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### Modification of program voltage level with read or program-verify adjustment for improving reliability in memory devices

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#### Abstract

A method for receiving a request for performing a programming operation on one or more memory blocks of a memory device, identifying a value of a media endurance metric associated with the one or more memory blocks, determining a programming voltage offset corresponding to the value of the media endurance metric, and performing, using the programming voltage offset, the programming operation on the one or more memory blocks. The method further includes identifying a program-verify voltage level associated with the one or more memory blocks, determining a program-verify voltage offset associated with the program-verify voltage level and the value of the media endurance metric, and performing, using the program-verify voltage level and the program-verify voltage offset, a program-verify operation on the one or more memory blocks.

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## Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS (1) This patent application claims priority of Provisional patent application Ser. No. 63/445,812, titled “MODIFICATION OF PROGRAM VOLTAGE LEVEL WITH READ OR PROGRAM-VERIFY ADJUSTMENT FOR IMPROVING RELIABILITY IN MEMORY DEVICES,” filed on Feb. 15, 2023, the entire contents of which is incorporated herein by reference.

## TECHNICAL FIELD

(1) Embodiments of the disclosure are generally related to memory sub-systems, and more specifically, are related determining voltage offsets for read and program-verify operations.

## BACKGROUND

(2) A memory sub-system can include one or more memory devices that store data. The memory devices can be, for example, non-volatile memory devices and volatile memory devices. In general, a host system can utilize a memory sub-system to store data at the memory devices and to retrieve data from the memory devices.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) The present disclosure will be understood more fully from the detailed description given below and from the accompanying drawings of some embodiments of the disclosure.

(2) FIG. 1 illustrates an example computing system that includes a memory sub-system in accordance with some embodiments of the present disclosure.

(3) FIG. 2 schematically illustrates example metadata maintained by the memory sub-system controller for associating blocks with voltage bins, in accordance with embodiments of the present disclosure.

(4) FIG. 3 illustrates an example method of calibrating voltage bins of a memory device based on threshold voltage offset of blocks approaching a transition boundary between voltage bins, in accordance with one or more aspects of the present disclosure.

(5) FIG. 4 schematically illustrates a method for adjusting a program voltage based on the number of program-erase cycles (PEC) performed on memory blocks of a memory device, in accordance with one or more aspects of the present disclosure.

(6) FIG. 5 illustrates a look-up table (LUT) stored in a memory sub-system controller for adjusting program and read voltage offsets based at least on the number of program-erase cycles (PEC) performed on memory blocks of a memory device, in accordance with some embodiments of the present disclosure.

(7) FIGS. 6A and 6B illustrate example operations in a method for determining a voltage offset for performing a read operation on memory blocks of a memory device, in accordance with one or more aspects of the present disclosure.

(8) FIG. 7 illustrates a look-up table (LUT) stored in a memory sub-system controller for adjusting program and program-verify voltage offsets based at least on the number of program-erase cycles (PEC) performed on memory blocks of a memory device, in accordance with some embodiments of the present disclosure.

(9) FIGS. 8A and 8B illustrate example operations in a method for determining a voltage offset for performing a program-verify operation on memory blocks of a memory device, in accordance with one or more aspects of the present disclosure.

(10) FIG. 9 is a flow diagram of an example method for adjusting voltage offsets of read, program, and program-verify operations performed on memory blocks of a memory device, in accordance with one or more aspects of the present disclosure.

(11) FIG. 10 illustrates an example machine of a computer system within which a set of instructions, for causing the machine to perform any one or more of the methodologies discussed herein, can be executed.

### DETAILED DESCRIPTION

(12) Embodiments of the present disclosure are directed to methods and systems for adjusting voltage offsets of read, program, and program-verify operations based on values of a chosen media endurance metric (e.g., number of program-erase cycles (PEC)) of a memory device. A memory

sub-system can be a storage device, a memory module, or a hybrid of a storage device and memory module. Examples of storage devices and memory modules are described below in conjunction with FIG. 1. In general, a host system can utilize a memory sub-system that includes one or more components, such as memory devices that store data. The host system can provide data to be stored at the memory sub-system and can request data to be retrieved from the memory sub-system.

(13) A memory sub-system can utilize one or more memory devices, including any combination of the different types of non-volatile memory devices and/or volatile memory devices, to store the data provided by the host system. In some embodiments, non-volatile memory devices can be provided by not-and (NAND) type flash memory devices. Other examples of non-volatile memory devices are described below in conjunction with FIG. 1. A non-volatile memory device is a package of one or more dies. Each die can consist of one or more planes. Planes can be grouped into logic units (LUN). For some types of non-volatile memory devices (e.g., NAND devices), each plane consists of a set of physical blocks. A “block” herein shall refer to a set of contiguous or non-contiguous memory pages. An example of a “block” is an “erasable block,” which is a minimal erasable unit of memory, while “page” is a minimal writable unit of the memory device. Each page includes of a set of memory cells. A memory cell is an electronic circuit that stores information.

(14) Data operations can be performed by the memory sub-system. The data operations can be host-initiated operations. For example, the host system can initiate a data operation (e.g., write, read, erase, etc.) on a memory sub-system. The host system can send access requests (e.g., write command, read command) to the memory sub-system, such as to store data on a memory device at the memory sub-system and to read data from the memory device on the memory sub-system. The data to be read or written, as specified by a host request, is hereinafter referred to as “host data.” A host request can include logical address information (e.g., logical block address (LBA), namespace) for the host data, which is the location the host system associates with the host data. The logical address information (e.g., LBA, namespace) can be part of metadata for the host data. Metadata can also include error handling data (e.g., error correction code (ECC), parity code), data version (e.g., used to distinguish age of data written), valid bitmap (which LBAs or logical transfer units contain valid data), etc. For example, upon reading data from a memory device, the memory sub-system controller can perform an error detection and correction operation. The error detection and correction operation includes identifying one or more errors (e.g., bit flip errors) in the read data. The memory sub-system can have the ability to correct a certain number of errors per management unit (e.g., using an error correction code (ECC)). As long as the number of errors in the management unit is within the ECC capability of the memory sub-system, the errors can be corrected before the data is provided to the requestor (e.g., the host system). The fraction of bits that contain incorrect data before applying ECC is called the raw bit error rate (RBER). The fraction of bits that contain incorrect data after applying ECC is called the uncorrectable bit error rate (UBER).

(15) A memory device includes multiple memory cells, each of which can store, depending on the memory cell type, one or more bits of information. A memory cell can be programmed (written to) by applying a certain voltage to the memory cell, which results in an electric charge being held by the memory cell, thus allowing modulation of the voltage distributions produced by the memory cell. Moreover, precisely controlling the amount of the electric charge stored by the memory cell allows the establishment of multiple threshold voltage levels corresponding to different logical levels, thus effectively allowing a single memory cell to store multiple bits of information. For example, a memory cell operated with  $2^n$  different threshold voltage levels is capable of storing  $n$  bits of information. Thus, the read operation can be performed by comparing the measured voltage exhibited by the memory cell to one or more reference read voltage levels in order to distinguish between two logical levels for single-level cells and between multiple logical levels for multi-level cells. The read reference voltages and the state widths of the threshold voltage distributions determine the edge margins available. The even edges determine the margin for program disturb

and over-program, while the odd edges determine the margin for charge loss. The sum of all edge margins is usually defined as the read window budget (RWB). Therefore, a larger window allows larger margins, e.g., to read the cell correctly in the event of charge loss or disturb/over-program. (16) The reliability of a NAND device, however, decreases with increase in program-erase cycles (PEC). In order to maintain the reliability, some NAND devices employ a step decrease in program voltage based on the number of PEC performed on the memory device. For example, memory blocks with lower number of PEC may employ a larger program voltage offset while memory blocks with higher number of PEC may employ a lower program voltage offset to maintain reliability. Additionally, larger program voltage offsets result in wider threshold voltage distributions and smaller program voltage offset result in tighter threshold voltage distributions, thereby improving reliability of blocks with a high number of PECs. However, this increases the time needed to perform the program operation because more program pulses would be needed to perform the same amount of programming. Additionally, a step decrease in program voltage may also result in an edge sum gain of RWB and lower ideal RBER. For example, the threshold voltage distribution may be aligned at the left edge rather than the center, resulting in even larger edge margin on the left side and slightly smaller edge margin on the right side. This imbalance between even and odd edges may also cause reliability and data retention issues.

(17) Embodiments of the present disclosure address the above-noted and other deficiencies by implementing a memory sub-system that applies a read level adjustment in addition to a step decrease in program voltage associated with a media endurance metric (e.g., the number of PEC) of the memory device. The voltage offset values used for adjusting the read level voltage and/or the program voltage can be stored in the metadata of the memory device, which may be initialized during manufacture of the memory device. In one implementation, the voltage offset values used for adjusting the read level voltage and/or the program voltage can be stored in a look-up table (LUT) that may be stored in the metadata of the memory device. The voltage offset values used for adjusting the read level voltage and/or the program voltage can be determined using threshold voltage ( $V_t$ ) data that may be collected by performing program operations on the wordlines of the memory device, and generating corresponding threshold voltage ( $V_t$ ) curves, which may be used to determine the voltage offset values. The values may then be stored in the metadata of the memory device, which may be initialized during the manufacturing process.

(18) In some embodiments, the memory sub-system applies a program-verify level adjustment in addition to a step decrease in program voltage associated with a media endurance metric (e.g., the number of PEC) of the memory device. The voltage offset values used for adjusting the program-verify level voltage and/or the program voltage can be stored in the metadata of the memory device, which may be initialized during manufacture of the memory device. In one implementation, the voltage offset values used for adjusting the program-verify level voltage and/or the program voltage can be stored in a look-up table (LUT) that may be stored in the metadata of the memory device. The voltage offset values used for adjusting the program-verify level voltage and/or the program voltage can be determined using threshold voltage ( $V_t$ ) data that may be collected by performing one or more program operations on one or more wordlines of the memory device, and generating corresponding threshold voltage ( $V_t$ ) curves, which may be used to determine the voltage offset values. The values may then be stored in the metadata of the memory device, which may be initialized upon manufacture.

(19) Therefore, advantages of the systems and methods implemented in accordance with some embodiments of the present disclosure include, but are not limited to, improving RBER and reliability for memory blocks with high PECs. The methods disclosed can also improve system performance by reducing folding activities after data retention. The systems and methods disclosed can also slow the process of degradation such that memory blocks reach higher voltage bins slower when compared to the current method of using only step decrease in program voltage.

(20) FIG. 1 illustrates an example computing system **100** that includes a memory sub-system **110** in

accordance with some embodiments of the present disclosure. The memory sub-system **110** can include media, such as one or more volatile memory devices (e.g., memory device **140**), one or more non-volatile memory devices (e.g., memory device **130**), or a combination of such.

(21) A memory sub-system **110** can be a storage device, a memory module, or a hybrid of a storage device and memory module. Examples of a storage device include a solid-state drive (SSD), a flash drive, a universal serial bus (USB) flash drive, an embedded Multi-Media Controller (eMMC) drive, a Universal Flash Storage (UFS) drive, a secure digital (SD) card, and a hard disk drive (HDD). Examples of memory modules include a dual in-line memory module (DIMM), a small outline DIMM (SO-DIMM), and various types of non-volatile dual in-line memory module (NVDIMM).

(22) The computing system **100** can be a computing device such as a desktop computer, laptop computer, network server, mobile device, a vehicle (e.g., airplane, drone, train, automobile, or other conveyance), Internet of Things (IoT) enabled device, embedded computer (e.g., one included in a vehicle, industrial equipment, or a networked commercial device), or such computing device that includes memory and a processing device (e.g., a processor).

(23) The computing system **100** can include a host system **120** that is coupled to one or more memory sub-systems **110**. In some embodiments, the host system **120** is coupled to different types of memory sub-systems **110**. FIG. 1 illustrates one example of a host system **120** coupled to one memory sub-system **110**. As used herein, “coupled to” or “coupled with” generally refers to a connection between components, which can be an indirect communicative connection or direct communicative connection (e.g., without intervening components), whether wired or wireless, including connections such as electrical, optical, magnetic, etc.

(24) The host system **120** can include a processor chipset and a software stack executed by the processor chipset. The processor chipset can include one or more cores, one or more caches, a memory controller (e.g., NVDIMM controller), and a storage protocol controller (e.g., PCIe controller, SATA controller). The host system **120** uses the memory sub-system **110**, for example, to write data to the memory sub-system **110** and read data from the memory sub-system **110**.

(25) The host system **120** can be coupled to the memory sub-system **110** via a physical host interface. Examples of a physical host interface include, but are not limited to, a serial advanced technology attachment (SATA) interface, a peripheral component interconnect express (PCIe) interface, universal serial bus (USB) interface, Fibre Channel, Serial Attached SCSI (SAS), a double data rate (DDR) memory bus, Small Computer System Interface (SCSI), a dual in-line memory module (DIMM) interface (e.g., DIMM socket interface that supports Double Data Rate (DDR)), Open NAND Flash Interface (ONFI), Double Data Rate (DDR), Low Power Double Data Rate (LPDDR), etc. The physical host interface can be used to transmit data between the host system **120** and the memory sub-system **110**. The host system **120** can further utilize an NVM Express (NVMe) interface to access components (e.g., memory devices **130**) when the memory sub-system **110** is coupled with the host system **120** by the PCIe interface. The physical host interface can provide an interface for passing control, address, data, and other signals between the memory sub-system **110** and the host system **120**. FIG. 1 illustrates a memory sub-system **110** as an example. In general, the host system **120** can access multiple memory sub-systems via a same communication connection, multiple separate communication connections, and/or a combination of communication connections.

(26) The memory devices **130**, **140** can include any combination of the different types of non-volatile memory devices and/or volatile memory devices. The volatile memory devices (e.g., memory device **140**) can be, but are not limited to, random access memory (RAM), such as dynamic random access memory (DRAM) and synchronous dynamic random access memory (SDRAM).

(27) Some examples of non-volatile memory devices (e.g., memory device **130**) include negative- and (NAND) type flash memory and write-in-place memory, such as a three-dimensional cross-

point (“3D cross-point”) memory device, which is a cross-point array of non-volatile memory cells. A cross-point array of non-volatile memory can perform bit storage based on a change of bulk resistance, in conjunction with a stackable cross-gridded data access array. Additionally, in contrast to many flash-based memories, cross-point non-volatile memory can perform a write in-place operation, where a non-volatile memory cell can be programmed without the non-volatile memory cell being previously erased. NAND type flash memory includes, for example, two-dimensional NAND (2D NAND) and three-dimensional NAND (3D NAND).

(28) Each of the memory devices **130** can include one or more arrays of memory cells. One type of memory cell, for example, single level cells (SLC) can store one bit per cell. Other types of memory cells, such as multi-level cells (MLCs), triple level cells (TLCs), and quad-level cells (QLCs), can store multiple bits per cell. In some embodiments, each of the memory devices **130** can include one or more arrays of memory cells such as SLCs, MLCs, TLCs, QLCs, or any combination of such. In some embodiments, a particular memory device can include an SLC portion, and an MLC portion, a TLC portion, or a QLC portion of memory cells. The memory cells of the memory devices **130** can be grouped as pages that can refer to a logical unit of the memory device used to store data. With some types of memory (e.g., NAND), pages can be grouped to form blocks.

(29) Although non-volatile memory devices such as 3D cross-point array of non-volatile memory cells and NAND type memory (e.g., 2D NAND, 3D NAND) are described, the memory device **130** can be based on any other type of non-volatile memory, such as read-only memory (ROM), phase change memory (PCM), self-selecting memory, other chalcogenide based memories, ferroelectric transistor random-access memory (FeTRAM), ferroelectric random access memory (FeRAM), magneto random access memory (MRAM), Spin Transfer Torque (STT)-MRAM, conductive bridging RAM (CBRAM), resistive random access memory (RRAM), oxide based RRAM (OxRAM), negative-or (NOR) flash memory, and electrically erasable programmable read-only memory (EEPROM).

(30) A memory sub-system controller **115** (or controller **115** for simplicity) can communicate with the memory devices **130** to perform operations such as reading data, writing data, or erasing data at the memory devices **130** and other such operations. The memory sub-system controller **115** can include hardware such as one or more integrated circuits and/or discrete components, a buffer memory, or a combination thereof. The hardware can include digital circuitry with dedicated (i.e., hard-coded) logic to perform the operations described herein. The memory sub-system controller **115** can be a microcontroller, special purpose logic circuitry (e.g., a field programmable gate array (FPGA), an application specific integrated circuit (ASIC), etc.), or other suitable processor.

(31) The memory sub-system controller **115** can include a processor **117** (e.g., processing device) configured to execute instructions stored in a local memory **119**. In the illustrated example, the local memory **119** of the memory sub-system controller **115** includes an embedded memory configured to store instructions for performing various processes, operations, logic flows, and routines that control operation of the memory sub-system **110**, including handling communications between the memory sub-system **110** and the host system **120**.

(32) In some embodiments, the local memory **119** can include memory registers storing memory pointers, fetched data, etc. The local memory **119** can also include read-only memory (ROM) for storing micro-code. While the example memory sub-system **110** in FIG. 1 has been illustrated as including the controller **115**, in another embodiment of the present disclosure, a memory sub-system **110** does not include a controller **115**, and can instead rely upon external control (e.g., provided by an external host, or by a processor or controller separate from the memory sub-system).

(33) In general, the memory sub-system controller **115** can receive commands or operations from the host system **120** and can convert the commands or operations into instructions or appropriate commands to achieve the desired access to the memory devices **130**. The memory sub-system

controller **115** can be responsible for other operations such as wear leveling operations, garbage collection operations, error detection and error-correcting code (ECC) operations, encryption operations, caching operations, and address translations between a logical address (e.g., logical block address (LBA), namespace) and a physical address (e.g., physical block address) that are associated with the memory devices **130**. The memory sub-system controller **115** can further include host interface circuitry to communicate with the host system **120** via the physical host interface. The host interface circuitry can convert the commands received from the host system into command instructions to access the memory devices **130** as well as convert responses associated with the memory devices **130** into information for the host system **120**.

(34) In some implementations, memory sub-system **110** can use a striping scheme, according to which every the data payload (e.g., user data) utilizes multiple dies of the memory devices **130** (e.g., NAND type flash memory devices), such that the payload is distributed through a subset of dies, while the remaining one or more dies are used to store the error correction information (e.g., parity bits). Accordingly, a set of blocks distributed across a set of dies of a memory device using a striping scheme is referred herein to as a “superblock.”

(35) The memory sub-system **110** can also include additional circuitry or components that are not illustrated. In some embodiments, the memory sub-system **110** can include a cache or buffer (e.g., DRAM) and address circuitry (e.g., a row decoder and a column decoder) that can receive an address from the controller **115** and decode the address to access the memory devices **130**.

(36) In some embodiments, the memory devices **130** include local media controllers **135** that operate in conjunction with memory sub-system controller **115** to execute operations on one or more memory cells of the memory devices **130**. An external controller (e.g., memory sub-system controller **115**) can externally manage the memory device **130** (e.g., perform media management operations on the memory device **130**). In some embodiments, a memory device **130** is a managed memory device, which is a raw memory device combined with a local controller (e.g., local controller **135**) for media management within the same memory device package. An example of a managed memory device is a managed NAND (MNAND) device.

(37) The memory sub-system **110** includes a memory access manager **113**, which can be used to implement techniques for applying a read level adjustment in addition to a step decrease in program voltage based on the number of PEC performed on the memory device. In some embodiments, the memory access manager **113** may implement a counter (e.g., a PEC counter), which may be incremented every time a program-erase operation is performed on one or more blocks of the memory device. The counter may be stored in the metadata of the memory device, and may be updated each time a program-erase operation is performed on one or more blocks of the memory device. In some embodiments, the memory access manager **113** may receive a request for performing a program operation on one or more blocks of memory device **130**. The memory access manager **113** may then determine, using the counter, the number of PECs that have been performed on the blocks of memory device **130**. Depending on the number of PECs, the memory access manager **113** may assign a voltage offset for performing the program operation. In one implementation, the memory access manager **113** may assign a larger program voltage offset to memory blocks with lower number of PECs and assign a lower program voltage offset to memory blocks with larger number of PECs. In some embodiments, the memory access manager **113** may access an offset look-up table (LUT) that may be stored on one or more memory devices **130**. In some implementations, at least part of the offset LUT can be cached in the local memory **119** of the memory sub-system controller **115**. The offset LUT can be indexed by a trim, which may include one or more blocks sharing a common characteristic (e.g., a wordline group or a voltage bin number), and a record of the offset LUT specifies a read operation threshold voltage offset associated with a media endurance metric (e.g., a number of PECs) of the memory blocks. In one implementation, the offset LUT may categorize memory blocks based on the number of PECs performed on the block. For example, the offset LUT may categorize memory blocks having PECs



of less than Q cycles (e.g., **3000** PECs) in a first column of the offset LUT, between Q cycles and R cycles in a second column, between R cycles and S cycles in a third column, between S cycles and T cycles in a fourth column, and some more than T cycles (e.g., **5000** PECs) in a fifth column, and so on and so forth. The memory access manager **113** may use this offset LUT for adjusting program and read voltage offsets in the memory device.

(38) In some embodiments, the memory access manager **113** may receive a request for performing a program operation on one or more blocks of the memory device. The memory access manager **113** may then identify, based on the PEC counter stored in the metadata of the memory device, the number of PECs that have been performed on the blocks of the memory device, and based on the number of PECs, the memory access manager **113** may assign a voltage offset for performing the program operation on a wordline group. The memory access manager **113** may chose a value for the voltage offset from the offset LUT, which may be in the form of a matrix defined by the number of PECs (columns) and the trim (rows). The “trim” may include one or more blocks sharing a common characteristic (e.g., wordline group or voltage bin). In other words, each voltage offset value in the offset LUT is a vector defined by the trim (e.g., wordline group or voltage bin) (row) and the number of PECs (column). The memory access manager **113** may then perform the program operation on the memory blocks of the wordline group **506** using a program voltage adjusted for the voltage offset identified using the offset LUT. For example, if the program voltage is 1.0V and the offset value according to the LUT is -0.5V, then the adjusted program voltage that is used for performing the program operation is 0.5V (1.0V-0.5V). In some embodiments, the memory access manager **113** may, using the LUT, identify a read level associated with a voltage bin of the memory blocks in memory device. Based on the read level of the voltage bin (e.g., Read levels 0-7) and the number of PECs performed on the memory blocks, the memory access manager **113** may assign a read voltage offset (from the LUT) in addition to the program voltage offset.

(39) The memory access manager **113** may then perform the read operation on the memory blocks of memory device using a read voltage adjusted for the assigned read voltage offset.

(40) In some embodiments, the voltage offset values used for adjusting the read level voltage and/or the program voltage can be stored in the metadata of the memory device, which may be initialized during manufacture of the memory device. The voltage offset values can be determined using threshold voltage ( $V_t$ ) data that may be collected by performing one or more program operations on one or more wordlines of the memory device, and generating corresponding threshold voltage ( $V_t$ ) curves, which may be used to determine the voltage offset values. The values may then be stored in the metadata of the memory device, which may be initialized upon manufacture.

(41) In one implementation, the read voltage offset may be determined by computing, during or upon manufacture of the memory device, a distance between a first edge of a first threshold voltage distribution valley associated with the voltage bin and a second edge of a subsequent threshold voltage distribution valley, and determining the read voltage offset based on a difference between the read level associated with the voltage bin and a center of the distance between the first edge and the second edge.

(42) In some embodiment, the memory access manager **113** may implement techniques for applying a program-verify level adjustment in addition to a step decrease in program voltage based on the number of PEC performed on the memory device. The memory access manager **113** may receive a request for performing a program operation on one or more blocks of memory device **130**. The memory access manager **113** may then determine, using the counter, the number of PECs that have been performed on the blocks of memory device **130**. Depending on the number of PECs, the memory access manager **113** may assign a voltage offset for performing the program operation. In some embodiments, the memory access manager **113** may access an offset look-up table (LUT) that may be stored on one or more memory devices **130**. In some implementations, at least part of the offset LUT can be cached in the local memory **119** of the memory sub-system controller **115**.

The offset LUT can be indexed by a trim (e.g., a wordline group or a voltage bin number), and a record of the offset LUT specifies a program-verify operation threshold voltage offset associated with a media endurance metric (e.g., a number of PECs) of the memory blocks. In one implementation, the offset LUT may categorize memory blocks based on the number of PECs performed on the block. The memory access manager **113** may use this offset LUT for adjusting program and program-verify voltage offsets in the memory device.

(43) In some embodiments, the memory access manager **113** may receive a request for performing a program operation on one or more blocks of the memory device. The memory access manager **113** may then identify, based on the PEC counter stored in the metadata of the memory device, the number of PECs that have been performed on the blocks of the memory device, and based on the number of PECs, the memory access manager **113** may assign a voltage offset for performing the program operation on a wordline group. The memory access manager **113** may choose a value for the voltage offset from the offset LUT, which is vectorized by number of PECs and the trim (e.g., wordline group or voltage bin). In other words, each voltage offset value in the offset LUT is a vector defined by the trim (e.g., wordline group or voltage bin) and the number of PECs. The memory access manager **113** may then perform the program operation on the memory blocks of the wordline group **506** using a program voltage adjusted for the voltage offset identified using the offset LUT. In some embodiments, the memory access manager **113** may, using the LUT, identify a program-verify level associated with a voltage bin of the memory blocks in memory device. Based on the program-verify level of the voltage bin (e.g., Program-verify levels 0-7) and the number of PECs performed on the memory blocks, the memory access manager **113** may assign a program-verify voltage offset in addition to the program voltage offset. The memory access manager **113** may then perform the program-verify operation on the memory blocks of memory device using a program-verify voltage adjusted for the assigned program-verify voltage offset.

(44) In some embodiments, the voltage offset values used for adjusting the program-verify level voltage and/or the program voltage can be stored in the metadata of the memory device, which may be initialized during manufacture of the memory device. The voltage offset values can be determined using threshold voltage ( $V_t$ ) data that may be collected by performing one or more program operations on one or more wordlines of the memory device, and generating corresponding threshold voltage ( $V_t$ ) curves, which may be used to determine the voltage offset values. The values may then be stored in the metadata of the memory device, which may be initialized upon manufacture. In one implementation, the program-verify voltage offset can be determined by aligning a first center of a first threshold voltage distribution valley applying the program voltage offset with a second center of the first threshold voltage distribution valley without applying the program voltage offset, and determining the program-verify voltage offset based on a difference between the program-verify voltage level associated with the voltage bin and a second edge of the first threshold voltage distribution valley applying the program voltage offset.

(45) FIG. 2 schematically illustrates example metadata maintained by the memory sub-system controller **115** for associating blocks and/or partitions with voltage bins, in accordance with embodiments of the present disclosure. As schematically illustrated by FIG. 2, the memory sub-system controller can maintain the superblock table **210**, the block table **220**, and the offset table **230**. Each record of the superblock table **210** specifies the block associated with the specified superblock and partition combination. In some implementations, the superblock table records can further include time and temperature values associated with the specified superblock and partition combination.

(46) The block table **220** is indexed by the block number, such that each record of the block table **220** specifies, for the block referenced by the index of the record, a set of voltage bins associated with respective dies of the block. In other words, each record of the block table **220** includes a vector, each element of which specifies the voltage bin associated with the die referenced by the index of the vector element.

(47) Finally, the offset table **230** is indexed by the bin number. A record of the offset table **230** specifies a set of read operation threshold voltage offsets (e.g., for TLC, MLC, and/or SLC) associated with a voltage bin. Another record specifies a set of bin determination threshold voltage offsets (e.g., for TLC, MLC, and/or SLC) associated with the voltage bin. The metadata tables **210-230** can be stored on one or more memory devices **130** of FIG. **1**. In some implementations, at least part of the metadata tables can be cached in the local memory **119** of the memory sub-system controller **115** of FIG. **1**.

(48) In operation, upon receiving a read command, the memory sub-system controller determines the physical address corresponding to the logical block address (LBA) specified by the read command. Components of the physical address, such as the physical block number and the die identifier, are utilized for performing the metadata table walk: first, the superblock table **210** is used to identify the block identifier corresponding to the physical block number; then, the block identifier is used as the index to the block table **220** in order to determine the voltage bin associated with the block and the die; finally, the identified voltage bin is used as the index to the offset table **230** in order to determine the read operation threshold voltage offset and the bin determination threshold voltage offset corresponding to the bin. The memory sub-system controller can then additively apply the identified read operation threshold voltage offset to the base voltage read level in order to perform the requested read operation.

(49) In the illustrative example of FIG. **2**, the superblock table **210** maps partition 0 of the superblock 0 to block 4, which is utilized as the index to the block table **220** in order to determine that die 0 is mapped to voltage bin 3. The latter value is used as the index to the offset table in order to determine the threshold voltage offset values for voltage bin 3.

(50) FIG. **3** illustrates an example method of calibrating voltage bins of a memory device based on threshold voltage offset of blocks approaching a transition boundary between voltage bins, in accordance with one or more aspects of the present disclosure. Method **300** may be performed by processing logic that includes hardware (e.g., circuitry, dedicated logic, programmable logic, microcode, etc.), software (e.g., instructions run on a processor to perform hardware simulation), or a combination thereof. In some embodiments, the method **300** is performed by memory access manager **113** of FIG. **1**. In one implementation, graph **310** schematically illustrates a set of voltage bins (e.g., bin 0 to bin 3), in accordance with embodiments of the present disclosure for a selected read level. Threshold voltage offset curve **315** illustrates the dependency of the threshold voltage offset, on the y-axis, on the time after program (which can be time normalized with respect to a particular temperature), the period of time elapsed since the block had been programmed, on the x-axis for the selected read level. In one implementation, blocks of the memory device that have been programmed within a specified time window are assigned to a voltage bin that corresponds to the time after program of the blocks. As noted herein above, given that wear-leveling can keep program/erase cycles similar on all blocks, the time elapsed after programming and temperature of the memory device are the main factors affecting the temporal voltage shift. Using normalized time takes into account the temperature profile and hence temperature information is incorporated. Accordingly, all blocks programmed within a specific time window (i.e., normalized time window) are presumed to exhibit similar distributions of threshold voltages in memory cells, and thus can be assigned to the same voltage bin and can utilize the same voltage offsets for read operations.

(51) In one implementation, a newly programmed block can be associated with bin 0. Then, the memory sub-system controller can periodically perform a foreground or background calibration process in order to associate each die of every block with one of the predefined threshold voltage bins (e.g., bins 0-3 in the illustrative example of FIG. **3**), which is in turn associated with the voltage offsets to be applied for read operations. The associations of blocks with voltage bins and dies can be stored in respective metadata tables maintained by the memory sub-system controller, as explained in more details herein with respect to FIG. **2**. The threshold voltage offset of FIG. **3** are associated with a single valley. The threshold voltage offset value become more negative going

down the y-axis, which corresponds to higher SCL. For each voltage bin, a separate threshold voltage offset can be assigned to each valley.

(52) As schematically illustrated by FIG. 3, graph **310** can be subdivided into multiple voltage bins **320**, such that each voltage bin corresponds to a predetermined range of threshold voltage offsets based on a corresponding range of TAP of the voltage bin. While the illustrative example of FIG. 3 defines four voltage bins, in other implementations, various other numbers of voltage bins can be employed (e.g., 7 bins or even 10 bins). Based on a periodically performed calibration process, the memory sub-system controller associates each die of every block with a voltage bin, which defines a set of threshold voltage offsets to be applied to the base voltage read level in order to perform read operations of data of the block, as described in more detail herein below.

(53) Graph **325** of FIG. 3 illustrates the process of calibrating voltage bins by assigning a threshold voltage offset to a voltage bin based on a threshold voltage offset of blocks approaching a transition boundary between voltage bins. In an implementation, a processing logic executing method **300** can determine a time after program (TAP) **330** corresponding to a transition boundary between bin 1 and bin 2. In an implementation, TAP **330** can be a specific value of time elapsed since programming a block. In other implementations, TAP **330** can be a range of values, such that a block having a TAP value that is within the TAP **330** range can be transitioned from voltage bin 1 to voltage bin 2.

(54) In certain implementations, the processing logic can determine a set of blocks assigned to voltage bin 1 that are approaching boundary TAP **330** between voltage bin 1 and voltage bin 2. As an example, the processing logic can determine the set of blocks having a TAP value that is within a predetermined distance from TAP **330**. When the set of blocks approaching the transition boundary corresponding to TAP **330** are determined, the processing logic can determine a threshold voltage offset that is efficient for read operations of the determined set of blocks, to be used as an initial threshold voltage offset for the selected read level of voltage bin 2. In an implementation, a set of efficient threshold voltage offsets (one for each valley) of the set of blocks can be determined by performing read operations of data stored at the set of blocks and determining a set of threshold voltage offsets that result in a minimum bit error rate of the read operations. When the set of threshold voltage offsets of the set of blocks is determined, the processing logic can assign the determined threshold voltage offset set as an initial value of the threshold voltage offsets of the selected read level of voltage bin 2. In an implementation, the processing logic can then assign blocks to voltage bin 2 and can utilize the initial value of the threshold voltage offsets to perform read operations of the newly assigned blocks that are associated with the selected read level. For each voltage bin, the set of read offsets includes one offset per valley, such as 7 offsets for TLC wordlines, for example. Page reads correspond to different valleys and as such can use corresponding read offsets. Read operations used to determine the set of read offsets can use different page types to cover all valleys.

(55) Similarly, the processing logic can determine a TAP **340** corresponding to a transition boundary between voltage bin 2 and voltage bin 3. In an implementation, TAP **340** can be a specific value of time elapsed since programming a block. In other implementations, TAP **340** can be a range of values, such that a block having a TAP value that is within the TAP **340** range can be transitioned from voltage bin 2 to voltage bin 3. In certain implementations, the processing logic can determine a set of blocks assigned to voltage bin 2 that are approaching boundary TAP **340** between voltage bin 2 and voltage bin 3. As an example, the processing logic can determine the set of blocks having a TAP value that is within a predetermined distance from TAP **340**. When the set of blocks approaching the transition boundary corresponding to TAP **340** are determined, the processing logic can determine a set of threshold voltage offsets that are efficient for read operations of the determined set of blocks, to be used as an initial set of threshold voltage offsets for the selected read level of voltage bin 3. When the set of threshold voltage offsets of the set of blocks is determined, the processing logic can assign the determined threshold voltage offset set as

an initial value of the threshold voltage offset of the selected read level of voltage bin 3. In an implementation, the processing logic can then assign blocks to voltage bin 3 and can utilize the initial values of the threshold voltage offset to perform read operations of the newly assigned blocks that are associated with the selected read level.

(56) FIG. 4 illustrates example methods **400**, **420** for adjusting program voltage based on the number of PECs performed on the memory device, in accordance with one or more aspects of the present disclosure. Methods **400**, **420** may be performed by processing logic that includes hardware (e.g., circuitry, dedicated logic, programmable logic, microcode, etc.), software (e.g., instructions run on a processor to perform hardware simulation), or a combination thereof. In some embodiments, methods **400**, **420** are performed by the memory access manager **113** of FIG. 1. In one implementation, the method **400**, **420** may include using a counter that may be incremented every time a program-erase operation (e.g., program-erase cycle (PEC)) is performed on one or more memory blocks of the memory device. The method **400** may further include assigning a program voltage offset **405** depending on the number of PECs already performed on the memory device. For example, blocks with low number of PECs (e.g., 3000 PEC or less) may be assigned a higher program voltage offset **405**. Similarly, in method **420**, blocks with high number of PECs (e.g., more than 3000 PEC) may be assigned a smaller program voltage offset **415**. As illustrated in FIG. 4, blocks with lower number of PECs tend to have wider threshold voltage ( $V_t$ ) distributions **410**, and blocks with higher number of PECs tend to have tighter threshold voltage ( $V_t$ ) distributions **425**. The program level adjustment can be determined using threshold voltage ( $V_t$ ) data collected by performing one or more program operations on one or more wordlines or a portion of a wordline, and generating corresponding threshold voltage ( $V_t$ ) curves. This process may be repeated several times over one or more wordlines in order to gather sufficient threshold voltage data, generate the threshold voltage distributions, and arrive at the voltage offset values.

(57) FIG. 5 illustrates an offset look-up table (LUT) **500**, stored in the metadata of the memory device, for adjusting program and read voltage offsets based at least on the number of program-erase cycles (PEC) performed on memory blocks of a memory device, in accordance with some embodiments of the present disclosure. The offset LUT **500** may be vectorized by number of PECs **504** and the trim **502** (e.g., wordline group or voltage bin). In other words, each voltage offset value **508** in the offset LUT **500** is a vector defined by the trim **502** (e.g., wordline group or voltage bin) and the number of PECs **504**. The LUT **500** may categorize the memory blocks based on the number of PECs **504**. For example, the LUT **500** may include memory blocks with PECs of less than Q (e.g., 3000) PECs, between Q and R, between R and S, between S and T, and some more than T (e.g., 5000) PECs. The memory sub-system controller may use this LUT for adjusting program and read voltage offsets in the memory device. In some embodiments, the memory access manager **113** may receive a request for performing a program operation on one or more blocks of the memory device. The memory access manager **113** may then identify the number of PECs **504** that have been performed on the blocks of memory device. Based on the number of PECs **504**, the memory access manager **113** may assign a voltage offset **508** for performing the program operation on a wordline group **506**. For example, the memory access manager **113** may assign a larger program voltage offset to memory blocks of a wordline group with lower number of PECs and assign a lower program voltage offset to memory blocks of a wordline group with larger number of PECs. The memory access manager **113** may then perform the program operation on the memory blocks of the wordline group **506** using a program voltage adjusted for the assigned program voltage offset **508**.

(58) In some embodiments, the memory access manager **113** may, using the LUT **500**, identify a read level **510** associated with a voltage bin of the memory blocks in memory device. Based on the read level **510** of the voltage bin (e.g., Read levels 0-7) and the number of PECs **504** performed on the memory blocks, the memory access manager **113** may assign a read voltage offset **512** in addition to the program voltage offset **508**. The memory access manager **113** may then perform the

read operation on the memory blocks of memory device using a read voltage adjusted for the assigned read voltage offset **512**.

(59) FIG. **6A** illustrates example operations in a method **600** for determining a voltage offset for performing a program operation on memory blocks of a memory device, in accordance with one or more aspects of the present disclosure. The curves illustrated in FIGS. **6A** and **6B** and the voltage offset values used for adjusting the read level voltage and/or the program voltage can be stored in the metadata of the memory device, which may be initialized during manufacture of the memory device. The voltage offset values can be determined using threshold voltage ( $V_t$ ) data that may be collected by performing one or more program operations on one or more wordlines of the memory device, and generating corresponding threshold voltage ( $V_t$ ) curves, which may be used to determine the voltage offset values. The values may then be stored in the metadata of the memory device, which may be initialized upon manufacture. In one implementation, method **600** includes generating threshold voltage distribution valleys **610** using a program voltage offset (e.g., offset **508**), and generating threshold voltage distribution valleys **620** without using a program voltage offset (e.g., offset **508**). First valley **610** has a first edge **670** and a second edge, and second valley **610** has a first edge and a second edge **660**. However, when only a program voltage offset is used, the read level voltage **630** is not synchronized with the program level voltage change. As a result, the margin e.sub.12 increases on one side of the read level and margin e.sub.13 shrinks on the other side of the read level. This may cause reliability and data retention issues in the memory device.

(60) FIG. **6B** illustrates example operations in a method **650** for determining a voltage offset for performing a read operation on memory blocks of a memory device, in accordance with one or more aspects of the present disclosure. The method **650** includes determining a new read voltage level **640** based on an offset (e.g.,  $e_{\text{sub.12}} + e_{\text{sub.13}}/2$ ) that is the average of the margin e.sub.12 on one side of the read level and margin e.sub.13 on the other side of the read level **630**. For example, the memory access manager **113** may determine a distance between a first edge **670** of a first threshold voltage distribution valley **610** associated with the voltage bin and a second edge **660** of a subsequent threshold voltage distribution valley **610**. The read voltage offset may be determined based on a difference between the read level **630** associated with the voltage bin and a center of the distance between the first edge **670** and the second edge **660**.

(61) FIG. **7** illustrates an offset look-up table (LUT) **700**, stored in the metadata of the memory device, for adjusting program and program-verify voltage offsets based at least on the number of program-erase cycles (PEC) **704** performed on memory blocks of a memory device, in accordance with some embodiments of the present disclosure. The offset LUT **700** may be vectorized by number of PECs **704** and the trim **702** (e.g., wordline group or voltage bin). In other words, each voltage offset value **708** in the offset LUT **700** is a vector defined by the trim **702** (e.g., wordline group or voltage bin) and the number of PECs **704**. The LUT **500** may include details of a trim **702**, which may include a wordline group or a voltage bin number. The LUT **700** may categorize the memory blocks based on the number of PECs **704**. For example, the LUT **700** may include memory blocks with PECs of less than Q (e.g., **3000**) PECs, between Q and R, between R and S, between S and T, and some more than T (e.g., **5000**) PECs. The memory sub-system controller may use this LUT **700** for adjusting program and program-verify voltage offsets in the memory device. In some embodiments, the memory access manager **113** may receive a request for performing a program operation on one or more blocks of the memory device. The memory access manager **113** may then identify the number of PECs **704** that have been performed on the blocks of memory device. Based on the number of PECs **704**, the memory access manager **113** may assign a voltage offset **708** for performing the program operation on a wordline group **706**. The memory access manager **113** may then perform the program operation on the memory blocks of the wordline group **706** using a program voltage adjusted for the assigned program voltage offset **708**.

(62) In some embodiments, the memory access manager **113** may, using the LUT **700**, identify a program-verify level **710** associated with a voltage bin of the memory blocks in memory device.

Based on the program-verify level **710** of the voltage bin (e.g., Read levels 0-7) and the number of PECs **704** performed on the memory blocks, the memory access manager **113** may assign a program-verify voltage offset **712** in addition to the program voltage offset **708**. The memory access manager **113** may then perform the program-verify operation on the memory blocks of memory device using a read voltage adjusted for the assigned read voltage offset **712**.

(63) FIG. **8A** illustrates example operations in a method **800** for determining a voltage offset for performing a program-verify operation on memory blocks of a memory device, in accordance with one or more aspects of the present disclosure. The curves illustrated in FIGS. **8A** and **8B** and the voltage offset values used for adjusting the program-verify level voltage and/or the program voltage can be stored in the metadata of the memory device, which may be initialized during manufacture of the memory device. The voltage offset values can be determined using threshold voltage ( $V_t$ ) data that may be collected by performing one or more program operations on one or more wordlines of the memory device, and generating corresponding threshold voltage ( $V_t$ ) curves, which may be used to determine the voltage offset values. The values may then be stored in the metadata of the memory device, which may be initialized upon manufacture. In one implementation, the method **800** includes generating threshold voltage distribution valleys **810** using a program voltage offset (e.g., offset **508**), and generating threshold voltage distribution valleys **820** without using a program voltage offset (e.g., offset **508**). First valley **810** has a first edge **870** and a second edge, and second valley **810** has a first edge and a second edge **880**. However, when only a program voltage offset is used, the read level voltage **830** is not synchronized with the program level voltage change. As a result, the margin e.sub.12 increases on one side of the read level and margin e.sub.13 shrinks on the other side of the read level. This may cause reliability and data retention issues in the memory device.

(64) FIG. **8B** illustrates example operations in a method **850** for determining a voltage offset for performing a read operation on memory blocks of a memory device, in accordance with one or more aspects of the present disclosure. The method **850** includes determining a new program-verify voltage level **880** by aligning a center **840** of a threshold voltage distribution valley **810** applying the program voltage offset with a center of the threshold voltage distribution valley **820** without applying the program voltage offset. Similarly, the method **850** may include determining the new program-verify voltage level **880** by aligning a center **860** of a threshold voltage distribution valley **810** applying the program voltage offset with a center of the threshold voltage distribution valley **820** without applying the program voltage offset. The method **850** further includes determining the program-verify voltage offset **880** based on a difference between the program-verify voltage level **870** associated with the voltage bin and a second edge of the first threshold voltage distribution valley **810** applying the program voltage offset. Since the earlier program-verify level is associated with the threshold voltage distribution valley **820** without applying the program voltage offset, it would now be moved to **880** so the program-verify voltage level is in line with the edge of the threshold voltage distribution valley **810** applying the program voltage offset.

(65) FIG. **9** is a flow diagram of an example method **900** for adjusting voltage offsets of read, program, and program-verify operations performed on memory blocks of a memory device, in accordance with one or more aspects of the present disclosure. The method **900** can be performed by a processing logic that can include hardware (e.g., processing device, circuitry, dedicated logic, programmable logic, microcode, hardware of a device, integrated circuit, etc.), software (e.g., instructions run or executed on a processing device), or a combination thereof. In some embodiments, the method **900** is performed by the memory access manager **113** of FIG. **1**. Although shown in a particular sequence or order, unless otherwise specified, the order of the operations can be modified. Thus, the illustrated embodiments should be understood only as examples, and the illustrated operations can be performed in a different order, while some operations can be performed in parallel. Additionally, one or more operations can be omitted in some embodiments. Thus, not all illustrated operations are required in every embodiment, and

other process flows are possible.

(66) At operation **902**, the processing logic may receive a request from a host system (e.g., host system **120**) for performing a program operation on one or more blocks of the memory device. At operation **904**, the processing logic may identify the number of PECs (e.g., PECs **504**, **704**) that have been performed on the blocks of memory device. Depending on the number of PECs, the processing logic may, at operation **906**, assign a voltage offset (e.g., offset **508**, **708**) for performing the program operation on a wordline group (e.g., wordline group **506**, **706**). For example, the processing logic may assign a larger program voltage offset to memory blocks of a wordline group with lower number of PECs and assign a lower program voltage offset to memory blocks of a wordline group with larger number of PECs. At operation **908**, the processing logic may perform the program operation on the memory blocks of the wordline group using a program voltage adjusted for the assigned program voltage offset. At operation **910**, the processing logic may, using a LUT, identify a read level associated with a voltage bin of the memory blocks in memory device. At operation **912**, based on the read level of the voltage bin (e.g., Read levels 0-7) and the number of PECs performed on the memory blocks, the processing logic may assign a read voltage offset in addition to the program voltage offset. At operation **914**, the processing logic may then perform the read operation on the memory blocks of memory device using a read voltage adjusted for the assigned read voltage offset.

(67) The method may further include determining a new read voltage level based on an offset (e.g.,  $e.sub.12 + e.sub.13/2$ ) that is the average of the margin  $e.sub.12$  on one side of the read level (e.g., read level **630**) and margin  $e.sub.13$  on the other side of the read level. For example, the processing logic may determine a distance between a first edge (e.g., edge **670**) of a first threshold voltage distribution valley (e.g., valley **610**) associated with the voltage bin and a second edge (e.g., edge **660**) of a subsequent threshold voltage distribution valley (e.g., valley **610**). The read voltage offset may be determined based on a difference between the read level associated with the voltage bin and a center of the distance between the first edge and the second edge.

(68) In some embodiments, the processing logic may, using a LUT, identify a program-verify level associated with a voltage bin of the memory blocks in memory device. Depending on the program-verify level of the voltage bin (e.g., Read levels 0-7) and the number of PECs performed on the memory blocks, the processing logic may assign a program-verify voltage offset in addition to the program voltage offset. The processing logic may then perform the program-verify operation on the memory blocks of memory device using a read voltage adjusted for the assigned read voltage offset.

(69) Method **900** may include determining a new program-verify voltage level (e.g., level **880**) by aligning a center (e.g., center **840**) of a threshold voltage distribution valley (e.g., valley **810**) applying the program voltage offset with a center of the threshold voltage distribution valley (e.g., valley **820**) without applying the program voltage offset. The method **900** may further include determining the program-verify voltage offset (e.g., **880**) based on a difference between the program-verify voltage level associated with the voltage bin and a second edge of the first threshold voltage distribution valley applying the program voltage offset. Since the earlier program-verify level is associated with the threshold voltage distribution valley without applying the program voltage offset, it would now be moved so the program-verify voltage level is in line with the edge of the threshold voltage distribution valley applying the program voltage offset.

(70) FIG. **10** illustrates an example machine of a computer system **1000** within which a set of instructions, for causing the machine to perform any one or more of the methodologies discussed herein, can be executed. In some embodiments, the computer system **1000** can correspond to a host system (e.g., the host system **120** of FIG. **1**) that includes, is coupled to, or utilizes a memory sub-system (e.g., the memory sub-system **110** of FIG. **1**) or can be used to perform the operations of a controller (e.g., to execute an operating system to perform operations corresponding to memory access manager **113** of FIG. **1**). In alternative embodiments, the machine can be connected (e.g.,



networked) to other machines in a LAN, an intranet, an extranet, and/or the Internet. The machine can operate in the capacity of a server or a client machine in client-server network environment, as a peer machine in a peer-to-peer (or distributed) network environment, or as a server or a client machine in a cloud computing infrastructure or environment.

(71) The machine can be a personal computer (PC), a tablet PC, a set-top box (STB), a Personal Digital Assistant (PDA), a cellular telephone, a web appliance, a server, a network router, a switch or bridge, or any machine capable of executing a set of instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while a single machine is illustrated, the term “machine” shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein.

(72) The example computer system **1000** includes a processing device **1002**, a main memory **1004** (e.g., read-only memory (ROM), flash memory, dynamic random access memory (DRAM) such as synchronous DRAM (SDRAM) or Rambus DRAM (RDRAM), etc.), a static memory **1006** (e.g., flash memory, static random access memory (SRAM), etc.), and a data storage system **1018**, which communicate with each other via a bus **1030**.

(73) Processing device **1002** represents one or more general-purpose processing devices such as a microprocessor, a central processing unit, or the like. More particularly, the processing device can be a complex instruction set computing (CISC) microprocessor, reduced instruction set computing (RISC) microprocessor, very long instruction word (VLIW) microprocessor, or a processor implementing other instruction sets, or processors implementing a combination of instruction sets. Processing device **1002** can also be one or more special-purpose processing devices such as an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a digital signal processor (DSP), network processor, or the like. The processing device **1002** is configured to execute instructions **1026** for performing the operations discussed herein. The computer system **1000** can further include a network interface device **1008** to communicate over the network **1020**.

(74) The data storage system **1018** can include a machine-readable storage medium **1024** (also known as a computer-readable medium) on which is stored one or more sets of instructions **1026** or software embodying any one or more of the methodologies or functions described herein. The instructions **1026** can also reside, completely or at least partially, within the main memory **1004** and/or within the processing device **1002** during execution thereof by the computer system **1000**, the main memory **1004** and the processing device **1002** also constituting machine-readable storage media. The machine-readable storage medium **1024**, data storage system **1018**, and/or main memory **1004** can correspond to the memory sub-system **110** of FIG. 1.

(75) In one embodiment, the instructions **1026** include instructions to implement functionality corresponding to memory access manager **113** of FIG. 1. While the machine-readable storage medium **1024** is shown in an example embodiment to be a single medium, the term “machine-readable storage medium” should be taken to include a single medium or multiple media that store the one or more sets of instructions. The term “machine-readable storage medium” shall also be taken to include any medium that is capable of storing or encoding a set of instructions for execution by the machine and that cause the machine to perform any one or more of the methodologies of the present disclosure. The term “machine-readable storage medium” shall accordingly be taken to include, but not be limited to, solid-state memories, optical media, and magnetic media.

(76) Some portions of the preceding detailed descriptions have been presented in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These algorithmic descriptions and representations are the ways used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of operations leading to a desired result. The operations are those requiring physical manipulations of physical

quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like.

(77) It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. The present disclosure can refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage systems.

(78) The present disclosure also relates to an apparatus for performing the operations herein. This apparatus can be specially constructed for the intended purposes, or it can include a general purpose computer selectively activated or reconfigured by a computer program stored in the computer. Such a computer program can be stored in a computer readable storage medium, such as, but not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, and magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, or any type of media suitable for storing electronic instructions, each coupled to a computer system bus.

(79) The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose systems can be used with programs in accordance with the teachings herein, or it can prove convenient to construct a more specialized apparatus to perform the method. The structure for a variety of these systems will appear as set forth in the description below. In addition, the present disclosure is not described with reference to any particular programming language. It will be appreciated that a variety of programming languages can be used to implement the teachings of the disclosure as described herein.

(80) The present disclosure can be provided as a computer program product, or software, that can include a machine-readable medium having stored thereon instructions, which can be used to program a computer system (or other electronic devices) to perform a process according to the present disclosure. A machine-readable medium includes any mechanism for storing information in a form readable by a machine (e.g., a computer). In some embodiments, a machine-readable (e.g., computer-readable) medium includes a machine (e.g., a computer) readable storage medium such as a read only memory ("ROM"), random access memory ("RAM"), magnetic disk storage media, optical storage media, flash memory components, etc.

(81) In the foregoing specification, embodiments of the disclosure have been described with reference to specific example embodiments thereof. It will be evident that various modifications can be made thereto without departing from the broader spirit and scope of embodiments of the disclosure as set forth in the following claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

## Claims

1. A method, comprising: receiving, by a processing device, a request for performing a programming operation on one or more memory blocks of a memory device; identifying a value of a media endurance metric associated with the one or more memory blocks; determining a programming voltage offset corresponding to the value of the media endurance metric; performing, using the programming voltage offset, the programming operation on the one or more memory blocks; identifying a program-verify voltage level associated with the one or more memory blocks; determining a program-verify voltage offset associated with the program-verify voltage level and the value of the media endurance metric; and performing, using the program-verify voltage level

and the program-verify voltage offset, a program-verify operation on the one or more memory blocks.

2. The method of claim 1, wherein the media endurance metric reflects a number of program-erase cycles performed on the one or more memory blocks.
3. The method of claim 1, further comprising: identifying a read voltage level associated with the one or more memory blocks; determining a read voltage offset associated with the read voltage level and the value of the media endurance metric; and performing, using the read voltage level and the read voltage offset, a read operation on the one or more memory blocks.
4. The method of claim 1, wherein identifying the value of the media endurance metric associated with the one or more memory blocks further comprises: accessing a program-erase counter stored in a metadata of the memory device; and identifying, based on a value of the program-erase counter, a number of program-erase operations performed on the one or more memory blocks.
5. The method of claim 1, wherein determining the programming voltage offset corresponding to the value of the media endurance metric further comprises: identifying, in a look-up table, a record mapping a wordline group and the value of the media endurance metric to the programming voltage offset.
6. The method of claim 1, wherein determining the program-verify voltage offset further comprises: accessing an offset look-up table stored in a metadata of the memory device; identifying a voltage bin associated with the one or more memory blocks; and determining the program-verify voltage offset corresponding to the voltage bin and the value of the media endurance metric.
7. The method of claim 3, wherein determining the read voltage offset further comprises: accessing an offset look-up table stored in a metadata of the memory device; identifying a voltage bin associated with the one or more memory blocks; and determining the read voltage offset corresponding to the voltage bin and the value of the media endurance metric.
8. A system comprising: a memory device; and a processing device, operatively coupled with the memory device, to perform operations comprising: identifying a value of a media endurance metric associated with the one or more memory blocks of the memory device; determining a programming voltage offset corresponding to the value of the media endurance metric; performing, using the programming voltage offset, a programming operation on the one or more memory blocks; identifying a program-verify voltage level associated with the one or more memory blocks; determining a program-verify voltage offset associated with the program-verify voltage level and the value of the media endurance metric; and performing, using the program-verify voltage level and the program-verify voltage offset, a program-verify operation on the one or more memory blocks.
9. The system of claim 8, wherein the media endurance metric reflects a number of program-erase cycles performed on the one or more memory blocks.
10. The system of claim 8, wherein the operations further comprise: identifying a read voltage level associated with the one or more memory blocks; determining a read voltage offset associated with the read voltage level and the value of the media endurance metric; and performing, using the read voltage level and the read voltage offset, a read operation on the one or more memory blocks.
11. The system of claim 8, wherein identifying the value of the media endurance metric associated with the one or more memory blocks further comprises: accessing a program-erase counter stored in a metadata of the memory device; and identifying, based on the value of the program-erase counter, a number of program-erase operations performed on the one or more memory blocks.
12. The system of claim 8, wherein determining the programming voltage offset corresponding to the value of the media endurance metric further comprises: accessing an offset look-up table stored in a metadata of the memory device; identifying a wordline group associated with the one or more memory blocks; and determining the programming voltage offset corresponding to the wordline group and the value of the media endurance metric.
13. The system of claim 8, wherein determining the program-verify voltage offset further

comprises: accessing an offset look-up table stored in a metadata of the memory device; identifying a voltage bin associated with the one or more memory blocks; and determining the program-verify voltage offset corresponding to the voltage bin and the value of the media endurance metric.

14. The system of claim 10, wherein determining the read voltage offset further comprises: accessing an offset look-up table stored in a metadata of the memory device; identifying a voltage bin associated with the one or more memory blocks; and determining the read voltage offset corresponding to the voltage bin and the value of the media endurance metric.

15. A non-transitory computer-readable storage medium comprising instructions that, when executed by a processing device, cause the processing device to perform operations comprising: receiving a request for performing a programming operation on one or more memory blocks of a memory device; identifying a value of a media endurance metric associated with the one or more memory blocks of the memory device; determining a programming voltage offset corresponding to the value of the media endurance metric; performing, using the programming voltage offset, the programming operation on the one or more memory blocks; identifying a program-verify voltage level associated with the one or more memory blocks; determining a program-verify voltage offset associated with the program-verify voltage level and the value of the media endurance metric; and performing, using the program-verify voltage level and the program-verify voltage offset, a program-verify operation on the one or more memory blocks.

16. The non-transitory computer-readable storage medium of claim 15, wherein the media endurance metric reflects a number of program-erase cycles performed on the one or more memory blocks.

17. The non-transitory computer-readable storage medium of claim 15, wherein the operations further comprise: identifying a read voltage level associated with the one or more memory blocks; determining a read voltage offset associated with the read voltage level and the value of the media endurance metric; and performing, using the read voltage level and the read voltage offset, a read operation on the one or more memory blocks.

18. The non-transitory computer-readable storage medium of claim 15, wherein identifying the value of the media endurance metric associated with the one or more memory blocks further comprises: accessing a program-erase counter stored in a metadata of the memory device; and identifying, based on a value of the program-erase counter, a number of program-erase operations performed on the one or more memory blocks.

19. The non-transitory computer-readable storage medium of claim 15, wherein determining the programming voltage offset corresponding to the value of the media endurance metric further comprises: accessing an offset look-up table stored in a metadata of the memory device; identifying a wordline group associated with the one or more memory blocks; and determining the programming voltage offset corresponding to the wordline group and the value of the media endurance metric.

20. The non-transitory computer-readable storage medium of claim 15, wherein determining the program-verify voltage offset further comprises: accessing an offset look-up table stored in a metadata of the memory device; identifying a voltage bin associated with the one or more memory blocks; and determining the program-verify voltage offset corresponding to the voltage bin and the value of the media endurance metric.

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