



US009685218B2

(12) **United States Patent**
Sohn et al.

(10) **Patent No.:** **US 9,685,218 B2**
(45) **Date of Patent:** ***Jun. 20, 2017**

(54) **MEMORY DEVICE AND MEMORY SYSTEM HAVING THE SAME**

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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.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/236,895**

(22) Filed: **Aug. 15, 2016**

(65) **Prior Publication Data**

US 2016/0351244 A1 Dec. 1, 2016

Related U.S. Application Data

(63) Continuation of application No. 14/514,416, filed on Oct. 15, 2014, now Pat. No. 9,536,586.

(30) **Foreign Application Priority Data**

Feb. 21, 2014 (KR) 10-2014-0020751

(51) **Int. Cl.**

G11C 7/10 (2006.01)
G11C 11/406 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC **G11C 11/406** (2013.01); **G11C 11/4076** (2013.01); **G11C 11/4087** (2013.01)

(58) **Field of Classification Search**

CPC G11C 11/406; G11C 11/4087; G11C 11/4076

(Continued)

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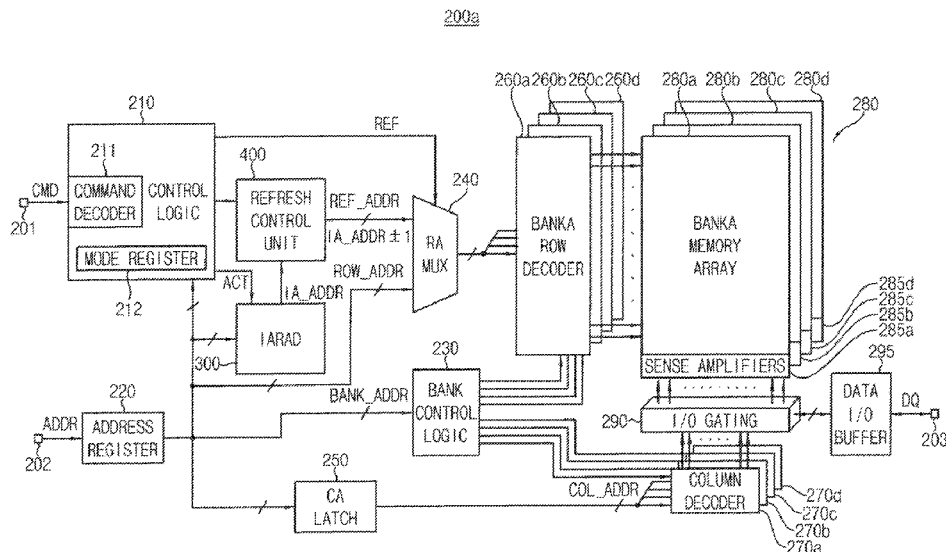
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(57) **ABSTRACT**

A memory device includes a memory cell array, an intensively accessed row detection circuit, and a refresh control circuit. The memory cell array includes a plurality of memory cell rows. The intensively accessed row detection circuit generates an intensively accessed row address indicating an intensively accessed memory cell row among the plurality of memory cell rows based on an accumulated access time for each of the plurality of memory cell rows. The refresh control unit preferentially refreshes neighboring memory cell rows adjacent to the intensively accessed memory cell row indicated by the intensively accessed row address when receiving the intensively accessed row address from the intensively accessed row detection unit. The memory device effectively reduces a rate of data loss.

20 Claims, 13 Drawing Sheets



(51) **Int. Cl.**

G11C 11/4076 (2006.01)

G11C 11/408 (2006.01)

(58) **Field of Classification Search**

USPC 365/189.05, 222, 189.011, 189.15

See application file for complete search history.

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FIG. 1

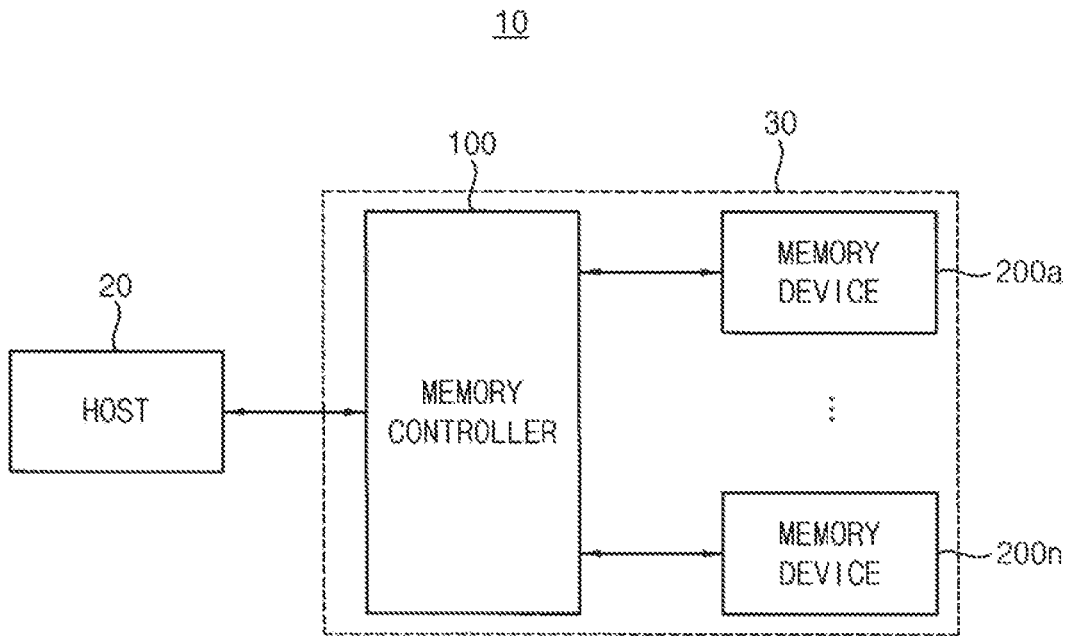


FIG. 2

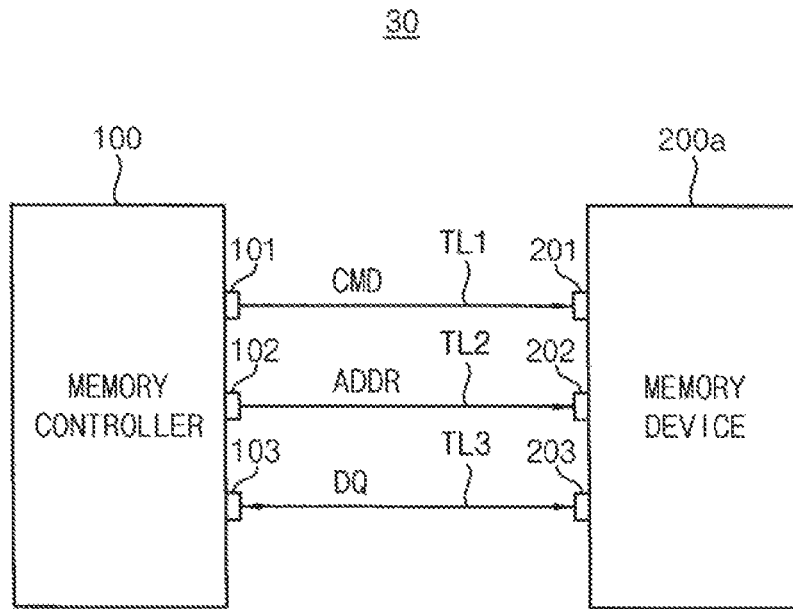


FIG. 3

200a

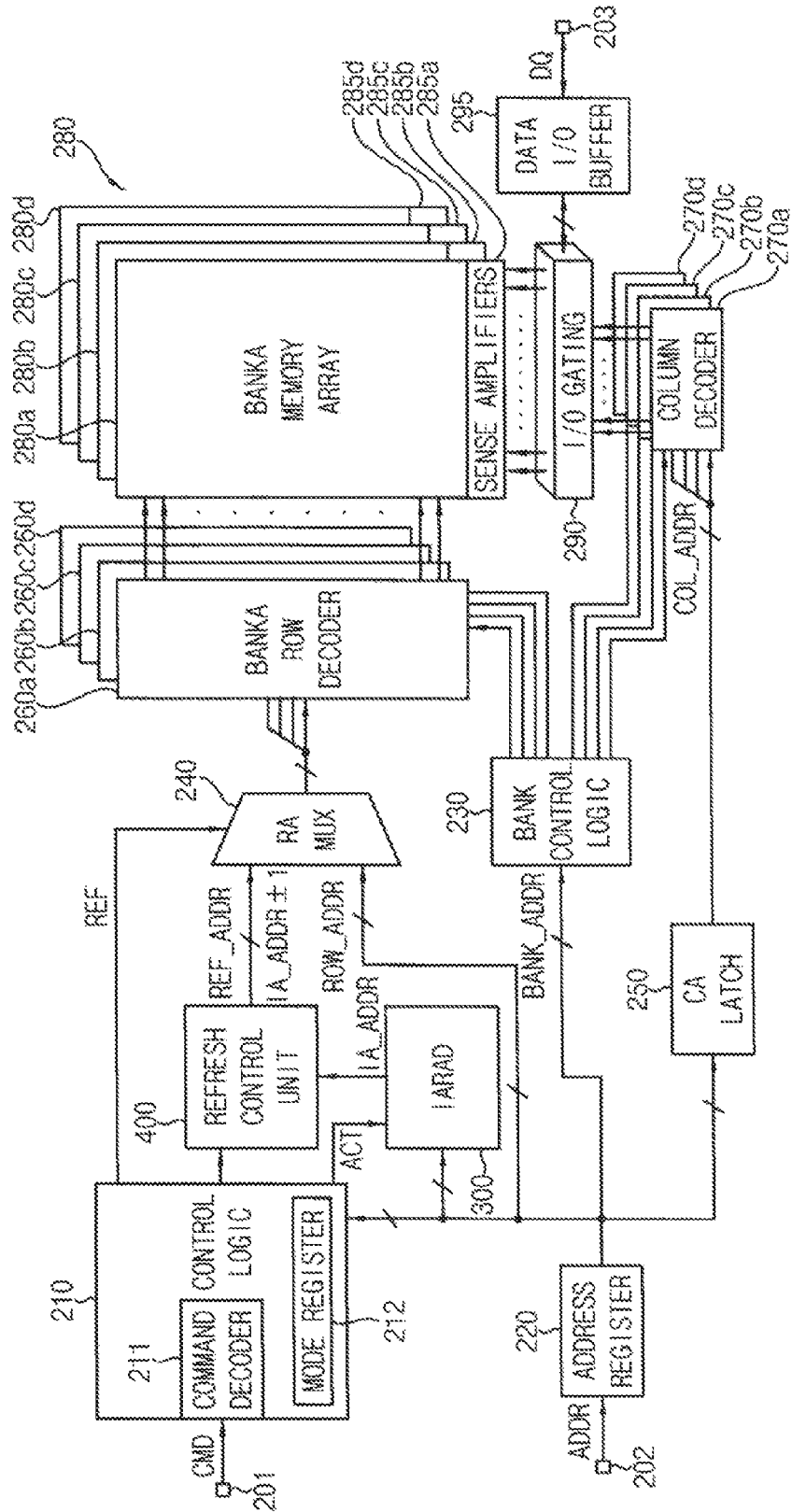


FIG. 4

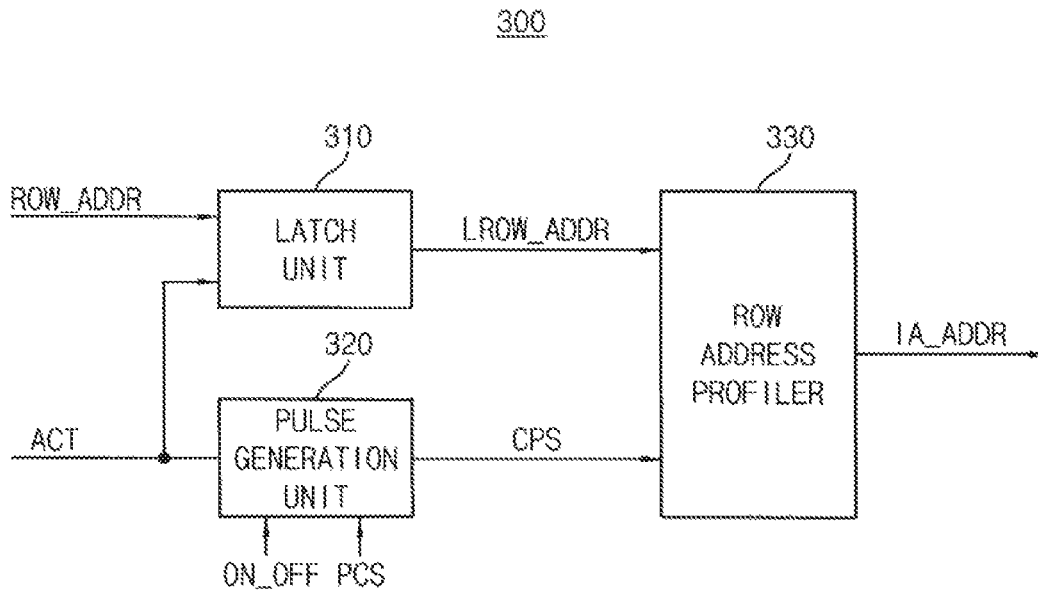


FIG. 5

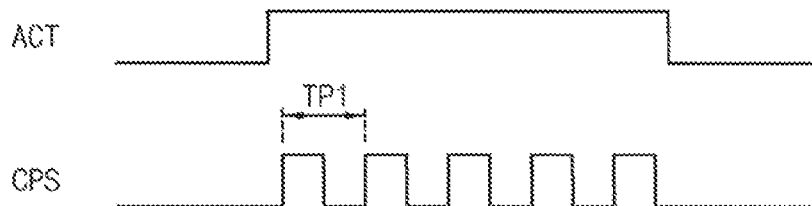


FIG. 6A

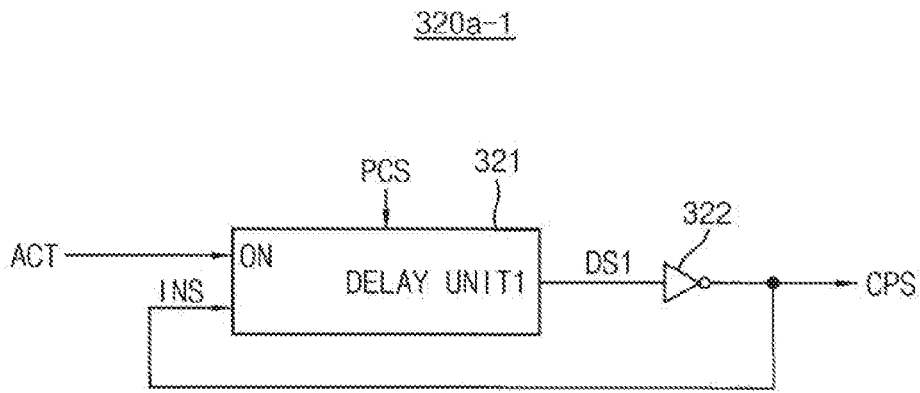


FIG. 6B

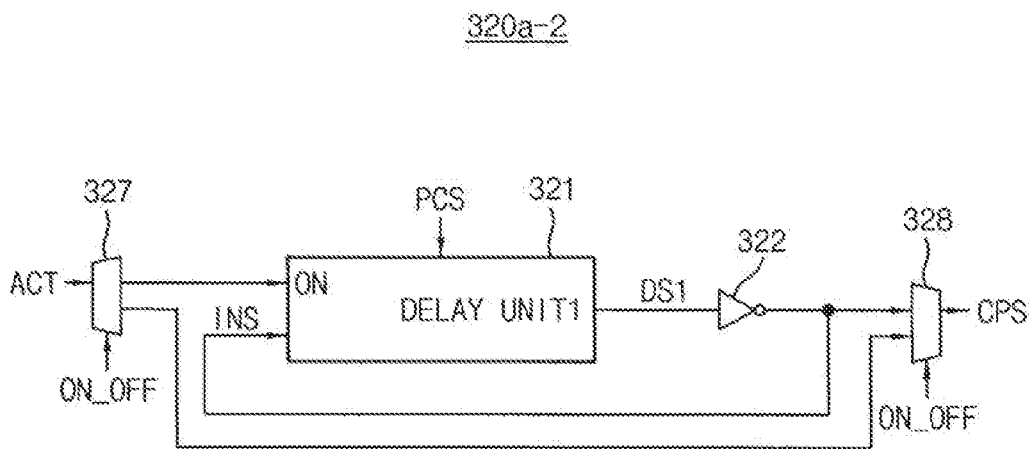


FIG. 7A

320b-1

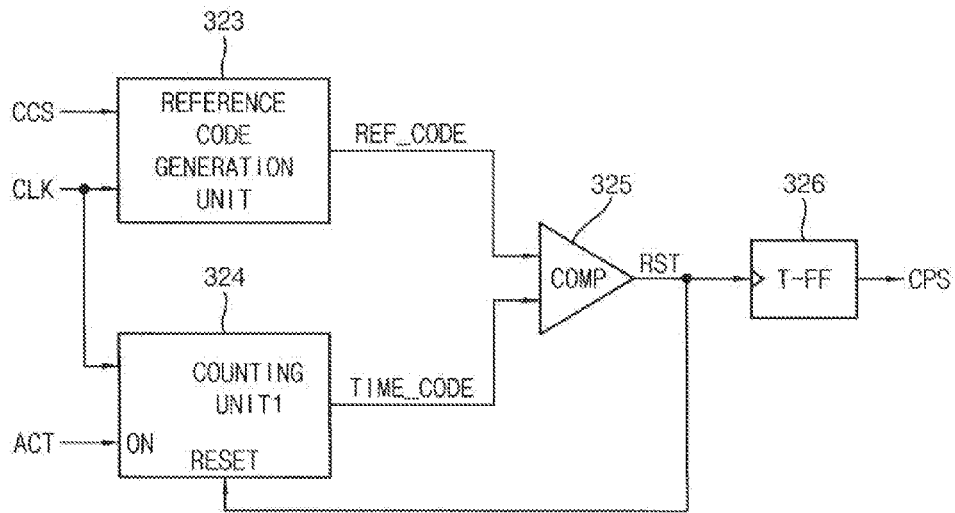


FIG. 7B

320b-2

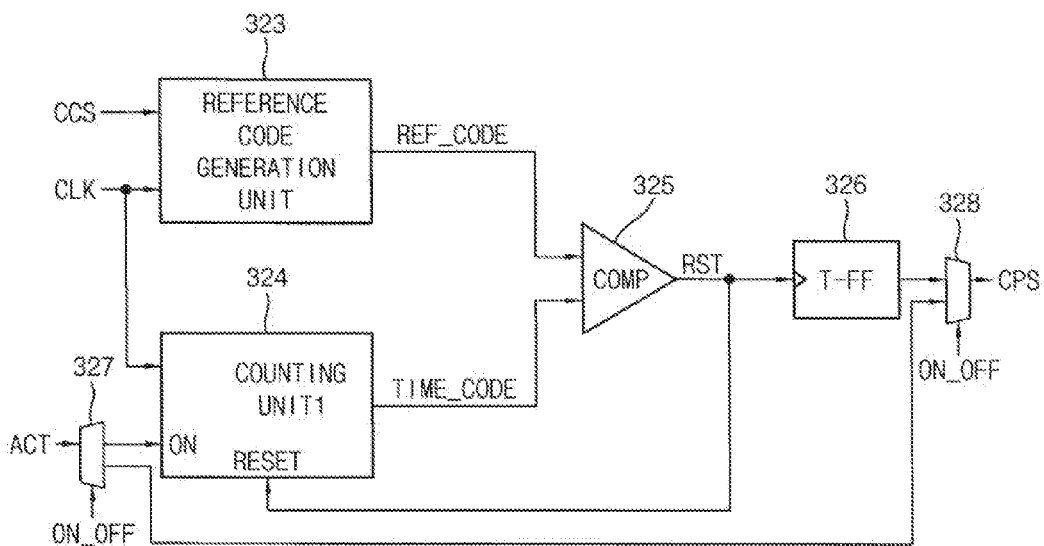


FIG. 8

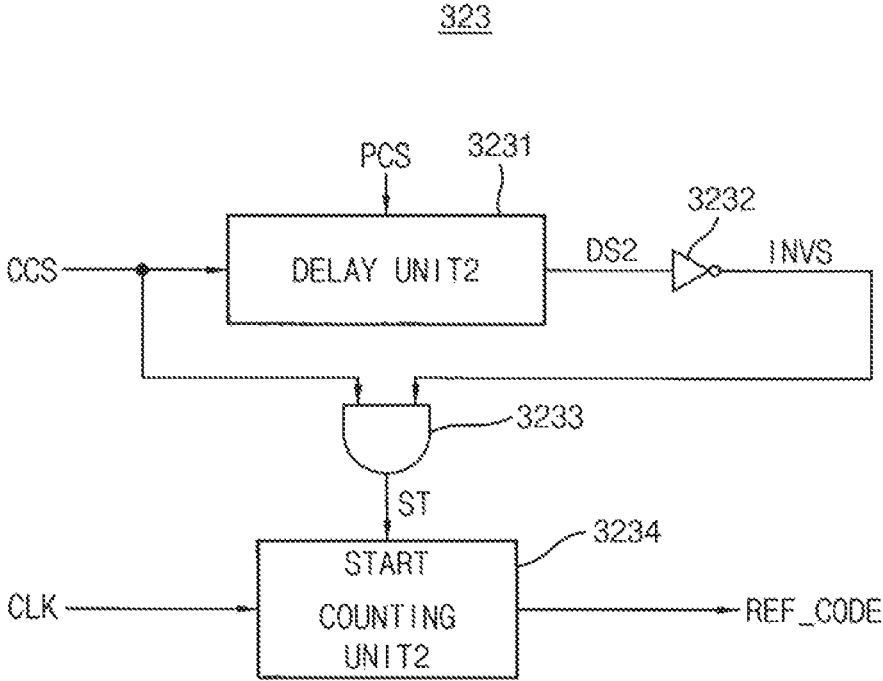


FIG. 9

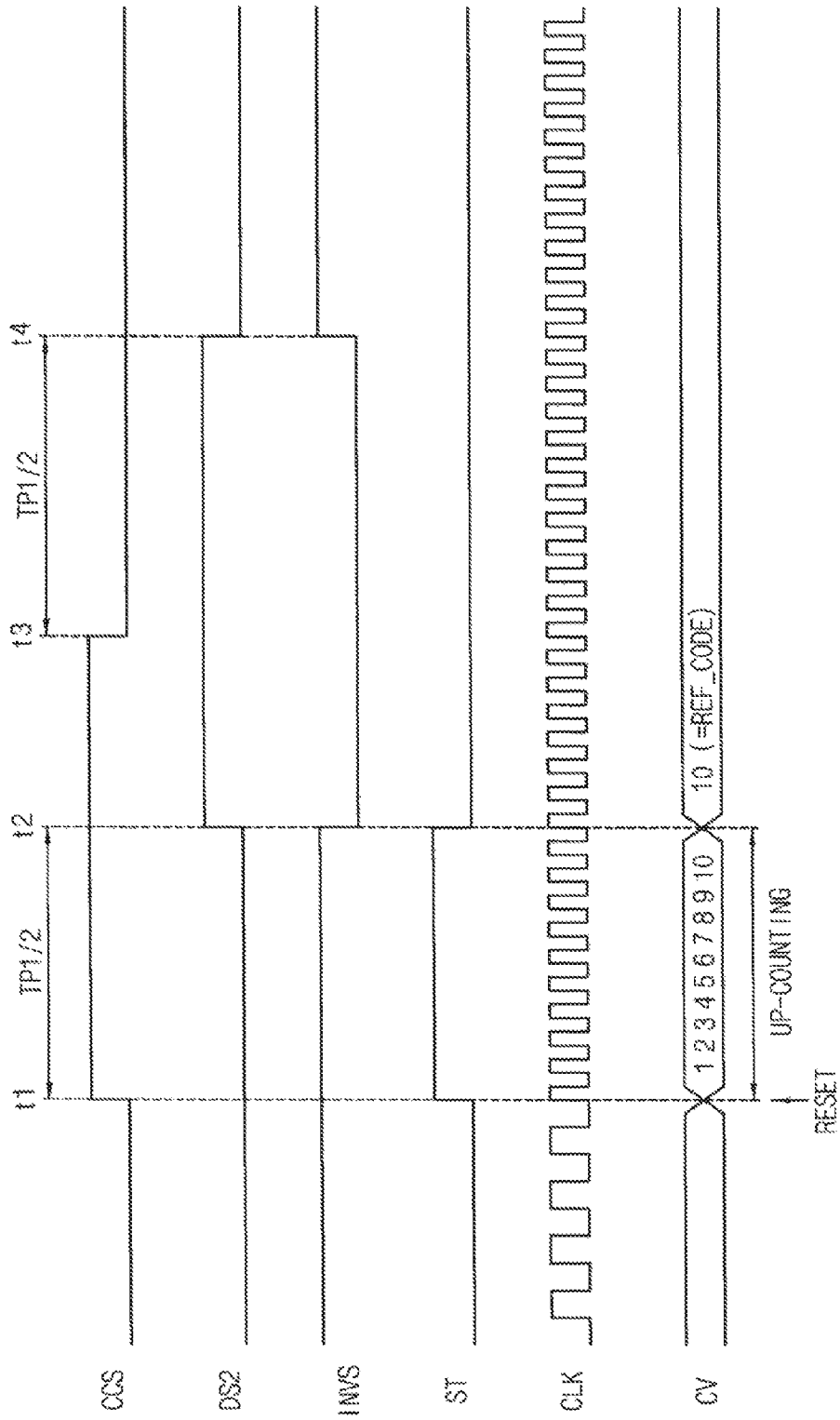


FIG. 10

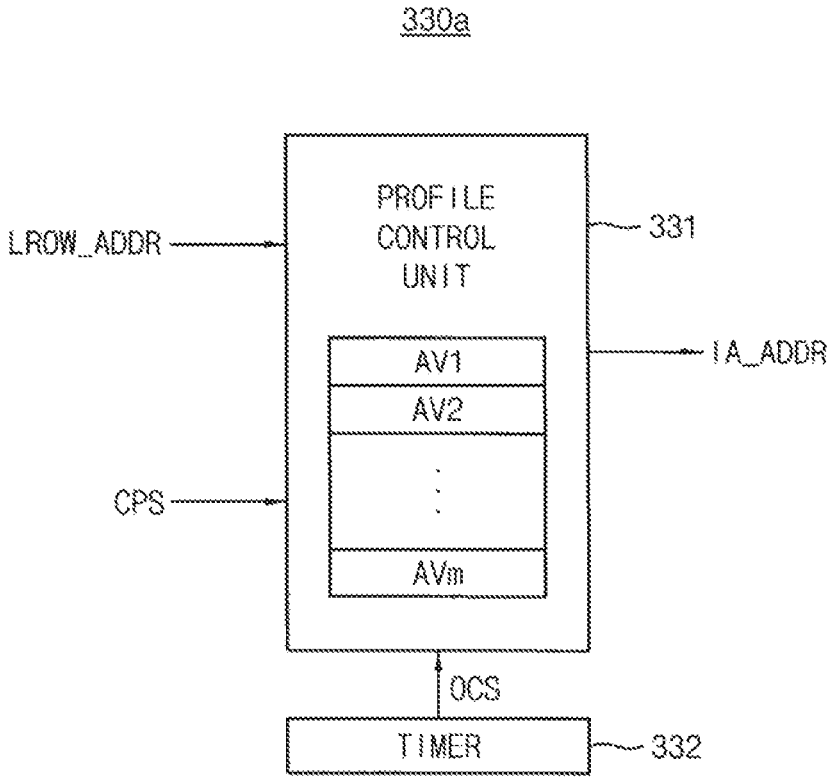


FIG. 11

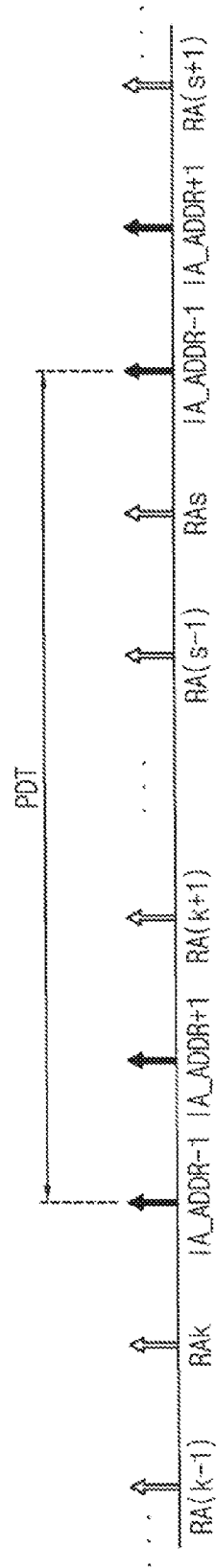


FIG. 12

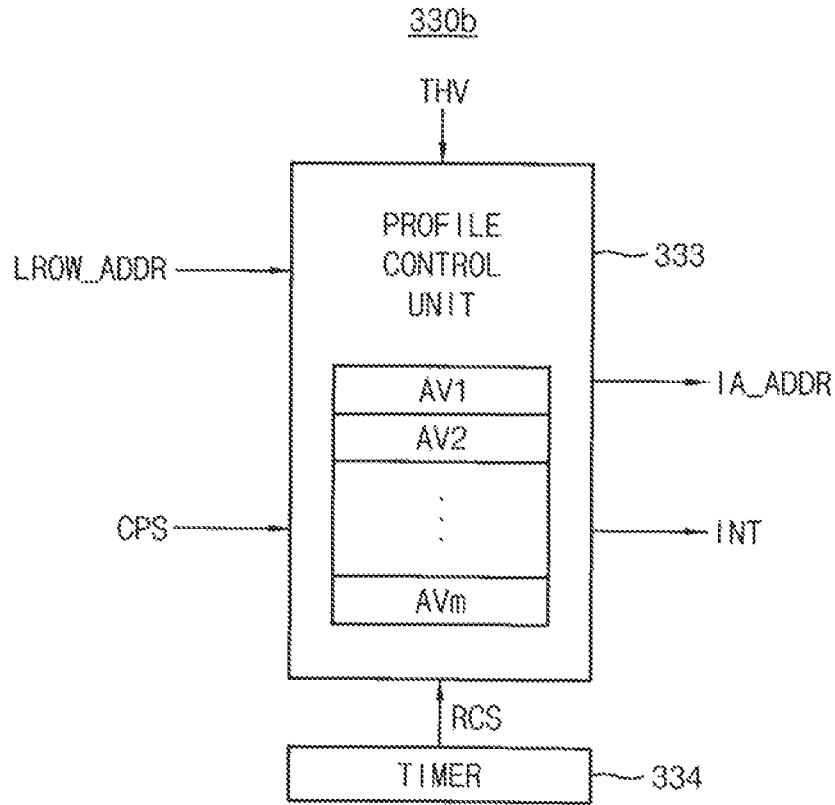


FIG. 13

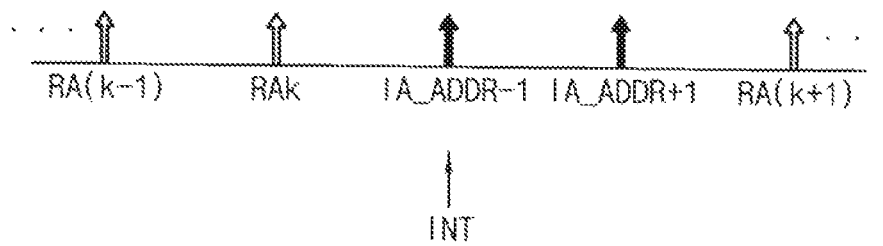


FIG. 14

700

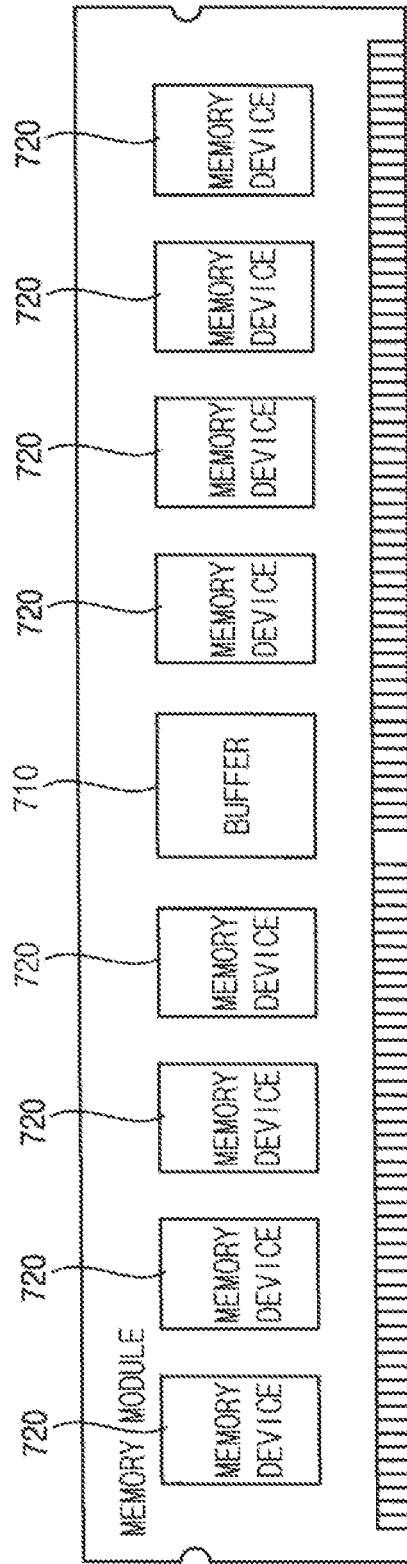


FIG. 15

800

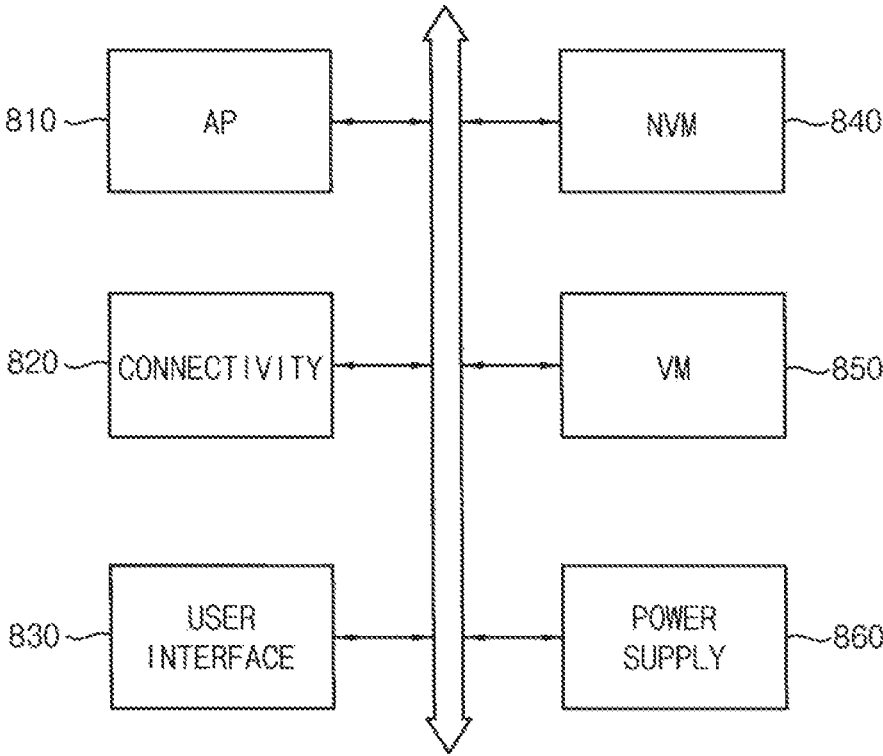
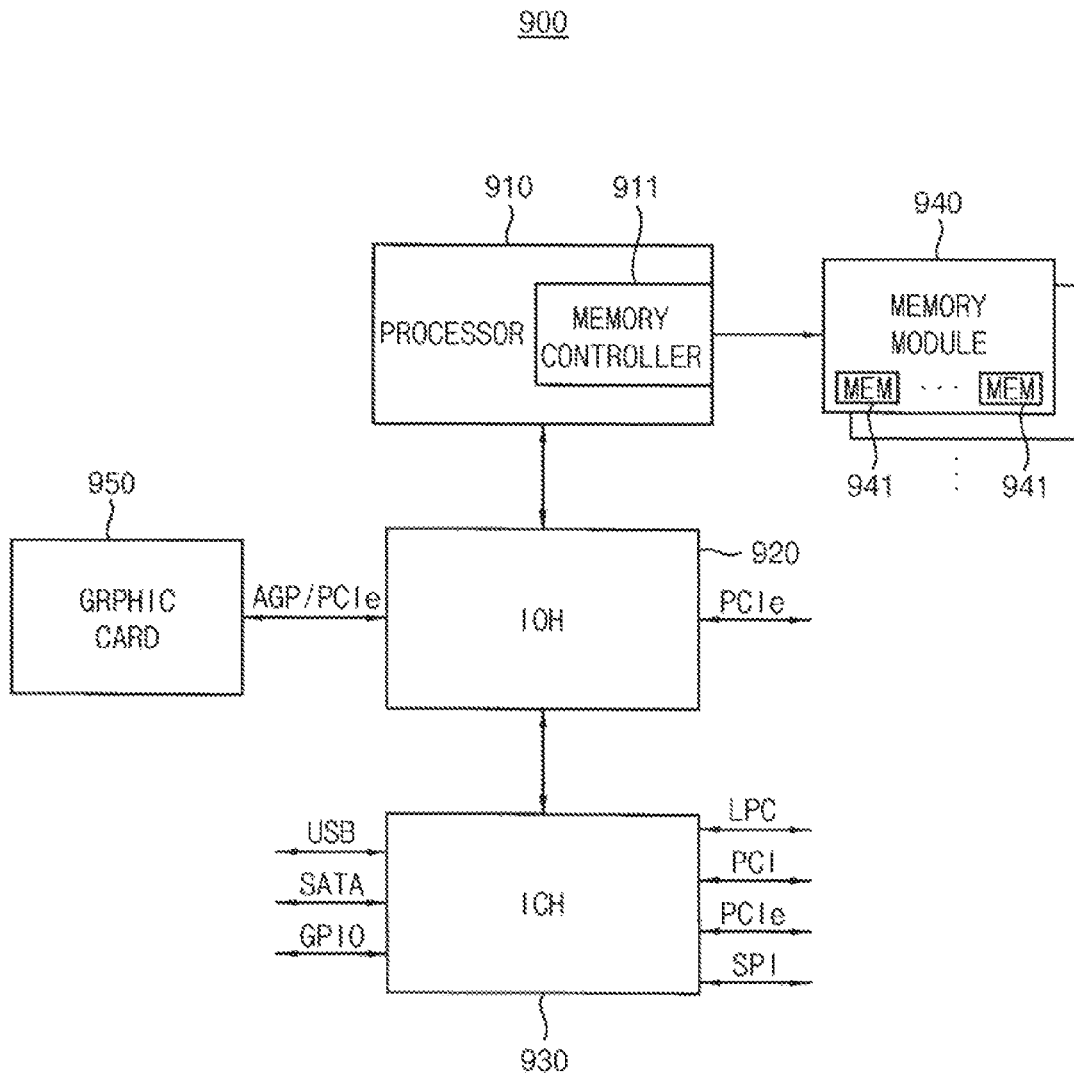


FIG. 16



MEMORY DEVICE AND MEMORY SYSTEM HAVING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application is a continuation of U.S. patent application Ser. No. 14/514,416, filed Oct. 15, 2014, in the United States Patent and Trademark Office (USPTO), which claims the benefit of priority under 35 USC §119 to Korean Patent Application No. 10-2014-0020751, filed on Feb. 21, 2014 in the Korean Intellectual Property Office (KIPO), the contents of both of which are herein incorporated by reference in their entirety.

BACKGROUND

1. Technical Field

Example embodiments relate to a semiconductor device, and more particularly to a memory device and a memory system having the memory device.

2. Description of the Related Art

Generally, a volatile memory device such as a dynamic random access memory (DRAM) stores data by charging a capacitor. Since the charge stored in the capacitor may leak with a passage of time, the volatile memory device is typically required to perform a refresh operation periodically.

As a fabrication process of the memory device is scaled down, space between word-lines becomes narrower. Therefore, disturbance phenomenon occurs more frequently than before, during which charge of a memory cell connected to one word-line is influenced by voltage distribution of adjacent word-lines.

When one particular word-line is intensively accessed, the disturbance phenomenon increases in which the charge of the memory cell connected to neighboring word-lines adjacent to the particular word-line may be lost due to an activated voltage of the particular word-line.

SUMMARY

Some example embodiments are directed to provide a memory device that effectively reduces a rate of data loss.

Some example embodiments are directed to provide a memory system including the memory device.

According to example embodiments, a memory device includes a memory cell array, an intensively accessed row detection circuit, and a refresh control circuit. The memory cell array includes a plurality of memory cell rows. The intensively accessed row detection circuit generates an intensively accessed row address indicating an intensively accessed memory cell row among the plurality of memory cell rows based on an accumulated access time for each of the plurality of memory cell rows. The refresh control circuit preferentially refreshes neighboring memory cell rows adjacent to the intensively accessed memory cell row indicated by the intensively accessed row address when receiving the intensively accessed row address from the intensively accessed row detection circuit.

In example embodiments, the intensively accessed row detection circuit may receive an active signal and a row address indicating one of the plurality of memory cell rows, and may generate the intensively accessed row address based on an amount of time intervals for which the active signal is activated for each of the plurality of memory cell rows.

In example embodiments, the intensively accessed row detection circuit may include a latch circuit configured to latch a row address when an active signal is activated and to output the latched row address, a pulse generation circuit configured to generate a count pulse signal having a first period while the active signal is activated, and a row address profiler. The row address profiler is configured to store access values corresponding to the plurality of memory cell rows, to sequentially increase one of the access values which corresponds to the latched row address in synchronization with the count pulse signal, and to generate the intensively accessed row address based on the access values.

The first period of the count pulse signal may correspond to a row cycle time of the memory device.

The pulse generation circuit may adjust the first period of the count pulse signal based on a period control signal.

The pulse generation circuit may include a delay circuit configured to be turned on while the active signal is activated, and to generate a delay signal by delaying an input signal for a delay time, which corresponds to a half of the first period, and an inverter configured to generate the count pulse signal by inverting the delay signal, and to provide the count pulse signal to the delay circuit as the input signal. The delay circuit may output the delay signal having a logic low level at an initial stage.

The delay circuit may adjust a length of the delay time based on a period control signal.

The pulse generation circuit may include a reference code generation circuit configured to generate a reference code that is proportional to a frequency of a clock signal, in response to a clock change signal. The pulse generation circuit may also include a first counting circuit configured to be turned on while the active signal is activated, to generate a time code by performing an up-count operation in synchronization with the clock signal, and to reset the time code in response to a rising edge of a reset signal. In addition, the pulse generation circuit may include a comparator configured to output the reset signal having a logic low level when the time code is less than the reference code, and to output the reset signal having a logic high level when the time code is equal to or greater than the reference code. Further, the pulse generation circuit may include a toggle flip flop configured to generate an output signal toggling in response to the rising edge of the reset signal, and to output the output signal as the count pulse signal.

The reference code generation circuit may include a delay circuit configured to generate a delay signal by delaying a clock change signal for a delay time, which corresponds to a half of the first period, an inverter configured to generate an inverted signal by inverting the delay signal, an AND gate configured to perform an AND operation on the clock change signal and the inverted signal to generate a start signal, and a second counting circuit configured to reset a count value and to perform an up-count operation on the count value in synchronization with the clock signal when the start signal is activated to the logic high level. The second counting circuit is configured to stop performing the up-count operation and to output the count value as the reference code when the start signal is deactivated to the logic low level.

The pulse generation circuit may bypass the active signal to output the active signal as the count pulse signal when the pulse generation circuit receives an on-off signal having a first logic level.

At every predetermined time interval, the row address profiler may output a row address, which corresponds to a

greatest access value among the access values, as the intensively accessed row address, and the row address profiler may reset the access values.

The refresh control circuit may generate a refresh row address that sequentially increases, and refresh a memory cell row corresponding to the refresh row address. When the refresh control circuit receives the intensively accessed row address from the row address profiler at the every predetermined time interval, the refresh control circuit may preferentially refresh a memory cell row corresponding to an address, which is less than the intensively accessed row address by one, and a memory cell row corresponding to an address, which is greater than the intensively accessed row address by one. Then, the refresh control circuit may refresh the memory cell row corresponding to the refresh row address.

When each of the access values exceeds a threshold value, the row address profiler may output an address, which corresponds to an access value exceeding the threshold value among the access values, as the intensively accessed row address together with an interrupt signal. The row address profiler may reset the access values at every predetermined time interval.

The predetermined time interval may correspond to a refresh period of the memory cell array during which the plurality of memory cell rows included in the memory cell array are refreshed.

The refresh control circuit may generate the refresh row address that sequentially increases, and refresh the memory cell row corresponding to the refresh row address. When the refresh control circuit receives the interrupt signal and the intensively accessed row address from the row address profiler, the refresh control circuit may preferentially refresh the memory cell row corresponding to the address, which is less than the intensively accessed row address by one, and the memory cell row corresponding to the address, which is greater than the intensively accessed row address by one. Then, the refresh control circuit may refresh the memory cell row corresponding to the refresh row address.

According to example embodiments, a memory system includes a memory device and a memory controller. The memory controller performs a read operation and a write operation on the memory device. The memory device includes a memory cell array including a plurality of memory cell rows, an intensively accessed row detection circuit configured to generate an intensively accessed row address indicating an intensively accessed memory cell row among the plurality of memory cell rows based on an accumulation of access time for each of the plurality of memory cell rows, and a refresh control circuit configured to preferentially refresh neighboring memory cell rows adjacent to the intensively accessed memory cell row indicated by the intensively accessed row address when receiving the intensively accessed row address from the intensively accessed row detection circuit.

In example embodiments, the intensively accessed row detection circuit may receive an active signal and a row address indicating one of the plurality of memory cell rows from the memory controller, and generate the intensively accessed row address based on an amount of time intervals for which the active signal is activated for each of the plurality of memory cell rows.

In example embodiments, the intensively accessed row detection circuit may include a latch circuit configured to latch a row address provided from the memory controller when an active signal provided from the memory controller is activated, and to output the latched row address, a pulse

generation circuit configured to generate a count pulse signal having a first period while the active signal is activated, and a row address profiler. The row address profiler is configured to store access values corresponding to the plurality of memory cell rows, to sequentially increase one of the access values which corresponds to the latched row address in synchronization with the count pulse signal, and to generate the intensively accessed row address based on the access values.

The pulse generation circuit may include a delay circuit configured to be turned on while the active signal is activated, and to generate a delay signal by delaying an input signal for a delay time, which corresponds to a half of the first period. The pulse generation circuit may also include an inverter configured to generate the count pulse signal by inverting the delay signal, and to provide the count pulse signal to the delay circuit as the input signal. The delay circuit may output the delay signal having a logic low level at an initial stage.

The pulse generation circuit may include a reference code generation circuit configured to generate a reference code that is proportional to a frequency of a clock signal in response to a clock change signal. The pulse generation circuit may also include a first counting circuit configured to be turned on while the active signal is activated, to generate a time code by performing an up-count operation in synchronization with the clock signal, and to reset the time code in response to a rising edge of a reset signal. In addition, the pulse generation circuit may include a comparator configured to output the reset signal having a logic low level when the time code is less than the reference code, and to output the reset signal having a logic high level when the time code is equal to or greater than the reference code. Further, the pulse generation circuit may include a toggle flip flop configured to generate an output signal toggling in response to the rising edge of the reset signal, and to output the output signal as the count pulse signal.

BRIEF DESCRIPTION OF THE DRAWINGS

Illustrative, non-limiting example embodiments will be more clearly understood from the following detailed description in conjunction with the accompanying drawings.

FIG. 1 is a block diagram illustrating an electronic system according to example embodiments.

FIG. 2 is a block diagram illustrating an example of the memory system of FIG. 1 according to example embodiments.

FIG. 3 is a block diagram illustrating an example of a memory device of FIG. 2 according to example embodiments.

FIG. 4 is a block diagram illustrating an example of an intensively accessed row detection unit included in the memory device of FIG. 3.

FIG. 5 is a diagram describing an exemplary operation of a pulse generation unit included in the intensively accessed row detection unit of FIG. 4.

FIGS. 6A and 6B are block diagrams illustrating examples of the pulse generation unit included in the intensively accessed row detection unit of FIG. 4.

FIGS. 7A and 7B are block diagrams illustrating other examples of the pulse generation unit included in the intensively accessed row detection unit of FIG. 4.

FIG. 8 is a block diagram illustrating an example of a reference code generation unit included in the pulse generation unit of FIGS. 7A and 7B.

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FIG. 9 is a diagram describing an exemplary operation of the reference code generation unit of FIG. 8.

FIG. 10 is a block diagram illustrating an example of a row address profiler included in the intensively accessed row detection unit of FIG. 4.

FIG. 11 is a diagram describing an exemplary operation of a refresh control unit included in the memory device of FIG. 3 when the intensively accessed row detection unit included in the memory device of FIG. 3 includes the row address profiler of FIG. 10.

FIG. 12 is a block diagram illustrating another example of the row address profiler included in the intensively accessed row detection unit of FIG. 4.

FIG. 13 is a diagram describing an exemplary operation of the refresh control unit included in the memory device of FIG. 3 when the intensively accessed row detection unit included in the memory device of FIG. 3 includes the row address profiler of FIG. 12.

FIG. 14 is a block diagram illustrating a memory module according to exemplary embodiments.

FIG. 15 is a block diagram illustrating a mobile system according to exemplary embodiments.

FIG. 16 is a block diagram illustrating a computing system according to exemplary embodiments.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Various example embodiments will be described more fully with reference to the accompanying drawings, in which some example embodiments are shown. The present disclosure may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Like reference numerals refer to like elements throughout this application.

It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. Unless the context indicates otherwise, these terms are used to distinguish one element from another, for example as a naming convention. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of the present disclosure. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

It will be understood that when an element is referred to as being “connected” or “coupled” to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being “directly connected” or “directly coupled” to another element, or as contacting another element, there are no intervening elements present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.).

The terminology used herein is for the purpose of describing particular embodiments and is not intended to be limiting of the present disclosure. As used herein, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “includes” and/or “including,” when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not

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preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the present disclosure belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

FIG. 1 is a block diagram illustrating an electronic system according to example embodiments.

Referring to FIG. 1, an electronic system 10 includes a host 20 and a memory system 30. The memory system 30 includes a memory controller 100 and a plurality of memory devices 200a-200n. Here, n represents a positive integer.

The host 20 may communicate with the memory system 30 through an interface protocol such as Peripheral Component Interconnect-Express (PCI-E), Advanced Technology Attachment (ATA), Serial ATA (SATA), Parallel ATA (PATA), or serial attached SCSI (SAS). In addition, the host 20 may communicate with the memory system 30 through the interface protocol such as Universal Serial Bus (USB), Multi-Media Card (MMC), Enhanced Small Disk Interface (ESDI), or Integrated Drive Electronics (IDE).

The memory controller 100 controls an overall operation of the memory system 30. The memory controller 100 controls an overall data exchange between the host 20 and the memory devices 200a-200n. For example, the memory controller 100 writes data in the memory devices 200a-200n or reads data from the memory devices 200a-200n in response to a request from the host 20.

In addition, the memory controller 100 applies an operation command to the memory devices 200a-200n for controlling the memory devices 200a-200n.

In some embodiments, each of the memory devices 200a-200n may be a dynamic random access memory (DRAM), such as a double data rate synchronous dynamic random access memory (DDR SDRAM), a low power double data rate synchronous dynamic random access memory (LPDDR SDRAM), a graphics double data rate synchronous dynamic random access memory (GDDR SDRAM), a Rambus dynamic random access memory (RDRAM), etc., or may be other volatile memory devices. Each of the memory devices may be, for example, a semiconductor chip, a stack of semiconductor chips, a semiconductor package including one or more semiconductor chips mounted on a package substrate, or a package-on-package semiconductor device.

FIG. 2 is a block diagram illustrating an example of the memory system of FIG. 1 according to example embodiments.

In FIG. 2, one memory device 200a corresponding to the memory controller 100 is illustrated for convenience.

Referring to FIG. 2, the memory system 30 includes the memory controller 100 and the memory device 200a. The memory controller 100 and the memory devices 200a may be connected to each other through corresponding command pins 101 and 201, corresponding address pins 102 and 202, and corresponding data pins 103 and 203. The command pins 101 and 201 transmit a command signal CMD through a command transmission line TL1, the address pins 102 and 202 transmit an address signal ADDR through an address transmission line TL2, and the data pins 103 and 203 exchange data DQ through a data transmission line TL3.

Referring to FIGS. 1 and 2, the memory controller 100 may provide a command to the memory device 200a through the command pins 101 and 201, provide an address to the memory device 200a through the address pins 102 and 202, and input data to the memory device 200a or output data from the memory device 200a through the data pins 103 and 203 based on the request from the host 20.

For example, in a read mode, the memory controller 100 may provide an active command and a row address to the memory device 200a through the command pins 101 and 201 and the address pins 102 and 202, respectively, and provide a read command and a column address to the memory device 200a through the command pins 101 and 201 and the address pins 102 and 202, respectively, after a row address-to-column address delay (tRCD). The memory device 200a may activate a memory cell row corresponding to the row address among a plurality of memory cell rows included in the memory device 200a in response to the active command, and provide read data stored in a memory cell corresponding to the column address of the activated memory cell row to the memory controller 100 through the data pins 103 and 203 in response to the read command.

In a write mode, the memory controller 100 may provide the active command and the row address to the memory device 200a through the command pins 101 and 201 and the address pins 102 and 202, respectively, and provide a write command and the column address to the memory device 200a through the command pins 101 and 201 and the address pins 102 and 202, respectively, after the row address-to-column address delay (tRCD). The memory controller 100 may provide write data to the memory device 200a through the data pins 103 and 203 after a write latency (tWL). The memory device 200a may activate the memory cell row corresponding to the row address among the plurality of memory cell rows included in the memory device 200a in response to the active command, and write the write data in the memory cell corresponding to the column address of the activated memory cell row in response to the write command.

FIG. 3 is a block diagram illustrating an example of the memory device of FIG. 2 according to example embodiments.

Referring to FIG. 3, the memory device 200a includes a control logic 210, an address register 220, a bank control logic 230, a row address multiplexer RA MUX 240, a column address latch CA LATCH 250, a row decoder, a column decoder, a memory cell array 280, a sense amplifier unit, an input/output gating circuit 290, a data input/output buffer 295, an intensively accessed row detection unit IARAD 300 and a refresh control unit 400.

The memory cell array 280 includes a plurality of memory cell rows. In some example embodiments, the memory cell array 280 may include first through fourth bank arrays 280a, 280b, 280c and 280d. Each of the first through fourth bank arrays 280a, 280b, 280c and 280d may include a plurality of memory cell rows.

The row decoder may include first through fourth bank row decoders 260a, 260b, 260c and 260d respectively coupled to the first through fourth bank arrays 280a, 280b, 280c and 280d. The column decoder may include first through fourth bank column decoders 270a, 270b, 270c and 270d respectively coupled to the first through fourth bank arrays 280a, 280b, 280c and 280d. The sense amplifier unit may include first through fourth bank sense amplifiers 285a, 285b, 285c and 285d respectively coupled to the first through fourth bank arrays 280a, 280b, 280c and 280d.

The first through fourth bank arrays 280a, 280b, 280c and 280d, the first through fourth bank row decoders 260a, 260b, 260c and 260d, the first through fourth bank column decoders 270a, 270b, 270c and 270d, and the first through fourth bank sense amplifiers 285a, 285b, 285c and 285d may form first through fourth banks. Although the memory device 200a is illustrated in FIG. 3 as including four banks, the memory device 200a may include any number of banks.

The control logic 210 may control operations of the memory device 200a. For example, the control logic 210 may generate control signals for the memory device 200a to perform a write operation or a read operation. The control logic 210 may include a command decoder 211 that decodes the command signal CMD received from the memory controller 100 through the command pin 201 and a mode register 212 that is used to set an operation mode of the memory device 200a. For example, the command decoder 211 may generate an active signal ACT, a read signal, a write signal, etc., corresponding to the command signal CMD by decoding a write enable signal (/WE), a row address strobe signal (/RAS), a column address strobe signal (/CAS), a chip select signal (/CS), etc. The control logic 210 may further receive a clock signal (CLK) and a clock enable signal (/CKE) for operating the memory device 200a in a synchronous manner.

The address register 220 may receive the address signal ADDR including a bank address BANK_ADDR, a row address ROW_ADDR and a column address COL_ADDR from the memory controller 100 through the address pin 202. The address register 220 may provide the bank address BANK_ADDR to the bank control logic 230, provide the row address ROW_ADDR to the row address multiplexer 240 and the intensively accessed row detection unit 300, and provide the column address COL_ADDR to the column address latch 250. The row address ROW_ADDR may indicate one of the plurality of memory cell rows included in the memory cell array 280.

The bank control logic 230 may generate bank control signals in response to the bank address BANK_ADDR. One of the first through fourth bank row decoders 260a, 260b, 260c and 260d corresponding to the bank address BANK_ADDR may be activated in response to the bank control signals, and one of the first through fourth bank column decoders 270a, 270b, 270c and 270d corresponding to the bank address BANK_ADDR may be activated in response to the bank control signals.

The intensively accessed row detection unit 300, which may be a detection circuit, receives the active signal ACT from the control logic 210 and receives the row address ROW_ADDR from the address register 220. The intensively accessed row detection unit 300 generates an intensively accessed row address IA_ADDR indicating an intensively accessed memory cell row among the plurality of memory cell rows included in the memory cell array 280, for example, based on a sum of access time (e.g., an accumulated access time) for each of the plurality of memory cell rows.

In some example embodiments, the intensively accessed row detection unit 300 may generate the intensively accessed row address IA_ADDR based on a sum of time intervals (e.g., an amount of time intervals) for which the active signal ACT, which is received together with the row address ROW_ADDR indicating one of the plurality of memory cell rows included in the memory cell array 280, is activated for each of the plurality of memory cell rows.

A structure and an operation of the intensively accessed row detection unit **300** will be described later in detail with reference to FIG. **4**.

The control logic **210** may control the row address multiplexer **240** such that the row address multiplexer **240** may perform a refresh operation. In addition, the control logic **210** may generate a refresh signal REF having an activated state while performing the refresh operation, and generate the refresh signal REF having a deactivated state after finishing the refresh operation.

The refresh control unit **400**, which may be a control circuit, sequentially refreshes the plurality of memory cell rows included in the memory cell array **280** under a control of the control logic **210**. When the refresh control unit **400** receives the intensively accessed row address IA_ADDR from the intensively accessed row detection unit **300**, the refresh control unit **400** preferentially refreshes neighboring memory cell rows adjacent to the intensively accessed memory cell row, which is indicated by the intensively accessed row address IA_ADDR. As described herein, to be intensively accessed may depend on an amount of times a row is accessed, such as a frequency of access, an accumulated amount of time that a row is accessed, or a combination of both. The term "intensively accessed row" refers to a row that has been accessed substantially more than other rows based on, for example, an accumulated time of access and/or a number of accesses, and may refer to a row that has been accessed (in accumulated time and/or number of accesses) over a particular threshold amount.

In some example embodiments, the refresh control unit **400** may generate a refresh row address REF_ADDR that sequentially increases, and refresh a memory cell row corresponding to the refresh row address REF_ADDR. When the refresh control unit **400** receives the intensively accessed row address IA_ADDR from the intensively accessed row detection unit **300**, the refresh control unit **400** may preferentially refresh a memory cell row corresponding to a row address that is less than the intensively accessed row address IA_ADDR by one, and a memory cell row corresponding to a row address that is greater than the intensively accessed row address IA_ADDR by one. Then, the refresh control unit **400** may refresh a memory cell row corresponding to the refresh row address REF_ADDR.

The row address multiplexer **240** may output one of the row address ROW_ADDR received from the address register **220** and an address received from the refresh control unit **400** in response to the refresh signal REF. For example, the row address multiplexer **240** may output the address received from the refresh control unit **400** when the refresh signal REF has an activated state, and output the row address ROW_ADDR received from the address register **220** when the refresh signal REF has a deactivated state. A row address ROW_ADDR that is output from the row address multiplexer **240** may be applied to the first through fourth bank row decoders **260a**, **260b**, **260c** and **260d**.

The activated one of the first through fourth bank row decoders **260a**, **260b**, **260c** and **260d** may decode the row address ROW_ADDR received from the row address multiplexer **240** and activate a word-line corresponding to the row address ROW_ADDR received from the row address multiplexer **240**. For example, the activated one of the first through fourth bank row decoders **260a**, **260b**, **260c** and **260d** may apply a word-line driving voltage to the word-line corresponding to the row address ROW_ADDR received from the row address multiplexer **240**.

The column address latch **250** may receive the column address COL_ADDR from the address register **220** and

temporarily store the column address COL_ADDR. In some embodiments, in a burst mode, the column address latch **250** may generate column addresses that increment from the column address COL_ADDR. The column address latch **250** may apply the temporarily stored or generated column address to the first through fourth bank column decoders **270a**, **270b**, **270c** and **270d**.

The activated one of the first through fourth bank column decoders **270a**, **270b**, **270c** and **270d** may decode the column address COL_ADDR received from the column address latch **250** and control the input/output gating circuit **290** to output data corresponding to the column address COL_ADDR.

The input/output gating circuit **290** may include a circuitry for gating input/output data. The input/output gating circuit **290** may further include an input data mask logic, read data latches for storing data received from the first through fourth bank arrays **280a**, **280b**, **280c** and **280d**, and write drivers for writing data to the first through fourth bank arrays **280a**, **280b**, **280c** and **280d**.

Data DQ to be read from one bank array of the first through fourth bank arrays **280a**, **280b**, **280c** and **280d** may be sensed by a sense amplifier coupled to the one bank array and be stored in the read data latches. The data DQ stored in the read data latches may be provided to the memory controller **100** through the data input/output buffer **295** and the data pin **203**. Data DQ to be written to one bank array of the first through fourth bank arrays **280a**, **280b**, **280c** and **280d** may be provided from the memory controller **100** to the data input/output buffer **295** through the data pin **203**. The data DQ provided to the data input/output buffer **295** may be written to the one bank array via the write drivers.

FIG. **4** is a block diagram illustrating an example of an intensively accessed row detection unit included in the memory device of FIG. **3**.

Referring to FIG. **4**, the intensively accessed row detection unit **400** may include a latch unit **310** (e.g., latch circuit), a pulse generation unit **320** (e.g., pulse generation circuit) and a row address profiler **330** (e.g., row address profile circuit).

When the active signal ACT received from the control logic **210** is activated, the latch unit **310** may latch the row address ROW_ADDR received from the control logic **210** and output the latched address as a latched row address LROW_ADDR.

The pulse generation unit **320** may generate a count pulse signal CPS having a first period TP1 while the active signal ACT is activated.

FIG. **5** is a diagram describing an exemplary operation of a pulse generation unit included in the intensively accessed row detection unit of FIG. **4**.

Referring to FIG. **5**, the pulse generation unit **320** may generate the count pulse signal CPS having the first period TP1 when the active signal ACT received from the control logic **210** is activated to a logic high level, and stop generating the count pulse signal CPS when the active signal ACT received from the control logic **210** is deactivated to a logic low level.

In some example embodiments, the first period TP1 of the count pulse signal CPS generated from the pulse generation unit **320** may correspond to a row cycle time (tRC) of the memory device **200a**.

In other example embodiments, the pulse generation unit **320** may adjust the first period TP1 of the count pulse signal CPS based on a period control signal PCS. The period control signal PCS may be provided from the control logic **210**.

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In some example embodiments, the pulse generation unit **320** may further receive an on-off signal ON_OFF. When the on-off signal ON_OFF has a first logic level, the pulse generation unit **320** may generate the count pulse signal CPS having the first period TP1 while the active signal ACT is activated. When the on-off signal ON_OFF has a second logic level, the pulse generation unit **320** may bypass the active signal ACT to output the active signal ACT as the count pulse signal CPS. In some example embodiments, the first logic level may be a logic high level, and the second logic level may be a logic low level. In other example embodiments, the first logic level may be a logic low level, and the second logic level may be a logic high level. The on-off signal ON_OFF may be provided from the control logic **210**. In some example embodiments, the control logic **210** may generate the on-off signal ON_OFF based on a configuration value stored in the mode register **212**. In other example embodiments, the control logic **210** may include at least one of a fuse circuit and an anti-fuse circuit, and generate the on-off signal ON_OFF based on a configuration value stored in the at least one of the fuse circuit and the anti-fuse circuit.

FIGS. **6A** and **6B** are block diagrams illustrating examples of a pulse generation unit included in the intensively accessed row detection unit of FIG. **4**.

Referring to FIG. **6A**, a pulse generation unit **320a-1** may include a first delay unit **321** and a first inverter **322**.

The first delay unit **321** (e.g., delay circuit) may be turned on while the active signal ACT is activated and be turned off while the active signal ACT is deactivated. While the first delay unit **321** is turned on, the first delay unit **321** may generate a first delay signal DS1 by delaying an input signal INS for a delay time. The delay time may correspond, for example, to a half of the first period TP1. The first delay unit **321** may output the first delay signal DS1 having a logic low level at an initial stage after the first delay unit **321** is turned on.

The first inverter **322** may generate the count pulse signal CPS by inverting the first delay signal DS1 and provide the count pulse signal CPS to the first delay unit **321** as the input signal INS.

Therefore, the first delay signal DS1 generated from the first delay unit **321** may toggle every half of the first period TP1. As such, as illustrated in FIG. **5**, the pulse generation unit **320a-1** may output the count pulse signal CPS having the first period TP1 through the first inverter **322**.

In some example embodiments, the first delay unit **321** may adjust a length of the delay time based on the period control signal PCS. In this case, the first period TP1 of the count pulse signal CPS generated from the first inverter **322** may be changed based on the period control signal PCS.

Referring to FIG. **6B**, a pulse generation unit **320a-2** may include the first delay unit **321**, the first inverter **322**, a demultiplexer **327** and a multiplexer **328**.

The first delay unit **321** and the first inverter **322** included in the pulse generation unit **320a-2** of FIG. **6B** may be the same as the first delay unit **321** and the first inverter **322** included in the pulse generation unit **320a-1** of FIG. **6A**.

The demultiplexer **327** may provide the active signal ACT to one of the first delay unit **321** and the multiplexer **328** based on a logic level of the on-off signal ON_OFF.

The multiplexer **328** may output one of a signal received from the first inverter **322** and the active signal ACT received from the demultiplexer **327** as the count pulse signal CPS based on the logic level of the on-off signal ON_OFF.

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When the on-off signal ON_OFF has a first logic level, the demultiplexer **327** may provide the active signal ACT to the first delay unit **321** and the multiplexer **328** may output the signal received from the first inverter **322** as the count pulse signal CPS. In this case, the pulse generation unit **320a-2** of FIG. **6B** may operate substantially the same as the pulse generation unit **320a-1** of FIG. **6A**.

When the on-off signal ON_OFF has a second logic level, the demultiplexer **327** may provide the active signal ACT to the multiplexer **328** and the multiplexer **328** may output the active signal ACT received from the demultiplexer **327** as the count pulse signal CPS. In this case, the pulse generation unit **320a-2** of FIG. **6B** may bypass the active signal ACT to output the active signal ACT as the count pulse signal CPS.

FIGS. **7A** and **7B** are block diagrams illustrating other examples of a pulse generation unit (e.g., circuit) included in the intensively accessed row detection unit of FIG. **4**.

Referring to FIG. **7A**, a pulse generation unit **320b-1** may include a reference code generation unit **323** (e.g., reference code generation circuit), a first counting unit **324** (e.g., first counting circuit), a comparator **325** and a toggle flip flop T-FF **326**.

The reference code generation unit **323** may generate a reference code REF_CODE that is proportional to a frequency of a clock signal CLK in response to a clock change signal CCS.

The clock signal CLK and the clock change signal CCS may be provided from the control logic **210**. The memory device **200a** may use the clock signal CLK to operate in a synchronous manner. When the frequency of the clock signal CLK is changed, the control logic **210** may activate the clock change signal CCS for a predetermined time.

FIG. **8** is a block diagram illustrating an example of a reference code generation unit included in the pulse generation unit of FIG. **7A**.

Referring to FIG. **8**, the reference code generation unit **323** may include a second delay unit **3231** (e.g., second delay circuit), a second inverter **3232**, an AND gate **3233** and a second counting unit **3234** (e.g., second counting circuit).

The second delay unit **3231** may generate a second delay signal DS2 by delaying the clock change signal CCS for a delay time. The delay time may correspond, for example, to a half of the first period TP1.

In some example embodiments, the second delay unit **3231** may adjust a length of the delay time based on the period control signal PCS.

The second inverter **3232** may generate an inverted signal INV_S by inverting the second delay signal DS2.

The AND gate **3233** may perform an AND operation on the clock change signal CCS and the inverted signal INV_S to generate a start signal ST.

When the start signal ST is activated to the logic high level, the second counting unit **3234** may reset a count value and perform an up-count operation on the count value in synchronization with the clock signal CLK. When the start signal ST is deactivated to the logic low level, the second counting unit **3234** may stop performing the up-count operation and output the count value as the reference code REF_CODE.

FIG. **9** is a diagram describing an operation of the reference code generation unit of FIG. **8**.

Referring to FIG. **9**, before a first time t1, the control logic **210** may generate the clock signal CLK having a constant frequency and the clock change signal CCS deactivated to the logic low level. Therefore, the second delay signal DS2 generated from the second delay unit **3231** may be main-

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tained at the logic low level, and the inverted signal INVS generated from the second inverter 3232 may be maintained at the logic high level. Since the clock change signal CCS has the logic low level and the inverted signal INVS has the logic high level, the start signal ST may be maintained at the logic low level.

At the first time t1, the frequency of the clock signal CLK may change such that the control logic 210 may activate the clock change signal CCS to the logic high level. Therefore, the start signal ST may be activated to the logic high level such that the second counting unit 3234 may reset the count value CV and perform the up-count operation on the count value CV in synchronization with the clock signal CLK.

Since the second delay unit 3231 generates the second delay signal DS2 by delaying the clock change signal CCS for the delay time, as illustrated in FIG. 9, the second delay signal DS2 may change to the logic high level at a second time t2. The difference between the second time t2 and the first time t1, which corresponds to the delay time, may correspond to a half of the first period TP1. Therefore, at the second time t2, the inverted signal INVS generated from the second inverter 3232 may change to the logic low level such that the start signal ST may be deactivated to the logic low level. As such, the second counting unit 3234 may stop performing the up-count operation and output the count value CV as the reference code REF_CODE. For example, in an example of FIG. 9, since the second counting unit 3234 receives ten cycles of the clock signal CLK while the start signal ST is activated, the second counting unit 3234 may generate the reference code REF_CODE having a value of ten at the second time t2.

At a third time t3, the control logic 210 may deactivate the clock change signal CCS to the logic low level. Therefore, at a fourth time t4, which is the delay time behind from the third time t3, the second delay signal DS2 may change to the logic low level and the inverted signal INVS may change to the logic high level.

The second counting unit 3234 may continuously output the reference code REF_CODE having a value of ten from the second time t2 until the frequency of the clock signal CLK is changed and the clock change signal CCS is activated to the logic high level.

As described above with reference to FIGS. 8 and 9, the reference code generation unit 323 may receive the clock signal CLK that is internally used by the memory device 200a and generate the reference code REF_CODE that is proportional to the frequency of the clock signal CLK.

Referring again to FIG. 7A, the first counting unit 324 may be turned on while the active signal ACT is activated, and the first counting unit 324 may be turned off while the active signal ACT is deactivated. While the first counting unit 324 is turned on, the first counting unit 324 may generate a time code TIME_CODE by performing an up-count operation in synchronization with the clock signal CLK, and reset the time code TIME_CODE in response to a rising edge of a reset signal RST.

The comparator 325 may generate the reset signal RST by comparing the time code TIME_CODE received from the first counting unit 324 with the reference code REF_CODE received from the reference code generation unit 323. For example, the comparator 325 may output the reset signal RST having the logic low level when the time code TIME_CODE is less than the reference code REF_CODE, and output the reset signal RST having the logic high level when the time code TIME_CODE is equal to or greater than the reference code REF_CODE.

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The toggle flip flop 326 may generate an output signal toggling in response to the rising edge of the reset signal RST and output the output signal as the count pulse signal CPS.

As described above with reference to FIGS. 8 and 9, the reference code REF_CODE may represent a number of cycles of the clock signal CLK received during a time corresponding to a half of the first period TP1. Therefore, the reset signal RST that is output from the comparator 325 may be activated to the logic high level every half of the first period TP1. Since the toggle flip flop 326 toggles the count pulse signal CPS in response to the rising edge of the reset signal RST, as illustrated in FIG. 5, the pulse generation unit 320b-1 may output the count pulse signal CPS having the first period TP1 through the toggle flip flop 326.

Referring to FIG. 7B, a pulse generation unit 320b-2 may include the reference code generation unit 323, the first counting unit 324, the comparator 325, the toggle flip flop T-FF 326, a demultiplexer 327 and a multiplexer 328.

The reference code generation unit 323, the first counting unit 324, the comparator 325 and the toggle flip flop 326 included in the pulse generation unit 320b-2 of FIG. 7B may be the same as the reference code generation unit 323, the first counting unit 324, the comparator 325 and the toggle flip flop 326 included in the pulse generation unit 320b-1 of FIG. 7A.

The demultiplexer 327 may provide the active signal ACT to one of the first counting unit 324 and the multiplexer 328 based on a logic level of the on-off signal ON_OFF.

The multiplexer 328 may output one of a signal received from the toggle flip flop 326 and the active signal ACT received from the demultiplexer 327 as the count pulse signal CPS based on a logic level of the on-off signal ON_OFF.

When the on-off signal ON_OFF has a first logic level, the demultiplexer 327 may provide the active signal ACT to the first counting unit 324 and the multiplexer 328 may output the signal received from the toggle flip flop 326 as the count pulse signal CPS. In this case, the pulse generation unit 320b-2 of FIG. 7B may operate substantially the same as the pulse generation unit 320b-1 of FIG. 7A.

When the on-off signal ON_OFF has a second logic level, the demultiplexer 327 may provide the active signal ACT to the multiplexer 328 and the multiplexer 328 may output the active signal ACT received from the demultiplexer 327 as the count pulse signal CPS. In this case, the pulse generation unit 320b-2 of FIG. 7B may bypass the active signal ACT to output the active signal ACT as the count pulse signal CPS.

Referring again to FIG. 4, the row address profiler 330 may store access values corresponding to the plurality of memory cell rows, respectively, that are included in the memory cell array 280. The row address profiler 330 may receive the latched row address LROW_ADDR from the latch unit 310 and receive the count pulse signal CPS received from the pulse generation unit 320. The row address profiler 330 may sequentially increase one of the access values, which corresponds to the latched row address LROW_ADDR, in synchronization with the count pulse signal CPS. The row address profiler 330 may generate the intensively accessed row address IA_ADDR based on the access values.

In some example embodiments, at every predetermined time interval, the row address profiler 330 may output a row address, which corresponds to a greatest access value among the access values, as the intensively accessed row address IA_ADDR, and the row address profiler 330 may reset the access values. In this case, the predetermined time interval

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may be shorter than a refresh period of the memory cell array **280** during which the plurality of memory cell rows included in the memory cell array **280** are refreshed.

In other example embodiments, when each of the access values exceeds a threshold value, the row address profiler **330** may output a row address, which corresponds to an access value exceeding the threshold value among the access values, as the intensively accessed row address IA_ADDR together with an interrupt signal. In addition, the row address profiler **330** may reset the access values at every predetermined time interval. In this case, the predetermined time interval may correspond to the refresh period of the memory cell array **280** during which the plurality of memory cell rows included in the memory cell array **280** are refreshed.

FIG. **10** is a block diagram illustrating an example of a row address profiler included in the intensively accessed row detection unit of FIG. **4**.

Referring to FIG. **10**, a row address profiler **330a** may include a profile control unit **331** (e.g., profile control circuit) and a timer **332**.

The profile control unit **331** may store the access values AV1, AV2, . . . , AVm corresponding to the plurality of memory cell rows, respectively, that are included in the memory cell array **280**. Here, m represents a positive integer.

The profile control unit **331** may receive the latched row address LROW_ADDR from the latch unit **310** and receive the count pulse signal CPS received from the pulse generation unit **320**. The profile control unit **331** may select one of the access values AV1, AV2, . . . , AVm, which corresponds to the latched row address LROW_ADDR, and perform an up-count operation on the selected access value in synchronization with the count pulse signal CPS.

The timer **332** may generate an output control signal OCS at every predetermined time interval. In one embodiment, the predetermined time interval may be shorter than a refresh period of the memory cell array **280** during which the plurality of memory cell rows included in the memory cell array **280** are refreshed.

When the profile control unit **331** receives the output control signal OCS from the timer **332**, the profile control unit **331** may output a row address, which corresponds to a greatest access value among the access values AV1, AV2, . . . , AVm, as the intensively accessed row address IA_ADDR, and the profile control unit **331** may reset the access values AV1, AV2, . . . , AVm.

Therefore, the row address profiler **330a** of FIG. **10** may output a row address corresponding to a memory cell row, which is accessed for the longest time among the plurality of memory cell rows included in the memory cell array **280**, as the intensively accessed row address IA_ADDR at every predetermined time interval.

FIG. **11** is a diagram describing an exemplary operation of a refresh control unit included in the memory device of FIG. **3** when the intensively accessed row detection unit included in the memory device of FIG. **3** includes the row address profiler of FIG. **10**.

Referring to FIGS. **3** and **11**, the refresh control unit **400** may generate row addresses RA(k-1), RAK, IRA(k+1), . . . , RA(s-1), RAs, RA(S+1), which increase sequentially, as the refresh row address REF_ADDR, and the refresh control unit **400** may refresh a memory cell row corresponding to the refresh row address REF_ADDR. Here, k and s represent positive integers.

As described above, the refresh control unit **400** may receive the intensively accessed row address IA_ADDR from the row address profiler **330a** at every predetermined

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time interval PDT. As illustrated in FIG. **11**, when the refresh control unit **400** receives the intensively accessed row address IA_ADDR from the row address profiler **330a**, the refresh control unit **400** may preferentially refresh a memory cell row corresponding to a row address that is less than the intensively accessed row address IA_ADDR by one, and a memory cell row corresponding to a row address that is greater than the intensively accessed row address IA_ADDR by one. Then, the refresh control unit **400** may refresh a memory cell row corresponding to the refresh row address REF_ADDR.

FIG. **12** is a block diagram illustrating another example of the row address profiler included in the intensively accessed row detection unit of FIG. **4**.

Referring to FIG. **12**, a row address profiler **330b** may include a profile control unit **333** and a timer **334**.

The profile control unit **333** may store the access values AV1, AV2, . . . , AVm corresponding to the plurality of memory cell rows, respectively, that are included in the memory cell array **280**. Here, m represents a positive integer.

The profile control unit **333** may receive the latched row address LROW_ADDR from the latch unit **310** and receive the count pulse signal CPS received from the pulse generation unit **320**. The profile control unit **333** may select one of the access values AV1, AV2, . . . , AVm, which corresponds to the latched row address LROW_ADDR, and perform an up-count operation on the selected access value in synchronization with the count pulse signal CPS.

When each of the access values AV1, AV2, . . . , AVm exceeds a threshold value THV, the profile control unit **333** may output a row address, which corresponds to an access value exceeding the threshold value THV among the access values AV1, AV2, . . . , AVm, as the intensively accessed row address IA_ADDR together with the interrupt signal INT. In some example embodiments, the profile control unit **333** may store the threshold value THV internally. In other example embodiments, the threshold value THV may be provided from the control logic **210**.

The timer **334** may generate a reset control signal RCS at every predetermined time interval. The predetermined time interval may correspond to a refresh period of the memory cell array **280** during which the plurality of memory cell rows included in the memory cell array **280** are refreshed.

When the profile control unit **333** receives the reset control signal RCS from the timer **334**, the profile control unit **333** may reset the access values AV1, AV2, . . . , AVm.

Therefore, when a certain memory cell row among the plurality of memory cell rows included in the memory cell array **280** is accessed for a time longer than a period corresponding to the threshold value THV during the refresh period of the memory cell array **280**, the row address profiler **330b** of FIG. **12** may immediately output a row address corresponding to the certain memory cell row as the intensively accessed row address IA_ADDR together with the interrupt signal INT.

FIG. **13** is a diagram describing an exemplary operation of a refresh control unit included in the memory device of FIG. **3** when the intensively accessed row detection unit included in the memory device of FIG. **3** includes the row address profiler of FIG. **12**.

Referring to FIGS. **3** and **13**, the refresh control unit **400** may generate row addresses RA(k-1), RAK, RA(k+1), which increase sequentially, as the refresh row address REF_ADDR, and refresh a memory cell row corresponding to the refresh row address REF_ADDR.

As illustrated in FIG. 13, when the refresh control unit 400 receives the interrupt signal INT and the intensively accessed row address IA_ADDR from the row address profiler 330b, the refresh control unit 400 may preferentially refresh a memory cell row corresponding to a row address that is less than the intensively accessed row address IA_ADDR by one, and a memory cell row corresponding to a row address that is greater than the intensively accessed row address IA_ADDR by one. Then, the refresh control unit 400 may refresh a memory cell row corresponding to the refresh row address REF. ADDR.

If the intensively accessed memory cell row is determined based on an access frequency of memory cell rows included in a memory cell array, a memory cell row, which is accessed for a long time during each access but has a low access frequency, may not be determined as the intensively accessed memory cell row.

However, as described above, the memory device 200a according to example embodiments generates the intensively accessed row address IA_ADDR indicating the intensively accessed memory cell row among the plurality of memory cell rows included in the memory cell array 280 based on a sum of access time for each of the plurality of memory cell rows. The memory device 200a preferentially refreshes neighboring memory cell rows adjacent to the intensively accessed memory cell row, which is indicated by the intensively accessed row address IA_ADDR.

Therefore, the memory device 200a may preferentially refresh neighboring memory cell rows adjacent to a certain memory cell row when the certain memory cell row is accessed for a long time during each access with a low access frequency as well as when the certain memory cell row is accessed frequently.

In addition, according to example embodiments, the pulse generation unit 320 included in the intensively accessed row detection unit 300 may adjust the first period TP1 of the count pulse signal CPS based on the period control signal PCS. Therefore, the memory device 200a may adjust weight values of an access frequency and a sum of access time for each of the plurality of memory cell rows, which are used in determining the intensively accessed memory cell row, by changing the first period TP1 of the count pulse signal CPS using the period control signal PCS. For example, a higher weight value may be applied to the access frequency than the sum of access time when the first period TP1 of the count pulse signal CPS increases. On the other hand, the higher weight value may be applied to the sum of access time than the access frequency when the first period TP1 of the count pulse signal CPS decreases.

Therefore, the memory device 200a may effectively reduce a rate of data loss.

FIG. 14 is a block diagram illustrating a memory module according to exemplary embodiments.

Referring to FIG. 14, a memory module 700 may include a plurality of memory devices 720. In some embodiments, the memory module 700 may be an unbuffered dual in-line memory module (UDIMM), a registered dual in-line memory module (RDIMM), a fully buffered dual in-line memory module (FBDIMM), a load reduced dual in-line memory module (LRDIMM), etc.

The memory module 700 may further include a buffer 710 that receives a command signal, an address signal and data from a memory controller through a plurality of transmission lines and buffers the command signal, the address signal and the data to provide the plurality of memory devices 720 with the command signal, the address signal and the data.

In some example embodiments, data transmission lines between the buffer 710 and the plurality of memory devices 720 may be coupled in a point-to-point topology. Command transmission lines and address transmission lines between the buffer 710 and the plurality of memory devices 720 may be coupled in a multi-drop topology, a daisy-chain topology, a fly-by daisy-chain topology, or the like. Since the buffer 710 buffers the command signal, the address signal and the data, the memory controller may interface with the memory module 700 by driving only a load of the buffer 710. Accordingly, the memory module 700 may include more memory devices 720 and/or more memory ranks, and a memory system may include more memory modules 700. For ease of description, each of the various devices or systems described herein may be referred to as an electronic device.

The memory device 720 may generate an intensively accessed row address indicating an intensively accessed memory cell row among a plurality of memory cell rows included in a memory cell array based on a sum of access time for each of the plurality of memory cell rows, and the memory device 720 may preferentially refresh neighboring memory cell rows adjacent to the intensively accessed memory cell row, which is indicated by the intensively accessed row address. Therefore, the memory device 720 may preferentially refresh neighboring memory cell rows adjacent to a certain memory cell row when the certain memory cell row is accessed for a long time during each access with a low access frequency as well as when the certain memory cell row is accessed frequently. As such, the memory device 720 may effectively reduce a rate of data loss.

The memory device 720 may be embodied with the memory device 200a of FIG. 3. A structure and an operation of the memory device 200a are described above with reference to FIGS. 3 to 13. Therefore, a detailed description of the memory device 720 will be omitted.

FIG. 15 is a block diagram illustrating a mobile system according to exemplary embodiments.

Referring to FIG. 15, a mobile system 800 includes an application processor 810, a connectivity unit 820, a user interface 830, a nonvolatile memory device NVM 840, a volatile memory device VM 850 and a power supply 860. In some embodiments, the mobile system 800 may be a mobile phone, a smart phone, a personal digital assistant (PDA), a portable multimedia player (PMP), a digital camera, a music player, a portable game console, a navigation system, etc.

The application processor 810 may execute applications, such as a web browser, a game application, a video player, etc. In some embodiments, the application processor 810 may include a single core or multiple cores. For example, the application processor 810 may be a multi-core processor, such as a dual-core processor, a quad-core processor, a hexa-core processor, etc. The application processor 810 may include an internal or external cache memory.

The connectivity unit 820 may perform wired or wireless communication with an external device. For example, the connectivity unit 820 may perform Ethernet communication, near field communication (NFC), radio frequency identification (RFID) communication, mobile telecommunication, memory card communication, universal serial bus (USB) communication, etc. In some embodiments, the connectivity unit 820 may include a baseband chipset that supports communications, such as a global system for mobile communications (GSM), general packet radio service (GPRS), wideband code division multiple access (WCDMA), high speed downlink/uplink packet access (HSxPA), etc.

The volatile memory device **850** may store data processed by the application processor **810**, or may operate as a working memory. The volatile memory device **850** may generate an intensively accessed row address indicating an intensively accessed memory cell row among a plurality of memory cell rows included in a memory cell array based on a sum of access time for each of the plurality of memory cell rows, and the volatile memory device **850** may preferentially refresh neighboring memory cell rows adjacent to the intensively accessed memory cell row, which is indicated by the intensively accessed row address. Therefore, the volatile memory device **850** may preferentially refresh neighboring memory cell rows adjacent to a certain memory cell row when the certain memory cell row is accessed for a long time during each access with a low access frequency as well as when the certain memory cell row is accessed frequently. As such, the volatile memory device **850** may effectively reduce a rate of data loss.

The volatile memory device **850** may be embodied with the memory device **200a** of FIG. 3. A structure and an operation of the memory device **200a** are described above with reference to FIGS. 3 to 13. Therefore, a detail description of the volatile memory device **850** will be omitted.

The nonvolatile memory device **840** may store a boot image for booting the mobile system **800**. For example, the nonvolatile memory device **840** may be an electrically erasable programmable read-only memory (EEPROM), a flash memory, a phase change random access memory (PRAM), a resistance random access memory (RRAM), a nano floating gate memory (NFGM), a polymer random access memory (PoRAM), a magnetic random access memory (MRAM), a ferroelectric random access memory (FRAM), etc.

The user interface **830** may include at least one input device, such as a keypad, a touch screen, etc., and at least one output device, such as a speaker, a display device, etc. The power supply **860** may supply a power supply voltage to the mobile system **800**.

In some embodiments, the mobile system **800** may further include an image processor, and/or a storage device, such as a memory card, a solid state drive (SSD), a hard disk drive (HDD), a CD-ROM, etc.

In some embodiments, the mobile system **800** and/or components of the mobile system **800** may be packaged in various forms, such as package on package (PoP), ball grid arrays (BGAs), chip scale packages (CSPs), plastic leaded chip carrier (PLCC), plastic dual in-line package (PDIP), die in wafer pack, die in wafer form, chip on board (COB), ceramic dual in-line package (CERDIP), plastic metric quad flat pack (MQFP), thin quad flat pack (TQFP), small outline IC (SOIC), shrink small outline package (SSOP), thin small outline package (TSOP), system in package (SIP), multi chip package (MCP), wafer-level fabricated package (WFP), or wafer-level processed stack package (WSP).

FIG. 16 is a block diagram illustrating a computing system according to exemplary embodiments.

Referring to FIG. 16, a computing system **900** includes a processor **910**, an input/output hub (IOH) **920**, an input/output controller hub (ICH) **930**, at least one memory module **940** and a graphics card **950**. In some embodiments, the computing system **900** may be a personal computer (PC), a server computer, a workstation, a laptop computer, a mobile phone, a smart phone, a personal digital assistant (PDA), a portable multimedia player (PMP), a digital camera, a digital television, a set-top box, a music player, a portable game console, a navigation system, etc.

The processor **910** may perform various computing functions, such as executing specific software for performing specific calculations or tasks. For example, the processor **910** may be a microprocessor, a central process unit (CPU), a digital signal processor, or the like. In some embodiments, the processor **910** may include a single core or multiple cores. For example, the processor **910** may be a multi-core processor, such as a dual-core processor, a quad-core processor, a hexa-core processor, etc. Although FIG. 16 illustrates the computing system **900** including one processor **910**, in some embodiments, the computing system **900** may include a plurality of processors.

The processor **910** may include a memory controller **911** for controlling operations of the memory module **940**. The memory controller **911** included in the processor **910** may be referred to as an integrated memory controller (IMC). A memory interface between the memory controller **911** and the memory module **940** may be implemented with a single channel including a plurality of signal lines, or may be implemented with multiple channels. At least one memory module **940** may be coupled to each of the multiple channels. In some embodiments, the memory controller **911** may be located inside the input/output hub **920**. The input/output hub **920** including the memory controller **911** may be referred to as a memory controller hub (MCH).

The memory module **940** may include a plurality of memory devices MEM **941** that store data provided from the memory controller **911**. The memory device **941** may generate an intensively accessed row address indicating an intensively accessed memory cell row among a plurality of memory cell rows included in a memory cell array based on a sum of access time for each of the plurality of memory cell rows, and the memory module **940** may preferentially refresh neighboring memory cell rows adjacent to the intensively accessed memory cell row, which is indicated by the intensively accessed row address. Therefore, the memory device **941** may preferentially refresh neighboring memory cell rows adjacent to a certain memory cell row when the certain memory cell row is accessed for a long time during each access with a low access frequency as well as when the certain memory cell row is accessed frequently. As such, the memory device **941** may effectively reduce a rate of data loss.

The memory device **941** may be embodied with the memory device **200a** of FIG. 3. A structure and an operation of the memory device **200a** are described above with reference to FIGS. 3 to 13. Therefore, a detail description of the memory device **941** will be omitted.

The input/output hub **920** may manage data transfer between the processor **910** and devices, such as the graphics card **950**. The input/output hub **920** may be coupled to the processor **910** via various interfaces. For example, the interface between the processor **910** and the input/output hub **920** may be a front side bus (FSB), a system bus, a HyperTransport, a lightning data transport (LDT), a Quick-Path interconnect (QPI), a common system interface (CSI), etc. The input/output hub **920** may provide various interfaces with the devices. For example, the input/output hub **920** may provide an accelerated graphics port (AGP) interface, a peripheral component interface-express (PCIe), a communications streaming architecture (CSA) interface, etc. Although FIG. 16 illustrates the computing system **900** including one input/output hub **920**, in some embodiments, the computing system **900** may include a plurality of input/output hubs.

The graphics card **950** may be coupled to the input/output hub **920** via the AGP interface or the PCIe. The graphics card

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950 may control a display device for displaying an image. The graphics card 950 may include an internal processor for processing image data and an internal memory device. In some embodiments, the input/output hub 920 may include an internal graphics device along with or instead of the graphics card 950 outside the graphics card 950. The graphics device included in the input/output hub 920 may be referred to as integrated graphics. Further, the input/output hub 920 including the internal memory controller and the internal graphics device may be referred to as a graphics and memory controller hub (GMCH).

The input/output controller hub 930 may perform data buffering and an interface arbitration to efficiently operate various system interfaces. The input/output controller hub 930 may be coupled to the input/output hub 920 via an internal bus, such as a direct media interface (DMI), a hub interface, an enterprise Southbridge interface (ESI), the PCIe, etc.

The input/output controller hub 930 may provide various interfaces with peripheral devices. For example, the input/output controller hub 930 may provide a universal serial bus (USB) port, a serial advanced technology attachment (SATA) port, a general purpose input/output (GPIO), a low pin count (LPC) bus, a serial peripheral interface (SPI), PCI, the PCIe, etc.

In some embodiments, the processor 910, the input/output hub 920 and the input/output controller hub 930 may be implemented as separate chipsets or separate integrated circuits. In other embodiments, at least two of the processor 910, the input/output hub 920 and the input/output controller hub 930 may be implemented as a single chipset.

The foregoing is illustrative of the present disclosure and is not to be construed as limiting thereof. Although a few example embodiments have been described, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from the novel teachings and advantages of the present disclosure. Accordingly, all such modifications are intended to be included within the scope of the present disclosure as defined in the claims. Therefore, it is to be understood that the foregoing is illustrative of various example embodiments and is not to be construed as limited to the specific example embodiments disclosed, and that modifications to the disclosed example embodiments, as well as other example embodiments, are intended to be included within the scope of the appended claims.

What is claimed is:

1. A method of refreshing a dynamic random access memory (DRAM), the DRAM including a memory cell array, the memory cell array including a plurality of memory cell rows, each of the plurality of memory cell rows being refreshed in accordance with corresponding refresh address, the method comprising:

counting a number of accesses to a first memory cell row of the plurality of memory cell rows during a predetermined time interval;

measuring an accumulated access time of the first memory cell row during the predetermined time interval; and

performing a first refresh operation on a second memory cell row and a third memory cell row based on the number of accesses to the first memory cell row and performing a second refresh operation on the second memory cell row and the third memory cell row based on the accumulated access time of the first memory cell row respectively, each of the second memory cell row

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and the third memory cell row being neighboring memory cell rows adjacent to the first memory cell row.

2. The method of claim 1, wherein the method further includes:

performing a normal refresh operation on each of the second memory cell row and the third memory cell row respectively with a refresh period of the memory cell array.

3. The method of claim 1, wherein the number of accesses to the first memory cell row indicates a number of times that the first memory cell row has been accessed during the predetermined time interval of the memory cell array.

4. The method of claim 1, wherein the accumulated access time of the first memory cell row indicates an accumulated time that the first memory cell row has been activated during the predetermined time interval.

5. The method of claim 1, wherein the first refresh operation is performed when the number of accesses to the first memory cell row exceeds a first threshold value.

6. The method of claim 1, wherein the second refresh operation is performed when the accumulated access time of the first memory cell row exceeds a second threshold value.

7. The method of claim 6, wherein the accumulated access time of the first memory cell row is measured by counting a number of count pulse signals which are generated periodically when the first memory cell row is activated for the predetermined time interval.

8. The method of claim 7, wherein each of the count pulse signals has a period equal to a row cycle time.

9. The method of claim 1, wherein the method further includes:

resetting the number of accesses to the first memory cell row when the number of accesses to the first memory cell row exceeds a first threshold value.

10. The method of claim 9, wherein the method further includes:

generating an interrupt signal when the number of accesses to the first memory cell row exceeds the first threshold value, the interrupt signal suspending operation of the DRAM except for refresh operations to be performed on the second memory cell row and the third memory cell row respectively.

11. The method of claim 1, wherein the method further includes:

resetting the accumulated access time of the first memory cell row when the accumulated access time of the first memory cell row exceeds a second threshold value.

12. The method of claim 11, wherein the method further includes:

generating an interrupt signal when the accumulated access time of the first memory cell row exceeds the second threshold value, the interrupt signal suspending operation of the DRAM except for refresh operations to be performed on the second memory cell row and the third memory cell row respectively.

13. The method of claim 1, wherein the predetermined time interval is equal to a refresh period of the memory cell array.

14. The method of claim 1, wherein the first refresh operation is performed on the second memory cell row and the third memory cell row when the number of accesses to the first memory cell row is greatest among numbers of accesses counted for each of the memory cell rows of the memory cell array during the predetermined time interval.

15. The method of claim 14, wherein the predetermined time interval is shorter than a refresh period of the memory cell array.

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16. The method of claim 14, wherein the method further includes:

resetting the numbers of accesses counted for each of the memory cell rows when the first refresh operation is performed.

17. The method of claim 1, wherein the second refresh operation is performed on the second memory cell row and the third memory cell row when the accumulated access time to the first memory cell row is greatest among accumulated access times measured for each of the memory cell rows of the memory cell array during the predetermined time interval.

18. A method of refreshing a dynamic random access memory (DRAM), the DRAM including a memory cell array, the memory cell array including a plurality of memory cell rows, each of the plurality of memory cell rows being refreshed in accordance with corresponding refresh address, the method comprising:

counting a number of accesses to a first memory cell row of the plurality of memory cell rows during a predetermined time interval;

measuring an accumulated access time of the first memory cell row during the predetermined time inter-

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val by counting a number of count pulse signals generated during activation of the first memory cell row; performing a first refresh operation on a second memory cell row and a third memory cell row respectively when the number of accesses to the first memory cell row exceeds a first threshold value and performing a second refresh operation on the second memory cell row and the third memory cell row respectively when the accumulated access time of the first memory cell row exceeds a second threshold value, each of the second memory cell row and the third memory cell row being neighboring memory cell rows adjacent to the first memory cell row; and

performing a normal refresh operation on each of the second memory cell row and the third memory cell row respectively with an interval of a refresh period of the memory cell array in response to a normal refresh address generated from a refresh counter.

19. The method of claim 18, wherein the count pulse signals have a period equal to a row cycle time.

20. The method of claim 18, wherein the predetermined time interval is equal to the refresh period of the memory cell array.

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