells 253-254 abut each other.

FIGS. 4A-4B are floor planning or layout views of several the scan flip-flops of FIGS. 2A-2B included in 8-bit flip-flop circuits 41-42 in the semiconductor device of FIG. 1A, in accordance with some embodiments. With respect to FIGS. 3A-3F, like elements in FIGS. 4A-4B are designated with the same reference numbers for ease of understanding.

Reference is now made to FIG. 4A. Compared with FIG. 3B, the multi-bit flip-flop circuits 41 includes cells corresponding to bit 5 to bit 8. For illustration, the multi-bit flip-flop circuits 41 includes cells 205 of bit 1, 205 of bit 3, 205 of bit 6, and 205 of bit 8, in which each has a width W3, smaller than the width W1 and larger than the width W2, and the cell height H1. In some embodiments, the cells 205 of bit 1, 205 of bit 3, 205 of bit 6, and 205 of bit 8 are configured with respect to, for example, the cell 201 of FIG. 2B. In some embodiments, the cells 205 of multi bits have the same equivalent circuit including, for example, the scan flip-flop 200 of FIG. 2A.

Specifically, the cell 205 of bit 1 and the cell 205 of bit 8 are arranged in the cell row ROW1. The cell 202 of bit 2, the cell 253, and the cell 202 of bit 7 are arranged in the cell row ROW2. The cell 205 of bit 3 and the cell 205 of bit 6 are arranged in the cell row ROW3. The cell 202 of bit 4, the cell 254, and the cell 202 of bit 5 are arranged in the cell row ROW4. In some embodiments, the cells of bit 1 to bit 8 are arranged clockwise in the cell corresponding to the multi-bit flip-flop circuit 41.

Reference is now made to FIG. 4B. Compared with FIG. 4A, the cells 253-254 abut each other. For illustration, the multi-bit flip-flop circuit 42 includes cells 206 of bit 4 and 206 of bit 5, in which each has the width W3 and the cell height H2. In some embodiments, the cells 206 of bit 4 and 206 of bit 5 are configured with respect to, for example, the cell 201 of FIG. 2B. In some embodiments, the cells 206 of multi bits have the same equivalent circuit including, for example, the scan flip-flop 200 of FIG. 2A.

The cell 203 of bit 2, the cell 254, and the cell 203 of bit 7 are arranged in the cell row ROW3. The cell 202 of bit 3, the cell 253, and the cell 202 of bit 6 are arranged in the cell row ROW2. The cell 202 of bit 3, the cell 253, and the cell 202 of bit 6 are arranged in the cell row ROW2.

The configurations of FIGS. 4A-4B are given for illustrative purposes. Various implements are within the contemplated scope of the present disclosure. For example, in some embodiments, instead of having the cells 203 of bit 2 and 203 of bit 7, the multi-bit flip-flop circuit 42 includes a cell 202 of bit 2, the cell 254, and a cell 202 of bit 7 in the cell row ROW2 and cells 205 of bit 4 and 205 of bit 5 in the cell row ROW4.

Reference is now made to FIG. 5A. FIG. 5A is a schematic diagram of part of a scan flip-flop 500, in accordance with some embodiments. With respect to the embodiments of FIG. 2A, like elements in FIG. 5A are designated with the same reference numbers for ease of understanding. The specific operations of similar elements, which are already discussed in detail in above paragraphs, are omitted herein for the sake of brevity, unless there is a need to introduce the co-operation relationship with the elements shown in FIG. 5B.

As illustratively shown in FIG. 5A, the scan flip-flop 500 includes a mux input circuit 510, a first latch circuit 520, a second latch circuit 530, and an output stage 540. In some embodiments, the mux input circuit 510 is configured with respect to, for example, the mux input circuit 210 of FIG. 2A. The first latch circuit 520 is configured with respect to, for example, the first latch circuit 220 of FIG. 2A. The second latch circuit 530 is configured with respect to, for example, the second latch circuit 230 of FIG. 2A. The output stage 540 is configured with respect to, for example, the output stage 240 of FIG. 2A.

Compared with the scan flip-flop 200 of FIG. 2A, instead of having the inverters 222 and 234, the scan flip-flop 500 includes an NOR gate 522 in the first latch circuit 520 and an NOR gate 534 in the second latch circuit 530. As illustratively shown in FIG. 5A, a first input terminal of the NOR gate 522 is coupled with the transmission gates 221 and 223, and a second input terminal of the NOR gate 522 is coupled to a control signal CD. A first input terminal of the NOR gate 534 is coupled with the inverters 232 and 241, and a second input terminal of the NOR gate 534 is coupled to a control signal CD. In some embodiments, the control signal CD is configured as a "Reset" signal which resets the output of the scan flip-flops to a particular logic state, (i.e., logic 1) at appropriate clock cycles.

In some embodiments, because of having the NOR gates 522 and 534, the scan flip-flop 500 of FIG. 5A occupies a greater area than the scan flip-flop 200 of FIG. 2A.

Reference is now made to FIG. 5B. With respect to FIG. 5A, like elements in FIG. 5B are designated with the same reference numbers for ease of understanding. As illustratively shown in FIG. 2B, the cell 501 includes the mux input circuit 510, the first latch circuit 520, the second latch circuit 530, and the output stage 540 that are arranged along a cell boundary direction 550. The configurations of the cell 501 corresponding to the scan flip-flop 500 are given for illustrative purposes. Various implements of the cell 501 are within the contemplated scope of the present disclosure. For example, in some embodiments, the mux input circuit 510, the first latch circuit 520, the second latch circuit 530, and the output stage 540 are arranged along both two cell boundary directions 550 and 560.

FIGS. 6A-6C are floor planning or layout views of several the scan flip-flops of FIGS. 2A-2B and several the scan flip-flops of FIGS. 5A-5B that are included in 4-bit flip-flop circuits 61-63 in the semiconductor device of FIG. 1A, in accordance with some embodiments.

Reference is now made to FIG. 6A. Compared with FIG. 3B, as shown in FIG. 6A, instead of having the cells 201 of bit 1 and 201 of bit 3, the multi-bit flip-flop circuits 61 includes the cell 501 of bit 1 in the cell ROW1, the cell 501 of bit 3 in the cell ROW3, in which the cells 501 of bit 1 and 501 of bit 3 has the width W1 and the cell height H1.

Reference is now made to FIG. 6B. Compared with FIG. 6A, instead of having the cell rows with different cell heights being arranged interlaced, the cell rows ROW2 and ROW4 having greater cell height are arranged interposed between

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the cell rows ROW1 and ROW3 having smaller cell height in the multi-bit flip-flop circuit 62. Alternatively stated, the cell 501 of bit 4 in the cell row ROW3 is exchanged with the cell 202 of bit 3 and the cell 254 that are arranged in the cell row ROW4, and the cells 253-254 abut each other.

Reference is now made to FIG. 6C. Compared with FIG. 6B, instead of having the cell rows having greater cell height interposed between the cell rows having smaller cell height, the cell rows ROW1 and ROW3 are interposed between the cell rows ROW2 and ROW4.

The configurations of FIGS. 6A-6C are given for illustrative purposes. Various implements are included in the contemplated scope of the present disclosure. For example, the scan flip-flops corresponding to bits in multi-bit flip-flop circuit are arranged in sequence along one of cell boundaries which elongate in a direction perpetual to the direction in which the cells extend.

FIGS. 7A-7B are floor planning or layout views of several the scan flip-flops of FIGS. 2A-2B and several the scan flip-flops of FIGS. 5A-5B included in 8-bit flip-flop circuits 71-72 in the semiconductor device of FIG. 1A, in accordance with some embodiments. With respect to FIGS. 2A-6C, like elements in FIGS. 7A-7B are designated with the same reference numbers for ease of understanding.

Reference is now made to FIG. 7A. Compared with FIG. 4A, instead of having the cells 205 of bit 1, 205 of bit 3, 205 of bit 6, and 205 of bit 8, the multi-bit flip-flop circuit 71 includes cells 502 of bit 1, 502 of bit 3, 502 of bit 6, and 502 of bit 8. In some embodiments, the cells 502 of bit 1, 502 of bit 3, 502 of bit 6, and 502 of bit 8 are configured with respect to, for example, the cell 501 of FIG. 5B. In some embodiments, the cells 502 of multi bits have the same equivalent circuit including, for example, the scan flip-flop 500 of FIG. 5A.

Reference is now made to FIG. 7B. Compared with FIG. 7A, the cell row ROW3 is exchanged with the cell row ROW4. Specifically, the cell 202 of bit 4 is interposed between the cell 202 of bit 2 and the cell 502 of bit 3. The cell 202 of bit 5 is interposed between the cell 202 of bit 7 and the cell 502 of bit 6. The cells 253-254 abut each other.

With the configurations of FIGS. 6A-7B, clock drivers, such like the inverters in the clock cells 253-254, are centralized in the multi-bit flip-flop circuit and abut some scan flip-flop. Alternatively stated, instead of each scan flip-flop having its own pair of clock driver, signals of the clock drivers centralized in the multi-bit flip-flop circuit are shared by all the scan flip-flop in the multi-bit flip-flop circuit. Accordingly, the total area of multi-bit flip-flop circuit is reduced.

Moreover, with the configurations of FIGS. 6A-7B, scan flip-flops, corresponding to bits of multi-bit flip-flop, with different flop functions are integrated together in different cell architectures. In some embodiments, different cell architectures feature different computing speed. Accordingly, timing path for each bit will be characterized separately and the EDA tools will do optimization and put timing critical path in the faster cell architecture and less timing critical path in power optimized cell.

Reference is now made to FIG. 8A. FIG. 8A is a schematic diagram of part of a first set of scan flip-flops 801-802 corresponding to the scan flip-flop 500 of FIG. 5A, in accordance with some embodiments. With respect to FIGS. 2A-7B, in FIG. 8A are designated with the same reference numbers for ease of understanding. The specific operations of similar elements, which are already discussed in detail in above paragraphs, are omitted herein for the sake of brevity,

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unless there is a need to introduce the co-operation relationship with the elements shown in FIG. 8A.

In some embodiments, each scan flip-flop in the first set of scan flip-flops 801-802 is configured with respect to, for example, the scan flip-flop 500 of FIG. 5A. The inverters 811-812 are configured with respect to, for example, the inverters 251-252 of FIG. 2A. As illustratively shown in FIG. 8A, the scan flip-flop 801-802 are configured to operate in response to an output signal CLKB1 of the inverter 811 and an output signal CLKBB1 of the inverter 812, while the scan flip-flop 802 receives the signal data input SI1. The clock signal CLKB1 is generated by the inverter 811 inverting the clock signal CP1, and the clock signal CLKBB1 is generated by the inverter 812 inverting the clock signal CLKB1. In some embodiments, the output data signal Q2 of the scan flip-flop 802 is received by the scan flip-flop 801, and the scan flip-flop 801 outputs the output data signal Q4.

Reference is now made to FIG. 8B. FIG. 8B is a schematic diagram of part of a second set of scan flip-flops 803-804 corresponding to the scan flip-flop 200 of FIG. 2A, in accordance with some embodiments. With respect to FIGS. 2A-8A, like elements in FIG. 8B are designated with the same reference numbers for ease of understanding. The specific operations of similar elements, which are already discussed in detail in above paragraphs, are omitted herein for the sake of brevity, unless there is a need to introduce the co-operation relationship with the elements shown in FIG. 8B.

In some embodiments, each scan flip-flop in the second set of scan flip-flops 803-804 is configured with respect to, for example, the scan flip-flop 200 of FIG. 2A. The inverters 813-814 are configured with respect to, for example, the inverters 251-252 of FIG. 2A. As illustratively shown in FIG. 8B, the scan flip-flop 803-804 are configured to operate in response to an output signal CLKB2 of the inverter 813 and an output signal CLKBB2 of the inverter 814, while the scan flip-flop 804 receives the signal data input SI2. The clock signal CLKB2 is generated by the inverter 813 inverting a clock signal CP2, and the clock signal CLKBB2 is generated by the inverter 814 inverting the clock signal CLKB2. In some embodiments, the output data signal Q1 of the scan flip-flop 804 is received by the scan flip-flop 803, and the scan flip-flop 803 outputs the output data signal Q3.

In some embodiments, the clock signals CP1 and CP2 are different. Accordingly, the first set of scan flip-flops 801-802 and the second set of scan flip-flops 803-804 have different timing characteristics. Alternatively stated, in some embodiments, the first set of scan flip-flops 801-802 and the second set of scan flip-flops 803-804 are configured to be in two independent multi-bit flip-flop circuits.

The configurations of FIGS. 8A-8B are given for illustrative purposes. Various implements are included in the contemplated scope of the present disclosure. For example, the clock signals CP1 and CP2 are the same. In various embodiments, the output data signals Q1-Q2 are not received by the scan flip-flops 801 and 803. Each of the scan flip-flops 801-804 receives the same signal data input SI.

FIGS. 9A-9C are floor planning or layout views of the first set of scan flip-flops 801-802 and the second set of scan flip-flops 803-804 that are included in 4-bit flip-flop circuits 91-93 in the semiconductor device of FIG. 1A, in accordance with some embodiments. With respect to FIGS. 2A-8B, like elements in FIGS. 9A-9C are designated with the same reference numbers for ease of understanding.

Reference is now made to FIG. 9A. The multi-bit flip-flop circuit 91 includes the cells 202-203, 503-504, a first pair of (clock) cells 815-816, and a second pair of clock cells

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817-818. The cells **503-504** have a width **W4** greater than the width **W1** and the cell height **H1**. In some embodiments, the scan flip-flops **801-802** in the first set of scan flip-flops are arranged in the cells **504** of bit **4** and **503** of bit **2** respectively. The scan flip-flops **803-804** in the second set of scan flip-flops are arranged in the cells **202** of bit **3** and **203** of bit **1** respectively. For illustration, the 4-bit flip-flop circuit **91** includes cells **815-818**. The clock cells **815-816** correspond to the inverters **813-814** of FIG. **8B** respectively. The clock cells **817-818** correspond to the inverters **811-812** of FIG. **8A** respectively.

As illustratively shown in FIG. **9A**, the cells **203** of bit **1** and the first pair of (clock) cells **815-816** are arranged in the cell row **ROW1**. The cells **202** of bit **3** and the second pair of clock cells **817-818** are arranged in the cell row **ROW2**. The cell **503** of bit **2** is arranged in the cell row **ROW3**. The cell **504** of bit **4** is arranged in the cell row **ROW4**.

Reference is made to FIG. **9B**. Compared with FIG. **9A**, instead of having the cell **503** of bit **2** abutting the cell **202** of bit **3** and the second pair of clock cells **817-818**, the cell **504** of bit **4** in the multi-bit flip-flop circuit **92** is arranged abutting the cell **202** of bit **3** and the second pair of clock cells **817-818**, while the cell **503** of bit **2** is arranged on the opposite side of the cell **504** of bit **4**.

Reference is now made to FIG. **9C**. Compared with FIG. **9A**, instead of arranging the cell **202** of bit **3** and the second pair of (clock) cells **817-818** abutting the cell **503** of bit **2**, the cell **203** of bit **1** and the first pair of (clock) cells **815-816** of the multi-bit flip-flop circuit **93** are arranged abutting the cell **503** of bit **2**, while the cell **202** of bit **3** and the second pair of (clock) cells **817-818** are arranged on the opposite side of the cell **203** of bit **1**.

The configurations of FIGS. **9A-9C** are given for illustrative purposes. Various implements are included in the contemplated scope of the present disclosure. For example, in some embodiments, the sequence of the cell rows **ROW1-ROW4** is different from what have been shown in the embodiments of FIGS. **9A-9C**.

Reference is now made to FIG. **10**. FIG. **10** is floor planning or layout view of several first sets of scan flip-flops and several second sets of scan flip-flops that are included in a 8-bit flip-flop circuit **101** in the semiconductor device **10** of FIG. **1A**, in accordance with some embodiments. With respect to FIGS. **2A-9C**, like elements in FIG. **10** are designated with the same reference numbers for ease of understanding.

As shown in FIG. **10**, compared with FIG. **9A**, instead of having the cells **503** of bit **2** and **504** of bit **4**, the multi-bit flip-flop circuit **101** includes cells **501** of bit **2**, **505** of bit **4**, **505** of bit **8**, and **501** of bit **6**. In some embodiments, the cells **505** of bit **4** and **505** of bit **8** have the width **W1** and the cell height **H2**, and are configured with respect to, for example, the cell **501** of FIG. **5B**. For illustration, the cells **505** of bit **4** and **505** of bit **8** are arranged in the cell row **ROW4**, and the cells **501** of bit **2** and **501** of bit **6** are arranged in the cell row **ROW3**.

In some embodiments, one of the first sets of scan flip-flops **801-802** corresponding to bit **2** and bit **4** are arranged in the cells **501** of bit **2** and **505** of bit **4**, and the other one corresponding to bit **6** and bit **8** are arranged in the cells **501** of bit **6** and **505** of bit **8**.

As illustratively shown in FIG. **10**, the multi-bit flip-flop circuit **101** further includes cells **203** of bit **5** and **202** of bit **7**. In some embodiments, one of the second sets of scan flip-flops **803-804** corresponding to bit **1** and bit **3** are arranged in the cells **203** of bit **1** and **202** of bit **3**, and the

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other one corresponding to bit **5** and bit **7** are arranged in the cells **203** of bit **5** and **202** of bit **7**.

The configurations of FIG. **10** are given for illustrative purposes. Various implements are included in the contemplated scope of the present disclosure. For example, in some embodiments, the sequence of the cell rows **ROW1-ROW4** is different from what have been shown in the embodiments of FIG. **10**.

With the configurations of FIGS. **9A-10**, by utilizing two pairs of clock cells in mixed cell row architecture, the flexibility of arranging two independent multi-bit flip-flop circuits is provided and further the total area of multi-bit flip-flop circuits is reduced.

FIG. **11** is a flow chart of a method **1100** of generating a layout design for fabricating an integrated circuit including the multi-bit flip-flop circuits **31-36**, **41-42**, **61**, in accordance with some embodiments of the present disclosure. It is understood that additional operations can be provided before, during, and after the processes shown by FIG. **11**, and some of the operations described below can be replaced or eliminated, for additional embodiments of the method. The order of the operations/processes may be interchangeable. Throughout the various views and illustrative embodiments, like reference numbers are used to designate like elements. The method **1100** includes operations **1110-1120** that are described below with reference to the multi-bit flip-flop circuit **61** of FIG. **6A**.

In operation **1110**, the cells **501** of bit **1**, **501** of bit **3**, **202** of bit **2**, and **204** of bit **4** are arranged in the cell rows **ROW1-ROW4**. As shown in the embodiments of FIG. **6A**, the cells **501** of bit **1**, **501** of bit **3** have the width **W1**, and the cells **202** of bit **2**, and **204** of bit **4** have the width **W2** different from the width **W1**.

In some embodiments, the width **W2** is smaller than the width **W1**.

In some embodiments, as mentioned above with respect to FIG. **6A**, the scan flip-flops corresponding to the cells **501** and **202** have different functions. For example, scan flip-flop in the cell **501** is further configured to operate in response to the control signal **CD**, compared with the scan flip-flop in the cell **202**.

In some embodiments, the cell rows **ROW1** and **ROW3** have the row height **H1**, and the cell rows **ROW2** and **ROW4** have the row height **H2**, in which the row height **H1** is smaller than the row height **H2**.

In some embodiments, as shown in FIG. **6A**, the cells **501** of bit **1** and **501** of bit **3** are arranged in the cell rows **ROW1** and **ROW3**. The cell **202** of bit **2** and **204** of bit **4** are arranged in the cell rows **ROW2** and **ROW4**.

In operation **1120**, the (clock) cells **253-254** are arranged in the cell rows **ROW2** and **ROW4**. In the embodiments of FIG. **6A**, the (clock) cell **253** abuts the cell **202** of bit **2**, and the (clock) cell **254** abuts the cell **204** of bit **4**.

In various embodiments, as shown in FIG. **9A**, the first pair of clock cells **815-816** are arranged in the cell row **ROW1**, and the second pair of clock cells **817-818** are arranged in the cell row **ROW2** having the cell height different from that of the cell row **ROW1**.

In some embodiments, as shown in FIG. **6A**, the cells **501** of bit **1**, **501** of bit **3**, **202** of bit **2**, **204** of bit **4**, the clock cells **253-254** are included in a standard cell operating as the multi-bit flip-flop circuit **61**.

Reference is now made to FIG. **12**. FIG. **12** is a block diagram of an electronic design automation (EDA) system **1200** for designing the integrated circuit layout design, in accordance with some embodiments of the present disclosure. EDA system **1200** is configured to implement one or

more operations of the method **1100** disclosed in FIG. **11**, and further explained in conjunction with FIGS. **1A-10**. In some embodiments, EDA system **1200** includes an APR system.

In some embodiments, EDA system **1200** is a general purpose computing device including a hardware processor **1202** and a non-transitory, computer-readable storage medium **1204**. Storage medium **1204**, amongst other things, is encoded with, i.e., stores, computer program code (instructions) **1206**, i.e., a set of executable instructions. Execution of computer program code **1206** by hardware processor **1202** represents (at least in part) an EDA tool which implements a portion or all of, e.g., the method **1100**.

The processor **1202** is electrically coupled to computer-readable storage medium **1204** via a bus **1208**. The processor **1202** is also electrically coupled to an I/O interface **1210** and a fabrication tool **1216** by bus **1208**. A network interface **1212** is also electrically connected to processor **1202** via bus **1208**. Network interface **1212** is connected to a network **1214**, so that processor **1202** and computer-readable storage medium **1204** are capable of connecting to external elements via network **1214**. The processor **1202** is configured to execute computer program code **1206** encoded in computer-readable storage medium **1204** in order to cause EDA system **1200** to be usable for performing a portion or all of the noted processes and/or methods. In one or more embodiments, processor **1202** is a central processing unit (CPU), a multi-processor, a distributed processing system, an application specific integrated circuit (ASIC), and/or a suitable processing unit.

In one or more embodiments, computer-readable storage medium **1204** is an electronic, magnetic, optical, electro-magnetic, infrared, and/or a semiconductor system (or apparatus or device). For example, computer-readable storage medium **1204** includes a semiconductor or solid-state memory, a magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk, and/or an optical disk. In one or more embodiments using optical disks, computer-readable storage medium **1204** includes a compact disk-read only memory (CD-ROM), a compact disk-read/write (CD-R/W), and/or a digital video disc (DVD).

In one or more embodiments, storage medium **1204** stores computer program code **1206** configured to cause EDA system **1200** (where such execution represents (at least in part) the EDA tool) to be usable for performing a portion or all of the noted processes and/or methods. In one or more embodiments, storage medium **1204** also stores information which facilitates performing a portion or all of the noted processes and/or methods. In one or more embodiments, storage medium **1204** stores IC layout diagram **1220** of standard cells including such standard cells as disclosed herein, for example, cells corresponding to the multi-bit flip-flop circuits **31-36**, **41-42**, **61-63**, **71-72**, **91-93**, and **101** discussed above with respect to FIGS. **1A-10**.

EDA system **1200** includes I/O interface **1210**. I/O interface **1210** is coupled to external circuitry. In one or more embodiments, I/O interface **1210** includes a keyboard, keypad, mouse, trackball, trackpad, touchscreen, and/or cursor direction keys for communicating information and commands to processor **1202**.

EDA system **1200** also includes network interface **1212** coupled to processor **1202**. Network interface **1212** allows EDA system **1200** to communicate with network **1214**, to which one or more other computer systems are connected. Network interface **1212** includes wireless network interfaces such as BLUETOOTH, WIFI, WIMAX, GPRS, or

WCDMA; or wired network interfaces such as ETHERNET, USB, or IEEE-1264. In one or more embodiments, a portion or all of noted processes and/or methods are implemented in two or more systems **1200**.

EDA system **1200** also includes the fabrication tool **1216** coupled to processor **1202**. The fabrication tool **1216** is configured to fabricate integrated circuits, e.g., the multi-bit flip-flop circuits **31-36**, **41-42**, **61-63**, **71-72**, **91-93**, and **101** discussed above with respect to FIGS. **1A-10**, according to the design files processed by the processor **1202**.

EDA system **1200** is configured to receive information through I/O interface **1210**. The information received through I/O interface **1210** includes one or more of instructions, data, design rules, libraries of standard cells, and/or other parameters for processing by processor **1202**. The information is transferred to processor **1202** via bus **1208**. EDA system **1200** is configured to receive information related to a UI through I/O interface **1210**. The information is stored in computer-readable medium **1204** as design specification **1222**.

In some embodiments, a portion or all of the noted processes and/or methods are implemented as a standalone software application for execution by a processor. In some embodiments, a portion or all of the noted processes and/or methods are implemented as a software application that is a part of an additional software application. In some embodiments, a portion or all of the noted processes and/or methods are implemented as a plug-in to a software application. In some embodiments, at least one of the noted processes and/or methods are implemented as a software application that is a portion of an EDA tool. In some embodiments, a portion or all of the noted processes and/or methods are implemented as a software application that is used by EDA system **1200**. In some embodiments, a layout diagram which includes standard cells is generated using a suitable layout generating tool.

In some embodiments, the processes are realized as functions of a program stored in a non-transitory computer readable recording medium. Examples of a non-transitory computer readable recording medium include, but are not limited to, external/removable and/or internal/built-in storage or memory unit, for example, one or more of an optical disk, such as a DVD, a magnetic disk, such as a hard disk, a semiconductor memory, such as a ROM, a RAM, a memory card, and the like.

FIG. **13** is a block diagram of IC manufacturing system **1300**, and an IC manufacturing flow associated therewith, in accordance with some embodiments. In some embodiments, based on a layout diagram, at least one of (A) one or more semiconductor masks or (B) at least one component in a layer of a semiconductor integrated circuit is fabricated using IC manufacturing system **1300**.

In FIG. **13**, IC manufacturing system **1300** includes entities, such as a design house **1320**, a mask house **1330**, and an IC manufacturer/fabricator ("fab") **1350**, that interact with one another in the design, development, and manufacturing cycles and/or services related to manufacturing an IC device **1360**. The entities in IC manufacturing system **1300** are connected by a communications network. In some embodiments, the communications network is a single network. In some embodiments, the communications network is a variety of different networks, such as an intranet and the Internet. The communications network includes wired and/or wireless communication channels. Each entity interacts with one or more of the other entities and provides services to and/or receives services from one or more of the other entities. In some embodiments, two or more of design house

1320, mask house **1330**, and IC fab **1350** is owned by a single entity. In some embodiments, two or more of design house **1320**, mask house **1330**, and IC fab **1350** coexist in a common facility and use common resources.

Design house (or design team) **1320** generates an IC design layout diagram **1322**. IC design layout diagram **1322** includes various geometrical patterns, for example, an IC layout design depicted in FIGS. 3A-4B, 6A-7B, and/or 9A-10, designed for an IC device **1360**, for example, integrated circuits **100** and **700** discussed above with respect to FIGS. 3A-4B, 6A-7B, and/or 9A-10. The geometrical patterns correspond to patterns of metal, oxide, or semiconductor layers that make up the various components of IC device **1360** to be fabricated. The various layers combine to form various IC features. For example, a portion of IC design layout diagram **1322** includes various IC features, such as an active region, gate electrode, source and drain, conductive segments or vias of an interlayer interconnection, to be formed in a semiconductor substrate (such as a silicon wafer) and various material layers disposed on the semiconductor substrate. Design house **1320** implements a proper design procedure to form IC design layout diagram **1322**. The design procedure includes one or more of logic design, physical design or place and route. IC design layout diagram **1322** is presented in one or more data files having information of the geometrical patterns. For example, IC design layout diagram **1322** can be expressed in a GDSII file format or DFII file format.

Mask house **1330** includes data preparation **1332** and mask fabrication **1344**. Mask house **1330** uses IC design layout diagram **1322** to manufacture one or more masks **1345** to be used for fabricating the various layers of IC device **1360** according to IC design layout diagram **1322**. Mask house **1330** performs (mask) data preparation **1332**, where IC design layout diagram **1322** is translated into a representative data file ("RDF"). (Mask) data preparation **1332** provides the RDF to mask fabrication **1344**. Mask fabrication **1344** includes a mask writer. A mask writer converts the RDF to an image on a substrate, such as a mask (reticle) **1345** or a semiconductor wafer **1353**. The IC design layout diagram **1322** is manipulated by (mask) data preparation **1332** to comply with particular characteristics of the mask writer and/or requirements of IC fab **1350**. In FIG. 13, data preparation **1332** and mask fabrication **1344** are illustrated as separate elements. In some embodiments, data preparation **1332** and mask fabrication **1344** can be collectively referred to as mask data preparation.

In some embodiments, data preparation **1332** includes optical proximity correction (OPC) which uses lithography enhancement techniques to compensate for image errors, such as those that can arise from diffraction, interference, other process effects and the like. OPC adjusts IC design layout diagram **1322**. In some embodiments, data preparation **1332** includes further resolution enhancement techniques (RET), such as off-axis illumination, sub-resolution assist features, phase-shifting masks, other suitable techniques, and the like or combinations thereof. In some embodiments, inverse lithography technology (ILT) is also used, which treats OPC as an inverse imaging problem.

In some embodiments, data preparation **1332** includes a mask rule checker (MRC) that checks the IC design layout diagram **1322** that has undergone processes in OPC with a set of mask creation rules which contain certain geometric and/or connectivity restrictions to ensure sufficient margins, to account for variability in semiconductor manufacturing processes, and the like. In some embodiments, the MRC modifies the IC design layout diagram **1322** to compensate

for limitations during mask fabrication **1344**, which may undo part of the modifications performed by OPC in order to meet mask creation rules.

In some embodiments, data preparation **1332** includes lithography process checking (LPC) that simulates processing that will be implemented by IC fab **1350** to fabricate IC device **1360**. LPC simulates this processing based on IC design layout diagram **1322** to create a simulated manufactured device, such as IC device **1360**. The processing parameters in LPC simulation can include parameters associated with various processes of the IC manufacturing cycle, parameters associated with tools used for manufacturing the IC, and/or other aspects of the manufacturing process. LPC takes into account various factors, such as aerial image contrast, depth of focus ("DOF"), mask error enhancement factor ("MEEF"), other suitable factors, and the like or combinations thereof. In some embodiments, after a simulated manufactured device has been created by LPC, if the simulated device is not close enough in shape to satisfy design rules, OPC and/or MRC are repeated to further refine IC design layout diagram **1322**.

It should be understood that the above description of data preparation **1332** has been simplified for the purposes of clarity. In some embodiments, data preparation **1332** includes additional features such as a logic operation (LOP) to modify the IC design layout diagram **1322** according to manufacturing rules. Additionally, the processes applied to IC design layout diagram **1322** during data preparation **1332** may be executed in a variety of different orders.

After data preparation **1332** and during mask fabrication **1344**, a mask **1345** or a group of masks **1345** are fabricated based on the modified IC design layout diagram **1322**. In some embodiments, mask fabrication **1344** includes performing one or more lithographic exposures based on IC design layout diagram **1322**. In some embodiments, an electron-beam (e-beam) or a mechanism of multiple e-beams is used to form a pattern on a mask (photomask or reticle) **1345** based on the modified IC design layout diagram **1322**. Mask **1345** can be formed in various technologies. In some embodiments, mask **1345** is formed using binary technology. In some embodiments, a mask pattern includes opaque regions and transparent regions. A radiation beam, such as an ultraviolet (UV) beam, used to expose the image sensitive material layer (for example, photoresist) which has been coated on a wafer, is blocked by the opaque region and transmits through the transparent regions. In one example, a binary mask version of mask **1345** includes a transparent substrate (for example, fused quartz) and an opaque material (for example, chromium) coated in the opaque regions of the binary mask. In another example, mask **1345** is formed using a phase shift technology. In a phase shift mask (PSM) version of mask **1345**, various features in the pattern formed on the phase shift mask are configured to have proper phase difference to enhance the resolution and imaging quality. In various examples, the phase shift mask can be attenuated PSM or alternating PSM. The mask(s) generated by mask fabrication **1344** is used in a variety of processes. For example, such a mask(s) is used in an ion implantation process to form various doped regions in semiconductor wafer **1353**, in an etching process to form various etching regions in semiconductor wafer **1353**, and/or in other suitable processes.

IC fab **1350** includes wafer fabrication **1352**. IC fab **1350** is an IC fabrication business that includes one or more manufacturing facilities for the fabrication of a variety of different IC products. In some embodiments, IC Fab **1350** is a semiconductor foundry. For example, there may be a

manufacturing facility for the front end fabrication of a plurality of IC products (front-end-of-line (FEOL) fabrication), while a second manufacturing facility may provide the back end fabrication for the interconnection and packaging of the IC products (back-end-of-line (BEOL) fabrication), and a third manufacturing facility may provide other services for the foundry business.

IC fab **1350** uses mask(s) **1345** fabricated by mask house **1330** to fabricate IC device **1360**. Thus, IC fab **1350** at least indirectly uses IC design layout diagram **1322** to fabricate IC device **1360**. In some embodiments, semiconductor wafer **1353** is fabricated by IC fab **1350** using mask(s) **1345** to form IC device **1360**. In some embodiments, the IC fabrication includes performing one or more lithographic exposures based at least indirectly on IC design layout diagram **1322**. Semiconductor wafer **1353** includes a silicon substrate or other proper substrate having material layers formed thereon. Semiconductor wafer **1353** further includes one or more of various doped regions, dielectric features, multi-level interconnects, and the like (formed at subsequent manufacturing steps).

As described above, integrated circuits in the present disclosure provide multi-bit flip flop architecture arranged in hybrid cell rows. By placing cells with different cell architectures and functions in cell rows with different cell heights, the area overhead is reduced and the flexibility of timing characteristics is provided.

In some embodiments, an integrated circuit is disclosed, including first bit cells, second bit cells, and clock cells. Each of first bit cells is arranged in one of multiple first cell rows having a first row height. Each of the second bit cells is arranged in one of multiple second cells rows having a second row height different from the first row height. The second bit cells extend to pass the first bit cells in a first direction. The clock cells are arranged in peripheral regions of a multi-bit flip flop cell in the first cell rows. The first and second bit cells and the clock cells are included in the multi-bit flip flop cell. In some embodiments, the clock cells include a first clock cell that is configured to output a first clock signal and arranged in a first row of the first cell rows; and a second clock cell that is configured to output a second clock signal inverted from the first clock signal and arranged in a second row of the first cell rows. The first and second bit cells are configured to operate in response to the first and second clock signals. In some embodiments, the first row height is greater than the second row height. In some embodiments, a first width of the first bit cells is smaller than a second width of the second bit cells. In some embodiments, a first number of fins in the first cell rows is smaller than a second number of fins in the second cell rows. In some embodiments, the clock cells are interposed between and about the second bit cells along a second direction different from the first direction. In some embodiments, a sum of widths of one in the clock cells and one in the first bit cells is equal to a width of one in the second bit cells. In some embodiments, the first bit cells have different widths.

Also disclosed is an integrated circuit that includes clock cells and bit cells abutting the clock cells. The bit cells include multiple first bit cells and multiple second bit cells that are aligned a first boundary, extending in a first direction in a layout view, of the bit cells. The second bit cells extend in a second direction different from the first direction to form protrusion regions of a second boundary, opposite of the first boundary, of the bit cells. The first bit cells and the second bit cells have different numbers of fin structures. In some embodiments, the clock cells abut the protrusion regions of the second boundary. In some embodiments, the bit cells are

configured to operate as a multi-bit flip flop circuit in response to first and second clock signals generated from the clock cells. In some embodiments, the clock cells are separated from each other in the first direction. The bit cells are configured to operate as a multi-bit flip flop circuit in response to first and second clock signals that have different logic states and generated from the clock cells. In some embodiments, the clock cells connect a boundary of the multi-bit flip flop circuit that overlaps the second boundary of the bit cells. In some embodiments, the bit cells and the clock cells are arranged in multiple cell rows having different row heights. In some embodiments, a width of each one in the second bit cells is greater than a width of each one in the first bit cells. In some embodiments, the clock cells and the first bit cells are arranged in same cell rows.

Also disclosed is a method including forming multiple first bit cells each having a first width, a first height, and a first number of fin structures; and forming multiple second bit cells that abut the first cells. Each in the second bit cells has a second width different the first width, a second height different from the first height, and a second number, different from the first number, of fin structures. The first and second bit cells are included in a standard cell operating as a multi bit flip-flop circuit. The first width is smaller than the second width, and the first and second plurality of cells have different functions. In some embodiments, the method further includes forming multiple clock cells that abut the first bit cells and the second bit cells and have the first height and the first number of fin structures. In some embodiments, the first bit cells and the second bit cells extend in a first direction and are interlaced in a second direction different from the first direction.

The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. An integrated circuit, comprising:

a plurality of first bit cells each arranged in one of a plurality of first cell rows having a first row height; a plurality of second bit cells each arranged in one of a plurality of second cells rows having a second row height different from the first row height, wherein the plurality of second bit cells extend to pass the plurality of first bit cells in a first direction; and

a plurality of clock cells arranged in peripheral regions of a multi-bit flip flop cell in the plurality of first cell rows, wherein the plurality of first and second bit cells and the plurality of clock cells are included in the multi-bit flip flop cell,

wherein a first clock cell in the plurality of clock cells has a first boundary abutting a first cell in the plurality of first bit cells and a second boundary abutting a first cell in the plurality of second bit cells, the first boundary and the second boundary being perpendicular to each other.

2. The integrated circuit of claim 1, wherein the first clock cell is configured to output a first clock signal and arranged

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in a first row of the plurality of first cell rows; wherein the plurality of clock cells further comprise:

a second clock cell that is configured to output a second clock signal inverted from the first clock signal and arranged in a second row of the plurality of first cell rows,

wherein the plurality of first and second bit cells are configured to operate in response to the first and second clock signals.

3. The integrated circuit of claim 2, wherein the first row height is greater than the second row height.

4. The integrated circuit of claim 1, wherein a first width of the plurality of first bit cells is smaller than a second width of the plurality of second bit cells.

5. The integrated circuit of claim 1, wherein a first number of fins in the plurality of first cell rows is smaller than a second number of fins in the plurality of second cell rows.

6. The integrated circuit of claim 1, wherein the plurality of clock cells are interposed between and about the plurality of second bit cells along a second direction different from the first direction.

7. The integrated circuit of claim 6, wherein a sum of widths of one in the plurality of clock cells and one in the plurality of first bit cells is equal to a width of one in the plurality of second bit cells.

8. The integrated circuit of claim 1, wherein the plurality of first bit cells have different widths.

9. An integrated circuit, comprising:

a plurality of clock cells; and

a plurality of bit cells abutting the plurality of clock cells and comprising:

a plurality of first bit cells and a plurality of second bit cells that are aligned a first boundary, extending in a first direction in a layout view, of the plurality of bit cells,

wherein the plurality of second bit cells extend in a second direction different from the first direction to form protrusion regions of a second boundary, opposite of the first boundary, of the plurality of bit cells, wherein the plurality of first bit cells and the plurality of second bit cells have different numbers of fin structures,

wherein a first cell in the plurality of clock cells abuts a first cell in the plurality of first bit cells along the second direction and further abuts a first cell in the plurality of second bit cells along the first direction.

10. The integrated circuit of claim 9, wherein the plurality of clock cells abut the protrusion regions of the second boundary.

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11. The integrated circuit of claim 10, wherein the plurality of bit cells are configured to operate as a multi-bit flip flop circuit in response to first and second clock signals generated from the plurality of clock cells.

12. The integrated circuit of claim 9, wherein the plurality of clock cells are separated from each other in the first direction,

wherein the plurality of bit cells are configured to operate as a multi-bit flip flop circuit in response to first and second clock signals that have different logic states and generated from the plurality of clock cells.

13. The integrated circuit of claim 12, wherein the plurality of clock cells connect a boundary of the multi-bit flip flop circuit that overlaps the second boundary of the plurality of bit cells.

14. The integrated circuit of claim 9, wherein the plurality of bit cells and the plurality of clock cells are arranged in a plurality of cell rows having different row heights.

15. The integrated circuit of claim 14, wherein a width of each one in the plurality of second bit cells is greater than a width of each one in the plurality of first bit cells.

16. The integrated circuit of claim 9, wherein the plurality of clock cells and the plurality of first bit cells are arranged in same cell rows.

17. An integrated circuit, comprising:

a plurality of first bit cells each having a first width, a first height and a first number of fin structures; and

a plurality of second bit cells that abut the plurality of first bit cells, wherein each in the plurality of second bit cells has a second width different the first width, a second height different from the first height, and a second number, different from the first number, of fin structures,

wherein the plurality of first and second bit cells are included in a standard cell operating as a multi bit flip-flop circuit, wherein each in the plurality of first and second bit cells is configured as a scan flip flop.

18. The integrated circuit of claim 17, wherein the first width is smaller than the second width, and the plurality of first and second cells have different functions.

19. The integrated circuit of claim 17, further comprising: a plurality of clock cells that abut the plurality of first bit cells and the plurality of second bit cells and have the first height and the first number of fin structures.

20. The integrated circuit of claim 17, wherein the plurality of first bit cells and the plurality of second bit cells extend in a first direction and are interlaced in a second direction different from the first direction.

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