

SEMICONDUCTOR MEMORY HAVING STAGGERED SENSE AMPLIFIERS ASSOCIATED WITH A LOCAL COLUMN DECODER

Field of the invention

The invention relates generally to a semiconductor memory, and more particularly to a Dynamic Random Access Memory (DRAM) wherein a local column decoder is associated with staggered sense amplifiers.

Background of the invention

Basically, a DRAM is an integrated circuit that stores data in binary form (e.g., "1" or "0") in a large number of cells. The data is stored in a cell as a charge on a capacitor located within the cell. Typically, a high logic level is approximately equal to the power supply voltage and a low logic level is approximately equal to ground.

The cells of a conventional DRAM are arranged in an array so that individual cells can be addressed and accessed. The array can be thought of as rows and columns of cells. Each row includes a word line that interconnects cells on the row with a common control signal. Similarly, each column includes a bit line that is coupled to at most one cell in each row. Thus, the word and bit lines can be controlled so as to individually access each cell of the array.

To read data out of a cell, the capacitor of a cell is accessed by selecting the word line associated with the cell. A complementary bit line that is paired with the bit line for the selected cell is equilibrated to an equilibrium voltage. This equilibration voltage (V_{eq}) is typically midway between the high V_{dd} and low V_{ss} (typically ground) logic levels. Thus, conventionally, the bit lines are equilibrated to one-half of the power supply voltage, $V_{dd}/2$. When the word line is activated for the selected cell, the capacitor of the selected cell discharges the stored voltage onto the bit line, thus changing the voltage on the bit line. A differential amplifier, conventionally referred to as a sense amplifier, is then used to detect and amplify the difference in voltage on the pair of bit lines.

Figure 1 represents a conventional memory architecture wherein in order to correctly read a data item from a memory cell of a memory array, a current read from a cell of an addressed memory matrix A_M is compared at a sense amplifier SA0-SA7 of a sense amplifier array SAA to a current read from a cell of a reference memory matrix R_M that serves in particular to compensate for unknown offset values that are due to irregularities in the fabrication process.

In order to reduce the surface area of a memory, a stacking technique, so-called "staggering" technique, is conventionally used to take into account the pitch difference in between the sense amplifier and the cells. Several sense amplifiers SA0-SA7, generally 4 or 8 as it is the case on figure 1, are therefore staggered one
 5 behind each other in the longitudinal direction of the bit lines, such as the bit lines BL₂ and bBL₂ (complementary to BL₂) coupled to sense amplifier SA2.

The architecture of figure 1 suffers that a bit line and its complementary run over all the staggered sense amplifiers. This leads to a congestion of the space available as metal-0 (metal used for the bit lines) indeed covers 100% of the sense
 10 amplifiers.

Moreover, addressing a specific cell of the memory necessitates row and column address buses built from metal tracks, generally metal-1 tracks. When 64 column address buses are used to decode the sense amplifiers of the sense amplifier array, around 100 metal-1 tracks need to be present for power supplies,
 15 control commands, I/Os and decoding (64 tracks for this latest group). But in the near future, there needs to be a lot of focus of the core circuits of a DRAM, especially on the sense amplifier. Indeed, with introduction of FDSOI (Fully Depleted Silicon On Insulator) technology or introduction of high-k/metal gate, devices will get smaller and the metal lines could become the limiting factor, not any more the size of
 20 the devices. It is therefore understood that 100 metal-1 tracks are far too many.

Figure 2 shows another memory architecture that helps limiting the available space congestion. In this architecture, the sense amplifiers array is split into pairs of staggered sense amplifier banks SABe, SABo and the bit lines adopt an interleaved arrangement whereby bit lines alternate in the lateral direction of the wordlines WL
 25 between a bit line BL0, bBL0, BL2, bBL2 coupled to a sense amplifier SA0, SA2 of the first bank SAB0 of the pair and a bit line BL1, bBL1 coupled to a sense amplifier SA1 of the second bank SAB1 of the pair. The alternative arrangement of the bit lines result in interconnect spaces available in each sense amplifier bank of the pair parallel to the bit lines. Taking bank SABe as an example, interconnect space is
 30 available in between bit lines BL0, bBL0 and bit lines BL2, bBL2. Taking bank SABo as an example, interconnect space is available before bit lines BL1, bBL1. With this

alternative arrangement, metal-0 now covers only 50% of the sense amplifiers. With relaxed constraints on the sense amplifiers, the layout is easier.

However, this architecture necessitates dividing the memory cells array into sub-arrays, which results on the top and bottom sub-arrays being only half-used.

5 Moreover, when 64 column addresses buses CAB are used (32 buses dedicated to each of the sense amplifier sections), around 140 metal-1 tracks needs to be drawn (around 70 per sense amplifier section). The architecture of figure 2 therefore also suffers from the high number of column address buses.

10 **Summary of the invention**

Embodiments of the invention aim at providing a semiconductor memory that does not suffer from the above mentioned drawbacks, and in particular a semiconductor memory necessitating less column address buses. In accordance with an aspect of the invention, there is provided a semiconductor memory, comprising:

- 15 – a plurality of bit lines and a plurality of word lines crossing each others,
- a memory cell array formed by a plurality of memory cells arranged in rows and columns on crossover points of said bit lines and said world lines,
- at least one pair of sense amplifier banks, wherein the sense amplifier banks of a pair are arranged on opposite side of the memory cell array, and wherein each
- 20 sense amplifier banks of a pair comprises a plurality of sense amplifiers staggered in the longitudinal direction of the bit lines, each sense amplifier being connected to a corresponding bit line according to an interleaved arrangement whereby bit lines alternate in the lateral direction of the wordlines between a bit line coupled to a sense amplifier of the first bank of the pair and a bit line coupled
- 25 to a sense amplifier of the second bank of the pair, the alternative arrangement of the bit lines resulting in interconnect spaces available in each sense amplifier bank of the pair parallel to the bit lines,

characterized in that each sense amplifier bank further comprises at least one local column decoder for selecting at least one sense amplifier of the sense amplifier

30 bank, the local column decoder being staggered with the sense amplifiers and being

coupled to the at least one sense amplifier of the sense amplifier bank by means of an output line running in an available interconnect space parallel to the bit lines.

Other preferred, although non limitative, embodiments of this memory are as follows:

- 5 – each sense amplifier bank comprises a single local column decoder coupled to each sense amplifier of the sense amplifier bank.
- wherein each sense amplifier bank comprises a plurality of local column decoders.
- the local column decoder is a NOR gate or a NAND gate.
- the local column decoder comprises a plurality of decoder sections, each decoder
- 10 section being coupled to respective sense amplifiers of the sense amplifier bank.
- the sense amplifier banks are implemented on a semiconductor-on-insulator substrate and a decoder section comprises a pseudo-inverter structure having two complementary double-gate transistors in series between a first input of the decoder section and the ground, each double-gate transistor having a first gate and a second
- 15 gate, the first gates of the transistors being both coupled to a second input of the decoder section while the second gates of the transistors are both coupled to the complementary of the first input, an output of the decoder section out being provided at the middle-point of the serial association of the two transistors.
- a first input of the local column decoder is connected to a first column address bus
- 20 by means of a first input line, a second input of the local column decoder is connected to a second column address bus by means of a second input line, and both the first and the second input lines run in an available interconnect space.
- the first input line is a metal-0 line and the first column address bus is a metal-1 bus.
- 25 – the second input line is a metal-0 line and the second column address bus is a metal-1 bus.
- the second input line is a metal-0 line, and the second column address bus comprises a metal-2 bus running in the longitudinal direction of the bit lines and a metal-1 bus coupled to the metal-2 bus, the metal-1 bus running in the transversal
- 30 direction of the wordlines.

Brief description of the drawings

Other aspects, goals and advantages of the invention will become more apparent upon reading the following detailed description of preferred embodiments thereof, given by way of examples and with reference to the accompanying drawings upon which:

- figure 1 already discussed above shows a conventional DRAM architecture;
- figure 2 already discussed above shows another conventional DRAM architecture, wherein the bit lines are interleaved;
- figure 3 schematically represents a DRAM according to an embodiment of the invention;
- figure 4 represents the column addressing of a DRAM according to a first embodiment of the invention;
- figure 5 represents the column addressing of a DRAM according to a second embodiment of the invention;
- figures 6a, 6b and 6c represent various possible embodiments of the invention;
- figure 7 represents a NOR gate on FDSOI that can be used as a local column decoder in a possible embodiment of the invention.

Detailed description of preferred embodiments of the invention

With reference to figure 3, the invention provides a semiconductor memory, in particular a DRAM, comprising a plurality of bit lines BL0, bBL0, BL1, bBL1, BL2, bBL2, ..., BL7, bBL7 and a plurality of word lines WL crossing each others. The memory further comprises a memory cell array MCA formed by a plurality of memory cells arranged in rows and columns on crossover points of said bit lines and said world lines. The memory further comprises at least one pair of sense amplifier banks SAB0 SAB1, wherein the sense amplifier banks of a pair are arranged on opposite side of the memory cell array MCA. Each sense amplifier banks of a pair comprises a plurality of sense amplifiers SA0, SA2, SA4, SA6; SA1, SA3, SA5, SA7 staggered in the longitudinal direction of the bit lines. The sense amplifier banks of a pair are laid out on opposite side of the memory cell array MCA.

Figure 3 represents a single pair of sense amplifier banks SAB0, SAB1, wherein each bank has four staggered sense amplifiers. It will be understood that the invention also applies to a larger number of pairs of sense amplifier banks, such as for instance 128 pairs, as well as to a different number of staggered sense amplifiers in a sense amplifier bank, such as for instance 2 or 8 staggered sense amplifiers.

Each sense amplifier is connected to a corresponding bit line according to an interleaved arrangement whereby bit lines alternate in the lateral direction of the wordlines between a bit line coupled to a sense amplifier of the first bank of the pair and a bit line coupled to a sense amplifier of the second bank of the pair. Taking bit lines bBL0, BL1 and bBL2 as examples of sequential bit lines in the wordline direction, bit line bBL0 is coupled to sense amplifier SA0 of the top sense amplifier bank SAB0, bit line BL1 is coupled to sense amplifier SA1 of the bottom sense amplifier bank SAB1, and bit line bBL2 is coupled to sense amplifier SA2 of the top sense amplifier bank SAB0. As a result of this interleaved arrangement, bit line BL1 does not run over the top sense amplifier bank SAB0, thereby leaving an interconnect space available between bit lines bBL0 and bBL2. Similarly, as bit lines bBL0 and bBL2 do not run over the bottom sense amplifier SAB1, interconnect spaces are available of each side of bit lines BL1, bBL1. More specifically, the available interconnect spaces are free spaces available for drawing metal-0 lines.

The invention further provides locally decoding the sense amplifiers by placing the logic of the column decoder within the sense amplifier banks. More specifically, each sense amplifier bank SAB0, SAB1 comprises at least one local column decoder LCD0, LCD1 for selecting at least one sense amplifier of the sense amplifier bank. The local column decoder LCD0, LCD1 is staggered with the sense amplifiers of the bank and is coupled to at least one sense amplifier of the bank by means of an output line OL0, OL1, typically a metal-0 line, running in an available interconnect space parallel to the bit lines, such as the interconnect space available between bit lines BL0 and BL2 over the top sense amplifier bank SAB0 for output line OL0 or the interconnect space available before bit line BL1 over the bottom sense amplifier bank SAB1 for output line OL1.

It will be noted that the pitch of the local column decoder is at most the pitch of a sense amplifier (8 memory columns in the illustrated example). In a preferred embodiment of the invention, the local column decoder is a multi-input logic gate, for instance a two-input gate, in particular a gate which generates a particular value from only a single combination of its inputs, such as a NOR gate or a NAND gate. It will be noted that a NOR gate is typically implemented when the sense amplifiers have N type pass gates, while a NAND gate is implemented when the sense amplifiers have P type pass gates. As all dual input function meets the 8 column pitch, the layout is relatively easy.

As shown on figure 3 and on figure 6a, a local column decoder, such as LCD1, can be coupled to all the sense amplifiers of the bank. When the bank counts four sense amplifiers as exemplified by these figures, the local column decoder LCD1 allows decoding the four sense amplifiers SA1, SA3, SA5, SA7: four consecutive bits of a same word therefore share the same address.

Preferably, the sense amplifier banks comprises an even number of staggered sense amplifiers, and the local column decoders is placed centrally in the bank so as to have an equal number of sense amplifiers of each of its sides.

Alternatively, a sense amplifier bank may comprise a plurality of local column decoders. A possible arrangement of a plurality of local column decoders within a sense amplifier bank is shown on figure 6b where a sense amplifier bank comprises two local column decoders LCD3, LCD5, where each local column decoder is coupled to half of the sense amplifiers of the bank. In the staggered arrangement of figure 6b, each local column decoder LCD3, LCD5 has two immediately adjacent sense amplifiers SA1, SA3; SA5, SA7 to which it is coupled. With this arrangement, two consecutive bits of a same word share the same address. But addresses of local column decoders could also be identical, so that four consecutive bits of a same word share the same address.

In another variant, a local column decoder may comprise a plurality of decoder sections, such as two-decoder sections LCD7, LCD9 as shown on figure 6c, each section being coupled to respective sense amplifiers. In the arrangement of figure 6c, the local column decoder is centrally arranged and comprises two sections. A

first decoder section LCD9 of the local column decoder is coupled to the top and bottom sense amplifiers SA1, SA7, while a second decoder section LCD7 of the local column decoder is coupled to the intermediate sense amplifiers SA3, SA5. It will be noted that addresses of decoder sections can be the same or different depending upon the application. It will be understood that such an arrangement is possible only if the cumulative pitch of the decoder sections remain below the pitch of a sense amplifier (8 memory columns in the illustrated examples).

In this respect, it has to be noted that the Applicant has previously designed a NOR2 gate on FDSOI (Fully Depleted Silicon On Insulator) with only 2 transistors. Such a NOR2 gate can thus be drawn over only 4 memory columns. With such a design, two decoder sections can therefore be incorporated within a local column decoder staggered with sense amplifiers having the pitch of 8 memory columns. It will be appreciated that such a NOR2 FDSOI gate has been described in European patent application n°10175849.8 filed on September 8, 2010. This NOR2 FDSOI gate makes use of the pseudo-inverter structure shown on figure 7 which inputs are referenced A and B. The transistors of the pseudo-inverter structure are dual-gate FDSOI transistors having a front control gate and a back gate under the buried oxide layer SOI substrate, the back gates being controlled by a signal A# which is complementary to the input signal A applied to the source of the P-transistor. It will be appreciated that SOI FinFETs can also be used in place of such FDSOI transistors.

It will also be appreciated that the back gates of such a local column decoder can be used to boost a sense amplifier, in particular when the transistor drive of the sense amplifier is not sufficient to restore in time the data into the memory cell. This effect is further symmetrical on both sides of the sense amplifier and doesn't include mismatches.

FDSOI also proves advantageous in that FDSOI transistors exhibit less variability. Width and length of the transistors can be reduced as compared to an implementation of the invention on a bulk substrate, and the sense amplifier area can be divided by 2 to 2.5.

Anyhow, it will be appreciated that the local column decoder, such as for instance a multi-input logic gate, for instance a two-input gate, for instance the pseudo-inverter structure of figure 7, can make use of dual gate transistors. Each dual gate transistors can be a dual gate transistor having a back control gate under the buried insulating layer of a SeOI substrate (Semiconductor On Insulator). Each dual gate transistor can also be a Fin-type independent double gate transistor. It can also be made of two single gate transistors arranged in parallel.

Hence, it will be appreciated that the invention can be implemented on all technologies: bulk, PDSOI (Partially Depleted Silicon On Insulator), FDSOI (Fully Depleted Silicon On Insulator), as well as with FinFETs and other types of independent double gate transistors. As shown above, FDSOI proves advantageous it that it enhances the advantages as it allows smaller area per functionality than bulk.

Figure 4 shows two sense amplifiers banks, consecutive in the word line direction. Each bank comprises a local column decoder LCD00, LCD01 centrally staggered and coupled to all the sense amplifiers of the bank. In the example of figure 4, each local column decoder is implemented as a dual-input NOR gate. A first input of the NOR gate is connected to a first column address bus CAB-LSB, for instance for addressing the least significant bits, by means of a first input line I10, I11 running in an available interconnect space. A second input of the NOR gate is connected to a second column address bus CAB-MSB, for instance for addressing the most significant bits, by means of a second input line I20, I21 running in another available interconnect space. The first and second input lines I10, I11 and I20, I21 are preferably metal-0 lines running in spaces left free by the bit lines.

If the architecture of the conventional circuit initially required for instance 64 busses to decode each sense amplifier within a bank like on figure 1 or figure 2, then the new organization proposed by the invention requires only 16 busses CAB-LSB, CAB-MSB (8 least significant bits – LSB - and 8 most significant bits – MSB) to fulfil the same functionality. It will be appreciated that these buses CAB-LSB and CAB-MSB are coupled to a main column decoder configured to output column selection signals to corresponding local column decoders in the sense amplifier banks. These

16 buses correspond to around 40-45 metal-1 tracks, as compared to the 100 tracks necessary in the prior art architecture of figure 1. The bussing constraint is thus considerably minimized, and can be considered as equivalent to the transistor area constraint.

5 According a first embodiment represented on figure 4, the first and second column address busses CAB-LSB, CAB-MSB are metal-1 busses running in the transversal direction of the wordlines. The first MSB bus MSB0 is coupled to the first eight sense amplifiers banks consecutive in the wordline direction, while the LSB bus to which each of these eight banks is coupled is sequentially changed from the first
10 LSB bus LSB0 until reaching the eighth LSB bus LSB7. Once the eight first sense amplifier banks have been addressed, the MSB bus then changes from the first MSB bus MSB0 to the second MSB bus MSB1, and all LSB buses LSB0-LSB7 are once again sequentially used. This process is repeated for the 64 sense amplifier banks.

 According to another embodiment represented on figure 5, the first column
15 address busses CAB-LSB are metal-1 busses running in the transversal direction of the wordlines, while the second column address busses CAB-MSB comprises a set of metal-2 busses M20, M21,..., M27 running in the longitudinal direction of the bit lines, a metal-1 bus M10, M11,..., M17 running in the transversal direction of the wordlines being coupled to each metal-2 bus of the set.

20 In the embodiment of figure 5, metal-2 busses are spaced from each other by a distance corresponding to eight times the pitch of the sense amplifiers banks (64 memory cells). Metal-2 bus M20 and metal-1 bus M10 are used to address to the first eight sense amplifier banks, with the metal-1 bus M10 being coupled to the second input I21, I22 of the local column decoders of the eight first sense amplifier
25 banks (as schematically represented by the dots on figure 5). Similarly, metal-2 bus M21 and metal-1 bus M11 are used to address the sense amplifier banks nine to sixteen, with the metal-1 bus M11 being coupled to the second input of the local column decoders of the sense amplifier banks number nine to sixteen. This process is repeated for the 64 sense amplifier banks.

30 The invention finally proves advantageous in that most of the column decoder circuitry can be integrated into the on-pitch area and no longer need to be in the

periphery of the memory, i.e. it becomes an on-pitch circuit and thus becomes itself very small in area and has a much lower power consumption and a higher speed.

CLAIMS

1. A semiconductor memory, comprising:
 - a plurality of bit lines and a plurality of word lines crossing each others,
 - 5 – a memory cell array formed by a plurality of memory cells arranged in rows and columns on crossover points of said bit lines and said world lines,
 - at least one pair of sense amplifier banks, wherein the sense amplifier banks of a pair are arranged on opposite side of the memory cell array, and wherein each sense amplifier banks of a pair comprises a plurality of sense amplifiers
 - 10 staggered in the longitudinal direction of the bit lines, each sense amplifier being connected to a corresponding bit line according to an interleaved arrangement whereby bit lines alternate in the lateral direction of the wordlines between a bit line coupled to a sense amplifier of the first bank of the pair and a bit line coupled to a sense amplifier of the second bank of the pair, the alternative arrangement
 - 15 of the bit lines resulting in interconnect spaces available in each sense amplifier bank of the pair parallel to the bit lines,

characterized in that each sense amplifier bank further comprises at least one local column decoder for selecting at least one sense amplifier of the sense amplifier bank, the local column decoder being staggered with the sense amplifiers and being

 - 20 coupled to the at least one sense amplifier of the sense amplifier bank by means of an output line running in an available interconnect space parallel to the bit lines.
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2. The semiconductor memory of claim 1, wherein each sense amplifier bank comprises a single local column decoder coupled to each sense amplifier of the
 - 25 sense amplifier bank.
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3. The semiconductor memory of claim 1, wherein each sense amplifier bank comprises a plurality of local column decoders.
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- 30 4. The semiconductor memory of any one of claims 1-3, wherein the local column decoder is a NOR gate or a NAND gate.

5. The semiconductor memory of any one of claims 1-4, wherein the local column decoder comprises a plurality of decoder sections, each decoder section being coupled to respective sense amplifiers of the sense amplifier bank.

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6. The semiconductor memory of claim 5, wherein the sense amplifier banks are implemented on a semiconductor-on-insulator substrate and wherein a decoder section comprises a pseudo-inverter structure having two complementary double-gate transistors in series between a first input of the decoder section and the ground, each double-gate transistor having a first gate and a second gate, the first gates of the transistors being both coupled to a second input of the decoder section while the second gates of the transistors are both coupled to the complementary of the first input, an output of the decoder section out being provided at the middle-point of the serial association of the two transistors.

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7. The semiconductor memory of any one of claims 1-6, wherein a first input of the local column decoder is connected to a first column address bus by means of a first input line, wherein a second input of the local column decoder is connected to a second column address bus by means of a second input line, and wherein both the first and the second input lines run in an available interconnect space.

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8. The semiconductor memory of claim 7, wherein the first input line is a metal-0 line and the first column address bus is a metal-1 bus.

9. The semiconductor memory of any one of claims 7-8, wherein the second input line is a metal-0 line and the second column address bus is a metal-1 bus.

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10. The semiconductor memory of any one of claims 7-8, wherein the second input line is a metal-0 line, and wherein the second column address bus comprises a metal-2 bus running in the longitudinal direction of the bit lines and a metal-1 bus

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coupled to the metal-2 bus, the metal-1 bus running in the transversal direction of the wordlines.

ABSTRACT

5 SEMICONDUCTOR MEMORY HAVING STAGGERED SENSE AMPLIFIERS
 ASSOCIATED WITH A LOCAL COLUMN DECODER

10 The invention relates to a semiconductor memory, comprising:
 – bit lines,
 – a memory cell array and,
 – at least one pair of sense amplifier banks, wherein each sense amplifier is
 connected to a corresponding bit line according to an interleaved arrangement
15 resulting in interconnect spaces available in each sense amplifier bank of the pair
 parallel to the bit lines,
 characterized in that each sense amplifier bank further comprises at least one local
 column decoder for selecting at least one sense amplifier of the sense amplifier
 bank, the local column decoder being coupled to the at least one sense amplifier of
20 the sense amplifier bank by means of an output line running in an available
 interconnect space parallel to the bit lines.

FIGURE 3