



## U.S. PATENT DOCUMENTS

4,369,564	1/1983	Hiltbold	357/23.6
4,397,075	8/1983	Fatula et al.	357/23.6
4,412,237	10/1983	Matsumura et al.	357/42
4,432,006	2/1984	Takei	357/23.6
4,434,433	2/1984	Nishizawa	357/22
4,462,040	7/1984	Ho et al.	357/23.6
4,472,240	9/1984	Kameyama	357/55
4,476,623	10/1984	El-Kareh	357/51
4,536,785	8/1985	Gibbons	357/23.6
4,568,958	2/1986	Baliga	357/23.4
4,630,088	12/1986	Ogura et al.	357/23.6
4,636,281	1/1987	Buiguez et al.	357/59
4,649,625	3/1987	Lu	357/23.6
4,650,544	3/1987	Erb et al.	357/23.6
4,651,184	3/1987	Malhi	357/23.6
4,670,768	6/1987	Sunami et al.	357/42
4,672,410	6/1987	Miura et al.	357/23.6
4,673,962	6/1987	Chatterjee et al.	357/23.6
4,683,486	7/1987	Chatterjee	357/23.6
4,702,795	10/1987	Douglas	357/23.6
4,704,368	11/1987	Goth et al.	357/23.6
4,717,942	1/1988	Nakamura et al.	357/23.6
4,751,557	6/1988	Sunami et al.	357/23.6
4,751,558	6/1988	Kenney	357/23.6

## OTHER PUBLICATIONS

J. Fatula et al., "N Skin Elim. in UMOS Device by Re-Ox.", IBM Tech. Discl. Bull., vol. 22, #8A, Jan. 1980, pp. 3204-3205.

H. Lee et al., "Short-Channel FETs in V-Grooves", IBM Tech. Discl. Bull., vol. 22, #8B, Jan. 1980, pp. 3630-3634.

T. Chang et al., "Vertical FET RAM with Deep Trench Iso.", IBM Tech. Discl. Bull., vol. 22, #8B, Jan. 1980, pp. 3683-3687.

D. Kenney, "Reduced Bit Line Capacitance in VMOS Devices", IBM Tech. Discl. Bull., vol. 23, #9, Feb. 1981, pp. 4052-4053.

D. Kenney, "V-Groove Dynamic Memory Cell", IBM Tech. Discl. Bull., vol. 23, #3, Aug. 1980, pp. 967-969.

C. Jambotkar, "Compact One-Device DRAM Cell . . .", IBM Tech. Discl. Bull., vol. 27, #2, Jul. 1984, pp. 1313-1320.

S. Nakajima et al., "An Isolation-Merged Vert. Cap. Cell . . .", Proc. IEDM, Dec. 1984, pp. 240-243.

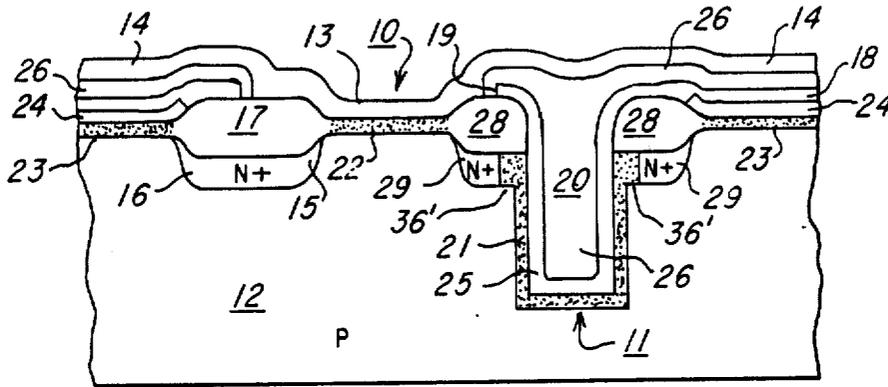
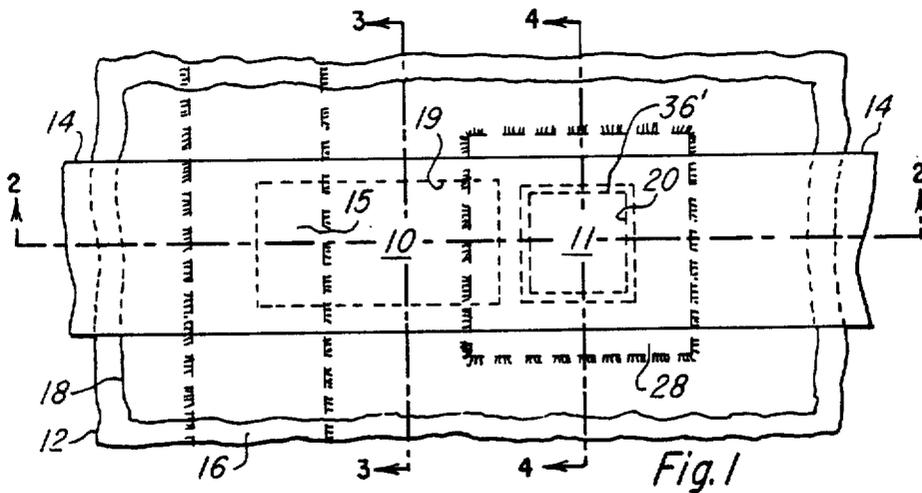


Fig. 2

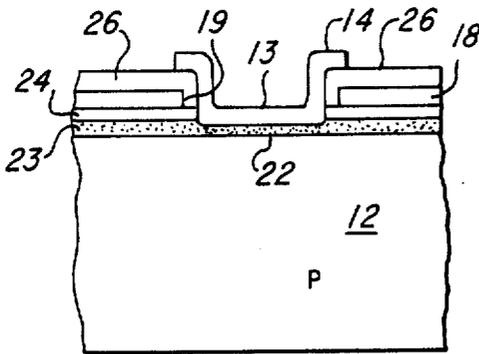


Fig. 3

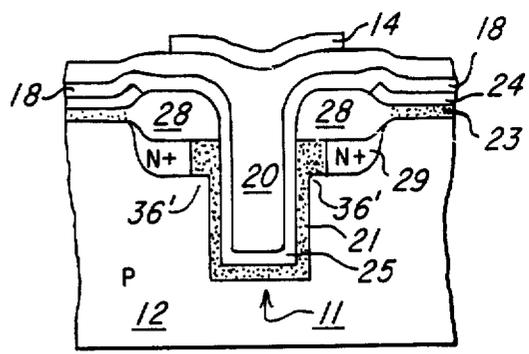


Fig. 4



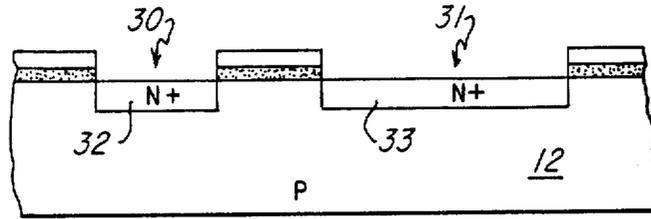


Fig. 6

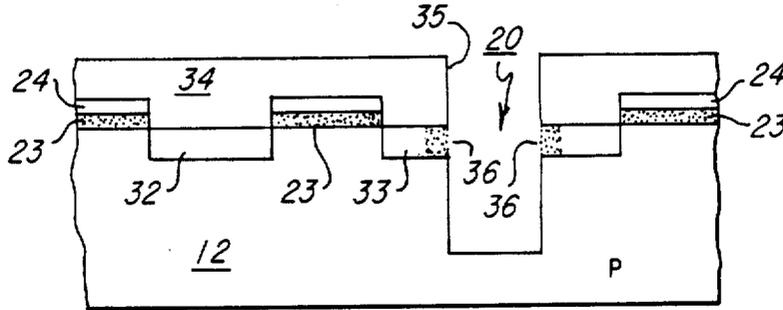


Fig. 7

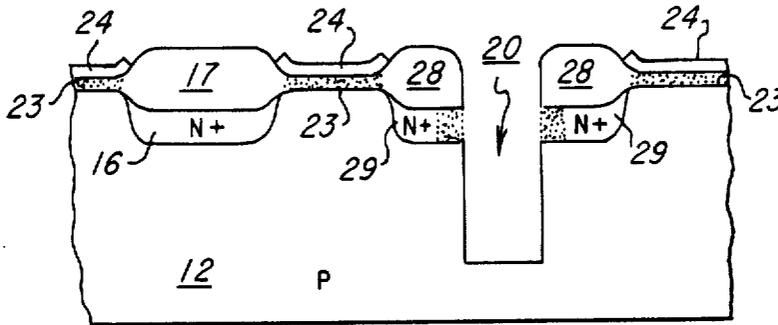


Fig. 8

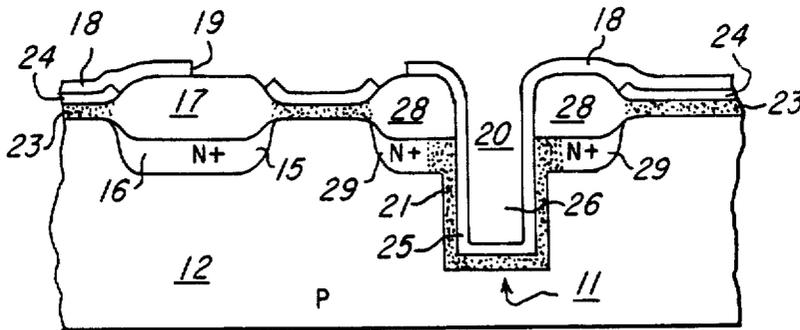


Fig. 9

## TRENCH CAPACITOR FOR HIGH DENSITY DYNAMIC RAM

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This invention relates to manufacture of semiconductor devices, and more particularly to a dynamic read/write memory cell of the MOS VLSI type.

Semiconductor dynamic RAM devices of the type shown in U.S. Pat. No. 4,081,701 issued to White, McAdams and Redwine (a 16K RAM), or U.S. Pat. No. 4,293,993 issued to McAlexander, White and Rao (a 64K RAM), have been manufactured by processes of the type described in U.S. Pats. Nos. 4,055,444 or 4,388,121, both issued to G. R. M. Rao; all of these patents are assigned to Texas Instruments. In order to reduce the size of a dynamic RAM cell to the level needed to produce very high density RAMs, such as the 1-Megabit DRAM, various methods of reducing the capacitor size have been proposed. The magnitude of the capacitor must be maintained at no less than a certain value so that sufficient charge is stored. One method of reducing capacitor area yet maintaining adequate charge storage is to reduce the oxide thickness as explained in U.S. Pat. No. 4,240,092 issued to Kuo, assigned to Texas Instruments; this approach reaches a limit in the area of about 100 to 200 Å oxide thickness because of yield and reliability problems. Another way of increasing the capacitance per unit area is to etch a groove, or trench, in the capacitance region, thus increasing the area; an example of this method is shown in U.S. Pat. No. 4,225,945, also assigned to Texas Instruments.

It is the principle object of this invention to provide an improved process for making high density dynamic RAM cells, particularly with an increased capacitance area due to a trench etched into the storage capacitor region. Another object is to provide an improved method of making trench capacitor type dynamic RAM cells in which the step of etching the trench avoids the effect of undercut. A further object is to provide a simple and reliable process for forming trench capacitors.

### SUMMARY OF THE INVENTION

In accordance with one embodiment of the invention, a dynamic one-transistor read/write memory cell employs a trench capacitor to increase the magnitude of the stored charge. The trench is etched into the silicon surface at a diffused N+ capacitor region similar to the N+ bit line, then thick oxide is grown over the bit line and over the capacitor region, but not in the trench; a partial etch followed by regrowth of oxide is used prior to the final etch for most of the depth of the trench, to thereby reduce the effect of undercut. The upper plate of the capacitor is a polysilicon layer extending into the trench and also forming field plate isolation over the face of the silicon bar. A refractory metal word line forms the gate of the access transistor at a hole in the polysilicon field plate.

### BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as other features and advan-

tages thereof, will be best understood by reference to the detailed description which follows, read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a plan view, greatly enlarged, of a small part of a memory cell array in a semiconductor dynamic read/write memory, including a memory cell according to the invention;

FIG. 2 is an elevation view, in section, of the cell of FIG. 1, taken along the line 2—2 in FIG. 1;

FIG. 3 is an elevation view, in section, of the cell of FIG. 1, taken along the line 3—3 in FIG. 1;

FIG. 4 is an elevation view, in section, of the cell of FIG. 1, taken along the line 4—4 in FIG. 1;

FIG. 5 is an electrical schematic diagram of the memory cell of FIGS. 1-4; and

FIGS. 6-9 are elevation views in section of the cell of FIGS. 1, corresponding to FIG. 2, at successive stages in the manufacture thereof.

### DETAILED DESCRIPTION OF THE SPECIFIC EMBODIMENT

Referring to FIGS. 1-5, a one-transistor dynamic memory cell is shown which is constructed according to the invention. This cell has an N-channel access transistor 10 and a storage capacitor 11 formed in a silicon substrate 12. The transistor 10 has a metal gate 13 which is part of an elongated strip 14 forming a row (or word) line for the memory array. The drain 15 of the transistor is part of an elongated bit line 16, perpendicular to the word line 14. The portion of the substrate shown is a very small part of a silicon bar of perhaps 150×400 mils containing 2<sup>20</sup> or 1,048,576 of these cells in an array of rows and columns, generally as shown in copending application Ser. No. 626,791, filed July 2, 1984, now U.S. Pat. No. 4,630,240 by Poteet & Chang, assigned to Texas Instruments.

The bit line 16 is buried beneath a thick thermal oxide layer 17, so the metal word line can pass directly over the bit line. Isolation laterally along the face is provided by a field plate 18, composed of polysilicon in this example, and electrically connected to the substrate voltage Vss. A hole 19 in the field plate 18 defines the area of the gate 13 of the transistor 10.

According to the invention, the capacitor 11 includes a trench 20, which is a hole etched into the silicon by an anisotropic etch technique such as RIE. The trench 20 is about one micron wide and three microns deep. A thin silicon oxide layer 21 provides the capacitor dielectric, and thin silicon oxide 22 the transistor gate insulator. A thicker oxide coating 23 and a silicon nitride layer 24 provide the insulator beneath the field plate 18. The grounded field plate 18 also provides a flat surface for the metal line 14, as well as insulating the polysilicon 16 from the metal word line.

The trench 20 and the capacitor 11 are formed in a square area of field oxide 28 having a N+ region 29 beneath it, similar to the oxide 17 and bit line 16. This N+ region 29 functions as the source of the access transistor 10, and is spaced from the drain 15 by the channel length of this transistor.

A method of making the cell of FIGS. 1-5 will be described with respect to FIGS. 6-9. A silicon slice has a layer of thermal silicon oxide 23 of about 1000 Å grown on the face, then a layer 24 of silicon nitride deposited over the oxide. The oxide-nitride sandwich is patterned by photolithographic steps, leaving an exposed area 30 for the bit line 16 and an area 31 where the capacitor will be formed. An ion implant is performed

to create the N+ regions 32 and 33 which will later form the N+ bit line 16 and N+ region 29.

Referring to FIG. 7 an etch mask 34 is deposited for the purpose of defining the trench. This etch mask is silicon oxide of a thickness of about 8000 Å, formed by low pressure chemical vapor deposition. Photoresist could also be used if the etch selectivity of silicon to photoresist is high enough. A hole 35 is formed in the layer 34 by photolithography to define the trench 20. Using an anisotropic etch, such as RIE (reactive ion etch) the trench 20 is created in the capacitor region to a depth of about three microns. Actually, the bottom of the trench may be narrower than the top, rather than being squared off, so the trench may be more cone-shaped than perfectly rectangular, depending upon the etch process used.

According to the invention, this trench etch is a two-step process. As seen in the enlarged view of FIG. 7a, the first etch is shallow, and removes some of the silicon in the hole 35 but also undercuts the mask 34 by etching into the region 33 by a small amount at area 36 encircling the hole. A thermal oxidation is then performed in steam to grow oxide 36a in the area 36, seen in FIG. 7b. Oxide 37 also grows in the trench, but much thinner because of the doping level of the silicon. A dip-out etch removes this oxide in the shallow trench, and so the etch can proceed to the full depth of the trench, using the oxide 36a in the area 36 as an etch stop to prevent further undercutting. The extent to which this area 36 propagates through to the final structure as a ring 36' of FIGS. 1, 2 and 4 is very slight.

The trench mask 34 is stripped off, using a conventional oxide etch such as HF since the etch will stop on the nitride 24. Turning to FIG. 8, the oxide 17 and 28 is now grown over the N+ regions 32 and 33. The oxide grows many times faster on the N+ silicon than on the very lightly doped silicon in the trench 20, so the thickness of the oxide 17 and 28 is about 4000 Å while only about 200 Å grows in the trench. This thin oxide is grown in the trench and stripped, then regrown as the oxide 21. As seen in FIG. 9, a layer of polysilicon is deposited by an isotropic process so it coats the side-walls of the trench and the face of the slice to about the same thickness, to about 2500 Å. Next, an oxide layer 26 is deposited over the entire face of the slice to planarize the face and fill up the trench 20; the oxide 26 will also isolate the word line from the face. This polysilicon/oxide stack is patterned using photoresist to leave the field plate 18 and capacitor plate 25; i.e., the hole 19 is cut for the transistor 10.

Referring back to FIGS. 1-4, the oxide in the gate area is stripped and regrown as the oxide 22, and at this point thermal oxide is grown over the exposed edge of the polysilicon around the periphery of the hole 19. Then the word line is formed by depositing a layer of molybdenum over the entire face of the slice and patterning it by photolithography to leave the gate 13 and word line 14. A protective coating is added on top, (not shown) and patterned to expose bonding pads, then the slice is tested, scribed and broken into individual bars, and the bars mounted in semiconductor packages.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications to the illustrative embodiments, as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to this description. It is therefore contemplated that appended

claims will cover any such modifications or embodiments as fall within the true scope of the invention.

What is claimed:

1. A dynamic memory cell formed in a face of a semiconductor body, said cell comprising:
  - an access transistor having a source-to-drain path at a channel area of said face, and a metal gate over said channel area separated therefrom by a thin gate oxide;
  - a bit line including an elongated N+ region of said face, the drain of said transistor being an edge of said N+ region;
  - a metal word line extending along said face perpendicular to said bit line, said metal gate being a part of said word line;
  - said N+ region of said bit line being insulated from said word line by thick thermal field oxide overlying said bit line;
  - a capacitor area at said face including a trench etched into said face and N+ region surrounding said trench, with a thick thermal field oxide overlying said N+ region;
  - a region of thermal field oxide encircling said trench inset into said N+ region surrounding said trench,
  - a field plate including a conductive layer covering said face overlying said capacitor area, said bit line and all areas except said channel area of said transistor, and extending down into said trench to provide the upper plate of the capacitor, insulated from the silicon in said trench by a thin oxide.
2. A memory cell according to claim 1 wherein said field plate is insulated from said face in areas except said capacitor area and said bit line by a layer of oxide and a layer of silicon nitride.
3. A memory cell according to claim 1 wherein said capacitor area is spaced laterally along said face from said drain region by said channel area, and said N+ region in said capacitor area forms the source of said transistor.
4. A memory cell according to claim 1 wherein said field oxide over said bit line is about the same thickness as the field oxide in said capacitor area.
5. A memory cell according to claim 1 wherein a coating of insulator over said field plate fills said trench to provide a level surface for said metal word line.
6. A memory cell according to claim 1 wherein the width of said trench is no more than about one micron and the depth of the trench is at least about twice the width.
7. A memory cell according to claim 1 wherein said body is P type silicon, said metal word line is molybdenum, and said conductive layer is polysilicon.
8. A dynamic memory cell formed in a face of a semiconductor body, said cell comprising:
  - an access transistor having a source-to-drain path at a channel area of said face, and a gate over said channel area separated therefrom by a thin gate oxide;
  - a bit line including an elongated N+ region of said face, the drain of said transistor being an edge of said N+ region;
  - a word line extending along said face perpendicular to said bit line, said gate being a part of said word line;
  - said N+ region of said bit line being insulated from said word line by thick thermal field oxide overlying said bit line;
  - a capacitor area at said face including a trench etched into said face and N+ region surrounding said

5

6

trench, with a thick thermal field oxide overlying said N+ region;  
 a region of thermal field oxide encircling said trench inset into said N+ region surrounding said trench, a field plate including a conductive layer covering said face overlying said capacitor area, said bit line and all areas except said channel area of said transistor, and extending down into said trench to provide the capacitor, insulated from the silicon in said trench by a thin oxide.

9. A memory cell according to claim 8 wherein said field plate is insulated from said face in areas except said capacitor area and said bit line by a layer of oxide and a layer of silicon nitride.

10. A memory cell according to claim 8 wherein said capacitor area is spaced laterally along said face from said

drain region by said channel area, and said N+ region in said capacitor area forms the source of said transistor.

11. A memory cell according to claim 8 wherein said field oxide over said bit line is about the same thickness as the field oxide in said capacitor area.

12. A memory cell according to claim 8 wherein a coating of insulator over said field plate fills said trench to provide a level surface for said metal word line.

13. A memory cell according to claim 8 wherein the width of said trench is no more than about one micron and the depth of the trench is at least about twice the width.

14. A memory cell according to claim 8 wherein said body is P type silicon, said word line is molybdenum, and said conductive layer is polysilicon.

\* \* \* \* \*

20

25

30

35

40

45

50

55

60

65