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Lee

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(54) **SYSTEMS AND METHODS FOR HANDSHAKING WITH A MEMORY MODULE**

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(60) Provisional application No. 61/186,799, filed on Jun. 12, 2009.

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G06F 9/445 (2006.01)
G06F 13/24 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 9/445*** (2013.01); ***G06F 13/24*** (2013.01)

(58) **Field of Classification Search**
USPC 711/170
See application file for complete search history.

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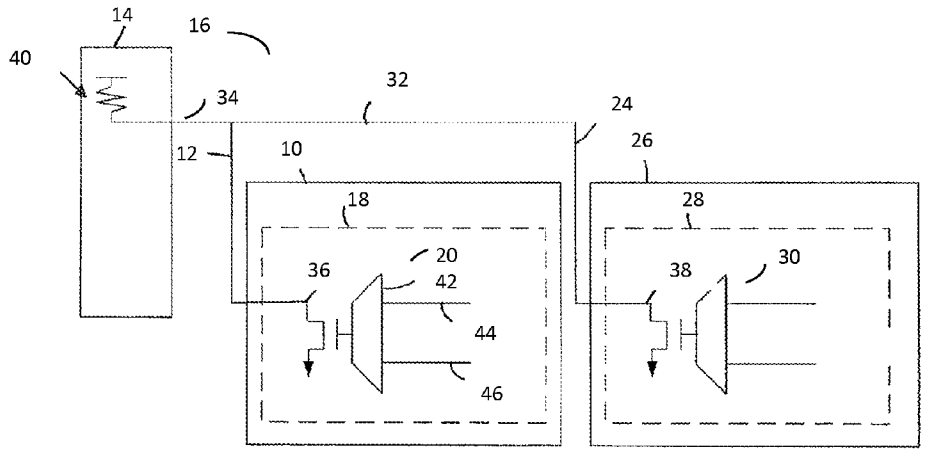
(57) **ABSTRACT**

A memory module is operatively coupled to a memory controller of a host computer system and configured to operate in at least two modes including an operational mode in which the memory module performs memory operations in response to memory commands from the memory controller in accordance with an industry standard. The memory module comprises a controller circuit configured to cause the memory module to enter an initialization mode during which the memory module executes at least one initialization sequence, the initialization mode being one of the at least two modes. The memory module further comprises at least one output having a defined function in the operational mode according to the industry standard but is undefined by the industry standard in the initialization mode. During the initialization mode, the memory module is configured to output a notification signal indicating a status of the initialization mode to the memory controller via the at least one output. The memory controller is configured to execute an interrupt routine in response to the notification signal.

20 Claims, 3 Drawing Sheets



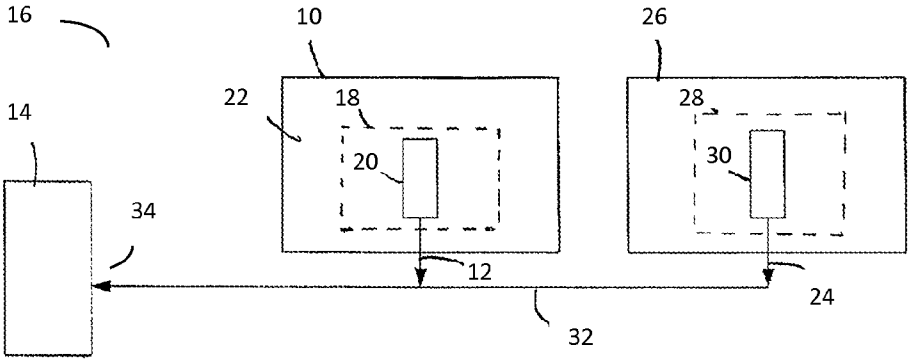


Figure 1

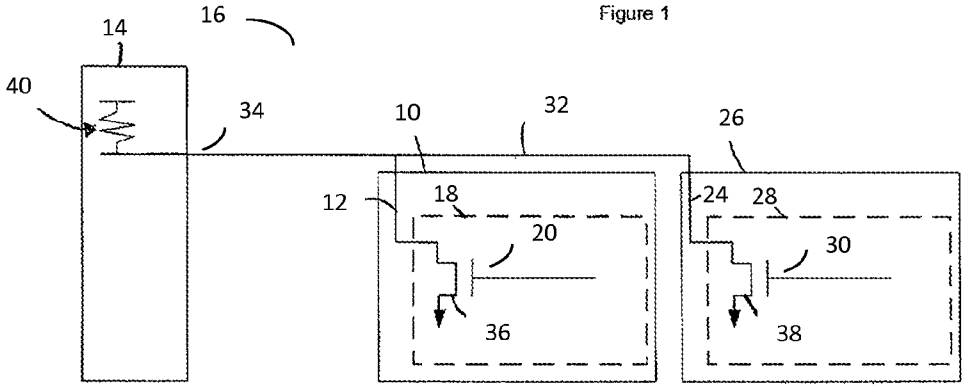


Figure 2

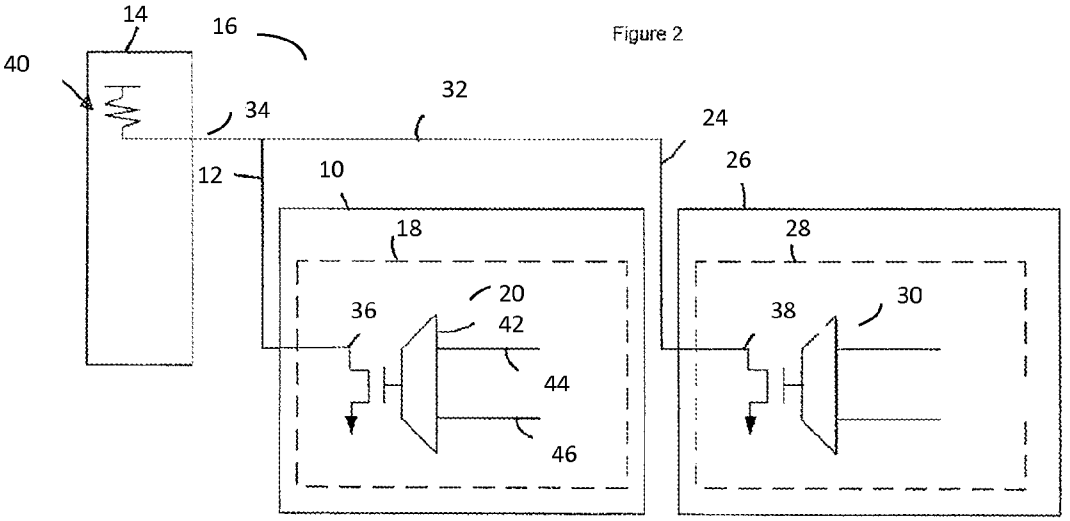


Figure 3

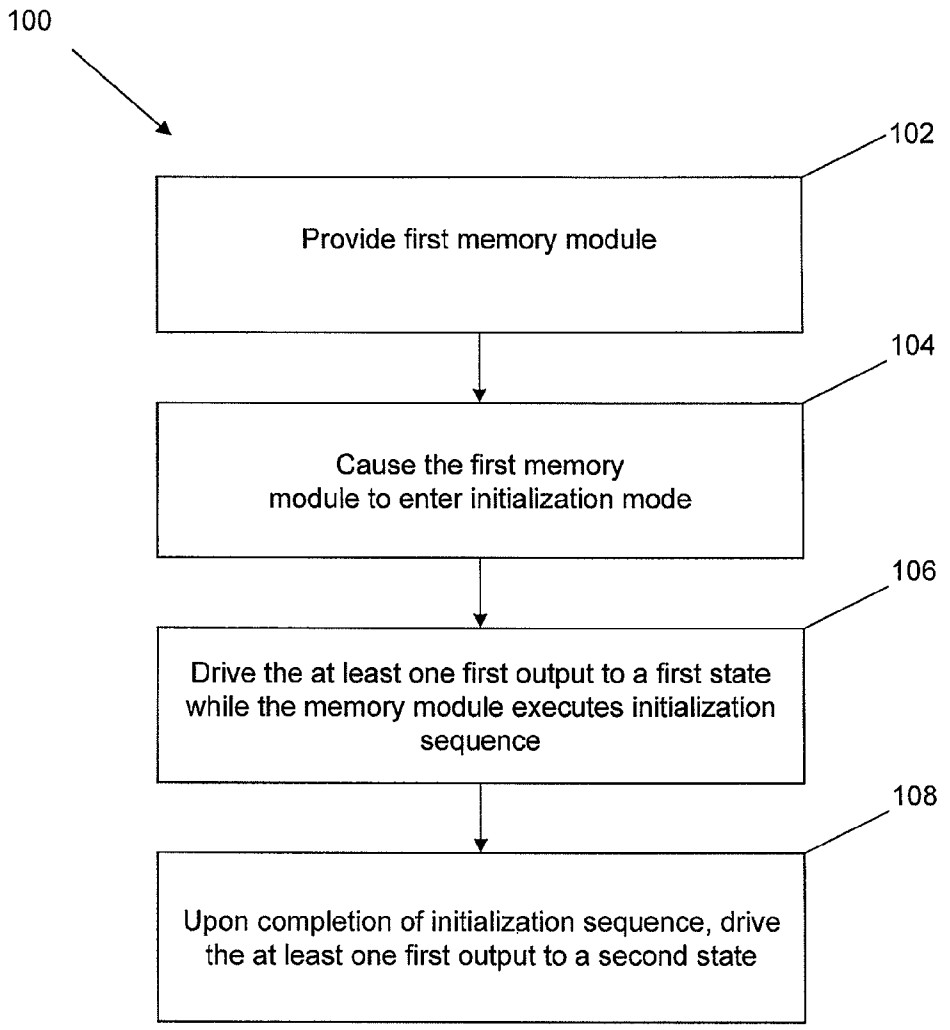

100
102
Provide first memory module
104
Cause the first memory module to enter initialization mode
106
Drive the at least one first output to a first state while the memory module executes initialization sequence
108
Upon completion of initialization sequence, drive the at least one first output to a second state

Figure 4

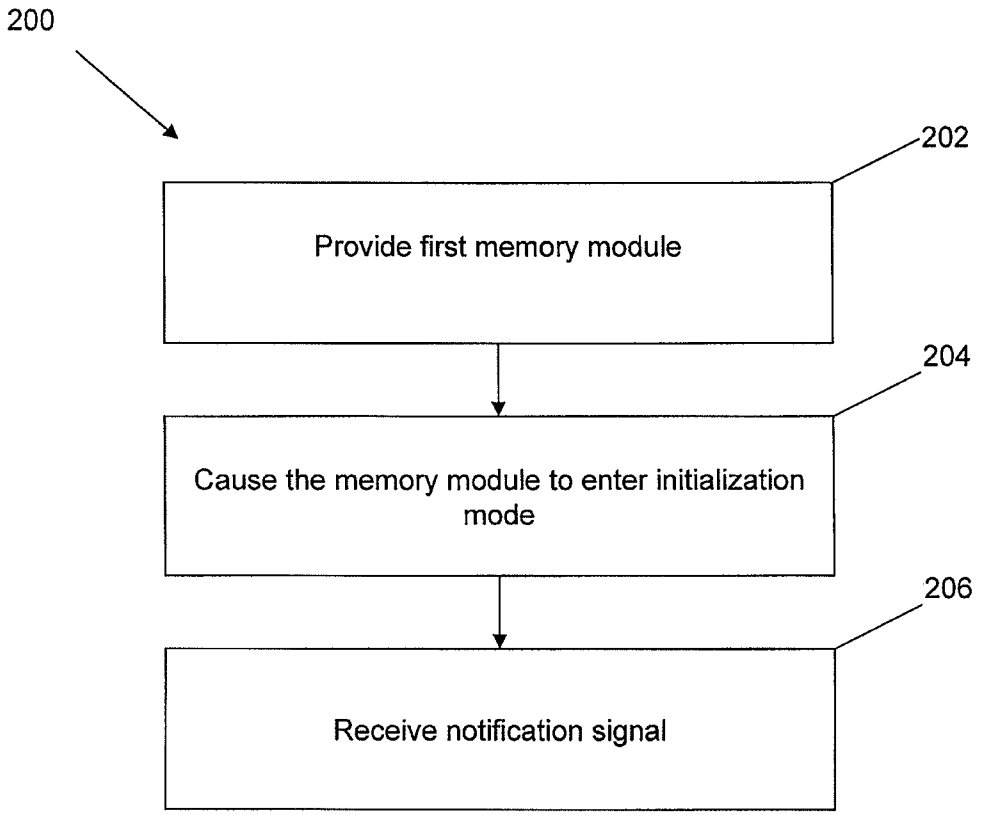

200
202
Provide first memory module
204
Cause the memory module to enter initialization mode
206
Receive notification signal

Figure 5

SYSTEMS AND METHODS FOR HANDSHAKING WITH A MEMORY MODULE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 12/815,339, filed Jun. 14, 2010, now U.S. Pat. No. 8,489,837, which claims the benefit of priority from U.S. Provisional App. No. 61/186,799, filed Jun. 12, 2009, each of which is incorporated in its entirety by reference herein.

FIELD OF THE DISCLOSURE

The present disclosure relates to the operation of memory modules. Specifically, the present disclosure relates to systems and methods for handshaking with a memory module during or upon completion of initialization.

BACKGROUND OF THE DISCLOSURE

Memory subsystems such as memory modules are generally involved in the initialization procedure for computer systems, including servers, personal computers, and the like. For example, during system-wide initialization, the memory subsystems may undergo internal initialization procedures, or the system memory controller may otherwise interact with the memory subsystems during the initialization procedure. As part of this interaction, the system memory controller may request that the memory subsystem perform one or more requested tasks during system initialization.

SUMMARY

According to certain aspects, a memory module comprises at least one output configured to be operatively coupled to a memory controller of a host computer system. The memory module can be configured to operate in at least two modes comprising an initialization mode during which the memory module executes at least one initialization sequence and an operational mode. In certain embodiments, the memory module comprises a controller circuit configured to cause the memory module to enter the initialization mode. The memory module can also comprise a notification circuit configured to drive the at least one output while the memory module is in the initialization mode to provide at least one notification signal to the memory controller indicating at least one status of the at least one initialization sequence.

In another aspect, a method of using at least one memory module comprises providing a first memory module comprising at least one first output operatively coupled to a memory controller of a host computer system. The first memory module can be configured to operate in at least two modes comprising an initialization mode during which the first memory module executes at least one initialization sequence and an operational mode. The method can further comprise causing the first memory module to enter the initialization mode. In certain embodiments, the method comprises driving the at least one first output to a first state while the memory module executes the at least one initialization sequence. In certain embodiments, the method further comprises, upon completion of the at least one initialization sequence, driving the at least one first output to a second state different than the first state.

According to additional aspects, a method of using at least one memory module comprises providing a memory module comprising at least one output operatively coupled to a memory controller of a host computer system. In certain embodiments, the memory module is configured to operate in at least two modes comprising an initialization mode during which the memory module executes at least one initialization sequence and an operational mode. The method may comprise causing the memory module to enter the initialization mode. In some embodiments, the method comprises receiving a notification signal from the at least one output of the memory module, the notification signal indicating that the memory module has completed the at least one initialization sequence.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an example host computer system including an example memory module configured to perform handshaking with a memory controller of the host computer system according to certain embodiments described herein.

FIG. **2** shows an example host computer system including example first and second memory modules configured to perform handshaking with a system memory controller of the host computer system according to certain embodiments described herein.

FIG. **3** shows a host computer system including example first and second memory modules configured to perform handshaking with a memory controller of the host system, where the notification circuits of the first and second memory modules have another example configuration according to certain embodiments described herein.

FIG. **4** and FIG. **5** show example methods of using at least one memory module according to certain embodiments described herein.

DETAILED DESCRIPTION

Existing initialization schemes have certain inefficiencies which lead to wasted time and expense. Thus, there is a need to reduce the time and complexity involved in system memory controller interactions with memory subsystems during initialization. Certain embodiments described herein advantageously satisfy at least a portion of this need by providing a system and method which utilizes a feedback path from a memory subsystem such as a memory module to a system memory controller, such as a Memory Controller Hub (MCH) of a computer system during initialization.

In general, there is no existing method of handshaking between the MCH (e.g., system memory controller) and a memory subsystem (e.g., memory module) during initialization. For example, in conventional systems, the system memory controller does not monitor the error-out signal from the memory subsystem. This causes the MCH to perform blind execution. In a typical server (e.g., an Intel or AMD or other chipset based server), the lack of any handshaking between the MCH and the memory subsystem during the server initialization period has not been a serious issue since the MCH generally has complete control over the initialization procedure. However, one possible configuration for LR-DIMM (Load Reduced DIMM) includes the MCH handing over one or more parts of the initialization operation sequence to the memory subsystem. This raises an unprecedented issue not addressed in conventional systems because, in such proposed configurations, the system can benefit from the MCH handshaking with the memory subsystem controller, as described more fully below.

Such an LR-DIMM configuration may have the MCH inserting a waiting period of predetermined length during

which the MCH is idle and the memory subsystem controller undergoes initialization. However, one shortcoming of this LR-DIMM configuration would be that it requires the MCH to be in standby (idle, or wait) while the memory subsystem controller completes its task. Under such an arrangement, since the time to complete a task can be dependent on the density, speed and configuration of the memory subsystem, and these parameters may be unknown to the MCH, the MCH may have to insert a single, predetermined standby period. In addition, if there are multiple occasions that the MCH needs to hand off control to the memory subsystem controller, the required MCH wait periods can be different from one occasion to another, and it complicates the correlation between the MCH and the memory subsystem controller. For example, the MCH according to such a scheme may give control to the local memory controller of a memory subsystem (e.g., memory module) for execution of a training sequence. The MCH may wait for a predetermined period of time and then assume that the local memory controller has completed the training sequence. However, depending on the memory subsystem parameters (e.g., memory capacity, speed, number of ranks, etc.), the time for actually completing the training sequence may vary and may be longer or shorter than predetermined period of time.

In general, handshaking can be implemented in at least two ways; polling and notifying. In the polling method, the MCH reads a status register in the memory subsystem controller to find out if the memory subsystem controller has completed the required or requested operation. For example, a status register may be read out through a serial interface such as System Management Bus (SMBus). However, a register polling method is generally inefficient because the system memory controller does not know exactly when the memory subsystem will have completed the required or requested operation. Thus, the system memory controller may wait longer than necessary to poll the memory subsystem, thereby delaying the overall initialization process. Additionally, the problem may be compounded because multiple training sequences or other initialization sequences may be run on the memory subsystem during a particular initialization period, resulting in accumulation of such unnecessary delays. Moreover, polling generally involves scheduling polling intervals during which the system memory controller is not performing other operations, resulting in further inefficiency.

Alternatively, the notifying method is an advantageous handshaking method between the MCH and the memory subsystem controller. According to a notifying method, the memory subsystem controller sends a signal to the MCH when the memory subsystem controller completes the required or requested operation. This method allows the MCH to execute one or more independent commands while it is waiting for a notification signal from the memory subsystem controller.

Certain embodiments described herein provide a method of establishing a handshake mechanism based on notification signaling. In certain embodiments, this mechanism can be implemented by adding a new interface (notifying) signal between the MCH and the memory subsystem controller, or by adding an additional functionality to an existing, non-timing critical signal without altering the memory subsystem hardware. In either case, the interface between the MCH and the memory subsystem controller of certain embodiments can be an open drain signaling from the memory subsystem controller to the MCH, although a variety of other configurations are possible. As will be appreciated by persons skilled in the art, the terms MCH, system memory controller, and memory subsystem are used generally interchangeable throughout this disclosure, and the terms memory module, memory subsystem controller, and local memory controller are used generally interchangeably throughout this disclosure.

FIG. **1** illustrates an example host computer system **16** including an example memory module **10** according to certain embodiments described herein. The memory module **10** can comprise at least one output **12** configured to be operatively coupled to a system memory controller **14** of the host computer system **16**. In certain embodiments, the memory module **10** is configured to operate in at least two modes comprising an initialization mode during which the memory module **10** executes at least one initialization sequence, and an operational mode. The memory module **10** may further include a controller circuit **18**. In some embodiments, the controller circuit **18** is configured to cause the memory module **10** to enter the initialization mode. The memory module **10** can further include a notification circuit **20** configured to drive the at least one output **12** while the memory module **10** is in the initialization mode to provide at least one notification signal to the memory controller **14** indicating at least one status of the at least one initialization sequence.

The memory module **10** may comprise a printed-circuit board (PCB) **22**. In certain embodiments, the memory module **10** has a memory capacity of 512-MB, 1-GB, 2-GB, 4-GB, 8-GB, 16-GB, or higher. Other memory capacities are also compatible with certain embodiments described herein. In addition, memory modules **10** having widths of 4 bytes, 8 bytes, 16 bytes, 32 bytes, or 32 bits, 64 bits, 128 bits, 256 bits, as well as other widths (in bytes or in bits), are compatible with embodiments described herein. The PCB **22** can have an industry-standard form factor. For example, the PCB **22** can have a low profile (LP) form factor with a height of 30 millimeters and a width of 133.35 millimeters. In certain other embodiments, the PCB **20** has a very high profile (VHP) form factor with a height of 50 millimeters or more. In certain other embodiments, the PCB **22** has a very low profile (VLP) form factor with a height of 18.3 millimeters. Other form factors including, but not limited to, small-outline (SO-DIMM), unbuffered (UDIMM), registered (RDIMM), fully-buffered (FBDIMM), mini-DIMM, mini-RDIMM, VLP mini-DIMM, micro-DIMM, and SRAM DIMM are also compatible with certain embodiments described herein. In other embodiments, certain non-DIMM form factors are possible such as, for example, single in-line memory module (SIMM), multimedia card (MMC), and small computer system interface (SCSI).

In certain embodiments, the memory module **10** is operatively coupled to (e.g., in electrical communication with) the host computer system **16**. In certain other embodiments, the memory module **10** may communicate with the host computer system **16** using some other type of communication, such as, for example, optical communication. Examples of host computer systems **16** include, but are not limited to, blade servers, 1U servers, personal computers (PCs), and other applications in which space is constrained or limited. The PCB **22** can comprise an interface (not shown) that is configured to be in electrical communication with the host computer system **16**. For example, the interface can comprise a plurality of edge connections which fit into a corresponding slot connector of the host system **16**. The interface of certain embodiments provides a conduit for power voltage as well as data, address, and control signals between the memory module **10** and the host system **16**. For example, the interface can comprise a standard 240-pin DDR2 edge connector. The at least one output **12** may be routed over the interface, for example.

The memory module **10** may also comprise one or more memory elements (not shown), such as dynamic random-access memory (DRAM) elements, for example. Types of DRAM elements compatible with certain embodiments described herein include, but are not limited to, DDR, DDR2, DDR3, DDR4, and synchronous DRAM (SDRAM). In addition, memory elements having bit widths of 4, 8, 16, 32, as well as other bit widths, are compatible with certain embodiments described herein. Memory elements compatible with certain embodiments described herein have packaging which include, but are not limited to, thin small-outline package (TSOP), ball-grid-array (BGA), fine-pitch BGA (FBGA), micro-BGA (μBGA), mini-BGA (mBGA), and chip-scale packaging (CSP). In certain embodiments, the memory module **10** may also include one or more non-volatile memory elements, such as one or more flash memory elements. Types of flash memory elements compatible with certain embodiments described herein include, but are not limited to, NOR flash, NAND flash, ONE-NAND flash, and multi-level cell (MLC).

The controller circuit **18** of certain embodiments generally controls the operation of the memory module **10**. For example, the controller circuit **18** may control the memory elements of the memory module **10** and/or communicate with the system memory controller **14**. For example, the controller circuit **18** may receive and process address and command signals (e.g., read, write commands) from the system memory controller **14** and transmit appropriate address and commands to the memory elements in response. See, e.g., U.S. Pat. Appl. Publ. Nos. 2006/0062047 A1 and 2006/0262586 A1, each of which is incorporated in its entirety by reference herein. In certain embodiments, the controller circuit **18** comprises a local memory controller. Additionally, depending on the architecture of the memory module **10**, such as for an FB-DIMM, the controller circuit **18** may comprise an advanced memory buffer (AMB). The controller circuit **18** can comprise one or more of a field-programmable gate array (FPGA), a programmable-logic device (PLD), an application-specific integrated circuit (ASIC), a custom-designed semiconductor device, and a complex programmable logic device (CPLD), for example. In certain embodiments, the controller circuit **18** comprises various discrete electrical elements, while in certain other embodiments, the controller circuit **18** comprises one or more integrated circuits.

As discussed, the memory module **10** is configured to operate in at least two modes comprising an initialization mode during which the memory module **10** executes at least one initialization sequence, and an operational mode. In one embodiment, for example, the at least one initialization sequence may comprise one or more training sequences. The initialization sequence (e.g., comprising one or more training sequences) may be initiated by the system memory controller **14**. In some embodiments, the controller circuit **18** is configured to cause the memory module **10** to enter the initialization mode. For example, the controller circuit **18** may be configured to execute a routine implementing the at least one initialization sequence when the appropriate signal or command is received from the memory controller **14** or is otherwise received from the host computer system **16** (e.g., upon receipt of a reset signal).

In certain embodiments, for example, the computer system **16** is coupled to a plurality of memory modules **10**, **26** including the memory module **10** and at least a second memory module **26**, and the memory controller **14** (e.g., MCH) trains each module **10**, **26** separately, in series. In one example scenario, the memory controller **14** issues a first command to the memory module **10**, and, in response, the memory module **10** executes an initialization sequence (e.g., one or more training sequences). Upon completion of the initialization sequence, the first memory module **10** advantageously issues a notification to the memory controller **14** in accordance with embodiments described herein. In response, the memory controller **14** issues a second command, this time to the memory module **26**, and, in response, the memory module **26** executes an initialization sequence (e.g., one or more training sequences). Upon completion of the initialization sequence, the second memory module **26**, similar to the first memory module **10**, advantageously issues a notification to the memory controller **14** in accordance with embodiments described herein. In response, where there are more than two memory modules **10**, **26**, the memory controller **14** issues a third command to a third memory module (not shown), and so forth. One example computer system **16** capable of implementing such a scenario is configured to execute an Intel Basic Input/Output System (BIOS), and comprises a plurality of memory modules **10**, **26** having an LRDIMM configuration. In such an example system, the Intel BIOS causes the system memory controller **14** to initialize the LRDIMM memory modules **10**, **26** serially.

The operational mode is the normal mode of the memory module **10**. For example, during the operational mode, the memory module **10** is generally accessed by the system memory controller **14** of the host computer **16** during standard computer operation not associated with initialization. For example, the system memory controller **14** may cause the memory module **10** to perform standard operations such as memory read/write, pre-charge, refresh, etc., while in operational mode, although it will be appreciated that one or more of these operations can also be performed by the memory module **10** while in initialization mode in certain embodiments.

The notification circuit **20** can be configured to drive the at least one output **12**, while the memory module **10** is in the initialization mode or after the memory module **10** completes one or more initialization sequences, to provide the at least one notification signal to the memory controller **14** indicating at least one status of the at least one initialization sequence. While shown in FIGS. **1-3** as forming a part of the controller circuit **18**, the notification circuit **20** may be a physically and/or logically separate circuit in certain embodiments. While a variety of configurations are possible, the notification circuit **20** may comprise one or more transistors, one or more logic elements (e.g., AND, OR, NOR, NAND, XOR gates, and the like), or a combination thereof. In some embodiments, the notification circuit **20** may additionally or alternatively comprise one or more of an FPGA, PLD, CPLD, ASIC, custom-designed semiconductor device, discrete electrical elements, and an integrated circuit.

The at least one status of certain embodiments comprises completion of the at least one initialization sequence, such that the at least one notification signal is indicative of the completion of the at least one initialization sequence. The at least one status of certain embodiments comprises execution of the at least one initialization sequence. For example, the at least one status may indicate that the at least one initialization sequence is currently being executed. In some embodiments, the at least one status may provide an indication that a certain task has been completed by the memory module **10**, such as a training task requested by the system memory controller **14**. In certain embodiments, the notification circuit **20** can be configured to drive the at least one output **12** to a first state indicative of execution of the at least one initialization sequence or to a second state indicative of completion of the at least one initialization sequence. As one example, the first

state may be a high or low logic level, and the second state may be a high impedance state. In another case, the first state is a high or low logic level, and the second state is the inverse logic level of the first state.

The at least one output **12** of certain embodiments is configured to be operatively coupled to at least one interrupt of the system memory controller **14**, and the system memory controller **14** is responsive to the at least one notification signal indicating completion of the at least one initialization sequence. For example, the system memory controller **14** may trigger execution of an interrupt routine upon receipt of the notification signal on the output **12**. The interrupt routine generally executes the appropriate operations for the at least one status indicated by the at least one notification signal. For example, if the at least one status indicates that the at least one initialization sequence is complete, execution of the interrupt routine may cause the system memory controller **14** to notify the host computer system **16** that the system initialization, or a portion thereof, is completed. In one embodiment, for example, the execution of the interrupt routine causes the system memory controller **14** to initiate a subsequent training sequence for the memory module **10** or on another memory module connected to the host system **16**. For example, in one embodiment, a central processing unit (CPU) of the host system **16** (not shown) enters a "Wait" state after issuing a command to the memory module **10** to enter the initialization mode. Receipt of the at least one notification signal on the output **12** triggers execution of the interrupt routine, which interrupts the CPU, causing the "Wait" state to be aborted and allowing the host system **16** to continue operation. In this manner, generation of the interrupt on the at least one output **12** can allow completion of the at least one initialization sequence to receive generally immediate attention from the CPU and/or memory controller **14** of the host system **16**. As will be appreciated, the CPU and memory controller **14** of the host system **16** may comprise separate modules, or may alternatively comprise a single integrated module, depending on the architecture of the host system **16** chip-set.

In certain embodiments, execution of the interrupt routine causes the system memory controller **14** to cause the memory module **10** to exit the initialization mode and to enter the operational mode. In another embodiment, the memory module **10** automatically enters the operational mode upon completion of the at least one initialization sequence without intervention from the memory controller **14**.

In some embodiments, the at least one output **12** is operated in conformance with a standard (e.g., an industry standard) when the memory module **10** is in the operational mode, but is not operated in conformance with the standard when the memory module **10** is in the initialization mode. An example of a standard in accordance with certain embodiments described herein is one or more of the industry standard promulgated by the Joint Electronic Devices Engineering Counsel (JEDEC). For example, the operation and behavior of the at least one output **12** may conform to an industry standard when the memory module **10** is in the operational mode, but the operation and behavior of the at least one output **12** may not conform to the industry standard when the memory module **10** is in the initialization mode. Because the at least one output **12** does not conform to the standard during initialization mode, an existing (e.g., JEDEC-specified) pin may be utilized to provide the at least one notification signal to the system memory controller **14** from the memory module **10** during the initialization mode. In one embodiment, for example, the at least one output **12** comprises an error-out pin of the memory module **10**. In conventional systems, the operation of the error-out pin is undefined by the standard during initialization. However, in certain embodiments described herein, during the operational mode, the error-out pin may be used according a conventional industry standard (e.g., a JEDEC standard) to indicate a parity error has occurred in the memory module **10**. During the initialization mode, the error-out pin can be used to transmit the at least one notification signal to the system memory controller **14**.

It is advantageous to use the error-out pin for initialization status notification according to certain embodiments because the error-out pin can be asserted by the memory module **10** independent from system memory controller **14** requests or commands. Also, because the error-out pin is a JEDEC-specified pin, design cost and complexity are reduced because additional pin-outs and interrupt design changes can be avoided (e.g., in cases where such changes in hardware or chipset may not be feasible to provide the at least one status to the system memory controller **14**). However, in certain other embodiments, providing the at least one status may be implemented by adding one or more pins to the system memory controller **14** (e.g., MCH) and to the controller circuit **18** (e.g., local memory controller), thereby utilizing changes in hardware or the chipset.

Moreover, the error-out pin may be coupled to an interrupt of the system memory controller **14** (e.g., according to the JEDEC standard). Thus, where the error-out pin is used, from the system point of view in accordance with certain embodiments, the notification of completion of the required or requested task from the memory module **10** (e.g., by the local memory controller) generates an interrupt communicated to the system during the initialization period and indicative of completion of the required or requested task. Assertion of the same pin during normal (non-initialization) operation upon an error occurring, on the other hand, generates an interrupt communicated to the system during the normal operation indicative of the occurrence of the error condition. Thus, in certain embodiments, the error-out pin and corresponding signal memory module **10** can be used to support the notifying function and to provide the at least one status generally without changing hardware. Certain other such embodiments involve modifying the basic input/output system (BIOS) or other programming change. For example, the BIOS may be modified to indicate to the system memory controller **14** how to respond to the notification signal (e.g., to the error_out signal or the interrupt corresponding thereto).

In certain other embodiments, the at least one output **12** may include other existing (e.g., JEDEC specified) pins instead of, or in addition to, the error-out pin. In yet other configurations, at least one additional (e.g., non-JEDEC specified) pin may be employed. In general, any pin not otherwise active during the initialization mode may be used (e.g., high-order address pins, read/write pins, data pins, etc.).

The at least one output **12** can further be configured to be operatively coupled to at least one second output **24** of a second memory module **26** in some embodiments, as schematically illustrated in FIGS. **1-3**. The second memory module **26** may be generally similar in structure and function to the memory module **10**, and may comprise a controller circuit **28** and a notification circuit **30**, for example. The second memory module **26** may be generally identical to the first memory module **10**, or may have a different memory capacity, form factor, etc., than the first memory module **10**. More than two such memory modules may be present in certain embodiments. As described above, the second memory module **26** can be configured to operate in at least two modes comprising an initialization mode during which the second memory module **26** executes at least one initialization sequence, and an operational mode. For example, the initial-

ization and operational modes may be similar to those describe above in relation to the first memory module **10**.

The second memory module **26** can also be configured to drive the at least one second output **24** to a third state indicative of execution of at least one initialization sequence of the second memory module **26** or to a fourth state indicative of completion of the at least one initialization sequence of the second memory module **26**. Additionally, in some embodiments, the at least one first output **12** of the first memory module **10** and the at least one second output **24** of the second memory module **26** are operatively coupled together by a bus **32** which is also operatively coupled to at least one input **34** of the system memory controller **14**. In other embodiments (not shown), the at least one first output **12** and the at least one second output **24** are not coupled together, and are coupled to two separate inputs of the system memory controller **14**.

FIG. **2** shows an example host computer system **16** including example first and second memory modules **10**, **26**. As shown, the notification circuits **20**, **30** of the first and second memory modules **10**, **26** each comprise at least one transistor **36**, **38**. The at least one transistor **36**, **38** can be in an open-drain configuration, as shown, although other configurations are possible. In certain such embodiments, the first state of the at least one first output **12** is a first logic level, the second state of the at least one first output **12** is a high-impedance state, the third state of the at least one second output **24** is the first logic level, and the fourth state of the at least one second output **24** is the high-impedance state. In the illustrated example, while the at least one initialization sequence is in progress, the first and second memory modules **10**, **26** drive the gates of the respective transistors **36**, **38** high. Thus, the transistors **36**, **38** are respectively low impedance while the memory modules **10**, **26** are executing each section of the initialization sequence, thereby pulling the first and second outputs **12**, **24** low. Thus, the first state and the third state are low logic levels (ground) in the example configuration. Also, because the first and second outputs **12**, **24** are coupled together by the bus **32**, if the at least one initialization sequence of either one of the first and second memory modules **10**, **26** are in progress, the bus **32** will be pulled to a low logic level.

As each of the two memory modules **10**, **26** completes its at least one initialization sequence, it can drive the corresponding at least one first and second outputs **12**, **24** respectively to a high impedance state, For example, once the at least one initialization sequence on each of the first and second memory modules **10**, **26** is completed, the first and second memory modules **10**, **26** can drive the gates of the respective transistors **36**, **38** low, resulting in a high-impedance state on the at least one first and second outputs **12**, **24** causing the bus **32** to be pulled high by the system memory controller **14**. Accordingly, only once the at least one initialization sequence of both the first and second memory modules **10**, **26** are complete, the bus **32** will be pulled high by the internal pull-up configuration **40** of the system memory controller **14**. The second state and the fourth state are therefore high-impedance values in the example embodiment. Thus, the system memory controller **14** can monitor the value on the bus **32** via the first input **34** to determine when both of the memory modules **10**, **26** have completed the at least one initialization sequence. As discussed, in other configurations the at least one first and second outputs **12**, **24** may be received on separate inputs of the system memory controller **14**, and the status of the at least one initialization sequence of each memory module **10**, **26** may be monitored independently.

As discussed above, in certain embodiments in which more than one memory module **10**, **26** is connected to the system memory controller **14**, each memory module **10**, **26** or associated controller circuit **18** (e.g., local memory controller) causes the corresponding notification circuit **20**, **30** to drive the at least one output **12**, **24** to the high impedance state from the low impedance state when it completes the requested or required operation. Thus, in certain such embodiments, the system memory controller **14** (e.g., MCH) can only pull the notifying signal high when all memory modules **10**, **26** or associated controller circuits (e.g., local memory controllers) have completed the required or requested operation (e.g., initialization sequence). This configuration allows the system memory controller **14** (e.g., MCH) to work with a non-homogenous memory subsystem. For example, the system memory controller **14** may be able to monitor the progress of multiple memory modules **10**, **26** including a mix of DIMMs or other memory modules having differing characteristics, such as DIMM density, rank configurations, DRAM density, speed, DRAM configuration, etc.

Additionally, the at least one output **12** of the first memory module **10** and the at least one second output **24** of the second memory module **26** are configured to be operatively coupled to at least one interrupt of the system memory controller **14** in certain embodiments. In certain such embodiments, the system memory controller **14** can be responsive to the second state of the first memory module **10** and the fourth state of the second memory module **26** by triggering execution of an interrupt routine by a processor of the system memory controller **14**. For example, in the example system of FIG. **2**, when the bus **32** is pulled high by the pull-up configuration **40** indicating the second state of the first memory module **10** and the fourth state of the second memory module **26**, the system memory controller **14** triggers execution of the interrupt routine.

In some embodiments, in which the at least one first output **12** and the at least one second output **24** are operatively coupled to separate inputs of the system memory controller **14**, the at least one first output **12** and the at least out second output **24** may be operatively coupled to two separate interrupts. For example, the system memory controller **14** may be responsive to the second state of the first memory module **10** by triggering execution of a first interrupt routine associated with a first interrupt, and may be responsive to the fourth state of the second memory module **26** by triggering execution of a second interrupt routine associated with the second interrupt. In yet other embodiments, the separate inputs of the memory controller **14** are internally operatively coupled to the same interrupt, or are operatively coupled to separate interrupts which trigger the same interrupt routine.

FIG. **3** shows a host computer system **16** including an example memory module **10** where the notification circuit **20** of the memory module **10** has another example configuration in accordance with certain embodiments described herein. In the example configuration of FIG. **3**, the at least one first output **12** is operatively coupled to an error-out pin of the memory module **10**, and a multiplexor **42** drives the transistor **36** with either of a task_in_progress signal **44** or an error signal **46** (e.g., parity error signal). In one embodiment, for example, the multiplexor **42** may be configured to drive the transistor **36** with the task_in_progress signal **44** when the memory module **10** is in the initialization mode or is executing the at least one initialization sequence, and with the error signal **46** when the memory module **10** is in the operational mode. Thus, the memory module **10** can be advantageously configured to both perform the standard (e.g., JEDEC-specified) error reporting functionality via the error-out pin during the operational mode and provide the status notification functionality during the system initialization mode, as described herein. As shown in FIG. **3**, a second memory module **26**

including a similar configuration can also be operatively coupled to the host computer system **16**. In certain embodiments, the at least one second output **24** of the second memory module **26** can be operatively coupled to the at least one first output **12** by the bus **32**, as described above (e.g., with respect to FIG. **2**).

FIG. **4** shows an example method **100** of using the at least one memory module **10** in accordance with certain embodiments described herein. While the description below of the method **100** refers to structure shown in FIGS. **1-3**, other structures may also be used in accordance with certain embodiments described herein. At block **102**, the method **100** of certain embodiments comprises providing a first memory module **10** comprising at least one first output **12** operatively coupled to a memory controller **14** of a host computer system **16**. The first memory module **10** can be configured to operate in at least two modes comprising an initialization mode during which the first memory module **10** executes at least one initialization sequence, and an operational mode. For example, the at least one initialization sequence may comprise one or more steps of a series of steps associated with an initialization procedure of the host computer system **16**.

At block **104**, the method **100** in some embodiments comprises causing the first memory module **10** to enter the initialization mode. At block **106**, the method **100** of certain embodiments comprises driving the at least one first output **12** to a first state while the memory module **10** executes the at least one initialization sequence. Upon completion of the at least one initialization sequence, the method of certain embodiments comprises driving the at least one first output **12** to a second state different than the first state. In certain embodiments, the first state is a first logic level and the second state is a high impedance state. Additionally, in certain embodiments, the at least one first output **12** is operatively coupled to at least one interrupt of the memory controller **14** such that driving the at least one output **12** to the second state triggers the memory controller to execute an interrupt routine.

In certain embodiments, the at least one output **12** is operated in conformance with JEDEC standard when the first memory module **10** is in the operational mode, but is not operated in conformance with the JEDEC standard when the first memory module **10** is in the initialization mode. The at least one first output **12** of certain embodiments include an error-out pin of the first memory module, for example.

The method **100** can further include providing a second memory module **26** comprising at least one second output **24** operatively coupled to the memory controller **14**. The second memory module **26** can be configured to operate in one of at least two modes comprising an initialization mode, during which the second memory module **26** executes at least one initialization sequence, and an operational mode. The method **100** can further include causing the second memory module **26** to enter the initialization mode. In certain embodiments, the method **100** also includes driving the at least one second output **24** of the second memory module **26** to a third state while the second memory module **26** executes the at least one initialization sequence. Upon completion of the at least one initialization sequence, the method **100** can further include driving the at least one second output **24** of the second memory module **26** to a fourth state different from the third state.

In certain embodiments, the at least one first output **12** of the first memory module **10** and the at least one second output **24** of the second memory module **26** are operatively coupled together by a bus **32** which is also operatively coupled to at least one input **34** of the memory controller **14**. In certain other embodiments, the at least one first output **12** of the first memory module **10** is operatively coupled to a first input **34** of the memory controller **14** and the at least one second output **24** of the second memory module **26** is operatively coupled to a second input (not shown) of the memory controller **14**.

FIG. **5** shows another example method **200** of using at least one memory module **10** in accordance with certain embodiments described herein. At block **202**, the method **200** may include providing a memory module **10** comprising at least one output **12** operatively coupled to a memory controller **14** of a host computer system **16**. The memory module **10** may be configured to operate in at least two modes comprising an initialization mode, during which the memory module **10** executes at least one initialization sequence, and an operational mode.

The method **200** can further include causing the memory module **10** to enter the initialization mode at block **204**. At block **206**, the method **200** can include receiving a notification signal from the at least one output **12** of the memory module **10**. The notification signal may indicate that the memory module **10** has completed the initialization sequence, for example. In certain embodiments, the method **200** further comprises executing an interrupt routine by the memory controller **14** in response to the notification signal.

Terminology/Alternative Embodiments

Embodiments have been described in connection with the accompanying drawings. However, it should be understood that the figures are not drawn to scale. Distances, angles, etc. are merely illustrative and do not necessarily bear an exact relationship to actual dimensions and layout of the devices illustrated. In addition, the foregoing embodiments have been described at a level of detail to allow one of ordinary skill in the art to make and use the devices, systems, etc. described herein. A wide variety of variation is possible. Components, elements, and/or steps can be altered, added, removed, or rearranged. While certain embodiments have been explicitly described, other embodiments will become apparent to those of ordinary skill in the art based on this disclosure.

Conditional language used herein, such as, among others, "can," "could," "might," "may," "e.g.," and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

Depending on the embodiment, certain acts, events, or functions of any of the methods described herein can be performed in a different sequence, can be added, merged, or left out all together (e.g., not all described acts or events are necessary for the practice of the method). Moreover, in certain embodiments, acts or events can be performed concurrently, e.g., through multi-threaded processing, interrupt processing, or multiple processors or processor cores, rather than sequentially.

The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein can be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, cir-

cuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. The described functionality can be implemented in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the disclosure.

The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein can be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor can be a microprocessor, but in the alternative, the processor can be any conventional processor, controller, microcontroller, or state machine. A processor can also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The blocks of the methods and algorithms described in connection with the embodiments disclosed herein can be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other form of computer-readable storage medium known in the art. An exemplary storage medium is coupled to a processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium can be integral to the processor. The processor and the storage medium can reside in an ASIC. The ASIC can reside in a user terminal. In the alternative, the processor and the storage medium can reside as discrete components in a user terminal.

Certain embodiments described herein are compatible with a memory system including memory devices with various attributes (see, e.g., FIGS. **2** and **3**). For example, the memory system of certain embodiments may include various data slice sizes (e.g., two, four, eight, or 16 bit data slices) and corresponding memories (e.g., memories having two, four, eight, or 16 bit data widths).

Although certain embodiments and examples are discussed above, it is understood that the inventive subject matter extends beyond the specifically disclosed embodiments to other alternative embodiments and/or uses of the invention and obvious modifications and equivalents thereof. It is intended that the scope of the inventions disclosed herein should not be limited by the particular disclosed embodiments. Thus, for example, in any method or process disclosed herein, the acts or operations making up the method/process may be performed in any suitable sequence and are not necessarily limited to any particular disclosed sequence.

Various aspects and advantages of the embodiments have been described where appropriate. It is to be understood that not necessarily all such aspects or advantages may be achieved in accordance with any particular embodiment. Thus, for example, it should be recognized that the various embodiments may be carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other aspects or advantages as may be taught or suggested herein.

The invention claimed is:

1. A memory module operable with a memory controller of a host computer system in an operational mode in which the memory module performs memory operations in response to memory commands from the memory controller in accordance with an industry standard, the memory module comprising:

a controller circuit configured to cause the memory module to enter an initialization mode in response to a command from the host computer system, the memory module executing at least one initialization sequence during the initialization mode;

at least one output having a defined function in the operational mode according to the industry standard but is undefined by the industry standard in the initialization mode; and

a notification circuit to output a notification signal indicating a status of the initialization mode to the memory controller via the at least one output.

2. The memory module of claim **1**, wherein the at least one status comprises completion of the at least one initialization sequence.

3. The memory module of claim **1**, wherein the at least one status comprises execution of the at least one initialization sequence.

4. The memory module of claim **1**, wherein the at least one notification signal triggers the memory controller to execute an interrupt routine.

5. The memory module of claim **1**, wherein the at least one output comprises an error-out pin of the memory module.

6. The memory module of claim **1**, wherein the notification circuit is configured to drive the at least one output to a first state indicative of execution of the at least one initialization sequence or to a second state indicative of completion of the at least one initialization sequence.

7. A method performed by a memory controller coupled to at least a first memory module, the first memory module configured to perform memory operations in response to memory commands from the memory controller in accordance with an industry standard while operating in a first mode, the method comprising:

outputting a command to the first memory module to cause the first memory module to operate in a second mode so as to execute an internal procedure, whereby the memory controller hands off control of the internal procedure to the first memory module;

receiving a notification signal via at least one input of the memory controller indicating a status of the internal procedure, the at least one input of the memory controller being coupled to at least one output of the first memory module, the at least one output of the first memory module having a defined function according to the industry standard while the first memory module is operating in the first mode but is undefined by the industry standard while the first memory module is operating in the second mode; and

resuming memory operations by issuing memory commands to the first memory module after receiving the notification signal.

8. The method of claim **7**, wherein the memory controller enters a "Wait" state while the memory module executes the internal procedure and exits the "Wait" state in response to receiving the notification signal.

9. The method of claim **7**, wherein the notification signal indicates completion of the internal procedure.

10. The method of claim **7**, wherein the memory controller is further coupled to a second memory module, the method

further comprising: outputting a command to the second memory module to cause the second memory module to execute an internal procedure after receiving the notification signal and before resuming memory operations.

11. The method of claim **7**, wherein the at least one first output of the first memory module is an error-out pin of the first memory module.

12. A memory module operable with a memory controller of a host computer system in a first mode in which the memory module performs memory operations in response to memory commands from the memory controller in accordance with an industry standard, the memory module comprising:

a module controller circuit configured to cause the memory module to operate in a second mode in response to a command to execute an internal procedure from the host computer system;

at least one output having a defined function in the first mode according to the industry standard but is undefined by the industry standard in the second mode; and

a notification circuit to output a notification signal indicating a status of the at least one internal procedure to the memory controller via the at least one output.

13. The memory module of claim **12**, wherein the at least one status indicates completion of the internal procedure.

14. The memory module of claim **12**, wherein the notification circuit is configured to drive the at least one output to a first state indicative of execution of the at least one internal procedure or to a second state indicative of completion of the internal procedure.

15. The memory module of claim **12**, wherein the at least one notification signal is an open-drain signal.

16. The memory module of claim **12**, wherein the at least one output comprises an error-out pin of the memory module.

17. The memory module of claim **12**, wherein the memory controller hands off control of to the module controller circuit by issuing the command to execute the internal procedure.

18. The memory module of claim **12**, wherein the module controller circuit is configured to process address and command signals from the memory controller in the first mode.

19. The memory module of claim **12**, wherein the notification circuit comprises a first input corresponding to the first mode, a second input corresponding to the second mode, and a multiplexor selecting between the first input and the second input based on whether the memory module is in the first mode or the second mode.

20. The method of claim **7**, wherein the at least one input of the memory controller is also coupled to at least one output of a second memory module, the at least one output of the second memory module having a defined function according to the industry standard while the second memory module is operating in a third mode but is undefined by the industry standard while the second memory module is operating in a fourth mode, the second memory module in the third mode being configured to perform memory operations in response to memory commands from the memory controller in accordance with the industry standard, the second memory module being configured to execute an internal procedure in the fourth mode, and wherein the notification signal indicates completion of the internal procedure at the first memory module and completion of the internal procedure at the second memory module.

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