

## MEMORY DEVICE WITH USER CONFIGURABLE DENSITY/PERFORMANCE

### TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to memory devices and in particular the  
5 present invention relates to non-volatile memory devices.

### BACKGROUND OF THE INVENTION

Memory devices are typically provided as internal, semiconductor, integrated  
circuits in computers or other electronic devices. There are many different types of memory  
10 including random-access memory (RAM), read only memory (ROM), dynamic random  
access memory (DRAM), synchronous dynamic random access memory (SDRAM), and flash  
memory.

Flash memory devices have developed into a popular source of non-volatile  
memory for a wide range of electronic applications. Flash memory devices typically use a  
15 one-transistor memory cell that allows for high memory densities, high reliability, and low  
power consumption. Common uses for flash memory include personal computers, personal  
digital assistants (PDAs), digital cameras, and cellular telephones. Program code and system  
data such as a basic input/output system (BIOS) are typically stored in flash memory devices  
for use in personal computer systems.

20 The present trend of electronic devices is increased performance at reduced cost.  
The component manufacturers, therefore, must continue to increase the performance of their  
devices while decreasing the cost to manufacture them.

One way to increase a flash memory device's density while lowering its  
manufacturing cost is to use multiple level cells (MLC). Such a device stores two logical bits  
25 per physical cell. This reduces the overall cost of the memory. NAND flash memory devices  
are designed to operate in either one of two configurations on the same die: single bit per cell  
(SBC) or MLC. The selection of the configuration is done at the factory when the die is  
manufactured through a metal mask or a programmable fuse option.

However, an MLC die, while having improved cost versus density, has drawbacks  
30 relative to performance. Both the programming and read operations can become slower for an

MLC die. Therefore, the user typically has to choose between having high memory density at low cost and lower memory density with higher performance.

For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for a memory device that combines the attributes of both MLC and SBC devices.

### SUMMARY

The above-mentioned problems with memory density and performance and other problems are addressed by the present invention and will be understood by reading and studying the following specification.

The embodiments of the present invention encompass a memory device that has user selectable MLC and SBC memory density options. Different memory blocks of the device can be assigned a different memory density.

The memory device is comprised of a memory array having a plurality of memory cells. Each memory cell is capable of storing a selectable quantity of data bits (e.g., MLC or SBC). Control circuitry controls the density configuration of read or write operations to the memory blocks in response to a configuration command.

In one embodiment, the memory density configuration is received as part of the read or write command. For example, special high density read and write commands can be used when high density/low performance is desired. Normal read and write commands can be used when single density/high performance is desired.

In another embodiment, a configuration register contains configuration bits that each correspond to a memory block of the array. The configuration data can then be preloaded into the register during an initialization operation.

Further embodiments of the invention include methods and apparatus of varying scope.

### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a diagram of one embodiment of a NAND flash memory array of the present invention.

Figure 2 shows a block diagram of one embodiment of a flash memory device of the present invention that incorporates the memory array of Figure 1.

Figure 3 shows a flowchart of one embodiment of a method for configuring the density/performance of a memory device.

Figure 4 shows a flowchart of another embodiment of a method for configuring the density/performance of a memory device.

### DETAILED DESCRIPTION

In the following detailed description of the invention, reference is made to the accompanying drawings that form a part hereof and in which is shown, by way of illustration, specific embodiments in which the invention may be practiced. In the drawings, like numerals describe substantially similar components throughout the several views. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims and equivalents thereof.

Figure 1 illustrates a NAND flash array is comprised of an array of floating gate cells 101 arranged in series strings 104, 105. Each of the floating gate cells are coupled drain to source in the series chain 104, 105. Word lines (WL0 – WL31) that span across multiple series strings 104, 105 are coupled to the control gates of every floating gate cell in order to control their operation. The memory array is arranged in row and column form such that the word lines (WL0 – WL31) form the rows and the bit lines (BL1 – BL2) form the columns.

In operation, the word lines (WL0 – WL31) select the individual floating gate memory cells in the series chain 104, 105 to be written to or read from and operate the remaining floating gate memory cells in each series string 104, 105 in a pass through mode. Each series string 104, 105 of floating gate memory cells is coupled to a source line 106 by a source select gate 116, 117 and to an individual bit line (BL1 – BL2) by a drain select gate

112, 113. The source select gates 116, 117 are controlled by a source select gate control line SG(S) 118 coupled to their control gates. The drain select gates 112, 113 are controlled by a drain select gate control line SG(D) 114.

The memory cells illustrated in Figure 1 can be operated as either single bit cells (SBC) or multilevel cells (MLC). Multilevel cells greatly increase the density of a flash memory device. Such cells enable storage of multiple bits per memory cell by charging the floating gate of the transistor to different levels. MLC technology takes advantage of the analog nature of a traditional flash cell by assigning a bit pattern to a specific voltage range stored on the cell. This technology permits the storage of two or more bits per cell, depending on the quantity of voltage ranges assigned to the cell.

For example, a cell may be assigned four different voltage ranges of 200 mV for each range. Typically, a dead space or guard band of 0.2V to 0.4V is between each range. If the voltage stored on the cell is within the first range, the cell is storing a 00. If the voltage is within the second range, the cell is storing a 01. This continues for as many ranges are used for the cell.

The embodiments of the present invention may refer to the MLC as a high density configuration. The embodiments of the present invention are not limited to two bits per cell. Some embodiments may store more than two bits per cell, depending on the quantity of different voltage ranges that can be differentiated on the cell. Therefore, the term high density generally refers to any density beyond single bit cells.

Figure 2 illustrates a block diagram of one embodiment of a flash memory device 200 of the present invention that incorporates the memory array illustrated in Figure 1. The memory device 200 has been simplified to focus on features of the memory that are helpful in understanding the present invention. A more detailed understanding of internal circuitry and functions of flash memories are known to those skilled in the art.

The memory device 200 includes an array of flash memory cells 230 as discussed previously. The cells of the memory array 230 can be grouped into memory blocks. In one embodiment, a memory block is comprised of 512 bytes in a row by 32 rows. Alternate embodiments are comprised of memory blocks having different quantities of memory cells.

An address buffer circuit 240 is provided to latch address signals provided on address input connections A0 – Ax 242. Address signals are received and decoded by a row

decoder 244 and a column decoder 246 to access the memory array 230. It will be appreciated by those skilled in the art, with the benefit of the present description, that the number of address input connections depends on the density and architecture of the memory array 230. That is, the number of addresses increases with both increased memory cell counts and increased bank and block counts.

The memory device 200 reads data in the memory array 230 by sensing voltage or current changes in the memory array columns using sense amplifier/buffer circuitry 250. The sense amplifier/buffer circuitry, in one embodiment, is coupled to read and latch a row of data from the memory array 230. Data input and output buffer circuitry 260 is included for bi-directional data communication over a plurality of data connections 262 with the controller 210. Write circuitry 255 is provided to write data to the memory array.

Control circuitry 270 decodes signals provided on a control bus 272. These signals are used to control the operations on the memory array 230, including single density data read and write, high density data read and write, and erase operations. The control circuitry 270 may be a state machine, a sequencer, or some other type of controller. The control circuitry 270, in one embodiment, is responsible for executing the embodiments of the methods of the present invention for configuring the memory blocks as high or single density.

The control circuitry 270 can also program the configuration registers 280 in which, in one embodiment, the high/single density configuration bits of the present invention can reside. This register may be a non-volatile, programmable fuse apparatus, a volatile memory array, or both. The configuration register 280 can also hold other data such as trimming data, memory block lock data, record keeping data for the memory device, and other data required for operation of the memory device.

Figure 3 illustrates a flowchart of one embodiment of a method for configuring the density/performance of a memory device. This embodiment uses special write and read commands to perform high density program and read operations. This embodiment puts the burden on the memory control circuitry to determine the density/performance configuration for a particular memory block. By having the control circuitry perform this task, the memory device does not require any extra hardware in order to switch blocks between high density and single density. The controller tracks the density/performance level.

This embodiment uses two sets of algorithms – one for SBC reading and writing and another for MLC reading and writing. A higher level routine determines which set of algorithms to use depending on the received command. In this embodiment, the erase operation is substantially similar for each memory density.

5           The method determines if the received command is a read or write command 301. If a write command was received, it is determined 303 whether the command is a single density write command or a special high density write command. A high density write command 307 causes the controller circuitry to program the specified memory block with two or more bits per cell. A single density write command 309 causes the controller circuitry  
10       to program the specified memory block with one bit per cell.

          If the received command is a read command, it is determined 305 whether the command is a single density read command or a high density read command. If the command is a high density read command 311, the memory block was previously programmed as an MLC cell and is, therefore, read with a high density read operation. A single density  
15       configuration read command causes the memory block to be read 313 assuming it was programmed as an SBC.

          In another embodiment of the present invention, illustrated in Figure 4, a configuration register is used to pre-assign blocks of memory to the SBC or MLC configuration of operation. This could occur when the system is initialized. This embodiment  
20       would not require special commands than those used in MLC or SBC flash memory devices. Additionally, an existing register could be used to store the configuration data so that additional hardware is not required or, in another embodiment, a dedicated configuration register could be added to the memory device.

          In one embodiment, the register of the present invention has a bit for every  
25       memory block for indicating the operating mode (e.g., MLC or SBC) of that particular block. For example, a logical 1 stored in the memory block 0 configuration bit would indicate that the block is an SBC block while a logical 0 would indicate the block is operating as an MLC block. In another embodiment, these logic levels are reversed.

          Alternate embodiments can assign different quantities of blocks to each bit of the  
30       configuration register. For example, the register may have a configuration bit assigned to

more than one memory block. Additionally, a configuration bit may be assigned to the sub-block level such that each block has multiple configuration bits.

In one embodiment, row 0 of the flash memory device of the present invention is a configuration row. At initialization and/or power-up of the device, the configuration data  
5 from row 0 is loaded into the configuration register 401.

When a command is received, it is determined whether it is a read or write command 403. For a read command, the configuration register is checked prior to the read operation to determine if the memory block has been assigned a high density or single density configuration 407. In a single density configuration 411, a single density read operation is  
10 performed 419. In a high density configuration 411, a high density read operation is performed 417.

If a write command was received, the configuration register is checked prior to write operation to determine if the memory block has been assigned a high density or a single density configuration 409. In a single density configuration 409, a single density write  
15 operation is performed 415. In a high density configuration 409, a high density write operation is performed 413.

In the embodiment of Figure 4, the user determines the configuration of each block, or other memory cell grouping, and stores this data into the configuration register. When the memory device is powered down, the data in the configuration register is copied to  
20 row 0 for more permanent storage in non-volatile memory. In another embodiment, the user can store the configuration directly to the non-volatile, configuration row of the memory device.

The flash memory of the present invention is comprised of memory blocks that can each be configured to store data in different densities. For example, one use of a single  
25 memory device might be to store both pictures and code. The picture data is more tolerant of corrupted data than the storage of code. Therefore, since the SBC configuration has a higher reliability than the MLC configuration, the user would typically choose the SBC configuration for the code storage and the MLC configuration for the picture storage.

Similarly, since the MLC configuration might be eight to nine times slower in  
30 read and programming performance as compared to the SBC configuration, the user might

choose the MLC configuration for memory blocks requiring faster read/write times. This could be useful in a system having fast bus speeds requiring fast storage and retrieval times.

### CONCLUSION

5 In summary, the embodiments of the present invention enable a memory device user to select between an MLC and an SBC configuration. Different configurations can be set up for different memory blocks or even to the sub-block level. Additionally, the configuration changes can be performed dynamically with configuration commands.

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

What is claimed is:

1. A memory device having selectable density configurations, the device comprising:  
a memory array comprising a plurality of memory cells, each memory cell capable of storing a selectable quantity of data bits; and  
control circuitry, coupled to the memory array, that controls the density configuration in response to a configuration command.
2. The device of claim 1 wherein the memory device is a NAND flash memory device.
3. The device of claim 1 wherein the configuration command is a configuration bit stored in a configuration register.
4. The device of claim 1 wherein the selectable density configurations include a single bit cell and a multiple level cell.
5. The device of claim 1 wherein the configuration command is a received write command comprising configuration information.
6. The device of claim 1 wherein the configuration command is a received read command comprising configuration information.
7. The device of claim 1 and further including a configuration register coupled to the control circuitry, the configuration register comprising a plurality of configuration bits, each configuration bit indicating the density configuration of a predetermined quantity of memory cells.
8. The device of claim 1 wherein the predetermined quantity of memory cells is a block of memory cells.
9. The device of claim 7 wherein a configuration bit comprising a logical one indicates a single bit cell density configuration and a logical zero indicates a multiple level cell configuration.

10. A NAND flash memory device having selectable density configurations, the device comprising:  
a memory array comprising a plurality of memory cells that are organized into predetermined sets, each memory cell capable of storing a selectable quantity of data bits;  
control circuitry, coupled to the memory array, that determines the density configuration for a predetermined set of memory cells in response to a configuration bit; and  
a configuration register, coupled to the control circuitry, for storing the configuration bits.
11. The memory device of claim 10 wherein the control circuitry is a state machine.
12. The memory device of claim 10 wherein the predetermined sets are blocks of memory cells.
13. The memory device of claim 10 wherein the configuration register is a plurality of non-volatile fuses.
14. The memory device of claim 10 wherein the configuration register is a volatile memory.
15. The memory device of claim 14 wherein the configuration register is adapted to be loaded from a predetermined row of the memory array.
16. The memory device of claim 15 wherein the predetermined row is row 0.
17. The memory device of claim 10 wherein the configuration register is comprised of non-volatile fuses and volatile memory such that the volatile memory is loaded from the non-volatile fuses after an initialization of the memory device.

18. A non-volatile memory device having a plurality of selectable density configurations, the device comprising:  
a memory array comprising a plurality of memory cells grouped into predetermined sets, each memory cell capable of storing a selectable quantity of data bits;  
a control bus for receiving density configuration commands; and  
control circuitry, coupled to the control bus, that controls the density configuration of each predetermined set in response to a received density configuration command.
19. The memory device of claim 18 wherein each predetermined set is a block of memory cells comprising 512 bytes by 32 rows.
20. The memory device of claim 18 wherein the selectable quantity of data bits includes a single data bit and two data bits.
21. The memory device of claim 18 wherein the density configuration commands comprise at least one of a high density write operation and a high density read operation.
22. A method for configuring performance of a memory array in a memory device, the memory device comprising control circuitry coupled to a configuration register, the method comprising:  
loading configuration data into the configuration register; and  
setting a performance configuration for at least a subset of the memory array in response to the configuration data.
23. The method of claim 22 wherein the performance configuration comprises one of high density/low performance or single density/high performance.
24. The method of claim 22 wherein loading comprises loading the configuration data from a row of the memory array in response to an initialization of the memory device.
25. The method of claim 22 wherein the subset of the memory array is a memory block.

26. The method of claim 22 wherein setting the performance configuration comprises setting the performance configuration for all of the memory cells in the memory array.
27. A method for configuring performance of a memory array in a memory device, the method comprising:  
receiving configuration data; and  
setting a performance configuration for at least a subset of the memory array in response to the received configuration data.
28. The method of claim 27 wherein receiving the configuration data comprises receiving a write command that includes the configuration data.
29. The method of claim 27 wherein receiving the configuration data comprises receiving a read command that includes the configuration data.
30. The method of claim 27 wherein the received configuration data includes one of high performance or low performance.
31. The method of claim 30 wherein the high performance configuration sets the subset of the memory array to single bit per cell density.
32. The method of claim 30 wherein the low performance configuration sets the subset of the memory array to multiple levels per cell.
33. A method for configuring the density of a memory array in a memory device, the memory array comprising a plurality of memory cells grouped into predetermined subsets of cells, the method comprising:  
receiving a command for initiating one of a read or a write operation on the predetermined subset of cells;  
determining if the command contains a memory density configuration; and  
executing the command on the predetermined subset of cells.

34. The method of claim 33 wherein the predetermined subsets of cells are 512 byte by 32 row memory blocks.
35. The method of claim 33 and further including:  
if the command contains the memory density configuration, performing either the  
read or the write operation at the density specified in the command; and  
if the command does not contain the memory density configuration, performing the  
read or the write operation as a single bit per cell operation.
36. The method of claim 33 wherein the memory density configuration comprises one of  
a single bit per cell configuration or a multiple level cell configuration.
37. The method of claim 36 wherein the multiple level cell configuration comprises  
storing a plurality of bits on one memory cell.
38. A method for configuring the density of a memory array in a memory device, the  
memory array comprising a plurality of NAND flash memory cells organized as a  
plurality of memory blocks, the memory device comprising control circuitry coupled  
to a configuration register having a plurality of configuration bits that each indicate  
the density of a corresponding memory block, the method comprising:  
loading the configuration bits into the configuration register;  
receiving a command to perform one of a read or a write operation on a first memory  
block of the plurality of memory blocks;  
reading the configuration bit corresponding to the first memory block; and  
executing the command on the first memory block in response to the configuration  
bit.
39. The method of claim 38 wherein loading the configuration bits comprises loading the  
configuration bits from a first row of the memory array.
40. The method of claim 38 wherein if the configuration bit is a logical 1, performing a  
high density read or write operation in response to the command.

41. The method of claim 38 wherein if the configuration bit is a logical 0, performing a single density read or write operation in response to the command.