

17

"A semiconductor integrated circuit".

The present invention relates to a semiconductor integrated circuit in which memory cells are integrated on a large scale.

A well-known type of semiconductor integrated circuit in which memory cells are integrated on a large scale (hereinbelow termed the "semiconductor memory") is the so-called RAM. The RAM (random access memory) is a device capable of storing information temporarily and reading it out when required. This type of memory is also called a "read/write memory".

Typically, a RAM includes memory cells which store information, an address circuit which externally selects a specified memory cell, and a timing circuit which controls the reading and writing of information.

In a RAM, a plurality of memory cells are arranged in the shape of a matrix. The operation of selecting a desired memory cell from among the plurality of memory cells is performed by selecting an intersection point in the matrix. The access time is therefore constant irrespective of the position (addresses) of the selected memory cells within the matrix.

RAMs are broadly classified into two sorts; bipolar RAMs and MOSRAMs.

The bipolar RAM has the following merits:

(1) As compared with the MOSRAM, it operates faster.

(2) The operation of the memory cell is of the static type, and the controls of timings, etc. are simple.

On the other hand, the bipolar RAM has the following demerits:

5 (3) As compared with the MOSRAM, it exhibits a higher power consumption (especially when it does not operate).

(4) As compared with the MOSRAM, it requires a more complicated manufacturing process and is more difficult to attain a high density of integration.

10 Bipolar RAMs are presently generally classified into the two types of the TTL type and the ECL type, depending upon differences in input/output levels. The access time (reading time) of the bipolar RAM of TTL interface falls within a range of 30 - 60 (nsec.), while the access time of the bipolar RAM of ECL
15 interface falls within a range of 4 - 35 (nsec.).

Accordingly, bipolar RAMs are applied to various memory systems where high speed operations are required.

Meanwhile, when compared with the bipolar RAM, the MOSRAM is simpler in structure and in the manufacturing process.
20 It is also more advantageous in terms of power consumption, storage density and price. Therefore, it is used in fields which do not require high speed operations.

MOSRAMs are classified into the dynamic type and the static type.

25 The dynamic type MOSRAM has its memory cell composed of a comparatively small number of transistors, namely, 1 - 3

19

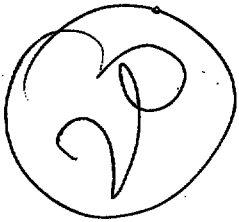
transistors per bit (1 - 3 transistors/bit). With an identical chip area, therefore, the bit density becomes higher than that of the static type MOSRAM to be described later.

In the dynamic MOSRAM, information is stored as charges in a capacitance within the memory cell. Since the charges stored in the capacitance are discharged due to a leakage current, etc., the information of the memory cell needs to be read out within a predetermined period of time and to be rewritten again (i.e., refreshed).

On the other hand, in the static MOSRAM, a flip-flop circuit which is usually composed of 6 elements is used as the memory cell. For this reason, the refresh which is required in the dynamic MOSRAM is not necessary.

The access time of the dynamic MOSRAM falls within a range of 100 - 300 (nsec.), while the access time of the static MOSRAM falls within a range of 30 - 200 (nsec.). Thus, it can be seen that the access time of the MOSRAM is a larger value when compared with that of the bipolar RAM.

Meanwhile, owing to improvements in photolithographic technology, reduction in the element dimensions of MISFETs within a semiconductor integrated circuit has been promoted. In IEEE Journal of Solid-State Circuit, Vol. SC-17, No. 5, pp. 793 - 797, issued in October 1982, there is contained a static MOSRAM of 64 kbits which employs wafer processing techniques based on design rules of 2 (μm) and which exhibits an access time of 65 (nsec.), an operating power consumption of 200 (mW) and a stand-by power consumption of 10 (μW).



Meanwhile, as an example of the bipolar RAM of the ECL type, an ECL type bipolar RAM of 4 kbits which exhibits an access time of 15 (nsec.) and a power consumption of 800 (mW) is manufactured and sold by Hitachi, Ltd. under the product name "HM100474-15".

5 As explained above, there has been a definite technical trend to enlarge the storage capacity of semiconductor memories which has taken place in the increments of 1 kbit, 4 kbits, 16 kbits, 64 kbits, 256 kbits, 1 Mbit, ..., quite independently of the features of the bipolar RAM of high speed and high power consumption and the
10 features of the MOSRAM of low speed and low power consumption.

At the present time, when the power consumption of the semiconductor memory and the present-day photolithographic techniques determining the element dimensions of bipolar transistors are taken into consideration, the storage capacity of the bipolar RAM will be
15 limited to 16 kbits.

Meanwhile, with the enlargement of the storage capacity of the semiconductor memory (particularly, at and above 64 kbits), the area of a semiconductor chip increases, and the signal line of the address circuit of the RAM is arranged over a long distance on the
20 semiconductor chip of large area. When the length of the signal line of the address circuit lengthens, naturally the stray capacitance of the signal line increases, and also the equivalent distributed resistance of the signal line increases. When, for the purpose of microminiaturization, the wiring width of the signal line of the
25 address circuit is established as 2 (μm) or less by improving photolithography, the equivalent distributed resistance of the signal line

51

increases more. In addition, since the fan-out of each circuit enlarges with the increase of the storage capacity, a load capacitance attributed to the gate capacitance of a MOSFET at the succeeding stage becomes high. Accordingly, in the 64-kbit MOSRAM which employs the photolithography of 2 (μm) and whose address circuit is entirely constructed of CMOSFETs, the access time of addresses will be limited to 30 (nsec.).

10 We have developed a semiconductor memory which has an access time equivalent to that of an ECL type bipolar RAM and a power consumption equivalent to that of a static MOSRAM.

15 It is therefore an object of the present invention to provide a semiconductor memory of high speed and low power consumption.

 According to the present invention there is provided a semiconductor integrated
20 circuit including:

23

- 6 -

(a) a plurality of memory cells;

(b) an address circuit for selecting a specified memory cell from among said plurality of memory cells;

5 (c) a signal circuit coupled to said memory cells and including means for respectively reading and writing information from and into said memory cells; and

(d) a timing circuit coupled to said
10 signal circuit for controlling operations of reading and writing information;

wherein one of the circuits, selected from the address circuit, the timing circuit, and the signal circuit, includes a principal
15 portion constructed of a CMOS circuit, and a bipolar transistor, which executes at least one of the functions of charge and discharge of a signal output line of the selected circuit.

23

The address circuit may include a principal portion constructed of a CMOS circuit, and at least one bipolar output transistor, which executes at least one of the functions of charge and discharge of a signal output line of at least one circuit in said address circuit.

The timing circuit may include a principal portion constructed of a CMOS circuit, and at least one bipolar output transistor, which executes at least one of the functions of charge and discharge of a signal output line of at least one circuit in said timing circuit.



The signal circuit may include a data output buffer for obtaining an information output signal, said data output buffer including a principal portion constructed of a CMOS circuit, and a plurality of bipolar transistors, which execute at least one of the functions of charge and discharge of gate capacitances of N-channel and P-channel output MISFETs of said data output buffer.

10 The signal circuit may include a data input amplifier which supplies complementary signals to a common data line pair, said data input amplifier including a principal portion constructed of a CMOS circuit and at least one
15 bipolar transistor, which executes at least one of the functions of charge and discharge of said common data line pair.

25

The present invention will now be described in greater detail by way of example with reference to the accompanying drawings, wherein:-

5 Figure 1 is a block diagram showing the internal arrangement of a static RAM according to one embodiment of the present invention;

 Figure 2 is a block diagram showing an address buffer ADB and row decoders R-DCR0,
10 R-DCR2 in Figure 1 in greater detail;

 Figure 3 is a block diagram showing the address buffer ADB, a column decoder C-DCR1, etc. in Figure 1 in greater detail;



Fig. 4 is a circuit diagram showing a quasi-CMOS non-inverting/inverting circuit for use in the present invention;

Fig. 5 is a circuit diagram showing a quasi-CMOS 3-input NAND circuit for use in the present invention;

5 Fig. 6 is a circuit diagram showing a pure CMOS 3-input NAND circuit for use in the present invention;

Fig. 7 is a circuit diagram showing a quasi-CMOS 2-input NOR circuit for use in the present invention;

10 Fig. 8 is a circuit diagram showing a pure CMOS 2-input NOR circuit for use in the present invention;

Fig. 9 is a circuit diagram showing a pure CMOS 2-input NAND circuit for use in the present invention;

Fig. 10 is a circuit diagram showing a quasi-CMOS inverter for use in the present invention;

15 Fig. 11 is a circuit diagram showing a sense amplifier selector circuit SASC and an internal control signal generator circuit COM-GE in Fig. 1 in greater detail;

20 Fig. 12 is a circuit diagram showing a sense amplifier SA1, a data output intermediate amplifier DOIA, a data output buffer DOB, etc. in Fig. 1 in greater detail;

Fig. 13 is a circuit diagram showing a data input buffer DIB, a data input intermediate amplifier DIIA1, etc. in Fig. 1 in greater detail; and

25 Fig. 14 is a diagram of the signal waveforms of the various parts of the static RAM of the embodiment shown in Figs. 1 to 13, in a read cycle and a write cycle.

27

Fig. 1 shows the internal arrangement of a static RAM which has a storage capacity of 64 kbits and the input/output operation which is executed in single bit units. Various circuit blocks enclosed with a broken line IC are formed in a single
5 silicon chip by semiconductor integrated circuit technology.

The static RAM of the present embodiment includes four matrices (memory arrays M-ARY1 to M-ARY4) each having a storage capacity of 16 kbits (= 16384 bits), thereby to have a total storage capacity of 64 kbits (more specifically 65536 bits).
10 The four memory arrays M-ARY1 to M-ARY 4 have arrangements similar to each other, and each of them has memory cells arranged in 128 rows x 128 columns.

An address circuit for selecting a desired memory cell from the memory arrays each having the plurality of memory cells
15 is constructed of an address buffer ADB, row decoders R-DCR0, R-DCR1 and R-DCR2, column decoders C-DCR1 to C-DCR4, column switches C-SW1 to C-SW4, etc.

Although not especially restricted, a signal circuit which handles the reading and writing of information is constructed of
20 a data input buffer DIB, data input intermediate amplifier D-IIA1 - DIIA4, a data output buffer DOB, a data output intermediate amplifier DOIA, and sense amplifiers SA1 - SA16.



Although the invention is not especially restricted thereto, a timing circuit for controlling the operations of reading and writing information is constructed of an internal control signal generator circuit COM-GE and a sense amplifier selector circuit SASC.

5 A decode output signal which is obtained on the basis of address signals $A_0 - A_8$ is transmitted from the row decoder R-DCR1 or R-DCR2 to any of row-group address selection lines (word lines WL11 - WL1128, WL21 - WL2128, WR11 - WR1128 and WR21 - WR2128). Among the address signals $A_0 - A_8$, those A_7 and A_8 are used for
10 selecting one memory matrix from among the four memory matrices M-ARY1 to M-ARY4.

 The address buffer ADB receives the address signals $A_0 - A_{15}$, and forms internal complementary address signals $\underline{a}_0 - \underline{a}_{15}$ based on them. The internal complementary address signal $\underline{a}_0$ is composed of
15 an internal address signal a_0 which is inphase with the address signal A_0 , and an internal address signal $\bar{a}_0$ whose phase is inverted to that of the address signal A_0 . The remaining internal complementary address signals $\underline{a}_1 - \underline{a}_{15}$ are similarly composed of internal address signals $a_1 - a_{15}$ and internal address signals $\bar{a}_1 - \bar{a}_{15}$.

20 Among the internal complementary address signals $\underline{a}_0 - \underline{a}_{15}$ formed by the address buffer ADB, those $\underline{a}_7$, $\underline{a}_8$ and $\underline{a}_9 - \underline{a}_{15}$ are supplied to the column decoders C-DCR1 to C-DCR4. The column decoders C-DCR1 to C-DCR4 decode these internal complementary address signals, and supply selection signals (decode output signals)
25 obtained by the decoding, to the gate electrodes of switching insulated-gate field effect transistors (hereinbelow termed "MISFETs")

29

$Q_{1001}, \bar{Q}_{1001}, Q_{1128}, \bar{Q}_{1128}, Q_{2001}, \bar{Q}_{2001}, Q_{3001}, \bar{Q}_{3001}, Q_{4001}$
and $\bar{Q}_{4001}$ within the column switches C-SW1 to C-SW4.

Among the word lines $WL_{11} - WL_{1128}, WL_{21} - WL_{2128},$
 $WR_{11} - WR_{1128}$ and $WR_{21} - WR_{2128},$ one appointed by the combi-
nation of the external address signals $A_0 - A_8$ is selected by the
row decoders R-DCR1 and R-DCR2 described above. One comple-
mentary data line pair appointed by the combination of the external
address signals $A_7, A_8,$ and $A_9 - A_{15}$ is selected from among a plu-
rality of complementary data line pairs $D_{1001}, \bar{D}_{1001} - D_{1128}, \bar{D}_{1128};$
 $D_{2001}, \bar{D}_{2001} - D_{2128}, \bar{D}_{2128}; D_{3001}, \bar{D}_{3001} - D_{3128}, \bar{D}_{3128};$ and
 $D_{4001}, \bar{D}_{4001} - D_{4128}, \bar{D}_{4128}$ by the column decoders C-DCR1 to
C-DCR4 and the column switches C-SW1 to C-SW4 described above.
Thus, the memory cell M-CEL which is located at the intersection
point between the selected word line and the selected complementary
data line pair is selected.

In the reading operation, switching MISFETs $Q_1, \bar{Q}_1 - Q_4,$
 $\bar{Q}_4, Q_8, \bar{Q}_8, Q_{12}, \bar{Q}_{12}, Q_{16}$ and $\bar{Q}_{16}$ are brought into "off" states
by a control signal which has been delivered from the internal control
signal generator circuit COM-GE, though this is not especially restric-
tive. Thus, common data lines $CDL_1, \bar{CDL}_1 - CDL_4, \bar{CDL}_4$ and write
signal input intermediate amplifiers DIIA1 - DIIA4 are electrically
isolated. The information of the selected memory cell is transmitted
to the common data lines through the selected complementary data line
pair. The information of the memory cell transmitted to the common
data lines is sensed by the sense amplifier, and is delivered out
through the data output intermediate amplifier DOIA as well as the
data output buffer DOB.

30

In the present embodiment, sixteen sense amplifiers are provided. Among these sense amplifiers SA1 - SA16, one sense amplifier, i.e., the sense amplifier whose input terminals are coupled to the selected complementary data line pair through the common data lines, is selected by a sense amplifier selection signal from the sense amplifier selector circuit SASC, and it executes the sensing operation.

In the writing operation, the switching MISFETs $Q_1, \bar{Q}_1 - Q_4, \bar{Q}_4, Q_8, \bar{Q}_8, Q_{12}, \bar{Q}_{12}, Q_{16}$ and $\bar{Q}_{16}$ are brought into "on" states by the control signal from the internal control signal generator circuit COM-GE. In the case where the column decoder C-DCR1, for example, has brought the switching MISFETs Q_{1001} and $\bar{Q}_{1001}$ into "on" states in accordance with the address signals $A_7 - A_{15}$, the output signal of the data input intermediate amplifier DI1A1 is transmitted to the complementary data line pair $D_{1001}, \bar{D}_{1001}$ through the common data line pair CDL1, $\bar{CDL}1$ and the MISFETs $Q_1, \bar{Q}_1, Q_{1001}, \bar{Q}_{1001}$. If, on this occasion, the word line WL11 is selected by the row decoder R-DCR1, information corresponding to the output signal of the data input intermediate amplifier DI1A1 is written into the memory cell which is located at the intersection point between the word line WL11 and the complementary data lines $D_{1001}, \bar{D}_{1001}$.

Although not especially restricted thereto, the common data line pair CDL1 and $\bar{CDL}1$ is composed of four sets of common data line pairs (subcommon data line pairs) in the present embodiment. Among these four sets of common data line pairs, two sets of common data line pairs are shown in the figure. Likewise to the illustrated

31

common data line pairs, the remaining two sets of common data line pairs are coupled to the data input intermediate amplifier DIIA1 through the switching MISFETs Q_2 , $\bar{Q}_2$ and Q_3 , $\bar{Q}_3$ respectively. The input terminals of one sense amplifier, and one input and output electrode of each of the 32 sets of switching MISFETs are coupled to each of the four sets of common data line pairs. That is, the input terminals of the sense amplifier SA1 and the input and output terminals of the switching MISFETs Q_{1001} , $\bar{Q}_{1001}$ - Q_{1032} , $\bar{Q}_{1032}$ are coupled to the first common data line pair; the input terminals of the sense amplifier SA2 and the input and output terminals of the switching MISFETs Q_{1033} , $\bar{Q}_{1033}$ - Q_{1064} , $\bar{Q}_{1064}$ are coupled to the second common data line pair; the input terminals of the sense amplifier SA3 and the input and output terminals of the switching MISFETs Q_{1065} , $\bar{Q}_{1065}$ - Q_{1096} , $\bar{Q}_{1096}$ are coupled to the third common data line pair; and the input terminals of the sense amplifier SA4 and the input and output terminals of the switching MISFETs Q_{1097} , $\bar{Q}_{1097}$ - Q_{1128} , $\bar{Q}_{1128}$ are coupled to the fourth common data line pair. In the writing operation, the four sets of common data line pairs are electrically coupled to each other through the switching MISFETs Q_1 , $\bar{Q}_1$ - Q_4 , $\bar{Q}_4$, whereas in the reading operation, they are electrically isolated from each other. Thus, it is possible in the reading operation to reduce stray capacitances which are coupled to the input terminals of the sense amplifier, so that enhancement in the speed of the reading operation can be achieved. In the reading operation, only the sense amplifier having its input

32 terminals coupled to the subcommon data line pair to which the information from the selected memory cell has been transmitted through the switching MISFETs is selected to execute the sensing operation. Each of the other common data line pairs CDL2, $\overline{\text{CDL2}}$ - CDL4, $\overline{\text{CDL4}}$ has an arrangement similar to that of the common data line pair CDL, $\overline{\text{CDL}}$ described above.

Although, in the present embodiment, the common control signal WECS is supplied to the switching MISFETs $Q_1, \overline{Q}_1 - Q_4, \overline{Q}_4, Q_8, \overline{Q}_8, Q_{12}, \overline{Q}_{12}, Q_{16}$ and $\overline{Q}_{16}$, the selection signals from the column decoders may well be supplied to the respective switching MISFETs. Thus, it is possible in the writing operation to reduce the load capacitance of the data input intermediate amplifier, so that enhancement in the speed of the writing operation can be achieved.

The internal control signal generator circuit COM-GE receives two external control signals, $\overline{\text{CS}}$ (chip select signal) and $\overline{\text{WE}}$ (write enable signal), and generates a plurality of control signals $\text{CS}_1, \text{CS}_2, \text{CS}_3, \overline{\text{WECS}}, \text{WECS}, \text{DOC}$, etc.

The sense amplifier circuit SASC receives the chip select signal $\overline{\text{CS}}$ and the internal complementary address signals $\underline{a}_7 - \underline{a}_{15}$, and forms the foregoing sense amplifier selection signal and internal chip select signals $\text{CS}, \overline{\text{CS}}$.

Fig. 2 is a block diagram which shows the address buffer ADB and row decoders R-DCR0, R-DCR1 and R-DCR2 in Fig. 2 in greater detail.

In Fig. 2, the circuits of those logic symbols whose output sides are marked black are quasi-CMOS circuits wherein an output

33

transistor for charging and discharging an output signal line is made of a bipolar transistor, while transistors for logic processing such as inversion, non-inversion, NAND or NOR operations are made of CMOSFETs. The circuit of an ordinary logic symbol is a pure CMOS circuit.

As shown in Fig. 2, in the address buffer ADB, there are arranged non-inverting/inverting circuits $G_0 - G_8$ whose inputs receive the address signals $A_0 - A_8$ of TTL levels from outside and which serve to transmit the non-inverted outputs $a_0 - a_8$ and the inverted outputs $\bar{a}_0 - \bar{a}_8$ to complementary output signal lines.

Each of the non-inverting/inverting circuits $G_0 - G_8$ is constructed of a quasi-CMOS circuit as shown in Fig. 4.

In Fig. 4, Q_{40} , Q_{42} , Q_{44} , Q_{46} , Q_{50} , Q_{52} and Q_{53} indicate N-channel MISFETs; Q_{41} , Q_{43} , Q_{45} and Q_{49} P-channel MISFETs; and Q_{47} , Q_{48} , Q_{51} and Q_{54} N-P-N bipolar transistors.

A resistor R_{40} and the MISFET Q_{40} constitute a gate protection circuit which serves to protect the gate insulator film of the MISFETs Q_{41} , Q_{42} from an external surge voltage applied to an input terminal.

Since the MISFETs Q_{41} , Q_{42} , Q_{43} and Q_{44} constitute a CMOS inverter of two-stage cascade connection, a signal inphase with the signal of a node N_1 is transmitted to a node N_3 .

Since also the MISFETs Q_{45} and Q_{46} constitute a CMOS inverter, a signal antiphase to the signal of the node N_3 is transmitted to a node N_4 .

The transistor Q_{47} is an output transistor for charging the capacitive load C_{41} of an output terminal OUT, while the transistor Q_{48} is an output transistor for discharging the capacitive load C_{41} .

Since also the MISFETs Q_{49} and Q_{50} constitute a CMOS inverter, a signal antiphase to the signal of the node N_3 is transmitted to a node N_5 .

The MISFET Q_{52} is a source-follower MISFET which is turned "on" by the signal of the node N_3 so as to apply a base current to the transistor Q_{54} for discharging the capacitive load C_{42} of an output terminal $\overline{OUT}$. The MISFET Q_{53} operates, not only as the load of the source-follower MISFET Q_{52} , but also as a switching MISFET for discharging charges stored in the base of the transistor Q_{54} .

In order to prevent the transistor Q_{48} from being driven in its saturation region, the source of the MISFET Q_{45} is connected to the collector of the transistor Q_{48} , not to a power source V_{CC} . Likewise, in order to prevent the transistor Q_{54} from being driven in its saturation region, the drain of the MISFET Q_{52} is connected to the collector of the transistor Q_{54} , not to the power source V_{CC} . This point is also an important feature in improvements.

Accordingly, when a signal of high level is applied to the input terminal IN in the non-inverting/inverting circuit of Fig. 4, the node N_3 becomes the high level, and the nodes N_4 and N_5 become a low level, to supply a base current to the base of the transistor Q_{47} through the transistor Q_{43} , so that the transistor Q_{47} is turned "on". When the output terminal $\overline{OUT}$ is at the high level, the MISFET Q_{52} is turned "on", so that the base current is supplied to the transistor Q_{54} through this MISFET Q_{52} . At this time, the MISFETs Q_{46} and Q_{50} are "on" because the node N_3 is at the high level. In consequence, the transistors Q_{45} and Q_{54} turn

35

"off" because charges stored in their bases are discharged through the MISFETs Q_{46} and Q_{50} . Therefore, the capacitive load C_{41} is charged rapidly by the bipolar output transistor Q_{47} of low output impedance, while the capacitive load C_{42} is discharged rapidly by the bipolar output transistor Q_{54} of low output impedance. When the charge of the capacitive load C_{41} has ended, current stops flowing through the collector-emitter path of the transistor Q_{47} . When the discharge of the capacitive load C_{41} has ended, currents stop flowing through the drain-source path of the MISFET Q_{52} and and the collector-emitter path of the bipolar transistor Q_{54} .

When a signal of low level is applied to the input terminal IN of the non-inverting/inverting circuit in Fig. 4, the transistors Q_{47} and Q_{54} turn "off" and those Q_{48} and Q_{51} turn "on", so that the capacitive load C_{41} is discharged fast, while the capacitive load C_{42} is charged fast. At this time, the MISFET Q_{53} turns "on" because the node N_5 becomes the high level. In consequence, charges stored in the base of the bipolar transistor Q_{54} are fast discharged to earth potential point through the MISFET Q_{53} , so that the turn-off speed of the bipolar transistor Q_{54} is enhanced. When the discharge of the capacitive load C_{41} has ended, currents stop flowing through the drain-source path of the MISFET Q_{45} and the collector-emitter path of the bipolar transistor Q_{48} . When the charge of the capacitive load C_{42} has ended, current stops flowing through the collector-emitter path of the bipolar transistor Q_{51} .

If the charge and discharge of the capacitive loads C_{41} and C_{42} are not executed by the bipolar output transistors Q_{47} , Q_{48} , Q_{51} and Q_{54} but are instead executed by MISFETs, they will be

executable only at low speed because the "on" resistance of the MISFET becomes a much larger value as compared with that of the bipolar transistor.

In contrast, in the address buffer of the embodiment in Fig. 2, the output transistors of the non-inverting/inverting circuits $G_0 - G_8$ for delivering the internal address signals $a_0, \bar{a}_0 - a_8, \bar{a}_8$ to the output signal lines thereof are made of the bipolar transistors as shown in Fig. 4, so that even when the output signal lines of the non-inverting/inverting circuits $G_0 - G_8$ are arranged over relatively long distances on the surface of the semiconductor chip, the non-inverting/inverting circuits $G_0 - G_8$ are permitted to operate at high speed.

The row decoder R-DCR0 in Fig. 2 operates as the pre-decoder of the address circuit. This row decoder R-DCR0 is constructed of 3-input NAND circuits $G_{16} - G_{23}, G_{24} - G_{31}$ and $G_{40} - G_{47}$ to which the internal address signals $a_0, \bar{a}_0 - a_8, \bar{a}_8$ obtained from the address buffer ADB are applied, and 2-input NOR circuits $G_{32} - G_{39}$ to which the chip select signal $\overline{CS}$ and the output signals of the 3-input NAND circuits $G_{24} - G_{31}$ are applied.

The output signal lines (that is, the output signal lines of the 3-input NAND circuits $G_{16} - G_{23}$ and $G_{40} - G_{47}$ and the output signal lines of the 2-input NOR circuits $G_{32} - G_{39}$) of the row decoder R-DCR0 as the pre-decoder are arranged over long distances in the vertical direction within the row decoders R-DCR1 and R-DCR2, which are the decoder drivers of the address circuit, as illustrated in Fig. 2.

37

Each of the 3-input NAND circuits $G_{16} - G_{23}$, $G_{24} - G_{31}$ and $G_{40} - G_{47}$ within the row decoder R-DCR0 in Fig. 2 is constructed of a quasi-CMOS circuit as shown in Fig. 5.

5 The quasi-CMOS 3-input NAND circuit in Fig. 5 includes an input logic processing portion which is composed of P-channel MISFETs $Q_{55} - Q_{57}$ and N-channel MISFETs $Q_{58} - Q_{61}$, and an output portion which is composed of N-P-N bipolar output transistors Q_{62} , Q_{63} . The MISFET Q_{61} operates as a switching MISFET for discharging charges stored in the base of the bipolar transistor Q_{63} .

10 When input signals of high level are applied to all of three input terminals $IN_1 - IN_3$, the transistors $Q_{55} - Q_{57}$ turn "off", the transistors $Q_{58} - Q_{60}$ turn "on", a node N_7 becomes a low level, and the transistor Q_{61} turns "off". Then, in the output portion, the transistor Q_{62} turns "off", and when an output terminal OUT is at
15 the high level, the transistor Q_{63} is supplied with a base current through the transistors $Q_{58} - Q_{60}$ and turns "on". Charges in the capacitive load C_{43} of the output terminal OUT are rapidly discharged to an earth potential point through the collector-emitter path of the transistor Q_{63} , while at the same time, a discharge current flow
20 through a route which extends along the capacitive load C_{43} , a diode Q_{64} , the MISFETs $Q_{58} - Q_{60}$ and the base-emitter junction of the bipolar transistor Q_{63} . A voltage drop across both the ends of the diode Q_{64} at this time controls the transistor Q_{62} into its "off" state reliably.

25 When an input signal of low level is applied to at least one of the three input terminals $IN_1 - IN_3$, the node N_7 becomes the high level, the transistor Q_{62} turns "on", and the capacitive

load C_{43} is rapidly charged through the collector-emitter path of the transistor Q_{62} . According to the high level of the node N_7 , the transistor Q_{61} turns "on", and the charges stored in the base of the transistor Q_{63} are rapidly discharged through the drain-source path of the transistor Q_{61} , so that the turn-off speed of the transistor Q_{63} can be enhanced.

In this manner, the output portion of the quasi-CMOS 3-input NAND circuit in Fig. 5 is constructed of the bipolar transistors Q_{62} and Q_{63} , and hence, the charge and discharge of the capacitive load C_{43} are executed at high speed.

Incidentally, since the 3-input NAND circuits $G_{24} - G_{31}$ within the row decoder R-DCR0 in Fig. 2 have their outputs connected to the inputs of the 2-input NOR circuits $G_{32} - G_{39}$ which is only a relatively short distance connection, each of them may well be constructed of a pure CMOS circuit as shown in Fig. 6.

The pure CMOS 3-input NAND circuit in Fig. 6 is composed of P-channel MISFETs $Q_{64} - Q_{66}$ and N-channel MISFETs $Q_{67} - Q_{69}$. Since the length of a signal line from an output terminal OUT is short as described above, the capacitance value of the stray capacitance C_{44} of the output terminal OUT is small.

Accordingly, even when the charge and discharge of the small stray capacitance C_{44} are executed by the MISFETs $Q_{64} - Q_{66}$ and $Q_{67} - Q_{69}$ having comparatively great "on" resistances, they can be executed at comparatively high speed.

Each of the 2-input NOR circuits $G_{32} - G_{39}$ within the row decoder R-DCR0 in Fig. 2 is constructed of a quasi-CMOS circuit as shown in Fig. 7.

39

The quasi-CMOS 2-input NOR circuit in Fig. 7 includes an input logic processing portion which is composed of P-channel MISFETs Q_{70} , Q_{71} and N-channel MISFETs $Q_{72} - Q_{74}$, and an output portion which is composed of N-P-N bipolar output transistors Q_{75} , Q_{76} . The MISFET Q_{74} operates as a switching MISFET which serves to discharge charges stored in the base of the bipolar transistor Q_{76} .

When input signals of low level are applied to both of two input terminals IN_1 and IN_2 , the transistors Q_{70} and Q_{71} turn "on", the transistors Q_{72} and Q_{73} turn "off", and a node N_9 becomes a high level. Then, the transistor Q_{75} turns "on", and the capacitive load C_{45} of an output terminal OUT is rapidly charged through the collector-emitter path of the transistor Q_{75} . The high level of the node N_9 turns "on" the transistor Q_{74} , and the charges stored in the base of the transistor Q_{76} are rapidly discharged through the drain-source path of the transistor Q_{74} , so that the turn-off speed of the transistor Q_{76} can be enhanced.

When an input signal of high level is applied to at least either of the two input terminals, for example, the input terminal IN_1 , the transistor Q_{70} turns "off", the transistor Q_{72} turns "on", and the node N_9 becomes the low level. Then, in the output portion, the transistor Q_{75} turns "off", and when the output terminal OUT is at the high level, the transistor Q_{76} is supplied with a base current through the transistors Q_{72} , Q_{77} and turns "on". Charges in the capacitive load C_{45} of the output terminal OUT are rapidly discharged through the collector-emitter path of the transistor Q_{76} , while at the same time, a discharge current flows through a route which extends

along the capacitive load C_{45} , a diode Q_{77} , the drain-source path of the MISFET Q_{72} and the base-emitter junction of the bipolar transistor Q_{76} . Owing to a voltage drop across both the ends of the diode Q_{77} at this time, the bipolar transistor Q_{75} is reliably controlled into its "off" state.

The row decoders R-DCR1 and R-DCR2 in Fig. 2 operate as the decoder drivers of the address circuit. The row decoder R-DCR1 includes a 2-input NOR circuit G_{48} which receives the output signals of the row decoder R-DCR0, 2-input NAND circuits $G_{49} - G_{56}$ which receive the output signal of the 2-input NOR circuit G_{48} and the output signals of the row decoder R-DCR0, and inverters $G_{57} - G_{64}$ which receive the output signals of the 2-input NAND circuits $G_{49} - G_{56}$.

The distances of the signal lines between the output of the 2-input NOR circuit G_{48} and the inputs of the 2-input NAND circuits $G_{49} - G_{56}$ are relatively long, and the stray capacitance values of these signal lines are large. Accordingly, the 2-input NOR circuit G_{48} is constructed of the quasi-CMOS circuit as shown in Fig. 7.

Since the 2-input NAND circuits $G_{49} - G_{56}$ within the row decoder R-DCR1 in Fig. 2 have their outputs connected to the inputs of the inverters $G_{57} - G_{64}$ which is only a relatively short distance connection, each of them is constructed of a pure CMOS circuit as shown in Fig. 9.

The pure CMOS 2-input NAND circuit in Fig. 9 is composed of P-channel MISFETs Q_{82} , Q_{83} and N-channel MISFETs Q_{84} , Q_{85} . Since the length of the signal line from an output terminal OUT is

41

short as described above, the capacitance value of the stray capacitance of the output terminal OUT is small.

Accordingly, even when the charge and discharge of the small stray capacitance C_{47} are executed by the MISFETs Q_{82} , Q_{83} , Q_{84} and Q_{85} having comparatively great "on" resistances, they are executed at high speed.

The outputs of the inverters $G_{57} - G_{64}$ within the row decoder R-DCR1 in Fig. 2 are connected to the word lines $WL_{11} - WL_{18}$ of the memory array M-ARY1. Accordingly, the output signal lines (that is, the output signal lines of the inverters $G_{57} - G_{64}$) of the row decoder R-DCR1 as the decoder driver are arranged to cover relatively long distances in the lateral direction inside the memory array M-ARY1 as the word lines $WL_{11} - WL_{18}$, so that the stray capacitances of the word lines $WL_{11} - WL_{18}$ become quite large.

Thus, each of the inverters $G_{57} - G_{64}$ within the row decoder R-DCR1 in Fig. 2 is constructed of a quasi-CMOS circuit as shown in Fig. 10.

The quasi-CMOS inverter in Fig. 10 is composed of a P-channel MISFET Q_{86} , N-channel MISFETs $Q_{87} - Q_{89}$, and N-P-N bipolar output transistors Q_{90} , Q_{91} . The operation of this quasi-CMOS inverter is the same as the operation of the circuit $Q_{49} - Q_{54}$ for obtaining the inverted output $\overline{OUT}$ of the non-inverting/inverting circuit in Fig. 4, and the detailed description shall therefore be omitted. The charge and discharge of a great stray capacitance C_{48} are executed at high speed by the N-P-N bipolar output transistors Q_{90} , Q_{91} .

42
In Fig. 2, the row decoder D-DCR2 is constructed similarly to the R-DCR1 stated above.

Fig. 3 is a block diagram which shows the address buffer ADB, the column decoder C-DCR1, etc. in Fig. 1 in greater detail.

5 Also in Fig. 3, the circuits of those logic symbols whose output sides are marked black are quasi-CMOS circuits wherein an output transistor for charging and discharging the stray capacitance of an output signal line is made of a bipolar transistor and wherein logic processing such as inversion, non-inversion, NAND or NOR is
10 executed by a CMOS circuit. The circuit of an ordinary logic symbol is a pure CMOS circuit.

As shown in Fig. 3, in the address buffer ADB, there are arranged non-inverting/inverting circuits $G_7 - G_{15}$ whose inputs receive the address signals $A_7 - A_{15}$ of TTL levels from outside and
15 which serve to transmit the non-inverted outputs $a_7 - a_{15}$ and the inverted outputs $\bar{a}_7 - \bar{a}_{15}$ to their complementary output signal lines.

Each of the non-inverting/inverting circuits $G_7 - G_{15}$ is constructed of the quasi-CMOS circuit as shown in Fig. 4. Accordingly, the output transistors of each of the non-inverting/inverting
20 $G_7 - G_{15}$ are made of the bipolar transistors as illustrated in Fig. 4, so that even when the output signal lines of the non-inverting/inverting circuits $G_7 - G_{15}$ are arranged to extend relatively long distances on the surface of the semiconductor chip, the non-inverting/inverting circuits $G_7 - G_{15}$ are permitted to operate at high speed.

25 The column decoder C-DCR1 includes 2-input NAND circuits $G_{74} - G_{77}$, $G_{78} - G_{81}$ and $G_{82} - G_{85}$ to which the internal address

43

signals $a_7 - a_{15}$ and $\bar{a}_7 - \bar{a}_{15}$ obtained from the address buffer ADB are applied, and 3-input NAND circuits $G_{86} - G_{93}$.

Further, as shown in Fig. 3, the output signal lines of the NAND circuits $G_{74} - G_{93}$ are arranged with long distances and are connected to the input terminals of a large number of NOR circuits $G_{94} - G_{95}$ inside the column decoder C-DCR1, so that the stray capacitances of the output signal lines of the NAND circuits $G_{74} - G_{93}$ become large capacitance values.

Accordingly, each of the 3-input NAND circuits $G_{86} - G_{93}$ is constructed of the quasi-CMOS 3-input NAND circuit as shown in Fig. 5, and each of the 2-input NAND circuits $G_{74} - G_{85}$ is constructed of a quasi-CMOS 2-input NAND circuit which is obtained by omitting the input terminal IN_3 and the MISFETs Q_{57}, Q_{60} from Fig. 5.

On the other hand, in Fig. 3, the output signal lines of the 3-input NOR circuits G_{94}, G_{95} are connected to the inputs of inverters G_{100}, G_{101} with short distances, so that the stray capacitances of the output signal lines of the 3-input NOR circuits $G_{94} - G_{95}$ have small capacitance values. Accordingly, each of the 3-input NOR circuits $G_{94} - G_{95}$ is constructed of a pure CMOS 3-input NOR circuit.

Further, the output signal lines of the inverters G_{100}, G_{101} are connected to the input terminals of 2-input NOR circuits G_{98}, G_{99} with a relatively short distance connection so that the stray capacitances of the output signal lines of the inverters G_{100}, G_{101} have small capacitance values. Accordingly, each of

the inverters G_{100} , G_{101} is constructed of a well-known pure CMOS inverter.

Further, the output signal lines of the 2-input NOR circuits G_{98} , G_{99} are connected to the gate electrodes of the switching MISFETs Q_{1001} , $\bar{Q}_{1001}$ of the column switch C-SW₁ with comparatively short distance connections, so that the stray capacitances of the output signal lines of the NOR circuits G_{98} , G_{99} are small. Accordingly, each of these NOR circuits is constructed of a pure CMOS 2-input NOR circuit as shown in Fig. 8.

The pure CMOS 2-input NOR circuit in Fig. 8 is composed of P-channel MISFETs Q_{78} , Q_{79} and N-channel MISFETs Q_{80} , Q_{81} . Since the distance of the signal line from an output terminal is comparatively short, the stray capacitance C_{46} of the output terminal OUT has a small capacitance value.

Accordingly, even when the charge and discharge of the small stray capacitance C_{46} are executed by the MISFETs Q_{78} , Q_{79} , Q_{80} and Q_{81} having comparatively great "on" resistances, they are executed at high speed.

Each of the aforementioned 3-input NOR circuits G_{94} - G_{95} is constructed of a pure CMOS 3-input circuit wherein a third input terminal IN_3 is added to the 2-input NOR circuit in Fig. 8, a third P-channel MISFET whose gate is connected to a third input terminal IN_3 is inserted in series with the MISFETs Q_{78} and Q_{79} , and a third N-channel MISFET whose gate is connected to the input terminal IN_3 is inserted in parallel with the MISFETs Q_{80} , Q_{81} .

In addition to the above, it can be seen that, in Fig. 3, the 1-bit memory cell M-CEL of the memory array M-ARY1 in Fig. 1 is

45

shown in greater detail. Specifically, the memory cell M-CEL is shown as being composed of a flip-flop in which the inputs and outputs of a pair of inverters consisting of load resistances R_1 , R_2 and N-channel MISFETs Q_{101} , Q_{102} are cross-connected, and N-channel MISFETs Q_{103} , Q_{104} which serve as transmission gates.

The flip-flop is employed as a means for storing information. The transmission gates are controlled by the address signal which is applied to the word line WL_{11} connected to the row decoder R-DCR1, and the information transmission between the complementary data line pair D_{1001} , $\bar{D}_{1001}$ and the flip-flop is controlled by the transmission gates.

Fig. 11 is a circuit diagram in which one example of the essential portions of the sense amplifier selector circuit SASC and one example of the internal control signal generator circuit COM-GE in Fig. 1 are shown more in detail.

Shown in the figure is the circuit of that part of the sense amplifier selector circuit SASC which receives the external chip select signal $\overline{CS}$ and which forms the control signals CS , $\overline{CS}$ to be supplied to the data output intermediate amplifier DOIA, the row decoder R-DCR0 and the column decoder C-DCR1.

The circuit of this portion to which the external chip select signal $\overline{CS}$ is applied is constructed of the same circuit as the non-inverting/inverting circuit in Fig. 4. Since the output signal CS of this circuit is obtained from bipolar output transistors T_1 , T_2 , T_3 and T_4 , the capacitance dependences of the charging and discharging speeds of the outputs $\overline{CS}$, CS of the sense amplifier selector circuit SASC are low. Accordingly, even when the output

46
CS of the sense amplifier selector circuit SASC is connected to the input terminals of the NOR gates $G_{32} - G_{39}$ of the row decoder R-DCR0 in Fig. 2 and to the input terminals of the NOR gates $G_{94} - G_{95}$ of the column decoder C-DCR1 in Fig. 3, this output CS becomes fast. Besides, even when the output CS of the sense amplifier selector circuit SASC is connected to the gate electrodes of a plurality of switching MISFETs within the data output intermediate amplifier DOIA, this output CS becomes fast.

Although no illustration is made in the figure, the sense amplifier selector circuit SASC includes a decoder circuit which receives the internal complementary address signals $a_7 - a_{15}$ and the aforementioned control signal CS and which forms a selection signal S1 to be supplied to the sense amplifier. Among the sense amplifiers SA1 - SA16, the sense amplifier whose input terminals are electrically coupled to the complementary data line pair to be selected is selected by this decoder circuit, whereupon the sensing operation thereof is executed. The output portion of this decoder circuit is constructed of a quasi-CMOS circuit so as to lower the capacitance dependences of the charge and discharge of the output. Thus, the speed of the operation of selecting the sense amplifier can be enhanced. Even in a case where the above control signal is supplied to the decoder circuit, the control signal CS is fast because it is formed by the bipolar transistors as stated above.

Although, in the present embodiment, the decoder circuit is located in the sense amplifier selector circuit SASC in order to select the sense amplifiers, the selection signals formed by the column decoders C-DCR1 to C-DCR4 may well be utilized for the selection

47

signals of the sense amplifiers. This measure can reduce the number of elements, and therefore permits enhancing the density of integration.

5 The internal control signal generator circuit COM-GE in Fig. 11 includes a circuit portion which is supplied with the external chip select signal $\overline{CS}$, thereby to generate a plurality of internal delay chip select signals CS_2 , $\overline{CS}_1$, CS_1 and CS_3 . The greater part of this circuit portion is constructed of CMOS circuits. Since, however, the outputs CS_2 , $\overline{CS}_1$, CS_1 and CS_3 are respectively
10 obtained from bipolar output transistors T_5 , T_6 ; T_9 , T_{10} ; T_{11} , T_{12} ; and T_7 , T_8 , the capacitance dependences of the charge and discharge of these outputs are low.

The internal control signal generator circuit COM-GE in Fig. 11 is further provided with a circuit portion which is supplied
15 with the external write enable signal $\overline{WE}$ and the internal delay chip select signals $\overline{CS}_1$, CS_2 , thereby to generate the write control signals $\overline{WECS}$, $WECS$ and a data output buffer control signal DOC . The greater part of this circuit portion is similarly constructed of CMOS circuits. Since, however, the signal $WECS$ is obtained from
20 bipolar output transistors T_{14} , T_{15} , the capacitance dependences of the charge and discharge of this output $WECS$ are low. Accordingly, even when the output $WECS$ is applied to the large number of input terminals of the NAND circuits (not shown) of the column decoder C-DCR1 in Fig. 3 or the gate electrodes of the switching
25 MISFETs Q_1 , $\overline{Q}_1 - Q_{16}$, $\overline{Q}_{16}$ in Fig. 1, this output $WECS$ becomes fast.

Fig. 12 is a circuit diagram in which the sense amplifier SA1, the data output intermediate amplifier DOIA, the data output buffer DOB, etc, in Fig. 1 are shown more in detail.

Fig. 13 is a circuit diagram in which the data input buffer DIB, the data input intermediate amplifier DIIA1, etc. in Fig. 1 are shown more in detail.

Fig. 14 is a diagram of the signal waveforms of various parts in the read cycle and write cycle of the static RAM which is one embodiment shown in Figs. 1 to 13.

First, the operation of the static RAM in the cycle of reading information will be described with reference to Figs. 12 and 14.

It is assumed that, as illustrated in Fig. 14, simultaneously with the application of the address signals $A_0 - A_{15}$, the chip select signal $\overline{CS}$ is changed to the low level, whereas the write enable signal $\overline{WE}$ is held at the high level as it is. As shown in Fig. 14, the internal delay chip select signals CS_1, CS_2, CS_3 , the write control signal $\overline{WECS}$ and the data output buffer control signal DOC are produced from the internal control signal generator circuit COM-GE at that time.

In the case where the supplied address signals $A_0 - A_{15}$ are, for example, those which appoint the word line WL_{11} and the complementary data line pair $D_{1001}, \overline{D}_{1001}$, the memory cell M-CEL which is located at the intersection point between the word line WL_{11} and the complementary data line pair $D_{1001}, \overline{D}_{1001}$ is selected. The internal information of the selected memory cell M-CEL is transmitted to both the inputs of the sense amplifier SA1 through the complementary data line pair $D_{1001}, \overline{D}_{1001}$ and the

49

switching MISFETs Q_{1001} , $\bar{Q}_{1001}$. The sense amplifier SA1 is composed of a differential pair of emitter-coupled transistors T_{21} , T_{22} and a constant current source MISFET T_{20} . When the selection signal S1 of high level is applied from the sense amplifier selector circuit SASC to the gate electrode of the constant current source MISFET T_{20} , the sense amplifier SA1 executes the sensing operation.

When the internal chip select signal CS of high level is applied from the sense amplifier selector circuit SASC to the gate electrodes of constant current source MISFETs T_{23} - T_{26} of the data output intermediate amplifier DOIA, this data output intermediate amplifier executes the amplifying operation.

Accordingly, the output signal of the sense amplifier SA1 is transmitted to the output node N_{11} of the data output intermediate amplifier DOIA through earthed -base transistors T_{27} , T_{28} , emitter-follower transistors T_{29} , T_{30} and output MISFETs T_{35} - T_{38} .

As illustrated in Fig. 12, the data output buffer DOB is supplied with the data output buffer control signal DOC from the internal control signal generator circuit COM-GE. In addition, as shown in Fig. 12, the data output buffer DOB is composed of a pure CMOS inverter of T_{39} and T_{40} , a quasi-CMOS 2-input NAND circuit of T_{41} - T_{48} , a quasi-CMOS 2-input NOR circuit of T_{49} - T_{56} , a P-channel switching MISFET T_{57} , an N-channel switching MISFET T_{58} , a P-channel output MISFET T_{59} , and an N-channel output MISFET T_{60} .

When the data output buffer control signal DOC is at the high level, the switching MISFETs T_{57} , T_{58} are turned "on", and the

50
output MISFETs T_{59} , T_{60} are simultaneously turned "off", so that the output D_{out} of the data output buffer DOB falls into a high impedance state (floating state).

5 In the cycle of reading information, the data output buffer control signal DOC becomes the low level to turn "off" the switching MISFETs T_{57} , T_{58} , and the gate electrodes of the output MISFETs T_{59} , T_{60} are controlled by the output of the quasi-CMOS 2-input NAND circuit and the output of the quasi-CMOS 2-input NOR circuit, the outputs being responsive to the signal level of the output node
10 N_{11} of the data output intermediate amplifier DOIA, whereby valid data is obtained from the output terminal D_{out} .

In order to reduce the "on" resistances of the output MISFETs T_{59} , T_{60} , the channel widths W of these MISFETs are set at very large values. Then, the gate capacitances of these MISFETs
15 T_{59} , T_{60} become very large. Since, however, the output portion of the quasi-CMOS 2-input NAND circuit is composed of the bipolar output transistors T_{47} , T_{48} and the output portion of the quasi-CMOS 2-input NOR circuit is composed of the bipolar output transistors T_{55} , T_{56} , the charge and discharge of the gate capacitances
20 of the output MISFETs T_{59} , T_{60} are executed at high speed.

Referring now to Figs. 13 and 14, the operation of the static RAM in the cycle of writing information will be described.

As illustrated in Fig. 14, simultaneously with the application of the address signals $A_0 - A_{15}$, the chip select signal $\overline{CS}$ changes
25 to the low level, whereupon the write enable signal $\overline{WE}$ changes to the low level. As shown in Fig. 14, the internal delay chip select signals CS_1 , CS_2 , CS_3 , the write control signal $\overline{WECS}$ and the data

51

output buffer control signal DOC are produced from the internal control signal generator circuit COM-GE at that time.

As shown in Fig. 13, input data D_{in} and the inverted internal chip select signal $\overline{CS}_1$ are applied to the data input buffer DIB. In writing information, the signal $\overline{CS}_1$ changes to the low level. Then, a P-channel switching MISFET T_{61} of the data input buffer changes into the "on" state, and an N-channel switching MISFET T_{62} into the "off" state. Thus, the input data D_{in} is transmitted to an output node N_{12} through pure CMOS inverters in multi-stage connection.

In writing information, the write control signal $\overline{WECS}$ changes to the low level. Then, within the data input intermediate amplifier DIIA1 in Fig. 13, P-channel MISFETs T_{63} , T_{65} turn "on", and N-channel MISFETs T_{64} , T_{66} turn "off", so that a signal inphase with the signal of the output node N_{12} of the data input buffer DIB appears at a node N_{13} , while a signal antiphase thereto appears at a node N_{14} .

The signal of the node N_{13} is transmitted to the common data line CDL_1 through a quasi-CMOS inverter composed of transistors $T_{67} - T_{72}$, while the signal of the node N_{14} is transmitted to the common data line $\overline{CDL}_1$ through a quasi-CMOS inverter composed of transistors $T_{73} - T_{78}$. Since the charge and discharge of the common data line pair CDL_1 , $\overline{CDL}_1$ of great parasitic capacitances are executed by the bipolar output transistors T_{71} , T_{72} and T_{77} , T_{78} of these quasi-CMOS inverters, they are executed at high speed.

Thus, the complementary output signals of the data input intermediate amplifier DIIA1 are transmitted to the memory cell M-CEL

through the common data line pair CDL_1 , $\overline{CDL}_1$, the switching MISFETs Q_1 , $\overline{Q}_1$, Q_{1001} , $\overline{Q}_{1001}$, and the complementary data line pair D_{1001} , $\overline{D}_{1001}$, whereby the writing of the information into the memory cell is executed.

5 As a result of the structure described in the foregoing description, the following advantages are achieved:

(1) Each of the non-inverting/inverting circuits $G_0 - G_{15}$ of an address buffer ADB is constructed of a quasi-CMOS circuit. Since, in the quasi-CMOS circuit, the greater part of a logic processing portion of non-inversion/inversion is constructed of CMOS
10 circuits, a low power consumption is possible. Further, output transistors which execute the charge and discharge of non-inverted and inverted outputs are made of bipolar transistors, so that even when the stray capacitances of the output signal lines of the non-
15 inverting/inverting circuits $G_0 - G_{15}$ become large, a high speed operation is obtained since the bipolar transistors can afford a lower output resistance with smaller element dimensions than a MISFET.

(2) Circuits whose output signal lines have large stray capacitances, such as the NAND circuits $G_{16} - G_{23}$, $G_{24} - G_{31}$,
20 $G_{40} - G_{47}$, the NOR circuits $G_{32} - G_{39}$, $G_{48} - G_{65}$ and the inverters $G_{57} - G_{64}$ of row decoders R-DCR0, R-DCR1, R-DCR2 are constructed of quasi-CMOS circuits, so that these circuits will be low in the power consumption and high in operating speed.

Further, circuits whose output signal lines have small stray
25 capacitances, such as NAND circuits $G_{49} - G_{56}$, are constructed of pure CMOS circuits, so that these circuits can be low in the power consumption.

53

(3) Circuits whose output signal lines have large stray capacitances, such as the NAND circuits $G_{74} - G_{93}$ of column decoders C-DCR1 to C-DCR4, are constructed of quasi-CMOS circuits, so that these circuits will be low in the power consumption and high in operating speed.

Further, circuits whose output signal lines have small stray capacitances, such as NOR circuits $G_{94} - G_{99}$ and inverters G_{100}, G_{101} , are constructed of pure CMOS circuits, so that these circuits will be low in the power consumption.

(4) Since a non-inverting/inverting circuit constituting a sense amplifier selector circuit SASC is constructed of a quasi-CMOS circuit, a low power consumption is achieved. Also, since outputs $CS, \overline{CS}$ are obtained from bipolar output transistors, these outputs $CS, \overline{CS}$ become fast even when their stray capacitances are large.

(5) Since an internal control signal generator circuit COM-GE is constructed of a quasi-CMOS circuit, a low power consumption is achieved, and since outputs $CS_2, CS_3, \overline{CS}_1, CS_1, WECS$ are obtained from bipolar output transistors, these outputs $CS_2, CS_3, \overline{CS}_1, CS_1, WECS$ become fast even when their stray capacitances are large.

(6) Since a data output buffer DOB is constructed of a quasi-CMOS circuit, a low power consumption is achieved.

Further, since the large gate capacitances of the output MISFETs of the data output buffer DOB are charged and discharged by bipolar output transistors, the charge and discharge of the gate capacitances are executed at high speed.

(7) Since a data input buffer DIB is constructed of a pure CMOS circuit, a low power consumption is achieved.

(8) Since a data input intermediate amplifier DIIA1 is constructed of a quasi-CMOS circuit, a low power consumption is achieved.

Further, since the charge and discharge of common data line pair CDL_1 , $\overline{CDL}_1$, which have large parasitic capacitances, are executed by bipolar output transistors, they are executed at high speed.

Owing to the synergistic effect of the above, the following characteristics could be obtained in the static SRAM described in the foregoing embodiment:

(a) The propagation delay time t_{pd} from the input to the output of each of the non-inverting/inverting circuits $G_0 - G_{15}$ of the address buffer ADB was shortened to about 3.0 (nsec). The stand-by power consumption of all the non-inverting/inverting circuits $G_0 - G_{15}$ was reduced to about 33.7 (mW), and the operating power consumption to about 45.8 (mW).

(b) The propagation delay time t_{pd} from the input to the output of each of the row decoders R-DCR0, R-DCR1, R-DCR2 and the column decoders C-DCR1 to C-DCR4 was reduced to about 4.8 (nsec). The stand-by power consumption of all the decoders was reduced to substantially zero, and the operating power consumption to about 153 (mW).

(c) The propagation delay time t_{pd} of all of a memory cell M-CEL, a sense amplifier SA1 and a data output intermediate amplifier DOIA was reduced to about 5.0 (nsec). The stand-by power consumption of all memory cells M-CEL numbering 64 k (65536), all sense amplifiers SA1 - SA16, and the data output intermediate

SS

amplifier DOIA was reduced to about 0.6 (mW), and the operating power consumption to about 160 (mW).

(d) The propagation delay time t_{pd} from the input to the output of the data output buffer DOB was shortened to 2.8 (nsec). The stand-by power consumption was reduced to substantially zero, and the operating power consumption to 23.5 (mW).

(e) Owing to the above (a) - (d), the access time (read time) was shortened to about 15.6 (nsec). This value is substantially equal to the 15 (nsec) access time of presently known ECL type bipolar RAMs.

(f) Owing to the above (a) - (d), the stand-by power consumption of the static SRAM of the present embodiment was reduced to about 34.3 (mW), and the operating power consumption to about 382.3 (mW). These values represent relatively low power consumption characteristics intermediate between those of a prior-art bipolar RAM and a prior-art static MOSRAM (and actually closer to those of the prior-art static MOSRAM).

Although, in the above, the invention has been described on the basis of a preferred embodiment, it is needless to say that the present invention is not restricted to the foregoing embodiment. A number of modifications are possible as follows:

For example, in the memory cell M-CEL in Fig. 3, the load resistances R_1 , R_2 may well be replaced with P-channel MISFETs so as to construct the flip-flop out of CMOS inverters. Besides, the flip-flop may well be constructed of multi-emitter N-P-N transistors.

Further, by performing refresh, the memory cell M-CEL may well be constructed of an information latch circuit based on the storage of charges in a cell capacitance, not of the flip-flop circuit.

5 The signal levels of the address signals $A_0 - A_{15}$ which are applied to the address buffer ADB may well be set to be ECL levels, rather than TTL levels, with the address buffer ADB executing a proper level conversion operation.

10 An input D_{in} or output D_{out} may well be constructed in the form of a plurality of bits (for example, 4 bits, 8 bits, ...), not 1 bit.

Also, of course, the number of the memory matrices is not restricted to four, but it may well be larger or smaller.

15 Further, although specific values have been given for various parameters or characteristics, it is to be understood that these are illustrative only, and do not serve to limit the present invention.

Finally, while, in the above, the invention made by the inventors has been chiefly described as to the case of application to the semiconductor memory, it is not restricted thereto.

20 For example, it is needless to say that, not only memory cells, address circuits for selecting a specified cell, signal circuits for handling the reading and writing of information, and the timing circuits for controlling the operations of reading and writing information can utilize the present invention. On the contrary, a variety of other circuits such as bipolar analog circuits, MOS analog circuits, 25 P-channel MOS logic, N-channel MOS logic, CMOS logic, I^2L circuits and ECL circuits can be arranged on the semiconductor chip as may be needed to incorporate the principles of the present invention.

57

Attention is drawn to our Application
Nos. 87. 14910 (Serial No. 2,)
and 87. 14911 (Serial No. 2,)
which have been divided out of the present
5 Application.

CLAIMS.

1. A semiconductor integrated circuit including:
- (a) a plurality of memory cells;
 - (b) an address circuit for selecting a specified memory cell from among said plurality of memory cells;
 - 5 (c) a signal circuit coupled to said memory cells and including means for respectively reading and writing information from and into said memory cells; and
 - (d) a timing circuit coupled to said signal circuit for controlling operations of reading and writing
 - 10 information;

wherein one of the circuits, selected from the address circuit, the timing circuit, and the signal circuit, includes a principal portion constructed of a CMOS circuit, and a bipolar transistor, which executes

15 at least one of the functions of charge and discharge of a signal output line of the selected circuit.

2. A semiconductor integrated circuit according to claim 1, wherein the address circuit includes a principal portion constructed of a CMOS circuit, and at
- 20 least one bipolar output transistor, which executes at least one of the functions of charge and discharge of a signal output line of at least one circuit in said address circuit.

3. A semiconductor integrated circuit according to claim 1, wherein the timing circuit includes a
- 25 principal portion constructed of a CMOS circuit, and at



59

least one bipolar output transistor, which executes at least one of the functions of charge and discharge of a signal output line of at least one circuit in said timing circuit.

5 4. A semiconductor integrated circuit according to claim 1, wherein the signal circuit includes a data output buffer for obtaining an information output signal, said data output buffer including a principal portion constructed of a CMOS circuit, and a plurality of bipolar
10 transistors, which execute at least one of the functions of charge and discharge of gate capacitances of N-channel and P-channel output MISFETs of said data output buffer.

5. A semiconductor integrated circuit according to claim 1, wherein the signal circuit includes a data
15 input amplifier which supplies complementary signals to a common data line pair, said data input amplifier including a principal portion constructed of a CMOS circuit and at least one bipolar transistor, which executes at least one of the functions of charge and
20 discharge of said common data line pair.

6. A semiconductor integrated circuit according to claim 2, wherein said address includes an address buffer to which address signals are applied, and wherein said bipolar output transistor comprises a bipolar output
25 transistor of said address buffer which executes at least one of the functions of charge and discharge of a signal output line of said address buffer.





7. A semiconductor integrated circuit according to claim 2, wherein said address circuit includes a row decoder which executes charge and discharge of word lines of the memory cells, and wherein a plurality of said
5 output bipolar transistors are provided to execute at least one of the functions of charge and discharge of said word lines.

8. A semiconductor integrated circuit according to claim 3, wherein said timing circuit includes an
10 internal control signal generator circuit which is supplied with a chip select signal and a write enable signal, thereby to generate an internal delayed chip select signal and a write control signal.

9. A semiconductor integrated circuit according to claim 4, wherein both said output MISFETs are controlled into a simultaneous "off" state by a data
15 output buffer control signal.

10. A semiconductor integrated circuit according to claim 5, wherein input data is transmitted to an input
20 terminal of said data input amplifier through a data input buffer which is constructed of said CMOS circuit.

11. A semiconductor integrated circuit constructed substantially as herein described with reference to and as illustrated in the accompanying drawings.

