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(54) **REWRITE PREVENTION IN A VARIABLE RESISTANCE MEMORY**

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**OTHER PUBLICATIONS**

Abdel-All, A.; Elshafie, A.; Elhawary, M.M., DC electric-field effect in bulk and thin-film Ge<sub>5</sub>As<sub>38</sub>Te<sub>57</sub> chalcogenide glass, Vacuum 59 (2000) 845-853.

(Continued)

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(57) **ABSTRACT**

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(52) **U.S. Cl.** ..... **365/222; 365/203; 365/207**

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See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

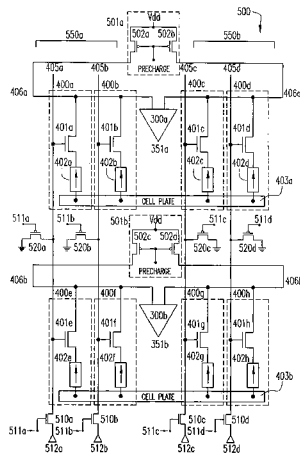
3,271,591 A 9/1966 Ovshinsky

(Continued)

**FOREIGN PATENT DOCUMENTS**

JP 56126916 10/1981

**36 Claims, 10 Drawing Sheets**



U.S. PATENT DOCUMENTS					
3,622,319 A	11/1971	Sharp	5,694,054 A	12/1997	Ovshinsky et al.
3,743,847 A	7/1973	Boland	5,714,768 A	2/1998	Ovshinsky et al.
3,961,314 A	6/1976	Klose et al.	5,726,083 A	3/1998	Takaishi
3,966,317 A	6/1976	Wacks et al.	5,751,012 A	5/1998	Wolstenholme et al.
3,983,542 A	9/1976	Ovshinsky	5,761,115 A	6/1998	Kozicki et al.
3,988,720 A	10/1976	Ovshinsky	5,789,277 A	8/1998	Zahorik et al.
4,177,474 A	12/1979	Ovshinsky	5,825,046 A	10/1998	Czubatyj et al.
4,267,261 A	5/1981	Hallman et al.	5,841,150 A	11/1998	Gonzalez et al.
4,269,935 A	5/1981	Masters et al.	5,846,889 A	12/1998	Harbison et al.
4,312,938 A	1/1982	Drexler et al.	5,883,827 A	3/1999	Morgan
4,316,946 A	2/1982	Masters et al.	5,896,312 A	4/1999	Kozicki et al.
4,320,191 A	3/1982	Yoshikawa et al.	5,912,839 A	6/1999	Ovshinsky et al.
4,405,710 A	9/1983	Balasubramanyam et al.	5,914,893 A	6/1999	Kozicki et al.
4,419,421 A	12/1983	Wichelhaus et al.	5,920,788 A	7/1999	Reinberg
4,499,557 A	2/1985	Holmberg et al.	5,933,365 A	8/1999	Klersy et al.
4,597,162 A	7/1986	Johnson et al.	5,998,066 A	12/1999	Block et al.
4,608,296 A	8/1986	Keem et al.	6,011,757 A	1/2000	Ovshinsky
4,637,895 A	1/1987	Ovshinsky et al.	6,072,716 A	6/2000	Jacobson et al.
4,646,266 A	2/1987	Ovshinsky et al.	6,077,729 A	6/2000	Harshfield
4,664,939 A	5/1987	Ovshinsky	6,084,796 A	7/2000	Kozicki et al.
4,668,968 A	5/1987	Ovshinsky et al.	6,087,674 A	7/2000	Ovshinsky et al.
4,670,763 A	6/1987	Ovshinsky et al.	6,117,720 A	9/2000	Harshfield
4,671,618 A	6/1987	Wu et al.	6,141,241 A	10/2000	Ovshinsky et al.
4,673,957 A	6/1987	Ovshinsky et al.	6,143,604 A	11/2000	Chiang et al.
4,678,679 A	7/1987	Ovshinsky	6,177,338 B1	1/2001	Liaw et al.
4,696,758 A	9/1987	Ovshinsky et al.	6,236,059 B1	5/2001	Wolstenholme et al.
4,698,234 A	10/1987	Ovshinsky et al.	RE37,259 E	7/2001	Ovshinsky
4,710,899 A	12/1987	Young et al.	6,297,170 B1	10/2001	Gabriel et al.
4,728,406 A	3/1988	Banerjee et al.	6,300,684 B1	10/2001	Gonzalez et al.
4,737,379 A	4/1988	Hudgens et al.	6,314,014 B1	11/2001	Lowrey et al.
4,766,471 A	8/1988	Ovshinsky et al.	6,316,784 B1	11/2001	Zahorik et al.
4,769,338 A	9/1988	Ovshinsky et al.	6,329,606 B1	12/2001	Freyman et al.
4,775,425 A	10/1988	Guha et al.	6,339,544 B1	1/2002	Chiang et al.
4,788,594 A	11/1988	Ovshinsky et al.	6,348,365 B1	2/2002	Moore et al.
4,795,657 A	1/1989	Formigoni et al.	6,350,679 B1	2/2002	McDaniel et al.
4,800,526 A	1/1989	Lewis	6,376,284 B1	4/2002	Gonzalez et al.
4,809,044 A	2/1989	Pryor et al.	6,388,324 B2	5/2002	Kozicki et al.
4,818,717 A	4/1989	Johnson et al.	6,391,688 B1	5/2002	Gonzalez et al.
4,843,443 A	6/1989	Ovshinsky et al.	6,404,665 B1	6/2002	Lowery et al.
4,845,533 A	7/1989	Pryor et al.	6,414,376 B1	7/2002	Thakur et al.
4,847,674 A	7/1989	Sliwa et al.	6,418,049 B1	7/2002	Kozicki et al.
4,853,785 A	8/1989	Ovshinsky et al.	6,423,628 B1	7/2002	Li et al.
4,891,330 A	1/1990	Guha et al.	6,429,064 B1	8/2002	Wicker
5,128,099 A	7/1992	Strand et al.	6,437,383 B1	8/2002	Xu
5,159,661 A	10/1992	Ovshinsky et al.	6,462,981 B2	10/2002	Numata et al.
5,166,758 A	11/1992	Ovshinsky et al.	6,462,984 B1	10/2002	Xu et al.
5,177,567 A	1/1993	Klersy et al.	6,469,364 B1	10/2002	Kozicki
5,219,788 A	6/1993	Abernathey et al.	6,473,332 B1	10/2002	Ignatiev et al.
5,238,862 A	8/1993	Blalock et al.	6,480,438 B1	11/2002	Park
5,272,359 A	12/1993	Nagasubramanian et al.	6,487,106 B1	11/2002	Kozicki
5,296,716 A	3/1994	Ovshinsky et al.	6,487,113 B1	11/2002	Park et al.
5,314,772 A	5/1994	Kozicki	6,501,111 B1	12/2002	Lowery
5,315,131 A	5/1994	Kishimoto et al.	6,507,061 B1	1/2003	Hudgens et al.
5,335,219 A	8/1994	Ovshinsky et al.	6,511,862 B2	1/2003	Hudgens et al.
5,341,328 A	8/1994	Ovshinsky et al.	6,511,867 B2	1/2003	Lowery et al.
5,350,484 A	9/1994	Gardner et al.	6,512,241 B1	1/2003	Lai
5,359,205 A	10/1994	Ovshinsky	6,514,805 B2	2/2003	Xu et al.
5,360,981 A	11/1994	Owen et al.	6,531,373 B2	3/2003	Gill et al.
5,406,509 A	4/1995	Ovshinsky et al.	6,534,781 B2	3/2003	Dennison
5,414,271 A	5/1995	Ovshinsky et al.	6,545,287 B2	4/2003	Chiang
5,500,532 A	3/1996	Kozicki et al.	6,545,907 B1	4/2003	Lowery et al.
5,512,328 A	4/1996	Yoshimura et al.	6,555,860 B2	4/2003	Lowery et al.
5,512,773 A	4/1996	Wolf et al.	6,563,164 B2	5/2003	Lowery et al.
5,534,711 A	7/1996	Ovshinsky et al.	6,566,700 B2	5/2003	Xu
5,534,712 A	7/1996	Ovshinsky et al.	6,567,293 B1	5/2003	Lowery et al.
5,536,947 A	7/1996	Klersy et al.	6,569,705 B2	5/2003	Chiang et al.
5,543,737 A	8/1996	Ovshinsky	6,570,784 B2	5/2003	Lowery
5,544,120 A *	8/1996	Kuwagata et al. .... 365/222	6,576,921 B2	6/2003	Lowery
5,591,501 A	1/1997	Ovshinsky et al.	6,586,761 B2	7/2003	Lowery
5,596,522 A	1/1997	Ovshinsky et al.	6,589,714 B2	7/2003	Maimon et al.
5,687,112 A	11/1997	Ovshinsky	6,590,807 B2	7/2003	Lowery
			6,593,176 B2	7/2003	Dennison
			6,597,009 B2	7/2003	Wicker

- 6,605,527 B2 8/2003 Dennison et al.  
6,613,604 B2 9/2003 Maimon et al.  
6,621,095 B2 9/2003 Chiang et al.  
6,625,054 B2 9/2003 Lowery et al.  
6,642,102 B2 11/2003 Xu  
6,646,297 B2 11/2003 Dennison  
6,649,928 B2 11/2003 Dennison  
6,667,900 B2 12/2003 Lowery et al.  
6,671,710 B2 12/2003 Ovshinsky et al.  
6,673,648 B2 1/2004 Lowery  
6,673,700 B2 1/2004 Dennison et al.  
6,674,115 B2 1/2004 Hudgens et al.  
6,687,153 B2 2/2004 Lowery  
6,687,427 B2 2/2004 Ramalingam et al.  
6,690,026 B2 2/2004 Peterson  
6,696,355 B2 2/2004 Dennison  
6,707,712 B2 3/2004 Lowery  
6,714,954 B2 3/2004 Ovshinsky et al.  
2002/0000666 A1 1/2002 Kozicki et al.  
2002/0072188 A1 6/2002 Gilton  
2002/0106849 A1 8/2002 Moore  
2002/0123169 A1 9/2002 Moore et al.  
2002/0123170 A1 9/2002 Moore et al.  
2002/0123248 A1 9/2002 Moore et al.  
2002/0127886 A1 9/2002 Moore et al.  
2002/0132417 A1 9/2002 Li  
2002/0163828 A1 11/2002 Krieger et al.  
2002/0168820 A1 11/2002 Kozicki  
2002/0168852 A1 11/2002 Harshfield et al.  
2002/0190289 A1 12/2002 Harshfield et al.  
2002/0190350 A1 12/2002 Kozicki  
2003/0001229 A1 1/2003 Moore et al.  
2003/0027416 A1 2/2003 Moore  
2003/0032254 A1 2/2003 Gilton  
2003/0035314 A1 2/2003 Kozicki  
2003/0035315 A1 2/2003 Kozicki  
2003/0038301 A1 2/2003 Moore  
2003/0043631 A1 3/2003 Gilton et al.  
2003/0045049 A1 3/2003 Campbell et al.  
2003/0045054 A1 3/2003 Campbell et al.  
2003/0047765 A1 3/2003 Campbell  
2003/0047772 A1 3/2003 Li  
2003/0047773 A1 3/2003 Li  
2003/0048519 A1 3/2003 Kozicki  
2003/0048744 A1 3/2003 Ovshinsky et al.  
2003/0049912 A1 3/2003 Campbell et al.  
2003/0068861 A1 4/2003 Li  
2003/0068862 A1 4/2003 Li  
2003/0095426 A1 5/2003 Hush et al.  
2003/0096497 A1 5/2003 Moore et al.  
2003/0107105 A1 6/2003 Kozicki  
2003/0117831 A1 6/2003 Hush  
2003/0128612 A1 7/2003 Moore et al.  
2003/0137869 A1 7/2003 Kozicki  
2003/0143782 A1 7/2003 Gilton et al.  
2003/0155606 A1 8/2003 Campbell et al.  
2003/0156447 A1 8/2003 Kozicki  
2003/0156463 A1 8/2003 Casper et al.  
2003/0212724 A1 11/2003 Ovshinsky et al.  
2003/0212725 A1 11/2003 Ovshinsky et al.  
2004/0035401 A1 2/2004 Ramachandran et al.
- Affi, M.A.; Labib, H.H.; Fouad, S.S.; El-Shazly, A.A., Electrical & thermal conductivity of the amorphous semiconductor  $GexSe_{1-x}$ , Egypt, J. Phys. 17 (1986) 335-342.  
Aleksiejevas, A.; Cesnys, A., Switching phenomenon and memory effect in thin-film heterojunction of polycrystalline selenium-silver selenide, Phys. Stat. Sol. (a) 19 (1973) K169-K171.  
Angell, C.A., Mobile ions in amorphous solids, Annu. Rev. Phys. Chem. 43 (1992) 693-717.  
Aniya, M., Average electronegativity, medium-range-order, and ionic conductivity in superionic glasses, Solid state Ionics 136-137 (2000) 1085-1089.  
Asahara, Y.; Izumitani, T., Voltage controlled switching in Cu-As-Se compositions, J. Non-Cryst. Solids 11 (1972) 97-104.  
Asokan, S.; Prasad, M.V.N.; Parthasarathy, G.; Gopal, E.S.R., Mechanical and chemical thresholds in IV-VI chalcogenide glasses, Phys. Rev. Lett. 62 (1989) 808-810.  
Baranovskii, S.D.; Cordes, H., On the conduction mechanism in ionic glasses, J. Chem. Phys. 111 (1999) 7546-7557.  
Belin, R.; Taillades, G.; Pradel, A.; Ribes, M., Ion dynamics in superionic chalcogenide glasses: complete conductivity spectra, Solid state Ionics 136-137 (2000) 1025-1029.  
Belin, R.; Zerouale, A.; Pradel, A.; Ribes, M., Ion dynamics in the argyrodite compound  $Ag_7GeSe_5I$ : non-Arrhenius behavior and complete conductivity spectra, Solid State Ionics 143 (2001) 445-455.  
Benmore, C.J.; Salmon, P.S., Structure of fast ion conducting and semiconducting glassy chalcogenide alloys, Phys. Rev. Lett. 73 (1994) 264-267.  
Bernede, J.C., Influence du metal des electrodes sur les caracteristiques courant-tension des structures M-Ag<sub>2</sub>Se-M, Thin solid films 70 (1980) L1-L4.  
Bernede, J.C., Polarized memory switching in MIS thin films, Thin Solid Films 81 (1981) 155-160.  
Bernede, J.C., Switching and silver movements in Ag<sub>2</sub>Se thin films, Phys. Stat. Sol. (a) 57 (1980) K101-K104.  
Bernede, J.C.; Abachi, T., Differential negative resistance in metal/insulator/metal structures with an upper bilayer electrode, Thin solid films 131 (1985) L61-L64.  
Bernede, J.C.; Conan, A.; Fousenan't, E.; Bouchairi, B.; Goureaux, G., Polarized memory switching effects in Ag<sub>2</sub>Se/Se/M thin film sandwiches, Thin solid films 97 (1982) 165-171.  
Bernede, J.C.; Khelil, A.; Kettaf, M.; Conan, A., Transition from S- to N-type differential negative resistance in Al-Al<sub>2</sub>O<sub>3</sub>-Ag<sub>2-x</sub>Se<sub>1+x</sub> thin film structures, Phys. Stat. Sol. (a) 74 (1982) 217-224.  
Bondarev, V.N.; Pikhitsa, P.V., A dendrite model of current instability in RbAg<sub>4</sub>I<sub>5</sub>, Solid State Ionics 70/71 (1994) 72-76.  
Boolchand, P., The maximum in glass transition temperature (T<sub>g</sub>) near X=1/2 in GexSe<sub>1-x</sub> Glasses, Asian Journal of Physics (2000) 9, 709-72.  
Boolchand, P.; Bresser, W.J., Mobile silver ions and glass formation in solid electrolytes, Nature 410 (2001) 1070-1073.  
Boolchand, P.; Georgiev, D.G.; Goodman, B., Discovery of the Intermediate Phase in Chalcogenide Glasses, J. Optoelectronics and Advanced Materials, 3 (2001), 703.  
Boolchand, P.; Selvanathan, D.; Wang, Y.; Georgiev, D.G.; Bresser, W.J., Onset of rigidity in steps in chalcogenide glasses, Properties and Applications of Amorphous Materials, M.F. Thorpe and Tichy, L. (eds.) Kluwer Academic Publishers, the Netherlands, 2001, pp. 97-132.  
Boolchand, P.; Enzweiler, R.N.; Tenhover, M., Structural ordering of evaporated amorphous chalcogenide alloy films: role of thermal annealing, Diffusion and Defect Data vol. 53-54 (1987) 415-420.  
Boolchand, P.; Grothaus, J.; Bresser, W.J.; Suranyi, P., Structural origin of broken chemical order in a GeSe<sub>2</sub> glass, Phys. Rev. B 25 (1982) 2975-2978.  
Boolchand, P.; Grothaus, J.; Phillips, J.C., Broken chemical order and phase separation in GexSe<sub>1-x</sub> glasses, Solid state comm. 45 (1983) 183-185.

## OTHER PUBLICATIONS

- Adler, D.; Moss, S.C., Amorphous memories and bistable switches, J. Vac. Sci. Technol. 9 (1972) 1182-1189.  
Adler, D.; Henisch, H.K.; Mott, S.N., The mechanism of threshold switching in amorphous alloys, Rev. Mod. Phys. 50 (1978) 209-220.  
Affi, M.A.; Labib, H.H.; El-Fazary, M.H.; Fadel, M., Electrical and thermal properties of chalcogenide glass system Se<sub>75</sub>Ge<sub>25-x</sub>Sbx, Appl. Phys. A 55 (1992) 167-169.

- Boolchand, P.; Bresser, W.J., Compositional trends in glass transition temperature ( $T_g$ ), network connectivity and nanoscale chemical phase separation in chalcogenides, Dept. of ECECS, Univ. Cincinnati (Oct. 28, 1999) 45221-0030.
- Boolchand, P.; Grothaus, J., Molecular Structure of Melt-Quenched GeSe<sub>2</sub> and GeS<sub>2</sub> glasses compared, Proc. Int. Conf. Phys. Semicond. (Eds. Chadi and Harrison) 17<sup>th</sup> (1985) 833-36.
- Bresser, W.; Boolchand, P.; Suranyi, P., Rigidity percolation and molecular clustering in network glasses, Phys. Rev. Lett. 56 (1986) 2493-2496.
- Bresser, W.J.; Boolchand, P.; Suranyi, P.; de Neufville, J.P., Intrinsically broken chalcogen chemical order in stoichiometric glasses, Journal de Physique 42 (1981) C4-193-C4-196.
- Bresser, W.J.; Boolchand, P.; Suranyi, P.; Hernandez, J.G., Molecular phase separation and cluster size in GeSe<sub>2</sub> glass, Hyperfine Interactions 27 (1986) 389-392.
- Cahen, D.; Gilet, J.-M.; Schmitz, C.; Chemyak, L.; Gartsman, K.; Jakubowicz, A., Room-Temperature, electric field induced creation of stable devices in CuInSe<sub>2</sub> Crystals, Science 258 (1992) 271-274.
- Chatterjee, R.; Asokan, S.; Titus, S.S.K., Current-controlled negative-resistance behavior and memory switching in bulk As-Te-Se glasses, J. Phys. D: Appl. Phys. 27 (1994) 2624-2627.
- Chen, C.H.; Tai, K.L., Whisker growth induced by Ag photodoping in glassy GexSe1-x films, Appl. Phys. Lett. 37 (1980) 1075-1077.
- Chen, G.; Cheng, J., Role of nitrogen in the crystallization of silicon nitride-doped chalcogenide glasses, J. Am. Ceram. Soc. 82 (1999) 2934-2936.
- Chen, G.; Cheng, J.; Chen, W., Effect of Si<sub>3</sub>N<sub>4</sub> on chemical durability of chalcogenide glass, J. Non-Cryst. Solids 220 (1997) 249-253.
- Cohen, M.H.; Neale, R.G.; Paskin, A., A model for an amorphous semiconductor memory device, J. Non-Cryst. Solids 8-10 (1972) 885-891.
- Croitoru, N.; Lazarescu, M.; Popescu, C.; Telnic, M.; and Vescan, L., Ohmic and non-ohmic conduction in some amorphous semiconductors, J. Non-Cryst. Solids 8-10 (1972) 781-786.
- Dalven, R.; Gill, R., Electrical properties of beta-Ag<sub>2</sub>Te and beta-Ag<sub>2</sub>Se from 4.2 to 300K, J. Appl. Phys. 38 (1967) 753-756.
- Davis, E.A., Semiconductors without form, Search 1 (1970) 152-155.
- Deamaley, G.; Stoneham, A.M.; Morgan, D.V., Electrical phenomena in amorphous oxide films, Rep. Prog. Phys. 33 (1970) 1129-1191.
- Dejus, R.J.; Susman, S.; Volin, K.J.; Montague, D.G.; Price, D.L., Structure of Vitreous Ag-Ge-Se, J. Non-Cryst. Solids 143 (1992) 162-180.
- den Boer, W., Threshold switching in hydrogenated amorphous silicon, Appl. Phys. Lett. 40 (1982) 812-813.
- Drusedau, T.P.; Panckow, A.N.; Klabunde, F., The hydrogenated amorphous silicon/nanodisperse metal (SIMAL) system-Films of unique electronic properties, J. Non-Cryst. Solids 198-200 (1996) 829-832.
- El Bouchairi, B.; Bernede, J.C.; Burgaud, P., Properties of Ag<sub>2</sub>-xSe<sub>1+x/n</sub>-Si diodes, Thin Solid Films 110 (1983) 107-113.
- El Gharras, Z.; Bourahla, A.; Vautier, C., Role of photoinduced defects in amorphous GexSe1-x photoconductivity, J. Non-Cryst. Solids 155 (1993) 171-179.
- El Ghrandi, R.; Calas, J.; Galibert, G.; Averous, M., Silver photodissolution in amorphous chalcogenide thin films, Thin Solid Films 218 (1992) 259-273.
- El Ghrandi, R.; Calas, J.; Galibert, G., Ag dissolution kinetics in amorphous GeSe<sub>5.5</sub> thin films from "in-situ" resistance measurements vs time, Phys. Stat. Sol. (a) 123 (1991) 451-460.
- El-kady, Y.L., The threshold switching in semiconducting glass Ge<sub>21</sub>Se<sub>17</sub>Te<sub>62</sub>, Indian J. Phys. 70A (1996) 507-516.
- Elliott, S.R., A unified mechanism for metal photodissolution in amorphous chalcogenide materials, J. Non-Cryst. Solids 130 (1991) 85-97.
- Elliott, S.R., Photodissolution of metals in chalcogenide glasses: A unified mechanism, J. Non-Cryst. Solids 137-138 (1991) 1031-1034.
- Elsamanoudy, M.M.; Hegab, N.A.; Fadel, M., Conduction mechanism in the pre-switching state of thin films containing Te As Ge Si, Vacuum 46 (1995) 701-707.
- El-Zahed, H.; El-Korashy, A., Influence of composition on the electrical and optical properties of Ge<sub>20</sub>BixSe<sub>80-x</sub> films, Thin Solid Films 376 (2000) 236-240.
- Fadel, M., Switching phenomenon in evaporated Se-Ge-As thin films of amorphous chalcogenide glass, Vacuum 44 (1993) 851-855.
- Fadel, M.; El-Shair, H.T., Electrical, thermal and optical properties of Se<sub>75</sub>Ge<sub>7</sub>Sb<sub>18</sub>, Vacuum 43 (1992) 253-257.
- Feng, X.; Bresser, W.J.; Boolchand, P., Direct evidence for stiffness threshold in Chalcogenide glasses, Phys. Rev. Lett. 78 (1997) 4422-4425.
- Feng, X.; Bresser, W.J.; Zhang, M.; Goodman, B.; Boolchand, P., Role of network connectivity on the elastic, plastic and thermal behavior of covalent glasses, J. Non-Cryst. Solids 222 (1997) 137-143.
- Fischer-Colbrie, A.; Bienenstock, A.; Fuoss, P.H.; Marcus, M.A., Structure and bonding in photodiffused amorphous Ag-GeSe<sub>2</sub> thin films, Phys. Rev. B 38 (1988) 12388-12403.
- Fleury, G.; Hamou, A.; Viger, C.; Vautier, C., Conductivity and crystallization of amorphous selenium, Phys. Stat. Sol. (a) 64 (1981) 311-316.
- Fritzsche, H., Optical and electrical energy gaps in amorphous semiconductors, J. Non-Cryst. Solids 6 (1971) 49-71.
- Fritzsche, H., Electronic phenomena in amorphous semiconductors, Annual Review of Materials Science 2 (1972) 697-744.
- Gates, B.; Wu, Y.; Yin, Y.; Yang, P.; Xia, Y., Single-crystalline nanowires of Ag<sub>2</sub>Se can be synthesized by templating against nanowires of trigonal Se, J. Am. Chem. Soc. (2001) currently ASAP.
- Gosain, D.P.; Nakamura, M.; Shimizu, T.; Suzuki, M.; Okano, S., Nonvolatile memory based on reversible phase transition phenomena in telluride glasses, Jap. J. Appl. Phys. 28 (1989) 1013-1018.
- Guin, J.-P.; Rouxel, T.; Keryvin, V.; Sangleboeuf, J.-C.; Serre, I.; Lucas, J., Indentation creep of Ge-Se chalcogenide glasses below  $T_g$ : elastic recovery and non-Newtonian flow, J. Non-Cryst. Solids 298 (2002) 260-269.
- Guin, J.-P.; Rouxel, T.; Sangleboeuf, J.-C.; Melscoet, I.; Lucas, J., Hardness, toughness, and scratchability of germanium-selenium chalcogenide glasses, J. Am. Ceram. Soc. 85 (2002) 1545-52.
- Gupta, Y.P., On electrical switching and memory effects in amorphous chalcogenides, J. Non-Cryst. Sol. 3 (1970) 148-154.
- Haberland, D.R.; Stiegler, H., New experiments on the charge-controlled switching effect in amorphous semiconductors, J. Non-Cryst. Solids 8-10 (1972) 408-414.
- Haifz, M.M.; Ibrahim, M.M.; Dongol, M.; Hammad, F.H., Effect of composition on the structure and electrical properties of As-Se-Cu glasses, J. Apply. Phys. 54 (1983) 1950-1954.
- Hajto, J.; Rose, M.J.; Osborne, I.S.; Snell, A.J.; Le Comber, P.G.; Owen, A.E., Quantization effects in metal/a-Si:H/metal devices, Int. J. Electronics 73 (1992) 911-913.
- Hajto, J.; Hu, J.; Snell, A.J.; Turvey, K.; Rose, M., DC and AC measurements on metal/a-Si:H/metal room temperature quantised resistance devices, J. Non-Cryst. Solids 266-269 (2000) 1058-1061.
- Hajto, J.; McAuley, B.; Snell, A.J.; Owen, A.E., Theory of room temperature quantized resistance effects in metal-a-Si:H-metal thin film structures, J. Non-Cryst. Solids 198-200 (1996) 825-828.
- Hajto, J.; Owen, A.E.; Snell, A.J.; Le Comber, P.G.; Rose, M.J., Analogue memory and ballistic electron effects in metal-amorphous silicon structures, Phil. Mag. B 63 (1991) 349-369.
- Hayashi, T.; Ono, Y.; Fukaya, M.; Kan, H., Polarized memory switching in amorphous Se film, Japan. J. Appl. Phys. 13 (1974) 1163-1164.
- Hegab, N.A.; Fadel, M.; Sedeek, K., Memory switching phenomena in thin films of chalcogenide semiconductors, Vacuum 45 (1994) 459-462.
- Hirose, Y.; Hirose, H., Polarity-dependent memory switching and behavior of Ag dendrite in Ag-photodoped amorphous As<sub>2</sub>S<sub>3</sub> films, J. Appl. Phys. 47 (1976) 2767-2772.
- Hong, K.S.; Speyer, R.F., Switching behavior in II-IV-V<sub>2</sub> amorphous semiconductor systems, J. Non-Cryst. Solids 116 (1990) 191-200.

- Hosokawa, S., Atomic and electronic structures of glassy GexSe1-x around the stiffness threshold composition, *J. Optoelectronics and Advanced Materials* 3 (2001) 199-214.
- Hu, J.; Snell, A.J.; Hajto, J.; Owen, A.E., Constant current forming in Cr/p+a-/Si:H/V thin film devices, *J. Non-Cryst. Solids* 227-230 (1998) 1187-1191.
- Hu, J.; Hajto, J.; Snell, A.J.; Owen, A.E.; Rose, M.J., Capacitance anomaly near the metal-non-metal transition in Cr-hydrogenated amorphous Si-V thin-film devices, *Phil. Mag. B* 74 (1996) 37-50.
- Hu, J.; Snell, A.J.; Hajto, J.; Owen, A.E., Current-induced instability in Cr-p+a-Si:H-V thin film devices, *Phil. Mag. B* 80 (2000) 29-43.
- Izizima, S.; Sugi, M.; Kikuchi, M.; Tanaka, K., Electrical and thermal properties of semiconducting glasses As-Te-Ge, *Solid State Comm.* 8 (1970) 153-155.
- Ishikawa, R.; Kikuchi, M., Photovoltaic study on the photo-enhanced diffusion of Ag in amorphous films of Ge2S3, *J. Non-Cryst. Solids* 35 & 36 (1980) 1061-1066.
- Iyetomi, H.; Vashishta, P.; Kalia, R.K., Incipient phase separation in Ag/Ge/Se glasses: clustering of Ag atoms, *J. Non-Cryst. Solids* 262 (2000) 135-142.
- Jones, G.; Collins, R.A., Switching properties to thin selenium films under pulsed bias, *Thin Solid Films* 40 (1977) L15-L18.
- Joullie, A.M.; Marucchi, J., On the DC electrical conduction of amorphous As2Se7 before switching, *Phys. Stat. Sol. (a)* 13 (1972) K105-K109.
- Joullie, A.M.; Marucchi, J., Electrical properties of the amorphous alloy As2Se5, *Mat. Res. Bull.* 8 (1973) 433-442.
- Kaplan, T.; Adler, D., Electrothermal switching in amorphous semiconductors, *J. Non-Cryst. Solids* 8-10 (1972) 538-543.
- Kawaguchi, T.; Maruno, S.; Elliott, S.R., Optical, electrical, and structural properties of amorphous Ag-Ge-S and Ag-Ge-Se films and comparison of photoinduced and thermally induced phenomena of both systems, *J. Appl. Phys.* 79 (1996) 9096-9104.
- Kawaguchi, T.; Masui, K., Analysis of change in optical transmission spectra resulting from Ag photodoping in chalcogenide film, *Jpn. J. Appl. Phys.* 26 (1987) 15-21.
- Kawasaki, M.; Kawamura, J.; Nakamura, Y.; Aniya, M., Ionic conductivity of Agx(GeSe3)1-x (0<=x<=0.571) glasses, *Solid state Ionics* 123 (1999) 259-269.
- Kluge, G.; Thomas, A.; Klages, R.; Grotzschel, R., Silver photodiffusion in amorphous GexSe100-x, *J. Non-Cryst. Solids* 124 (1990) 186-193.
- Kolobov, A.V., On the origin of p-type conductivity in amorphous chalcogenides, *J. Non-Cryst. Solids* 198-200 (1996) 728-731.
- Kolobov, A.V., Lateral diffusion of silver in vitreous chalcogenide films, *J. Non-Cryst. Solids* 137-138 (1991) 1027-1030.
- Korkinova, Ts.N.; Andreichin, R.E., Chalcogenide glass polarization and the type of contacts, *J. Non-Cryst. Solids* 194 (1996) 256-259.
- Kotkata, M.F.; Afif, M.A.; Labib, H.H.; Hegab, N.A.; Abdel-Aziz, M.M., Memory switching in amorphous GeSeTi chalcogenide semiconductor films, *Thin Solid Films* 240 (1994) 143-146.
- Lakshminarayan, K.N.; Srivastava, K.K.; Panwar, O.S.; Dumar, A., Amorphous semiconductor devices: memory and switching mechanism, *J. Instn Electronics & Telecom. Engrs* 27 (1981) 16-19.
- Lal, M.; Goyal, N., Chemical bond approach to study the memory and threshold switching chalcogenide glasses, *Indian Journal of pure & appl. phys.* 29 (1991) 303-304.
- Leimer, F.; Stotzel, H.; Kottwitz, A., Isothermal electrical polarisation of amorphous GeSe films with blocking Al contacts influenced by Poole-Frenkel conduction, *Phys. Stat. Sol. (a)* 29 (1975) K129-K132.
- Leung, W.; Cheung, N.; Neureuther, A.R., Photoinduced diffusion of Ag in GexSe1-x glass, *Appl. Phys. Lett.* 46 (1985) 543-545.
- Matsushita, T.; Yamagami, T.; Okuda, M., Polarized memory effect observed on Se-SnO2 system, *Jap. J. Appl. Phys.* 11 (1972) 1657-1662.
- Matsushita, T.; Yamagami, T.; Okuda, M., Polarized memory effect observed on amorphous selenium thin films, *Jpn. J. Appl. Phys.* 11 (1972) 606.
- Mazurier, F.; Levy, M.; Souquet, J.L., Reversible and irreversible electrical switching in TeO2-V2O5 based glasses, *Journal de Physique IV* 2 (1992) C2-185-C2-188.
- Messoussi, R.; Bernede, J.C.; Benhida, S.; Abachi, T.; Latef, A., Electrical characterization of M/Se structures (M=Ni,Bi), *Mat. Chem. And Phys.* 28 (1991) 253-258.
- Mitkova, M.; Boolchand, P., Microscopic origin of the glass forming tendency in chalcogenides and constraint theory, *J. Non-Cryst. Solids* 240 (1998) 1-21.
- Mitkova, M.; M.N., Silver incorporation in Ge-Se glasses used in programmable metallization cell devices, *J. Non-Cryst. Solids* 299-302 (2002) 1023-1027.
- Mitkova, M.; Wang, Y.; Boolchand, P., Dual chemical role of Ag as an additive in chalcogenide glasses, *Phys. Rev. Lett.* 83 (1999) 3848-3851.
- Miyatani, S.-y., Electronic and ionic conduction in (AgxCu1-x)2Se, *J. Phys. Soc. Japan* 34 (1973) 423-432.
- Miyatani, S.-y., Electrical properties of Ag2Se, *J. Phys. Soc. Japan* 13 (1958) 317.
- Miyatani, S.-y., Ionic conduction in beta-Ag2Te and beta-Ag2Se, *Journal Phys. Soc. Japan* 14 (1959) 996-1002.
- Mott, N.F., Conduction in glasses containing transition metal ions, *J. Non-Cryst. Solids* 1 (1968) 1-17.
- Nakayama, K.; Kitagawa, T.; Ohmura, M.; Suzuki, M., Nonvolatile memory based on phase transitions in chalcogenide thin films, *Jpn. J. Appl. Phys.* 32 (1993) 564-569.
- Nakayama, K.; Kojima, K.; Hayakawa, F.; Imai, Y.; Kitagawa, A.; Suzuki, M., Submicron nonvolatile memory cell based on reversible phase transition in chalcogenide glasses, *Jpn. J. Appl. Phys.* 39 (2000) 6157-6161.
- Nang, T.T.; Okuda, M.; Matsushita, T.; Yokota, S.; Suzuki, A., Electrical and optical parameters of GexSe1-x amorphous thin films, *Jap. J. App. Phys.* 15 (1976) 849-853.
- Narayanan, R.A.; Asokan, S.; Kumar, A., Evidence concerning the effect of topology on electrical switching in chalcogenide network glasses, *Phys. Rev. B* 54 (1996) 4413-4415.
- Neale, R.G.; Aseltine, J.A., The application of amorphous materials to computer memories, *IEEE transactions on electron dev. Ed-20* (1973) 195-209.
- Ovshinsky S.R.; Fritzsche, H., Reversible structural transformations in amorphous semiconductors for memory and logic, *Mettalurgical transactions* 2 (1971) 641-645.
- Ovshinsky, S.R., Reversible electrical switching phenonmena in disordered structures, *Phys. Rev. Lett.* 21 (1968) 1450-1453.
- Owen, A.E.; LeComber, P.G.; Sarabayrouse, G.; Spear, W.E., New amorphous-silicon electrically programmable nonvolatile switching device, *IEE Proc.* 129 (1982) 51-54.
- Owen, A.E.; Firth, A.P.; Ewen, P.J.S., Photo-induced structural and physico-chemical changes in amorphous chalcogenide semiconductors, *Phil. Mag. B* 52 (1985) 347-362.
- Owen, A.E.; Le Comber, P.G.; Hajto, J.; Rose, M.J.; Snell, A.J., Switching in amorphous devices, *Int. J. Electronics* 73 (1992) 897-906.
- Pearson, A.D.; Miller, C.E., Filamentary conduction in semiconducting glass diodes, *App. Phys. Lett.* 14 (1969) 280-282.
- Pinto, R.; Ramanathan, K.V., Electric field induced memory switching in thin films of the chalcogenide system Ge-As-Se, *Appl. Phys. Lett.* 19 (1971) 221-223.
- Popescu, C., The effect of local non-uniformities on thermal switching and high field behavior of structures with chalcogenide glasses, *Solid-state electronics* 18 (1975) 671-681.
- Popescu, C.; Croitoru, N., The contribution of the lateral thermal instability to the switching phenomenon, *J. Non-Cryst. Solids* 8-10 (1972) 531-537.
- Popov, A.I.; Geller, I.K.H.; Shemetova, V.K., Memory and threshold switching effects in amorphous selenium, *Phys. Stat. Sol. (a)* 44 (1977) K71-K73.
- Prakash, S.; Asokan, S.; Ghare, D.B., Easily reversible memory switching in Ge-As-Te glasses, *J. Phys. D: Appl. Phys.* 29 (1996) 2004-2008.
- Rahman, S.; Sivarama Sastry, G., Electronic switching in Ge-Bi-Se-Te glasses, *Mat. Sci. and Eng. B12* (1992) 219-222.
- Ramesh, K.; Asokan, S.; Sangunni, K.S.; Gopal, E.S.R., Electrical Switching in germanium telluride glasses doped with Cu and Ag, *Appl. Phys. A* 69 (1999) 421-425.

- Rose, M.J.; Hajto, J.; Lecomber, P.G.; Gage, S.M.; Choi, W.K.; Snell, A.J.; Owen, A.E., Amorphous silicon analogue memory devices, *J. Non-Cryst. Solids* 115 (1989) 168-170.
- Rose, M.J.; Snell, A.J.; Lecomber, P.G.; Hajto, J.; Fitzgerald, A.G.; Owen, A.E., Aspects of non-volatility in a -Si:H memory devices, *Mat. Res. Soc. Symp. Proc. V 258*, 1992, 1075-1080.
- Schuocker, D.; Rieder, G., On the reliability of amorphous chalcogenide switching devices, *J. Non-Cryst. Solids* 29 (1978) 397-407.
- Sharma, A.K.; Singh, B., Electrical conductivity measurements of evaporated selenium films in vacuum, *Proc. Indian Natn. Sci. Acad.* 46, A, (1980) 362-368.
- Sharma, P., Structural, electrical and optical properties of silver selenide films, *Ind. J. Of pure and applied phys.* 35 (1997) 424-427.
- Snell, A.J.; Lecomber, P.G.; Hajto, J.; Rose, M.J.; Owen, A.E.; Osborne, I.L., Analogue memory effects in metal/a-Si:H/metal memory devices, *J. Non-Cryst. Solids* 137-138 (1991) 1257-1262.
- Snell, A.J.; Hajto, J.; Rose, M.J.; Osborne, L.S.; Holmes, A.; Owen, A.E.; Gibson, R.A.G., Analogue memory effects in metal/a-Si:H/metal thin film structures, *Mat. Res. Soc. Symp. Proc. V 297*, 1993, 1017-1021.
- Steventon, A.G., Microfilaments in amorphous chalcogenide memory devices, *J. Phys. D: Appl. Phys.* 8 (1975) L120-L122.
- Steventon, A.G., The switching mechanisms in amorphous chalcogenide memory devices, *J. Non-Cryst. Solids* 21 (1976) 319-329.
- Stocker, H.J., Bulk and thin film switching and memory effects in semiconducting chalcogenide glasses, *App. Phys. Lett.* 15 (1969) 55-57.
- Tanaka, K., Ionic and mixed conductions in Ag photodoping process, *Mod. Phys. Lett B* 4 (1990) 1373-1377.
- Tanaka, K.; Iizima, S.; Sugi, M.; Okada, Y.; Kikuchi, M., Thermal effects on switching phenomenon in chalcogenide amorphous semiconductors, *Solid State Comm.* 8 (1970) 387-389.
- Thornburg, D.D., Memory switching in a Type I Amorphous chalcogenide, *J. Elect. Mat.* 2 (1973) 3-15.
- Thornburg, D.D., Memory switching in amorphous arsenic triselenide, *J. Non-Cryst. Solids* 11 (1972) 113-120.
- Thornburg, D.D.; White, R.M., Electric field enhanced phase separation and memory switching in amorphous arsenic triselenide, *Journal(?)* (1972) 4609-4612.
- Tichy, L.; Ticha, H., Remark on the glass-forming ability in  $GexSe_{1-x}$  and  $AsxSe_{1-x}$  systems, *J. Non-Cryst. Solids* 261 (2000) 277-281.
- Titus, S.S.K.; Chatterjee, R.; Asokan, S., Electrical switching and short-range order in As—Te glasses, *Phys. Rev. B* 48 (1993) 14650-14652.
- Tranchant, S.; Peytavin, S.; Ribes, M.; Flank, A.M.; Dexpert, H.; Lagarde, J.P., Silver chalcogenide glasses Ag-13 Ge—Se: Ionic conduction and exafs structural investigation, Transport-structure relations in fast ion and mixed conductors Proceedings of the 6th Riso International symposium. Sep. 9-13, 1985.
- Tregouet, Y.; Bernede, J.C., Silver movements in  $Ag_2Te$  thin films: switching and memory effects, *Thin Solid Films* 57 (1979) 49-54.
- Uemura, O.; Kameda, Y.; Kokai, S.; Satow, T., Thermally induced crystallization of amorphous  $Ge_{0.4}Se_{0.6}$ , *J. Non-Cryst. Solids* 117-118 (1990) 219-221.
- Uttecht, R.; Stevenson, H.; Sie, C.H.; Griener, J.D.; Raghavan, K.S., Electric field induced filament formation in As—Te—Ge glass, *J. Non-Cryst. Solids* 2 (1970) 358-370.
- Viger, C.; Lefrancois, G.; Fleury, G., Anomalous behaviour of amorphous selenium films, *J. Non-Cryst. Solids* 33 (1976) 267-272.
- Vodenicharov, C.; Paravanov, S.; Petkov, P., Electrode-limited currents in the thin-film M-GeSe-M system, *Mat. chem. And Phys.* 21 (1989) 447-454.
- Wang, S.-J.; Misium, G.R.; Camp, J.C.; Chen, K.-L.; Tigelaar, H.L., High-performance Metal/silicide antifuse, *IEEE electron dev. Lett.* 13 (1992) 471-472.
- Weirauch, D.F., Threshold switching and thermal filaments in amorphous semiconductors, *App. Phys. Lett.* 16 (1970) 72-73.
- West, W.C.; Sieradzki, K.; Kardynal, B.; Kozicki, M.N., Equivalent circuit modeling of the  $Ag_{0.24}S_{0.36}Ag_{0.40}As_0.40$  System prepared by photodissolution of Ag, *J. Electrochem. Soc.* 145 (1998) 2971-2974.
- West, W.C., Electrically erasable non-volatile memory via electrochemical deposition of multifractal aggregates, Ph.D. Dissertation, ASU 1998.
- Zhang, M.; Mancini, S.; Bresser, W.; Boolchand, P., Variation of glass transition temperature,  $T_g$ , with average coordination number,  $\langle m \rangle$ , in network glasses: evidence of a threshold behavior in the slope  $dT_g/d\langle m \rangle$  at the rigidity percolation threshold ( $\langle m \rangle = 2.4$ ), *J. Non-Cryst. Solids* 151 (1992) 149-154.
- PCT Written Opinion dated Aug. 20, 2003.
- Yoji Kawamoto et al., "Ionic Conduction in  $As_2S_3$ - $Ag_2S$ ,  $GeS_2$ - $GeS$ - $Ag_2S$  and  $P_2S_5$ - $Ag_2S$  Glasses," *Journal of Non-Crystalline Solids* 20 (1976) 393-404.
- Axon Technologies Corporation, Technology Description: *Programmable Metalization Cell (PMC)*, pp. 1-6 (Pre-May 2000).
- Helbert et al., *Intralevel hybrid resist process with submicron capability*, SPIE vol. 333 Submicron Lithography, pp. 24-29 (1982).
- Hilt, Dissertation: *Materials characterization of Silver Chalcogenide Programmable Metalization Cells*, Arizona State University, pp. Title p. 114 (UMI Company, May 1999).
- Hirose et al., *High Speed Memory Behavior and Reliability of an Amorphous  $As_2S_3$  Film Doped Ag*, *Phys. Stat. Sol. (a)* 61, pp. 87-90 (1980).
- Kawaguchi et al., *Mechanism of photosurface deposition*, 164-166 *J. Non-Cryst. Solids*, pp. 1231-1234 (1993).
- Kozicki et al., Silver incorporation in thin films of selenium rich Ge—Se glasses, *International Congress on Glass*, vol. 2, Extended Abstracts, Jul. 2001, pp. 8-9.
- Michael N. Kozicki, 1. Programmable Metallization Cell Technology Description, Feb. 18, 2000.
- Michael N. Kozicki, Axon Technologies Corp. and Arizona State University, Presentation to Micron Technology, Inc., Apr. 6, 2000.
- Kozicki et al., Applications of Programmable Resistance Changes In Metal-Doped Chalcogenides, *Electrochemical Society Proceedings*, vol. 99-13, 1999, pp. 298-309.
- Kozicki et al., Nanoscale effects in devices based on chalcogenide solid solutions, Superlattices and Microstructures, vol. 27, No. 516, 2000, pp. 485-488.
- Kozicki et al., Nanoscale phase separation in Ag—Ge—Se glasses, *Microelectronic Engineering* 63 (2002) pp. 155-159.
- McHardy et al., The dissolution of metals in amorphous chalcogenides and the effects of electron and ultraviolet radiation, 20 *J. Phys. C: Solid State Phys.*, pp. 4055-4075 (1987).
- Owen et al., Metal-Chalcogenide Photoresists for High Resolution Lithography and Sub-Micron Structures, *Nanostructure Physics and Fabrication*, pp. 447-451 (M. Reed ed. 1989).
- Shimizu et al., The Photo-Erasable Memory Switching Effect of Ag Photo-Doped Chalcogenide Glasses, 46 *B. Chem. Soc. Japan*, No. 12, pp. 3662-3365 (1973).

\* cited by examiner

FIG. 1  
(PRIOR ART)

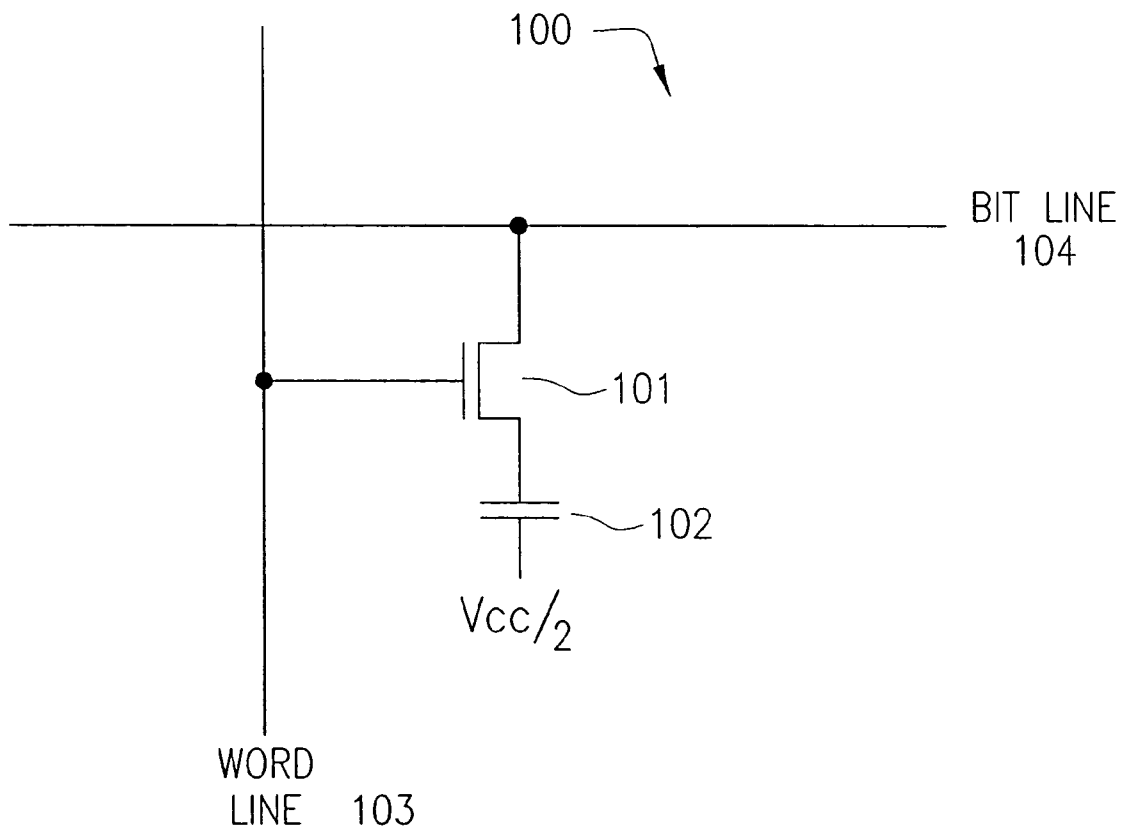


FIG. 2  
(PRIOR ART)

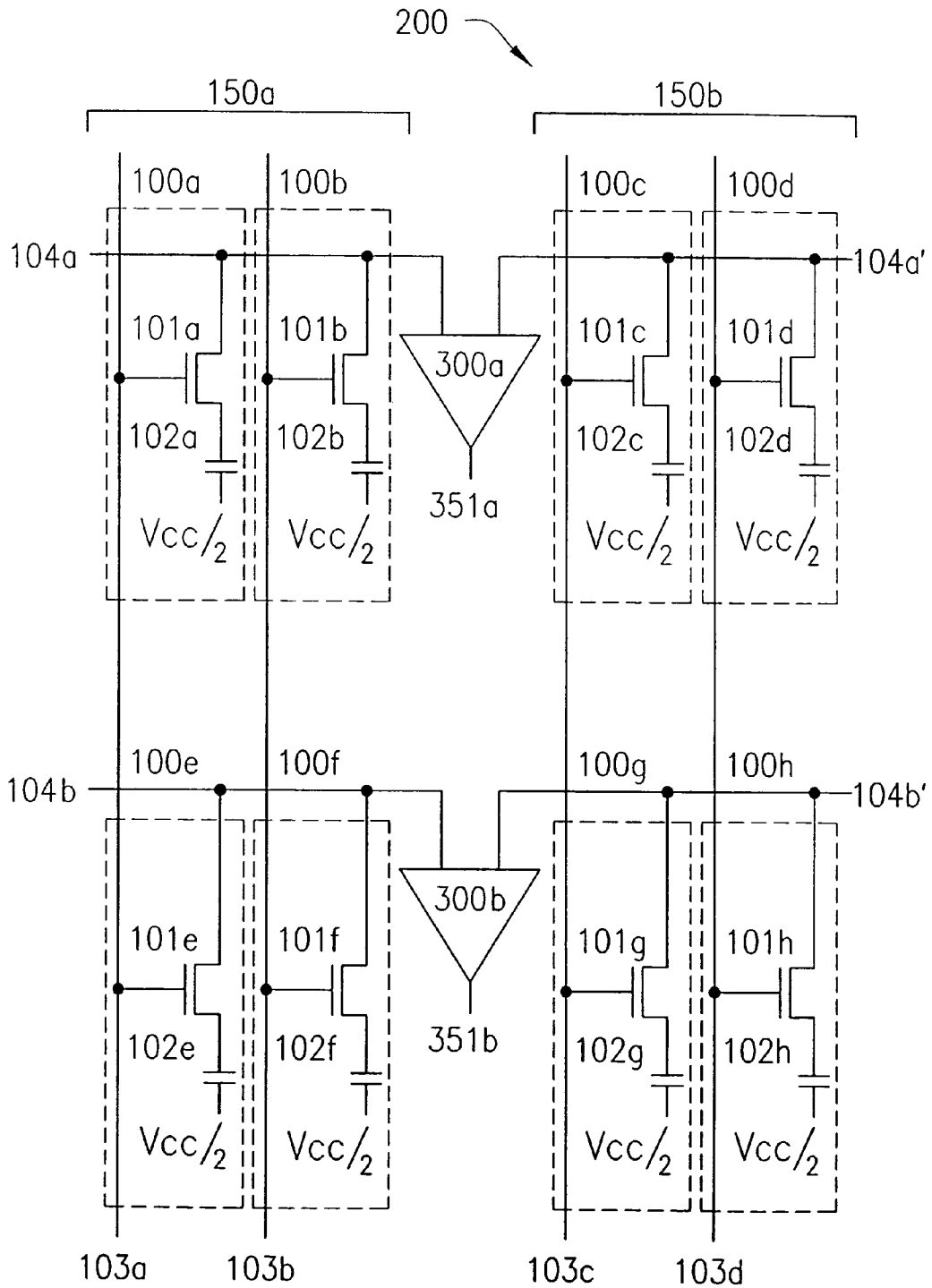




FIG. 3  
(PRIOR ART)

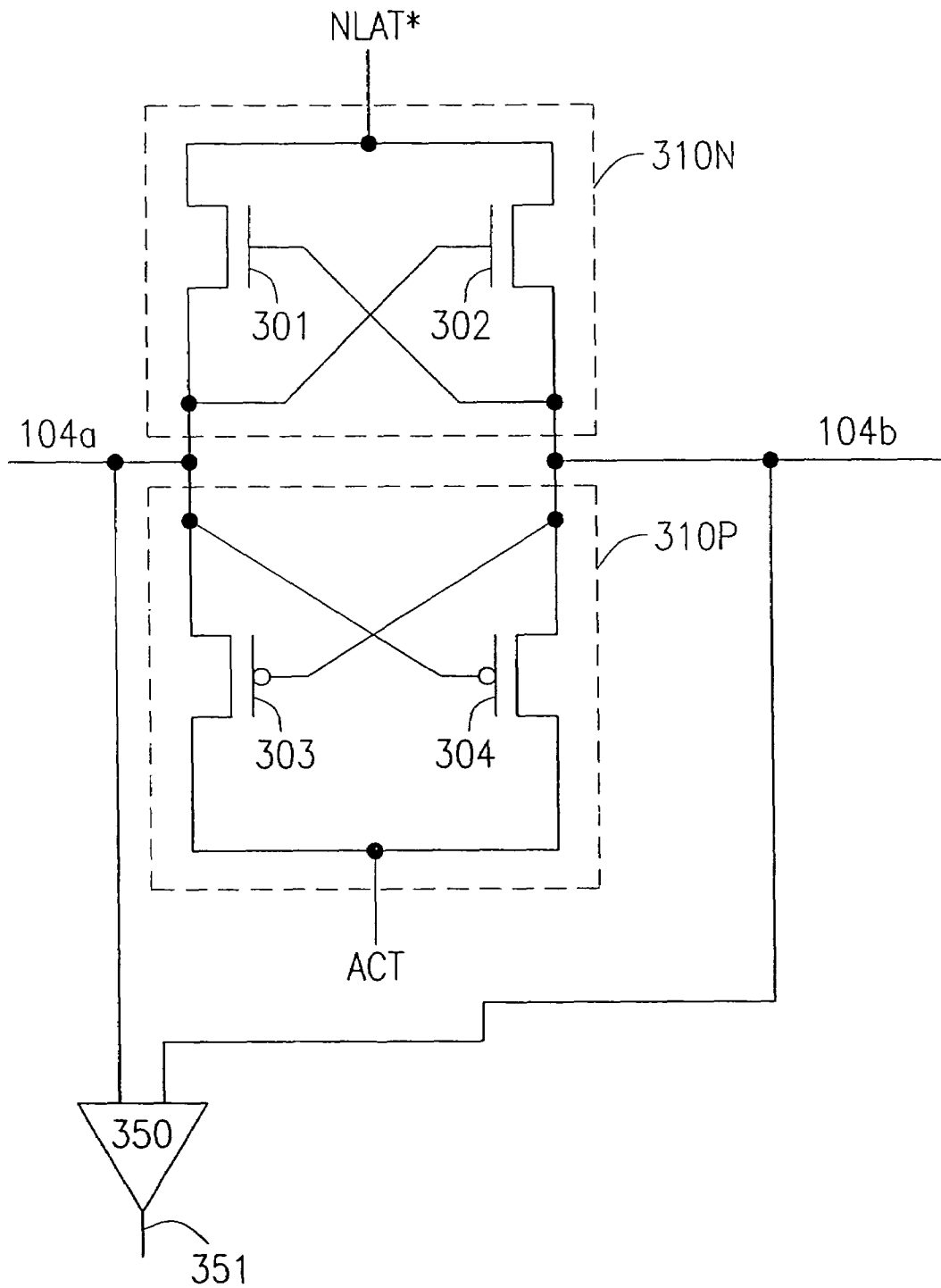
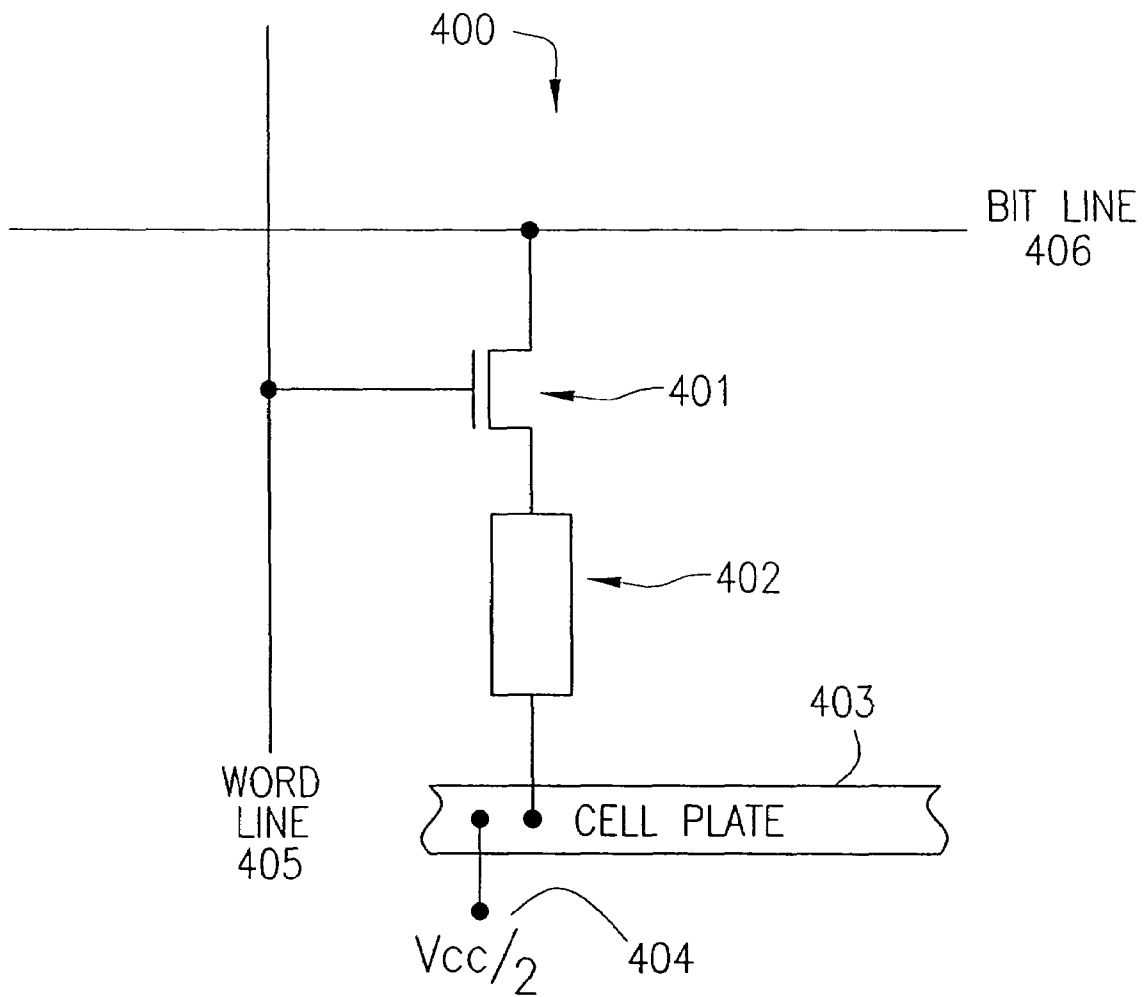


FIG. 4



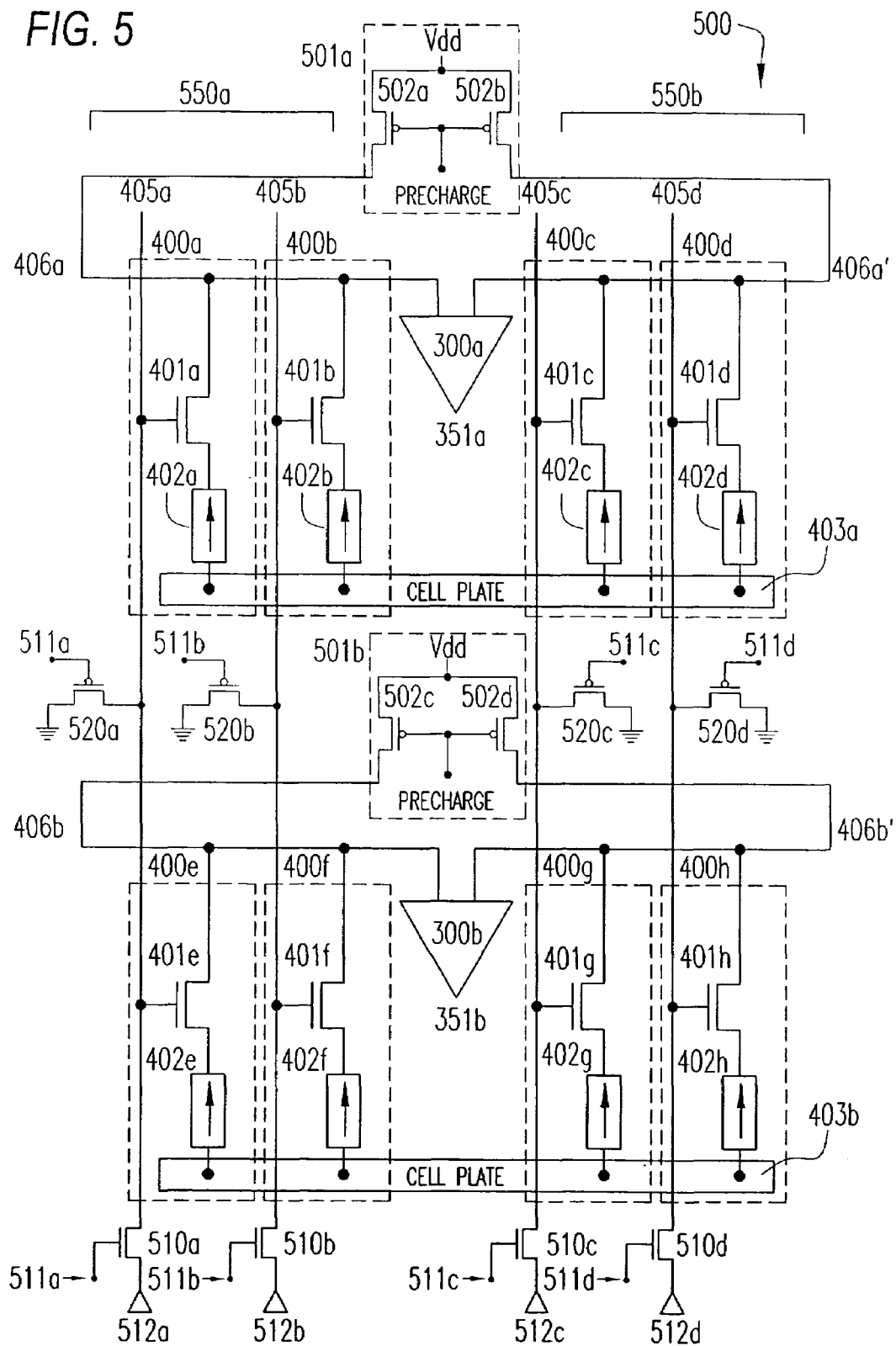


FIG. 6A

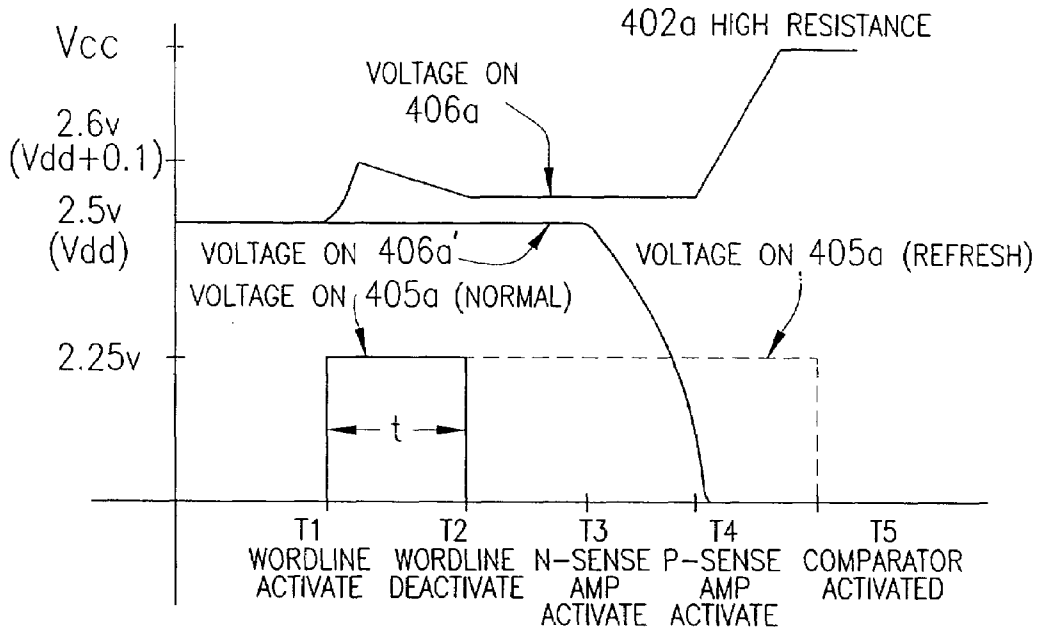


FIG. 6B

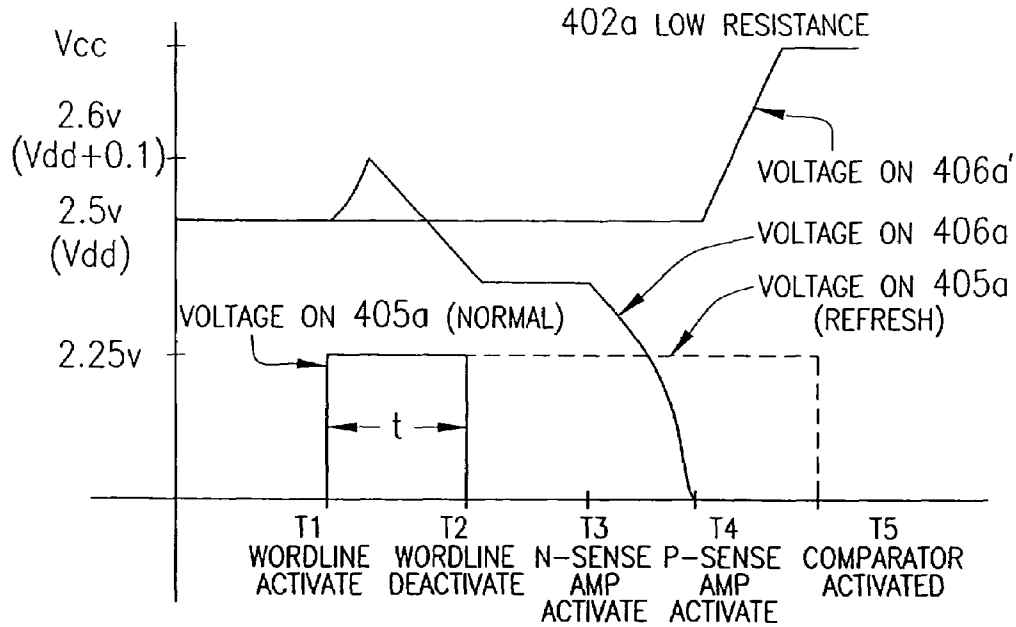


FIG. 7

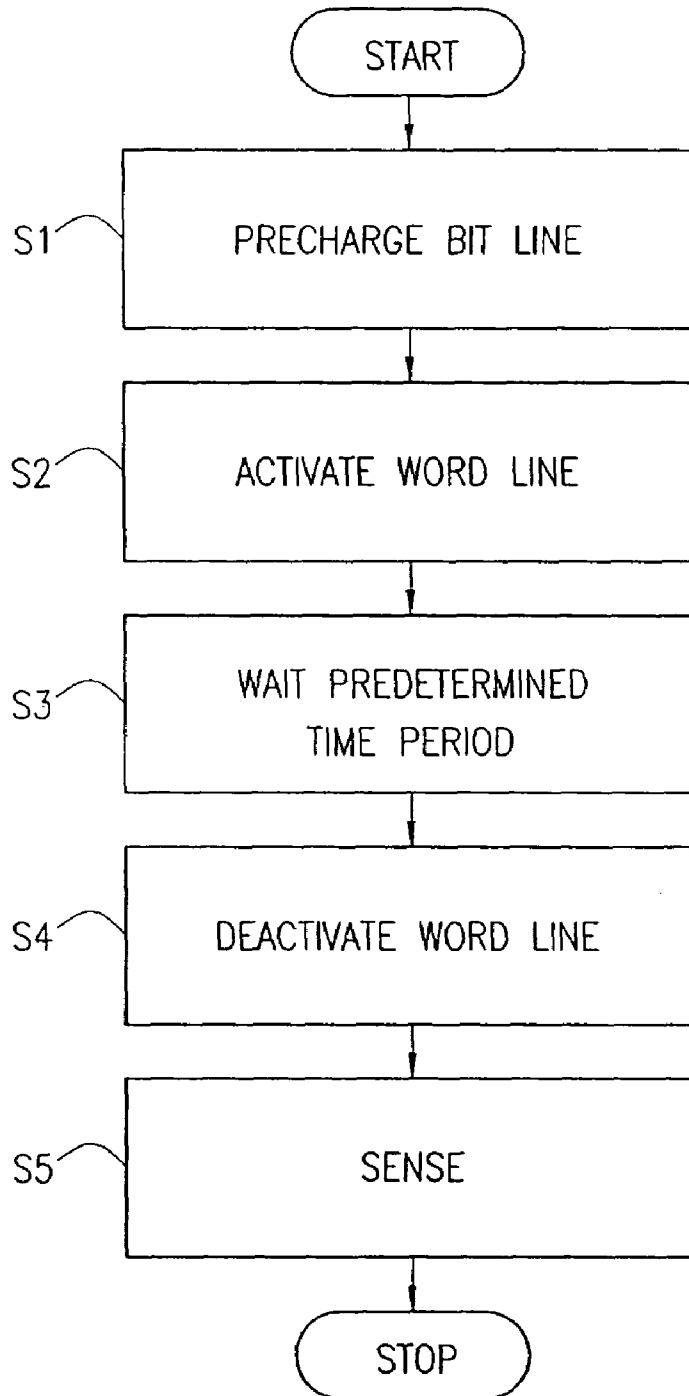


FIG. 8

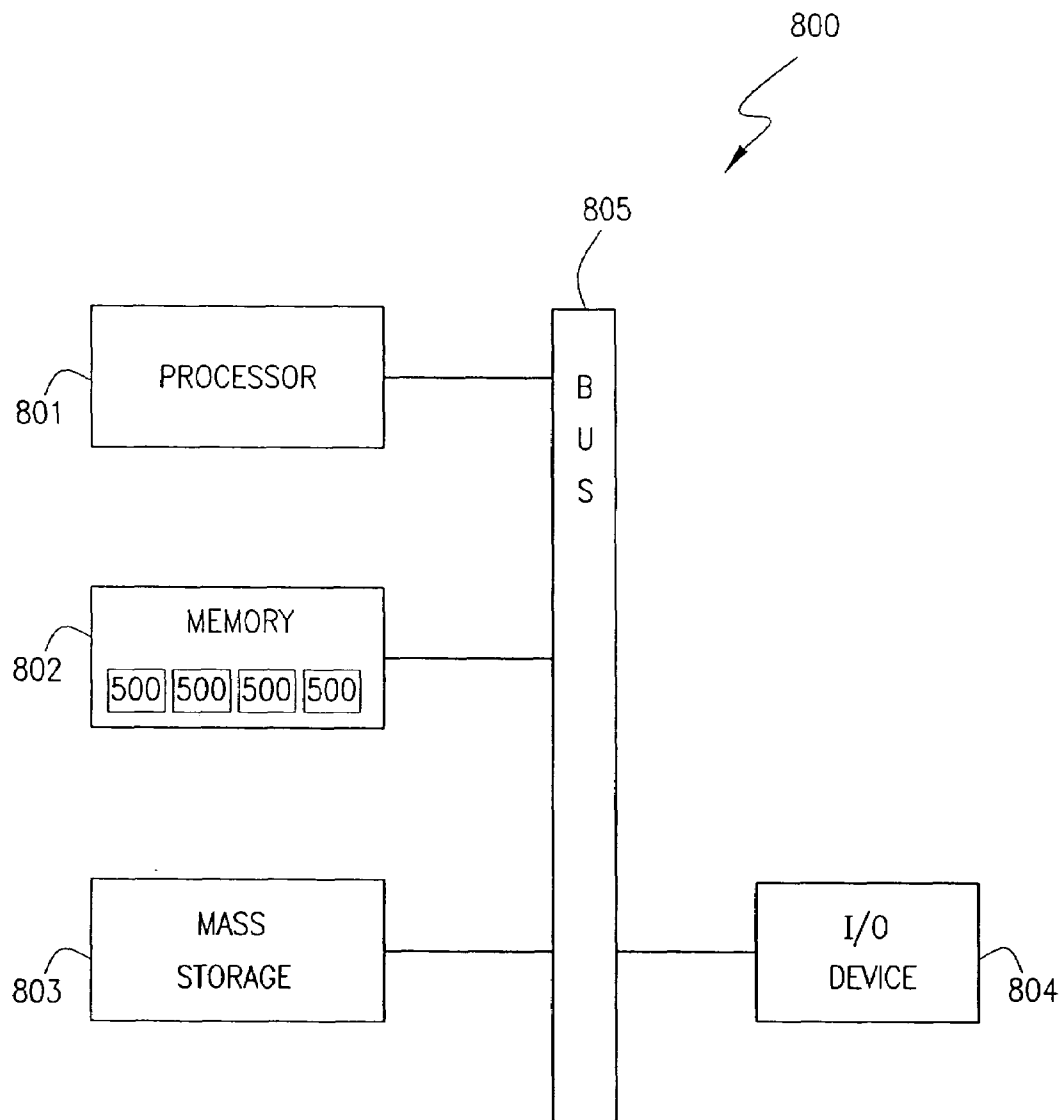


FIG. 9

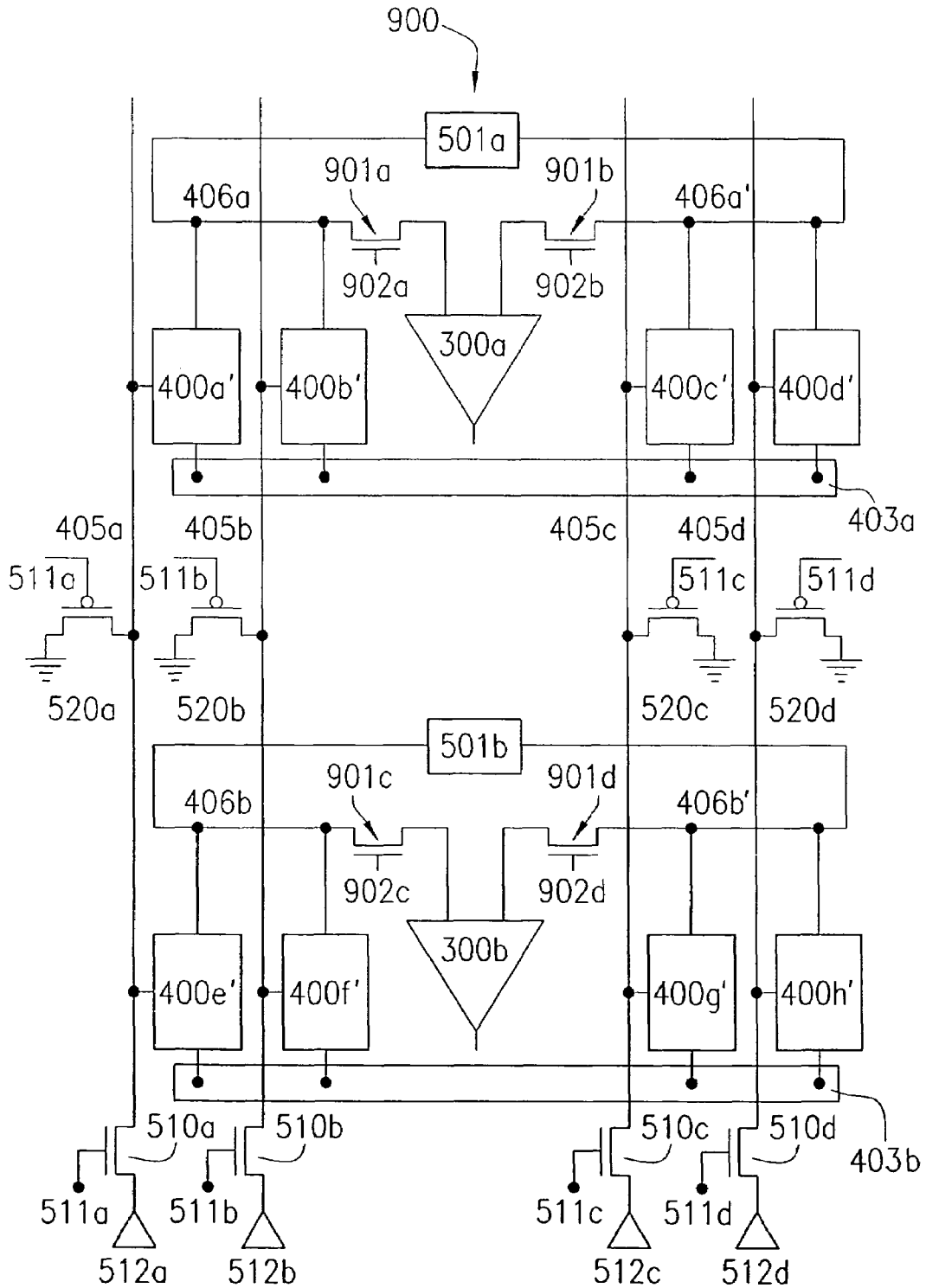
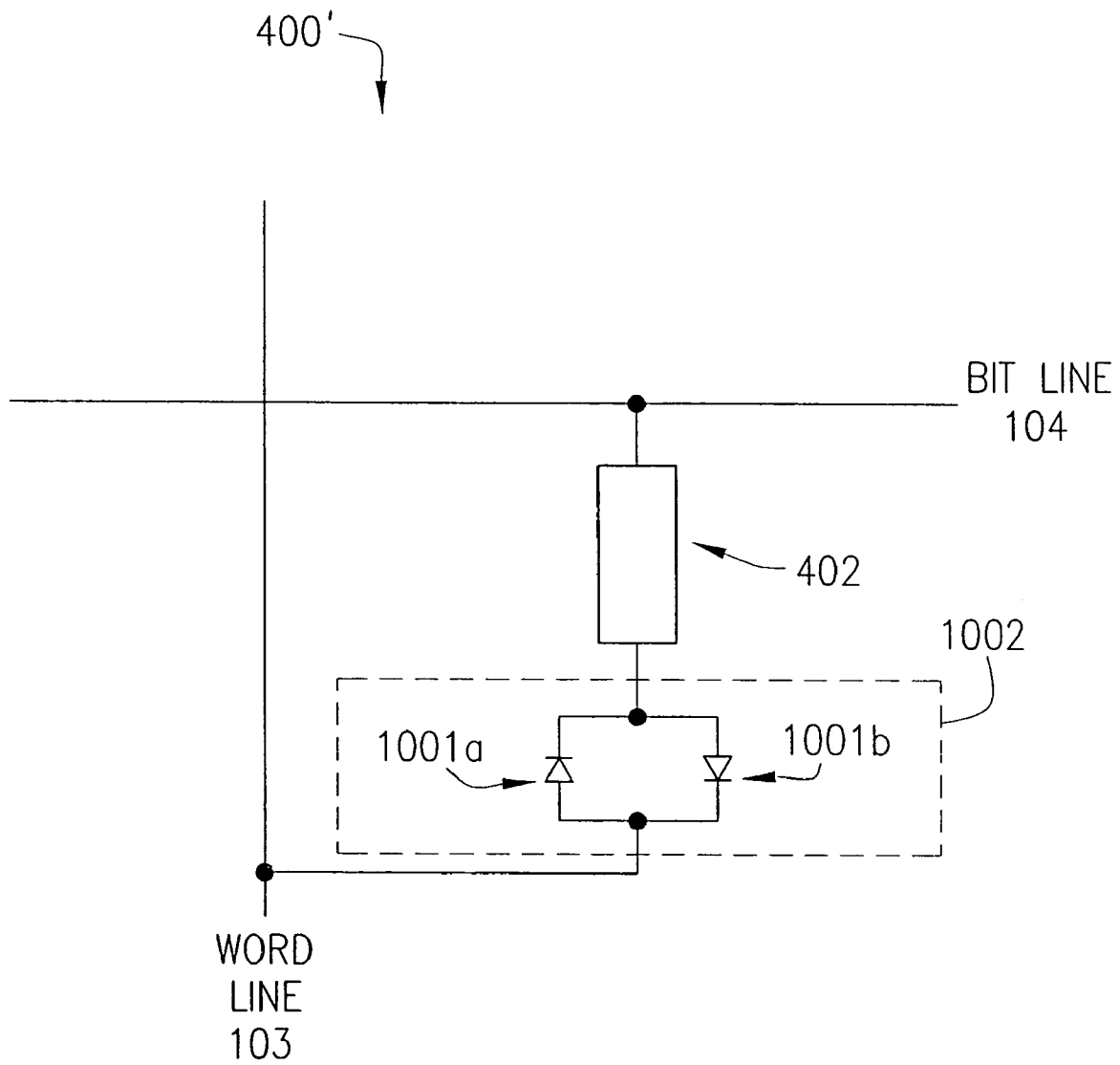


FIG. 10





## REWRITE PREVENTION IN A VARIABLE RESISTANCE MEMORY

This application is a continuation of application Ser. No. 10/680,161, filed Oct. 8, 2003, now U.S. Pat. No. 6,882,578, which is a divisional of application Ser. No. 10/035,197, filed Jan. 4, 2002, now U.S. Pat. No. 6,909,656, the subject matter of each are incorporated by reference herein.

### FIELD OF INVENTION

The present invention relates to integrated memory circuits. More specifically, it relates to a method for reading a programmable conductor random access memory (PCRAM) cell.

### BACKGROUND OF THE INVENTION

Dynamic random access memory (DRAM) integrated circuit arrays have existed for more than thirty years and their dramatic increase in storage capacity has been achieved through advances in semiconductor fabrication technology and circuit design technology. The tremendous advances in these two technologies have also achieved higher levels of integration that permit dramatic reductions in memory array size and cost, as well as increased process yield.

FIG. 1 is a schematic diagram of a DRAM memory cell **100** comprising an access transistor **101** and a capacitor **102**. The capacitor **102**, which is coupled to a  $V_{cc}/2$  potential source and the transistor **101**, stores one bit of data in the form of a charge. Typically, a charge of one polarity (e.g., a charge corresponding to a potential difference across the capacitor **102** of  $+V_{cc}/2$ ) is stored in the capacitor **102** to represent a binary "1" while a charge of the opposite polarity (e.g., a charge corresponding to a potential difference across the capacitor **102** of  $-V_{cc}/2$ ) represents a binary "0." The gate of the transistor **101** is coupled to a word line **103**, thereby permitting the word line **103** to control whether the capacitor **102** is conductively coupled via the transistor **101** to a bit line **104**. The default state of each word line **103** is at ground potential, which causes the transistor **101** to be switched off, thereby electrically isolating capacitor **102**.

One of the drawbacks associated with DRAM cells **100** is that the charge on the capacitor **102** may naturally decay over time, even if the capacitor **102** remains electrically isolated. Thus, DRAM cells **100** require periodic refreshing. Additionally, as discussed below, refreshing is also required after a memory cell **100** has been accessed, for example, as part of a read operation.

FIG. 2 illustrates a memory device **200** comprising a plurality of memory arrays **150a**, **150b**. (Generally, in the drawings, elements having the same numerical value are of the same type. For example, sense amplifiers **300a** and **300b** in FIG. 2 have identical circuitry to sense amplifier **300** of FIG. 3. A lower case alphabetic suffix is generally used to discriminate between different units of the same type. However, upper case prefixes, such as "N" and "P" may denote different circuitry associated with negative or positive typed variants.) Each memory array **150a**, **150b** includes a plurality of memory cells **100a–100d**, **100e–100h** arranged by tiling a plurality of memory cells **100** together so that the memory cells **100** along any given bit line **104a**, **104a'**, **104b**, **104b'** do not share a common word line **103a–103d**. Conversely, the memory cells **100** along any word line **103** do not share a common bit line **104a**, **104a'**, **104b**, **104b'**. Each memory array has its own set of bit lines. For example, memory array **150a** includes bit lines **104a**, **104b**, while

memory array **150b** includes bit lines **104a'**, **104b'**. The bit lines from each adjacent pair of memory arrays **150a**, **150b** are coupled to a common sense amplifier **300a**, **300b**. For example, bit lines **104a**, **104a'** are coupled to sense amplifier **300a**, while bit lines **104b**, **104b'** are coupled to sense amplifier **300b**. As explained below, the sense amplifiers **300a**, **300b** are used to conduct the sense/refresh portion when a memory cell **100a–100h** is read.

Reading a DRAM memory cell comprises the operations of accessing and sensing/refreshing.

The purpose of the access operation is to transfer charge stored on the capacitor **102** to the bit line **104** associated with the memory cell **100**. The access operation begins by precharging each bit line **104a**, **104a'**, **104b**, **104b'** to a predetermined potential (e.g.,  $V_{cc}/2$ ) by coupling each bit line **104a**, **104b** to a potential source (not illustrated). Each bit line **104a**, **104b** is then electrically disconnected. The bit lines **104a**, **104a'**, **104b**, **104b'** will float at the predetermined potential due to the inherent capacitance of the bit lines **104a**, **104a'**, **104b**, **104b'**. Subsequently, the word line (e.g., **103a**) associated with a memory cell being read (e.g., **100a**) is activated by raising its potential to a level which causes each transistor **101a**, **101e** coupled to the word line **103a** to gate. It should be noted that due to inherent parasitic capacitance between bit lines **104** and word lines **103**, activation of a word line **103** will cause the potential at each associated bit line **104** to increase slightly. However, in typical DRAM systems, the magnitude of this potential change is insignificant in comparison to the magnitude of the potential change on the bit lines due to charge sharing. Therefore, with respect to DRAM systems only, further discussion regarding the effect of parasitic capacitance is omitted.

Activation of the word line **103a** causes each capacitor **102a**, **102e** of each memory cell **100a**, **100e** coupled to that word line **103a** to share its charge with its associated bit line **104a**, **104b**. The bit lines **104a'**, **104b'** in the other array **150b** remain at the pre-charge potential. The charge sharing causes the bit line **104a**, **104b** potential to either increase or decrease, depending upon the charge stored in the capacitors **102a**, **102e**. Since only the bit lines **104a**, **104b** of one memory array has its potential altered, at each sense amplifier **300a**, **300b**, a differential potential develops between the bit lines **104a**, **104b** associated with the activated word line **103a** and the other bit lines **104a'**, **104b'** associated with the same sense amplifier **300a**, **300b**. Thus, the access operation causes the bit lines **104a**, **104b** associated with the cell **100a** being read to have a potential which is either greater than or less than the pre-charged voltage. However, the change in potential is small and requires amplification before it can be used.

The sense/refresh operation serves two purposes. First, the sense/refresh operation amplifies the small change in potential to the bit line coupled to the cell which was accessed. If the bit line has a potential which is lower than the pre-charge potential, the bit line will be driven to ground during sensing. Alternatively, if the bit line has a potential which is higher than the pre-charge potential, the bit line will be driven to  $V_{cc}$  during sensing. The second purpose of the sense/refresh operation is to restore the state of the charge in the capacitor of the accessed cell to the state it had prior to the access operation. This step is required since the access operation diluted the charge stored on the capacitor by sharing it with the bit line.

FIG. 3 is a detailed illustration of a sense amplifier **300**, which comprises a N-sense amp **310N** and a P-sense amp portion **310P**. The N-sense amp **310N** and the P-sense amp

310P include nodes NLAT\* and ACT, respectively. These nodes are coupled to controllable potential sources (not illustrated). Node NLAT\* is initially biased to the pre-charge potential of the bit lines 104 (e.g.,  $V_{cc}/2$ ) while node ACT is initially biased to ground. In this initial state, the transistors 301–304 of the N- and P-sense amps 310N, 310P are switched off. The sense/refresh operation is a two phased operation in which the N-sense amp 310N is triggered before the P-sense amp 310P.

The N-sense amp 310N is triggered by bringing the potential at node NLAT\* from the pre-charge potential (e.g.,  $V_{cc}/2$ ) towards ground potential. As the potential difference between node NLAT\* and the bit lines 104a, 104a', 104b, 104b' approach the threshold potential of NMOS transistors 301, 302, the transistor with the gate coupled to the higher voltage bit line begins to conduct. This causes the lower voltage bit line to discharge towards the voltage of the NLAT\* node. Thus, when node NLAT\* reaches ground potential, the lower voltage bit line will also reach ground potential. The other NMOS transistor never conducts since its gate is coupled to the low voltage digit line being discharged towards ground.

The P-sense amp 310P is triggered (after the N-sense amp 310N has been triggered) by bringing the potential at node ACT from ground towards  $V_{cc}$ . As the potential of the lower voltage bit line approaches ground (caused by the earlier triggering of the N-sense amp 310N), the PMOS transistor with its gate coupled to the lower potential bit line will begin to conduct. This causes the initially higher potential bit line to be charged to a potential of  $V_{cc}$ . After both the N- and P-sense amps 310N, 310P have been triggered, the higher voltage bit line has its potential elevated to  $V_{cc}$  while the lower potential bit line has its potential reduced to ground. Thus, the process of triggering both sense amps 310N, 310P amplifies the potential difference created by the access operation to a level suitable for use in digital circuits. In particular, the bit line 104a associated with the memory cell 100a being read is driven from the pre-charge potential of  $V_{cc}/2$  to ground if the memory cell 100a stored a charge corresponding to a binary 0, or to  $V_{cc}$  if the memory cell 100a stored a charge corresponding to a binary 1, thereby permitting a comparator (or differential amplifier) 350a coupled to bit lines 104a, 104a' to output a binary 0 or 1 consistent with the data stored in the cell 100a on signal line 351. Additionally, the charge initially stored on the capacitor 102a of the accessed cell is restored to its pre-access state.

Efforts continue to identify other forms of memory elements for use in memory cells. Recent studies have focused on resistive materials that can be programmed to exhibit either high or low stable ohmic states. A programmable resistance element of such material could be programmed (set) to a high resistive state to store, for example, a binary "1" data bit or programmed to a low resistive state to store a binary "0" data bit. The stored data bit could then be retrieved by detecting the magnitude of a readout current switched through the resistive memory element by an access device, thus indicating the stable resistance state it had previously been programmed to.

Recently chalcogenide glasses fabricated with solid electrolyte such as a metal doped chalcogenide have been investigated as data storage memory cells for use in memory devices, such as DRAM memory devices. U.S. Pat. Nos. 5,761,115, 5,896,312, 5,914,893, and 6,084,796 all describe this technology and are incorporated herein by reference. The storage cells are called programmable conductor cells (alternatively, they are also known as programmable metal-ization cells). One characteristic of such a cell is that it

typically includes solid metal electrolyte such as a metal doped chalcogenide and a cathode and anode spaced apart on a surface of the fast ion conductor. Application of a voltage across the cathode and anode causes growth of a metal dendrite which changes the resistance and capacitance of the cell which can then be used to store data.

One particularly promising programmable, bi-stable resistive material is an alloy system including Ge:Se:Ag. A memory element comprised of a chalcogenide material has a natural stable high resistive state but can be programmed to a low resistance state by passing a current pulse from a voltage of suitable polarity through the cell. This causes a programmable conductor, also known as a dendrite, to grow between the anode and cathode which lowers the cell resistance. A chalcogenide memory element is simply written over by the appropriate current pulse and voltage polarity (reverse of that which writes the cell to a low resistance state) to reprogram it, and thus does not need to be erased. Moreover, a memory element of chalcogenide material is nearly nonvolatile, in that it need only be rarely (e.g., once per week) connected to a power supply or refreshed, in order to retain its programmed low resistance state. Such memory cells, unlike DRAM cells, can be accessed without requiring a refresh.

While conventional sense amp circuitry, such as those associated with DRAM cells, are capable of sensing programmable conductor random access memory (PCRAM) cells, the natural refresh operation associated with these sense amplifiers are not required in a PCRAM context. Indeed, frequent rewriting of PCRAM cells is not desirable because it can cause the PCRAM cell to become resistant to rewriting. Accordingly, there is a need and desire for a circuit and method for reading PCRAM cells without refreshing them.

#### SUMMARY OF THE INVENTION

The present invention is directed to a method and apparatus for reading a PCRAM memory cell without refreshing the cell. At a predetermined time after the programmable conductor of the PCRAM cell has been coupled to its bit line, the programmable conductor is electrically decoupled from the bit line. The predetermined time is chosen to be a point in time before the N- and P-sense amplifiers have been activated. In this manner, the N- and P-sense amplifier can change the potential on the bit line without causing the altered potential to rewrite the PCRAM cell. In PCRAM arrays which use access transistors having gates coupled to word lines, the present invention may be practiced by deactivating the word line at the predetermined time after the word line has been activated. In PCRAM arrays which do not include access transistors, isolation transistors may be added on each bit line between the PCRAM cell and the sense amplifier to decouple the PCRAM cells from their associated bit lines.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages and features of the invention will become more apparent from the detailed description of exemplary embodiments of the invention given below with reference to the accompanying drawings in which:

FIG. 1 is a schematic diagram of a conventional DRAM cell;

FIG. 2 is a schematic diagram of a conventional DRAM array;

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FIG. 3 is schematic diagram a conventional sense amplifier;

FIG. 4 is a schematic diagram of a PCRAM cell;

FIG. 5 is a schematic diagram a PCRAM array;

FIGS. 6A and 6B are timing diagrams illustrating the voltages on the word and bit lines when a PCRAM cell is read in high resistance and low resistance states, respectively.

FIG. 7 is a flow chart illustrating the method of the invention;

FIG. 8 is a block diagram of a processor based system including a PCRAM in accordance with the principles of the present invention;

FIG. 9 is a schematic diagram of a PCRAM array according to a second embodiment of the present invention; and

FIG. 10 is a schematic diagram of an alternative embodiment of a PCRAM cell for use with the PCRAM array of FIG. 9.

#### DETAILED DESCRIPTION OF THE INVENTION

Now referring to the drawings, where like reference numerals designate like elements, there is shown in FIG. 4 a PCRAM cell 400 and in FIG. 5 a memory device 500 a memory device comprised of a plurality of PCRAM cells 400a-400h. As illustrated in FIG. 4, a PCRAM cell 400 comprises an access transistor 401, a programmable conductor memory element 402, and a cell plate 403. The access transistor 401 has its gate coupled to a word line 405 and one terminal coupled to a bit line 406. A small portion of an array of such cells is shown in FIG. 5 as including bit lines 406a, 406a', 406b, 406b', and word lines 405a, 405b, 405c, and 405d. As shown in FIG. 5, the bit lines 406a, 406b are coupled to a respective pre-charge circuits 501a, 105b, which can switchably supply a pre-charge potential to the bit lines 406a, 406a', 406b, 406b'. The other terminal of the access transistor 401 is coupled to one end of the programmable conductor memory element 402, while the other end of the programmable conductor memory element 402 is coupled to a cell plate 403. The cell plate 403 may span and be coupled to several other PCRAM cells. The cell plating 403 is also coupled to a potential source. In the exemplary embodiment the potential source is at 1.25 volts (Vdd/2).

The access transistor 401, as well as the other access transistors, are depicted as N-type CMOS transistors, however, it should be understood that P-type CMOS transistors may be used as long as the corresponding polarities of the other components and voltages are modified accordingly. The programmable conductor memory element 402 is preferably made of chalcogenide, however, it should be understood that any other bi-stable resistive material known to those with ordinary skill in the art may also be used. In the exemplary embodiment, the programmable conductor memory element 402 stores a binary 0 when has a resistance of approximately 10 K ohm, and a binary 1 when it has a resistance greater than 10 M ohm. The programmable conductor is ideally programmed to store a low resistance, e.g., binary 0, by a voltage of +0.25 volt and can be restored to a high resistance value, e.g., a binary 1, by a programming voltage of -0.25 volt. The programmable conductor can be nondestructively read by a reading voltage having a magnitude of less than 0.25 volt. In the exemplary embodiment, the reading voltage is 0.2 volt. However, it should be readily apparent that alternate parameters may be selected for the PCRAM cell without departing from the spirit and scope of the invention.

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FIG. 5 illustrates a memory device 500 comprising a plurality of memory arrays 550a, 550b. Each memory array 550a, 550b includes a plurality of memory cells 400a-400d, 400e-400h arranged by tiling a plurality of memory cells 400 together so that the memory cells 400 along any given bit line 406a, 406a', 406b, 406b' do not share a common word line 405a-405d. Conversely, the memory cells 400 along any word line 405a-405d do not share a common bit line 406a, 406a', 406b, 406b'. Each word line is switchably to a word line driver 512a-512d via a transistor 510a-510d. Additionally, each word line may also be switchably coupled to ground via transistors 520a-520d. The gates of the transistors 510a-510d, 520a-520d are coupled to signal lines 511a-511d used to selectively couple/decouple the word lines 405a-405d to/from the word line drivers 512a-512 b/ground. Each memory array 550a, 550b has its own set of bit lines. For example, memory array 550a includes bit lines 406a, 406b, while memory array 550b includes bit lines 406a', 406b'. The bit lines from each adjacent pair of memory arrays 550a, 550b are coupled to a common sense amplifier 600a, 600b. For example, bit lines 406a, 406a' are coupled to sense amplifier 600a, while bit lines 406b, 406b' are coupled to sense amplifier 600b. For simplicity, FIG. 5 illustrates a memory device having only two arrays 550a, 550b, and eight cells 400a-400h. However, it should be understood that real world memory devices would have significantly more cells and arrays. For example, a real world memory device may include several million cells 400.

The memory device 500 also includes a plurality of pre-charge circuits 501a-501b. One pre-charge circuit (e.g., 501a) is provided for each pair of bit lines coupled to a sense amplifier (e.g., 406a, 406a'). Each pre-charge circuit (e.g., 501a) includes two transistors (e.g., 501a, 501b). One terminal of each transistor is coupled to a potential source. In the exemplary embodiment, the potential source is at 2.5 volts (Vdd). Another terminal of each transistor (e.g., 502a, 502b) is coupled to its corresponding bit line (e.g., 406a, 406a', respectively). The gate of the each transistor (e.g., 502a, 502b) is coupled to a pre-charge control signal. As illustrated, the transistors (e.g., 502a, 502b) are P-MOS type transistor. Thus, when the pre-charge signal is low, the transistors (e.g., 502a, 502b) conducts, thereby pre-charging the bit lines (e.g., 406a, 406a'). When the pre-charge signal is high, the transistors (e.g., 502a, 502b) are switched off. Due to capacitance inherent in the bit lines (e.g., 406a, 406a'), the bit lines will remain at approximately the pre-charge voltage level of 2.5 volts for a predetermined period of time.

Reading a PCRAM cell, for example, cell 400a, in the PCRAM device 500 comprises the operations of accessing and sensing.

The purpose of the access operation is to create a small potential difference between the bit lines (e.g., 406a, 406a') coupled to the same sense amplifier (e.g., 300a) of the memory cell 400a being read. This small potential difference can be subsequently amplified by a sense amplifier 300 to the threshold required to subsequently drive a comparator coupled to the bit lines to output a value corresponding to the contents of the memory cell 400a. Now also referring to FIG. 7, the access operation begins with the pre-charging of the bit lines 406a, 406a', 406b, 406b' of the memory device 500 via pre-charge circuits 501a-501b (step S1). The bit lines may be pre-charged by temporarily bringing the pre-charge signal low, causing transistors 502a-502d to conduct the pre-charge voltage (Vdd) to the bit lines 406a, 406a', 406b, 406b'. Once the pre-charge signal returns to a high

state, the transistors **502a–502d** stop conducting, but the bit lines **406a, 406a', 406b, 406b'** will remain at the pre-charge potential for a predetermined period due to the capacitance inherent in the bit lines.

In the exemplary embodiment, bit lines **406a, 406a', 406b, 406b'** are pre-charged to 2.5 volts and the cell plate **403a, 403b** is tied to 1.25 volts. The 1.25 volt potential difference between the bit line and the cell plate will cause the bit line to discharge to the cell plate through the access transistor **401** (when it is in a conductive state) and the programmable conductor memory element **402**. The discharge rate is dependent upon the resistive state of the programmable conductor memory element **402**. That is, a low resistive state will cause the bit line to discharge faster than a high resistive state. As the bit line discharges, its voltage will fall from the pre-charge voltage toward the cell plate voltage.

In the memory device **500**, the word lines **405a–405d** are normally at ground potential. Thus the access transistors **401a–401e** are normally switched off. Now also referring to FIGS. **6A** and **6B**, at time **T1**, the word line **405a** associated with the cell **400a** to be read is activated by bringing its potential from ground to a predetermined level (step **S2**). The predetermined level is designed to create a reading voltage at the programmable contact **402a**, which as previously explained, must have a magnitude less than the magnitude of a writing voltage. In the exemplary embodiment, the word line **401a** is brought to 2.25 volt. Since the threshold voltage of the transistor **401a** is 0.8 volt, the potential at the interface between the transistor **401a** and the programmable contact **402a** is 1.45 volt. This results in a reading voltage of 0.2 volt since the voltage at the interface between the programmable contact **402a** and the cell plate **403a** is maintained at 1.25 volt.

Due to the inherent parasitic capacitance between the word line **401a** and its associated bit lines **406a** the potential in the associated bit line **406a** increase as the word line **401a** is activated. In the exemplary embodiment, the potential in bit line **406a** increases by 0.1 volt to 2.6 volt. It should be noted that the word lines **405c, 405d** coupled to complementary bit lines **406a', 406b'** remain at ground potential. Thus, bit lines **406a', 406b'** remain at the pre-charge potential, which is 2.5 volt in the exemplary embodiment.

The increased potential of bit line **406a** is used in combination with the two bi-stable resistive states of the programmable contact **402a** to cause one of the bit lines (e.g., **406a**) coupled to a sense amplifier (e.g., **300a**) to have either a greater or lesser voltage than the other bit line (e.g., **406a')** coupled to the same sense amplifier **300a**. Essentially, the parasitic capacitance between word lines and associated bit lines is used to achieve an initial state where the bit line (e.g., **406a**) associated with the cell **400a** being read is at a higher potential than the other bit line **406a'** coupled to the same sense amplifier **300a**. The memory is designed and operated so that if the programmable contact **402a** has a high resistive state, bit line **406a** discharges slowly, thereby causing it to maintain its relatively higher potential. However, if the programmable contact **402a** has a low resistive state, bit line **406a** discharges at a faster rate, so that bit line **406a** transitions to a lower potential state than bit line **406a'**. These two effects can be seen by comparing FIG. **6A** (illustrating the effects of a programmable contact at a high resistive state) and FIG. **6B** (illustrating the effects of a programmable contact at a low resistive state.)

At time **T2**, a predetermined time **t** after time **T1** (step **S3**), the word line **405a** associated with the cell **400a** being read is deactivated by returning its potential to ground (step **S4**). Word line deactivation may be achieved by, for example,

grounding terminal **511a**, which will cause the transistor **510a** serially coupling the word line driver **512a** to the word line **405a** to stop conducting. This shuts off access transistors **401a, 401** thereby preventing further discharge of the bit line through the programmable contact **402a, 402e**. This also prevents the amplified potential difference developed during the subsequent sensing operation from refreshing (writing) the programmable contact **402a, 402e**. In the rare instance when it would be desirable to refresh the contents of the programmable contact **402a, 402e**, the word line can be held high for a longer period of time. This mode of operation is shown via the dashed trace in FIGS. **6A** and **6B**. In the exemplary embodiment, the predetermined time **t** is approximately 15 nanosecond (i.e.,  $T2 = T1 + 15$  ns).

It should be noted that the values of **t** and **T2** may be varied without departing from spirit of the invention. In particular, the objectives of the present invention will be realized by electrically decoupling the programmable contact from the bit line at any time before the bit line voltages are amplified by the sense amplifiers **310N, 310P** to a level which result in the potential difference across the programmable contact reaching threshold required to write the programmable contact. Thus, while FIGS. **6A** and **6B** illustrate **T2** occurring prior to either sense amplifiers **310N, 310P** being activated, depending upon the electrical characteristics of the memory device **500**, **T2** may occur, for example, between the activation of the N-sense amp **310N** and the P-sense amp **310P**. Regardless, the predetermined time **t** must be sufficiently long to permit the logical state of the programmable conductor **402a** to be reflected on the bit line **406a**; i.e., the bit line **406a** voltage to be sufficiently altered from the pre-charge voltage by the discharge through the programmable conductor **402a** so that the two resistive states of the programmable conductor **402a** can be distinguished and amplified by the sense amplifier **300a**.

At time period **T3**, the N-sense amplifier **310N** is activated (start of step **S5**). As previously noted with respect to DRAM systems, activating the N-sense amplifier causes the bit line (e.g., **406a')** having the lower potential to be pulled with the NLAT signal toward ground. In the exemplary embodiment, **T3** is approximately 30 nanosecond after **T1**. However, it should be noted that the value **T3** may be varied without departing from spirit of the invention.

At time period **T4**, the P-sense amplifier **310P** is activated. As previously noted with respect to DRAM systems, activating the P-sense amplifier causes the bit line (e.g., **406a**) having the higher potential to be pulled towards **Vcc**. In the exemplary embodiment, **T4** is approximately 35 nanosecond after **T1** (end of step **S5**). However, it should be noted that the value of **T4** may be varied without departing from spirit of the invention.

At time **T5**, the sense amplifier **300a** associated with the cell **400a** being read will have one of its bit lines (e.g., **406a**) at **Vcc** potential and the other bit line (e.g., **406a')** at ground potential. Since one bit line coupled to sense amplifier **300a** is now at ground potential while the other bit line is now at **Vcc** potential, a comparator (or differential amplifier) **350** can be used to output a value corresponding to the contents of the cell **400a** on signal line **351a**.

FIG. **9** is an illustration of a memory device **900** according to an alternate embodiment of the present invention. This alternate embodiment is designed for use with PCRAM cells which do not include an access transistor **401**. For example, FIG. **10** illustrates one example of a PCRAM cell **400'** which utilizes a pair of diodes **1001a, 1001b** in lieu of an access transistor. As illustrated, the PCRAM cell **400'** features a programmable conductor memory element **402** which is

coupled to a bit line 104. The programmable conductor memory element 402 is also coupled to the word line via a diode circuit 1002. The diode circuit comprises two diodes 1001a, 1001b arranged as shown.

The memory device 900 is otherwise very similar to the memory device 500 of the first embodiment. However, memory device 900 includes new isolation transistors 901a–901d which serially connect the sense amplifiers 300a, 300d to the bit lines 406a, 406a', 406b, 406b'. The invention operates in memory device 900 in a manner very similar to memory device 500 except that instead of deactivating word lines 405a to electrically decouple memory cell 400a from amplified voltages on the bit line 406a' prior to sensing, the isolation transistor 901a, which is normally conducting, is turned off, thereby bifurcating the bit line 406a. The portion of the bit line between the transistor 901a and the sense amplifier 301a will then be sensed while the portion of the bit line between the transistor 901a and the pre-charge circuit 501a will be isolated from the sense amplifier.

FIG. 8 is a block diagram of a processor based system 800, such as a computer system, containing a PCRAM semiconductor memory 802 as described in connection with the other figures. The memory 802 may be constituted as one or more memory chips or memory integrated circuits mounted on a memory module, for example, a plug-in memory module such as a SIMM, DIMM, or other plug-in memory module. The processor based system 800 includes a processor 801, a memory 802, a mass storage 803, and an I/O device 804, each coupled to a bus 805. While a single processor 801 is illustrated, it should be understood that processor 801 could be any type of processor and may include multiple processor and/or processors and co-processors. Memory 802 is illustrated in FIG. 9 as having a plurality of PCRAM chips 500. However, memory 802 may only include a single PCRAM device 500, or a larger plurality of PCRAM devices 500 than illustrated, and/or may include additional forms of memories, such as non-volatile memory or cache memories. While one mass storage 803 device is illustrated, the processor based system 800 may include a plurality of mass storage devices, possibly of varying types such as, but not limited to, floppy disks, CDROMs, CD-R, CD-RW, DVD, hard disks, and disk arrays. I/O device 804 may likewise comprise a plurality of I/O devices of varying types, including, but not limited to keyboard, mouse, graphic cards, monitors, and network interfaces. Bus 805, while illustrated as a single bus may comprise a plurality of buses and/or bridges, which may be coupled to each other or bridged by other components. Some of the devices 801–804 may be coupled to only a single bus 805, others may be coupled to a plurality of buses 805.

The present invention provides a PCRAM cell 400 and a method for reading the contents of the cell 400 using sense amplifiers but without rewriting the contents of the cell. Rewrite prevention is achieved by isolating the programmable conductor 402 of the cell 400 from the bit line 406 a predetermined amount of time after the programmable conductor 402 has been electrically coupled to the bit line 406. The predetermined amount of time corresponds a time prior to the activation time of both the N- and P-sense amps 310N, 310P. In the exemplary embodiment, the PCRAM cell 400 includes an access transistor 401 for electrically coupling and decoupling the cell to the bit line. The access transistor 401 has a gate coupled to a word line. Thus, in the exemplary embodiment, the word line is deactivated the predetermined amount of time after it has been activated, thereby ensuring that the activation of the N- and P-sense amplifiers 310N,

310P do not rewrite the cell 400. In another embodiment, the PCRAM cell 400 does not include an access transistor. For example, the PCRAM cell instead utilize diodes. In any embodiment without an access transistor, isolation transistor may be inserted between the programmable contact memory element and the bit line associated with the programmable contact memory element. The isolation transistors, which are normally conducting, may be switched off at the same predetermined time as in the exemplary embodiment, after the word line has been activated, thereby achieving the same result of isolating the programmable contact memory element from the elevated voltages generated during sensing.

While the invention has been described in detail in connection with the exemplary embodiment, it should be understood that the invention is not limited to the above disclosed embodiment. Rather, the invention can be modified to incorporate any number of variations, alternations, substitutions, or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Accordingly, the invention is not limited by the foregoing description or drawings, but is only limited by the scope of the appended claims.

What is claimed as new and desired to be protected by letters Patent of the United States is:

1. An apparatus for reading data from a variable resistance memory cell, comprising:

an access circuit for coupling said memory cell between an addressed and activated word line and an addressed and activated bit line during a read operation;

a sense amplifier coupled to said addressed and activated bit line for sensing a logical state of said memory cell;

and

preventing circuitry for preventing said memory cell from being refreshed in response to said read operation;

wherein said access circuit is a transistor circuit and said preventing circuitry causes said activated word line to be deactivated after a logical state of said memory cell is transferred to said activated bit line and before said sense amplifier senses a logical state of said memory cell.

2. The apparatus of claim 1, wherein said preventing circuitry comprises a transistor which causes said activated word line to be deactivated.

3. The apparatus of claim 2, wherein said transistor is serially connected between said word line and a driver for said word line and is turned on during said read operation and turned off to deactivate said row line.

4. The apparatus of claim 2, wherein said transistor is connected between said word line and ground and is turned off during said read operation and is turned on to deactivate said word line.

5. An apparatus for reading data from a variable resistance memory cell, comprising:

an access circuit for coupling said memory cell between an addressed and activated word line and an addressed and activated bit line during a read operation;

a sense amplifier coupled to said addressed and activated bit line for sensing a logical state of said memory cell;

and

preventing circuitry for preventing said memory cell from being refreshed in response to said read operation;

wherein said preventing circuitry comprises a transistor serially connected between an activated bit line and a sense amplifier associated with the activate bit line, said serially connected transistor being turned on during a read operation and turned off before said memory cell can be refreshed.

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6. An apparatus for reading data from a variable resistance memory cell, comprising:

an access circuit for coupling said memory cell between an addressed and activated word line and an addressed and activated bit line during a read operation;

a sense amplifier coupled to said addressed and activated bit line for sensing a logical state of said memory cell; and

preventing circuitry for preventing said memory cell from being refreshed in response to said read operation;

wherein said preventing circuitry causes said activated word line to be deactivated a predetermined amount of time after said memory cell begins to transfer a logical state to said activated bit line.

7. The apparatus of claim 6, wherein said sense amplifier further comprises a first sense amplifier portion and a second sense amplifier portion.

8. The apparatus of claim 7, wherein said predetermined amount of time is after said first sense amplifier portion is activated and before said second sense amplifier portion is activated.

9. The apparatus of claim 7, wherein said first sense amplifier portion is a N-sense amplifier, and said second sense amplifier portion is a P-sense amplifier.

10. The apparatus of claim 1, further comprising:

a pre-charge circuit for pre-charging the addressed and activated bit line and an another bit line, wherein said addressed and accessed bit line and said other bit line are coupled to the sense amplifier.

11. The apparatus of claim 10, wherein said pre-charge circuit pre-charges the addressed and activated bit line and the another bit line prior to the sense amplifier sensing said addressed and activated bit line.

12. A system, comprising:

a processor; and

a memory comprising an apparatus for reading data from a variable resistance memory cell, said apparatus comprising:

an access circuit for coupling said memory cell between an addressed and activated word line and an addressed and activated bit line during a read operation;

a sense amplifier coupled to said addressed and activated bit line for sensing a logical state of said memory cell; and

preventing circuitry for preventing said memory cell from being refreshed in response to said read operation;

wherein said access circuit is a transistor circuit and said preventing circuitry causes said activated word line to be deactivated after a logical state of said memory cell is transferred to said activated bit line and before said sense amplifier senses a logical state of said memory cell.

13. The system of claim 12, wherein said preventing circuitry comprises a transistor which causes said activated word line to be deactivated.

14. The system of claim 13, wherein said transistor is serially connected between said word line and a driver for said word line and is turned on during said read operation and turned off to deactivate said row line.

15. The system of claim 13, wherein said transistor is connected between said word line and ground and is turned off during said read operation and is turned on to deactivate said word line.

## 12

16. A system, comprising:

a processor; and

a memory said memory comprising an apparatus for reading data from a variable resistance memory cell, said apparatus comprising:

an access circuit for coupling said memory cell between an addressed and activated word line and an addressed and activated bit line during a read operation;

a sense amplifier coupled to said addressed and activated bit line for sensing a logical state of said memory cell; and

preventing circuitry for preventing said memory cell from being refreshed in response to said read operation;

wherein said preventing circuitry comprises a transistor serially connected between an activated bit line and a sense amplifier associated with the activate bit line, said serially connected transistor being turned on during a read operation and turned off before said memory cell can be refreshed.

17. A system, comprising:

a processor; and

a memory comprising an apparatus for reading data from a variable resistance memory cell, said apparatus comprising:

an access circuit for coupling said memory cell between an addressed and activated word line and an addressed and activated bit line during a read operation;

a sense amplifier coupled to said addressed and activated bit line for sensing a logical state of said memory cell; and

preventing circuitry for preventing said memory cell from being refreshed in response to said read operation;

wherein said preventing circuitry causes said activated word line to be deactivated a predetermined amount of time after said memory cell begins to transfer a logical state to said activated bit line.

18. The system of claim 17, wherein said sense amplifier further comprises a first sense amplifier portion and a second sense amplifier portion.

19. The system of claim 18, wherein said predetermined amount of time is after said first sense amplifier portion is activated and before said second sense amplifier portion is activated.

20. The system of claim 18, wherein said first sense amplifier portion is a N-sense amplifier and said second sense amplifier portion is a P-sense amplifier.

21. The system of claim 12, further comprising:

a pre-charge circuit for pre-charging the addressed and activated bit line and an another bit line, wherein said addressed and accessed bit line and said other bit line are coupled to the sense amplifier.

22. The system of claim 21, wherein said pre-charge circuit pre-charges the addressed and activated bit line and the another bit line prior to the sense amplifier sensing said addressed and activated bit line.

23. A method for reading data from a variable resistance memory cell, said method comprising:

activating an addressed word line containing said memory cell and transferring a logical value in said cell to an associated addressed bit line;

deactivating said addressed word line; and

sensing a logical value transferred to said bit line after said word line is deactivated.

24. The method of claim 23, wherein said deactivating takes place a predetermined amount of time after said activating.

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25. The method of claim 23, wherein said sensing further comprises, activating a first sense amplifier unit; and activating a second sense amplifier unit a second predetermined time after said activating of said first sense amplifier unit.

26. The method of claim 23, wherein said deactivating takes place a first predetermined amount of time after said activating of an addressed word line.

27. The method of claim 26, wherein said first predetermined amount of time is after said activating of said first sense amplifier unit and before said activating of said second sense amplifier unit.

28. The method of claim 26, wherein said first predetermined amount of time is before said activating of said first sense amplifier unit and before said activating of said second sense amplifier unit.

29. A method for reading data from a programmable conductor random access memory cell, said method comprising:

- activating an addressed word line containing said memory cell and transferring a logical value in said cell to an associated addressed bit line;
- switching off an isolation transistor located on the associated addressed bit line and serially connecting a sense amplifier and said cell;
- sensing a logical value transferred to said bit line after said word line is deactivated.

30. The method of claim 29, wherein said switching off takes place a predetermined amount of time after said activating.

31. The method of claim 29, wherein said sensing further comprises,

- activating a first sense amplifier unit; and
- activating a second sense amplifier unit a second predetermined time after said activating of said first sense amplifier unit.

32. The method of claim 30, wherein said switching off takes place a first predetermined amount of time after said activating of an addressed word line.

33. The method of claim 32, wherein said first predetermined amount of time is after said activating of said first sense amplifier unit and before said activating of said second sense amplifier unit.

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34. The method of claim 32, wherein said first predetermined amount of time is before said activating of said first sense amplifier unit and before said activating of said second sense amplifier unit.

35. A method for reading data from a variable resistance memory cell, said method comprising:

- pre-charging a first bit line coupled to the memory cell, said memory cell including a variable resistance element;
- pre-charging a second bit line;
- increasing voltage on said first bit line;
- switching on an access transistor of said cell to couple the variable resistance element to said first bit line;
- switching off the access transistor of said cell to decoupling the variable resistance element from said first bit line;
- sensing voltage on said first bit line and said second bit line to determine a logical state of said variable resistance element;
- wherein said switching off is performed before said sensing.

36. A method for reading data from a variable resistance memory cell, said method comprising:

- switching on an isolation transistor to couple a first bit line to a sense amplifier, said first bit line also coupled to a variable resistance element of the variable resistance memory cell;
- pre-charging said first bit line;
- pre-charging a second bit line;
- increasing voltage on said first bit line;
- switching off said isolation transistor to decouple said variable resistance element from said sense amplifier;
- sensing voltage on said first bit line and said second bit line to determine a logical state of said variable resistance memory element;
- wherein said switching off is performed before said sensing.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 7,224,632 B2  
APPLICATION NO. : 11/070213  
DATED : May 29, 2007  
INVENTOR(S) : John T. Moore et al.

Page 1 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

**Column 5:**

Line 1, "diagram a" should read --diagram of a--;

Line 4, "diagram a" should read --diagram of a--;

Line 35, "to a respective" should read --to respective--; and

Line 55, "when has" should read --when it has--.

**Column 6:**

Line 9, "switchably" should read --switchable--.

**Column 7:**

Lines 7, 27, 28, 30, 31, 33, 38, and 42, "volt" should read --volts--; and

Line 36, "increase" should read --increases--.

**Column 8:**

Line 21, "result" should read --results--; and

Lines 41 and 48, "nanosecond" should read --nanoseconds--.

**Column 9:**

Line 17, "301a" should read --300a--; and

Line 59, "corresponds a" should read --corresponds to a--.



UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 7,224,632 B2  
APPLICATION NO. : 11/070213  
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Page 2 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

**Column 10:**


Line 3, "utilize" should read --utilizes--; and

Line 4, "isolation" should read --an isolation--.

Line 64, Claim 5, "activate" should read --activated--.

Signed and Sealed this

Fourth Day of September, 2007

A handwritten signature in black ink on a light gray dotted background. The signature reads "Jon W. Dudas" in a cursive style.

JON W. DUDAS

*Director of the United States Patent and Trademark Office*