Tutorial on Solid State Recording Technology

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Presentation Overview

- Summary technology lists.
- Review of principles of operation.

Broad Technology Categories

Electronic Technologies	Magnetic Technologies	Optical Technologies
Dynamic RAM	Josephson Junction	ETOM
EEPROM	Magnetic Bubble	Holographic
Ferroelectric RAM	Magnetic Core	Near-Field Scanning
Flash EEPROM	Magnetic Disk	Optical Disk
Molecular	Magnetic RAM	Optical Tape
Scanning Tunneling	Magnetic Tape	Photochemical
Single-Electron	Magnetoresistive RAM	Photon-Echo
Static RAM	Magneto-Optic Disk	Raman
	Magneto-Optic Tape	Spectral Hole-Burning
	Plated Wire	Two-Photon 3D
	Spin Switches	
	Vertical Bloch Line	

Summary Table of Selected Technologies

Technology	Principle of Operation: Store and sense..	Type	Bit access	Readiness
Dynamic RAM	electrons in capacitive bit cells	Solid-state	Random	Production
EEPROM	electrons in a floating ***gate***	Solid-State	Random	Production
Electron Trapping	energy quanta in traps	Optical	Block	Research
FLASH EEPROM	a block-erasable EEPROM	Solid-State	Random	Production
Ferroelectric RAM	data in a polarizable ferroelectric	Solid-State	Random	Development/Small Quantity
Holographic	Interference wave patterns	Optical	Block	Prototyping
Josephson Junction	trapped flux in superconductors	Solid-State	Random	Research
Magnetic Bubbles	cylindrical magnetic domains	Solid-State	Block	Limited Production
Magnetic Core	data in discrete magnetizable toroids	Discrete	Random	Limited Production
Magnetic Disk	magnetic transitions in rotating media	Mechanical	Block	Production
-Magnetic Tape	magnetic transitions in spooled media	Mechanical	Serial	Production
Magnetoresistive RAM	data in polarizable magnetic cells using magnetoresistive sensing	Solid-State	Random	Development/Small Quantity
Near-Field Scanning	domains optically in close proximity	Optical	Block	Research
Photo-Chemical	chemically-altered bits optically	Optical	Block	Research
Photon-Echo	optically stimulated emission	Optical	Block	Research
Raman-Optical	Raman scattering properties	Optical	Block	Research
Static RAM	electronic flip-flop states	solid-state	Random	Production
Scanning Tunneling	data using a cathodic tunneling probe and a medium	Mechanical	Serial	Research
Spectral Hole Burning	induced changes in absorption or fluorescence spectra	Optical	Block	Research
Two-Photon 3D	induced media changes using two cooperatively-selected light sources	Optical	Block	Research
Vertical Bloch Line	transitions in magnetic domain walls	Solid-State	Block	Prototyping

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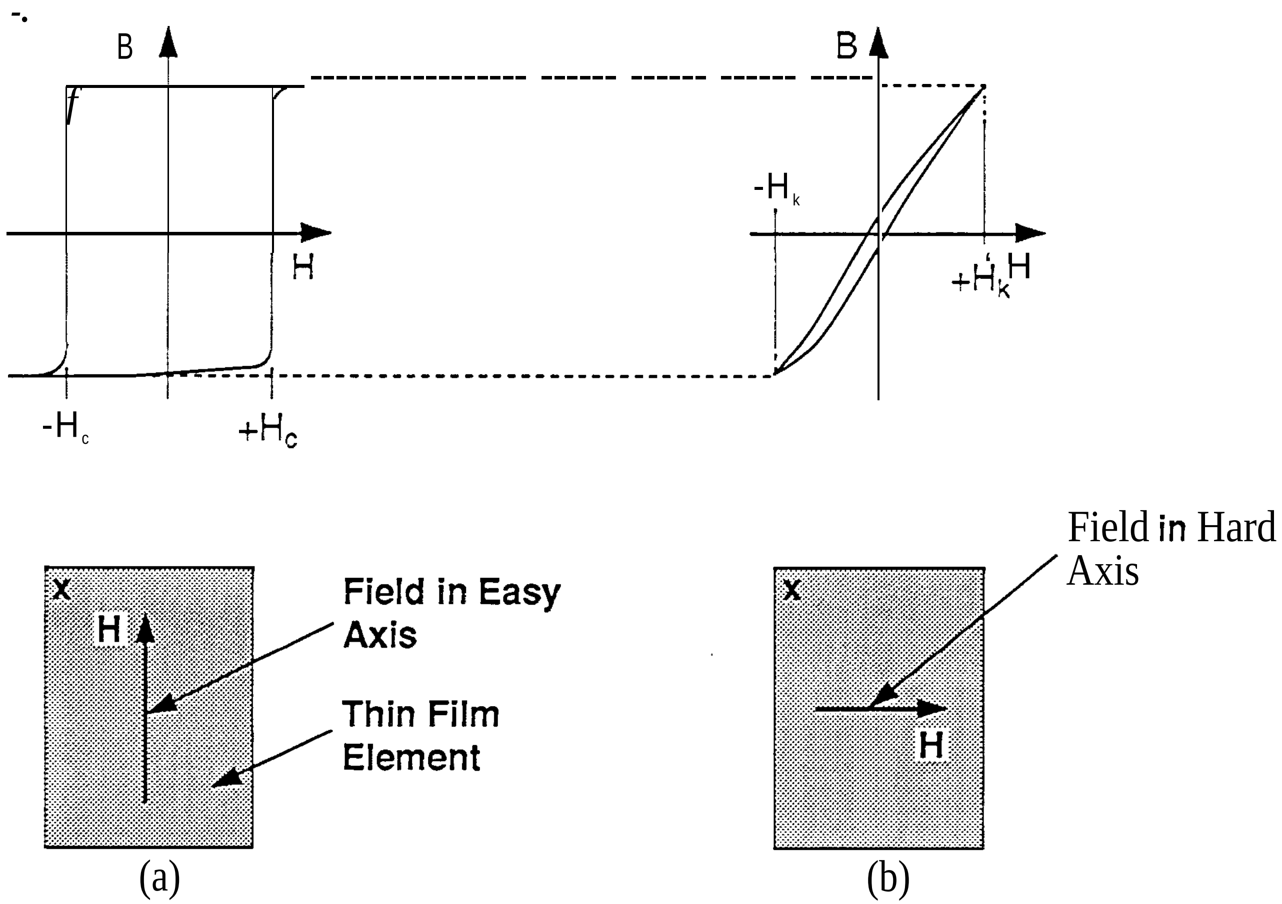
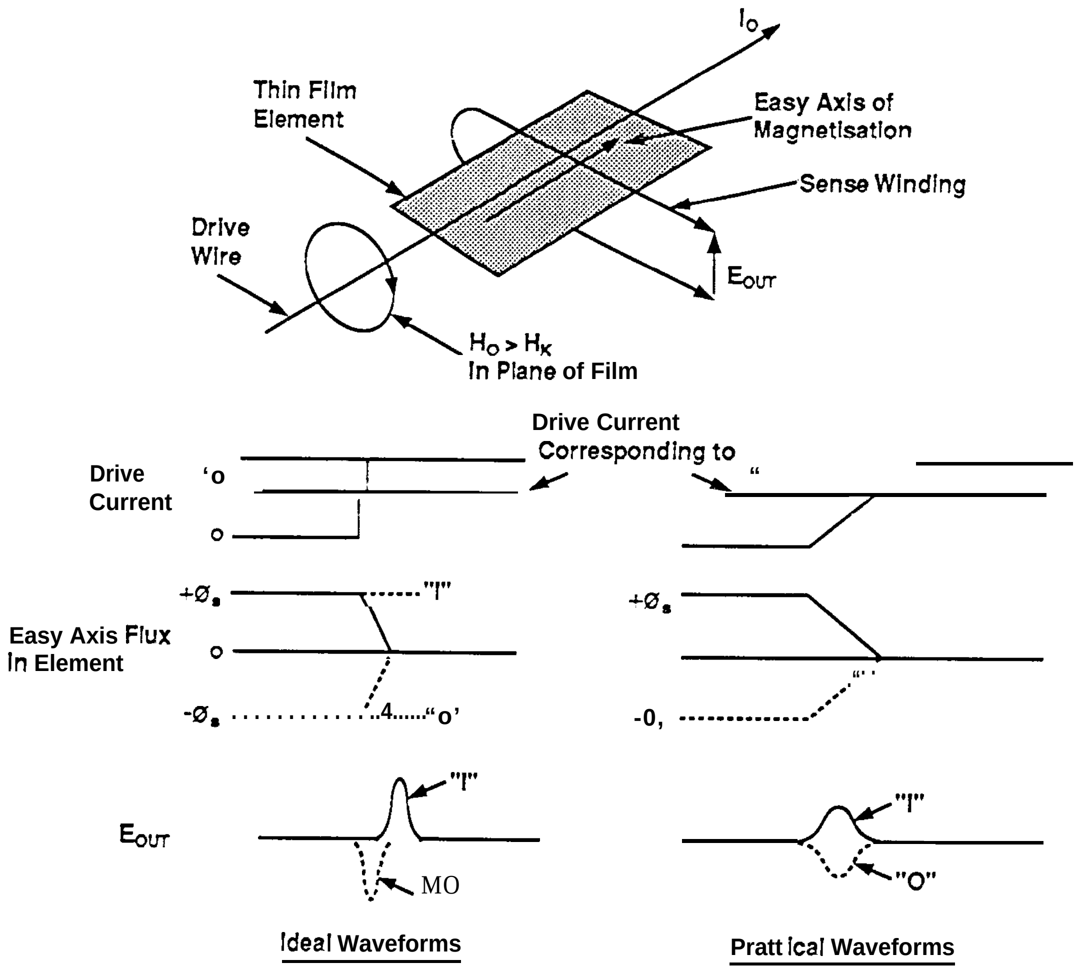
Thin Film Properties. BH loops: (a) BH loop in easy axis; (b) BH loop in hard axis. *Source: Dakin, C.J. and Cooke, C.E.G.,* Circuits for Digital Equipment. *Iliffe Books Ltd., London, 1967.*



Sensing method for thin film elements. ***Source:*** *Dakin, C.J. and* ***Cooke,*** *C.E.G.,* ***Circuits*** for Digital Equipment. *Iliffe* ***Books Ltd. London, 1967.***



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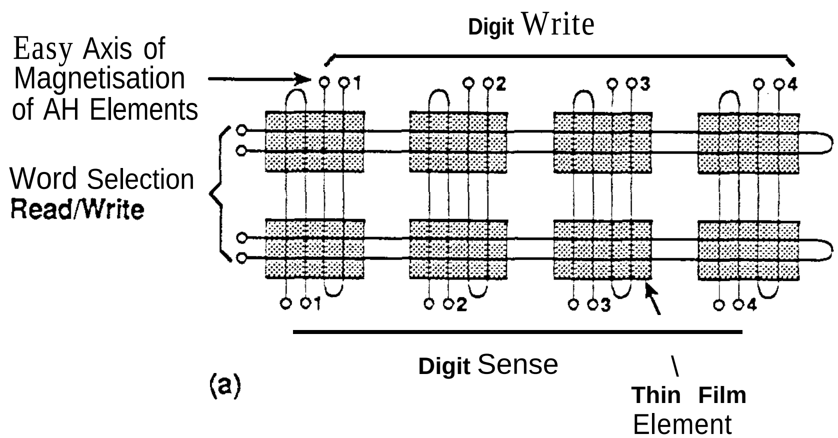
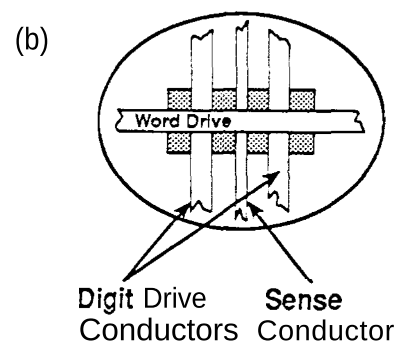
Two word, four bit per word thin film plane store: (a) wiring schematic arrangement; (b) practical winding detail of one element. *Source: Dakin, C.J. and Cooke, C.E.G.,* Circuits for Digital Equipment. *Iliffe Books Ltd., London, 1967.*





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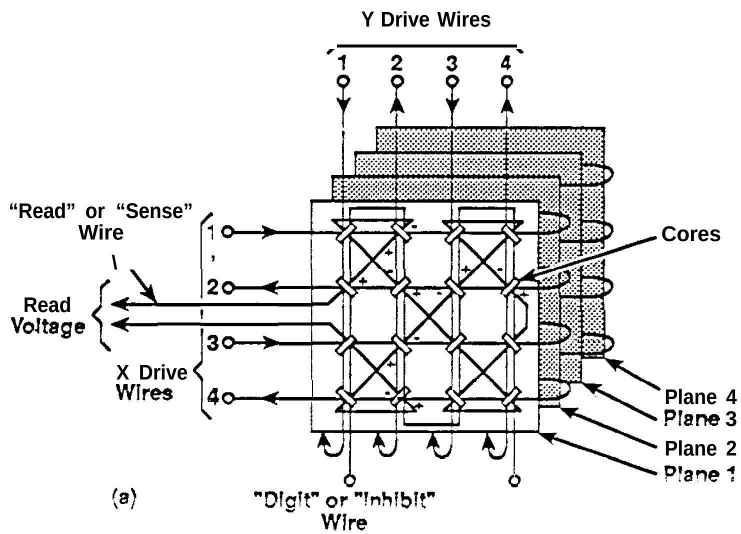
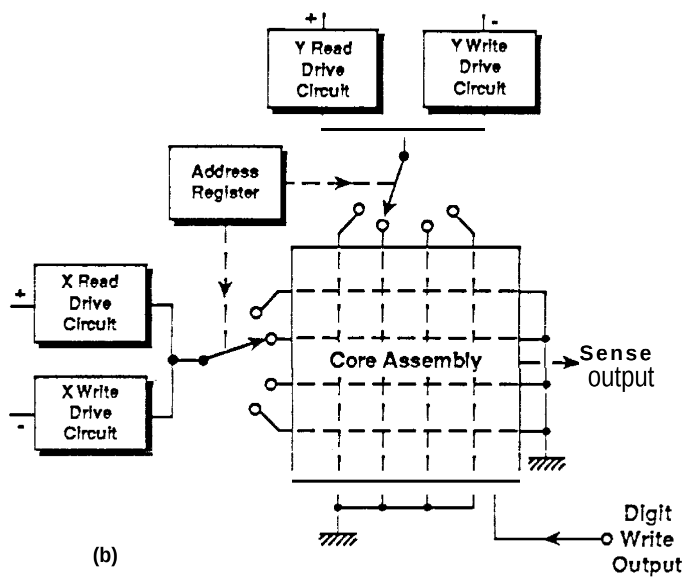
MIT Storage System: (a) 16 word store. 4 bits per word; (b) selection circuits arrangement.

Source: Dakin, C.J. and Cooke, C.E.G., Circuits for Digital Equipment. *Iliffe Books Ltd., London, 1967.*

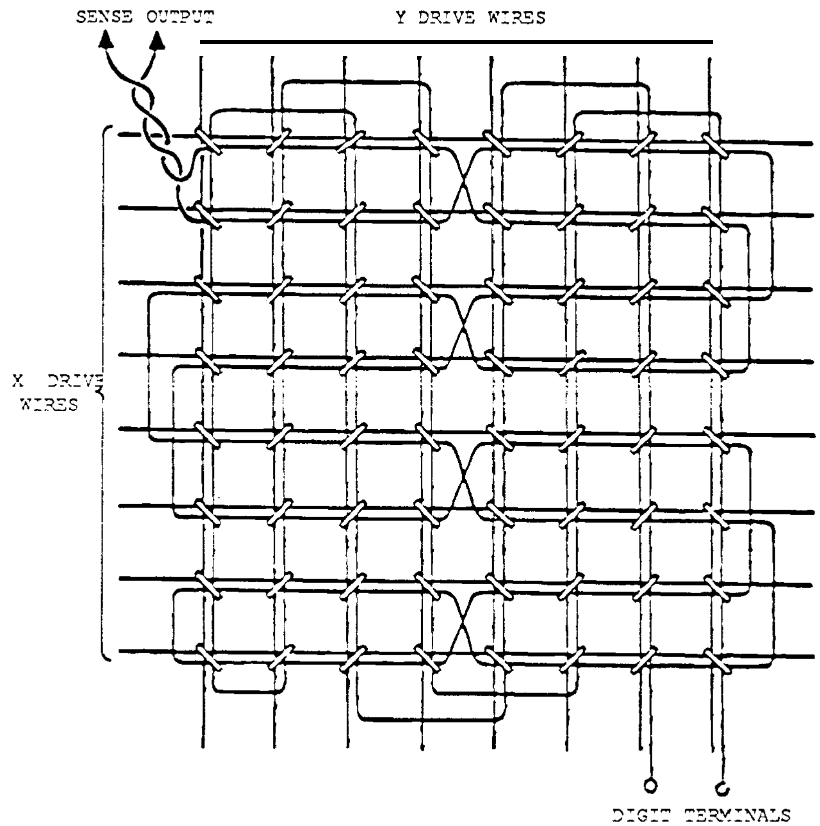


(a)



(b)

MIT store rectangular sense winding. *Source: Dakin, C.J. and Cooke, C.E.G.,* Circuits for Digital Equipment. *Iliffe Books Ltd., London, 1967.*



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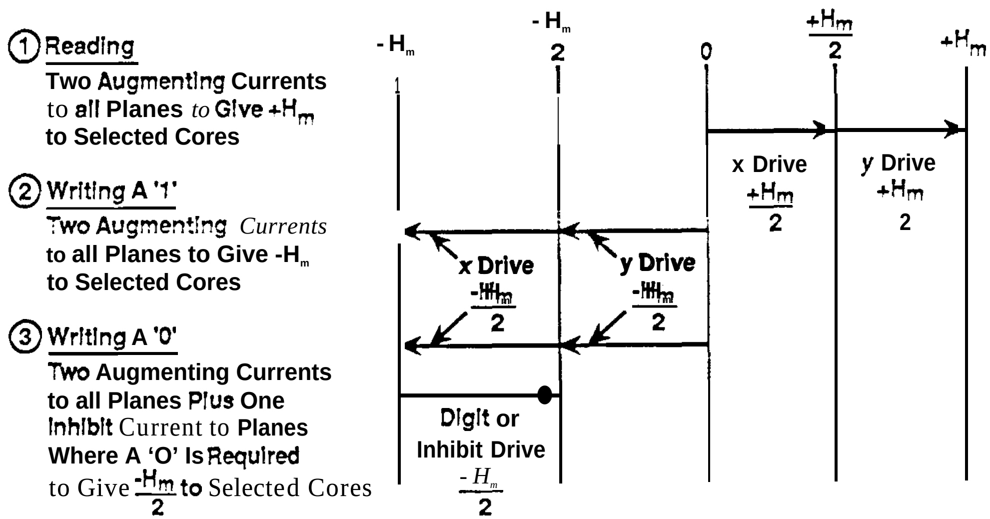
Reading and writing method in MIT Skin. *Source: Dakin, C.J. and Cooke,* ***C.E.G.,*** Circuits for Digital Equipment. *Iliffe Books Ltd., London,* 1967.



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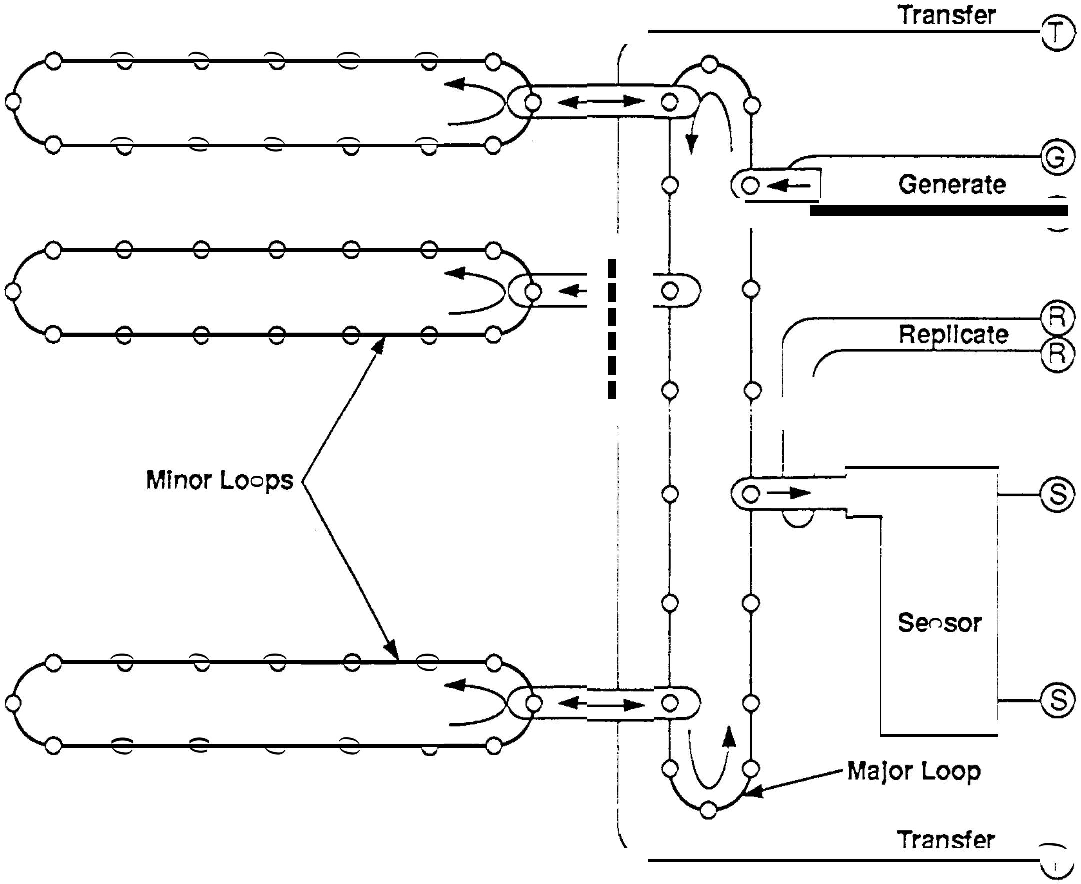
Source: Watson, J.K., Applications of Magnetism. *John Wiley and Sons, New York, 1980.*



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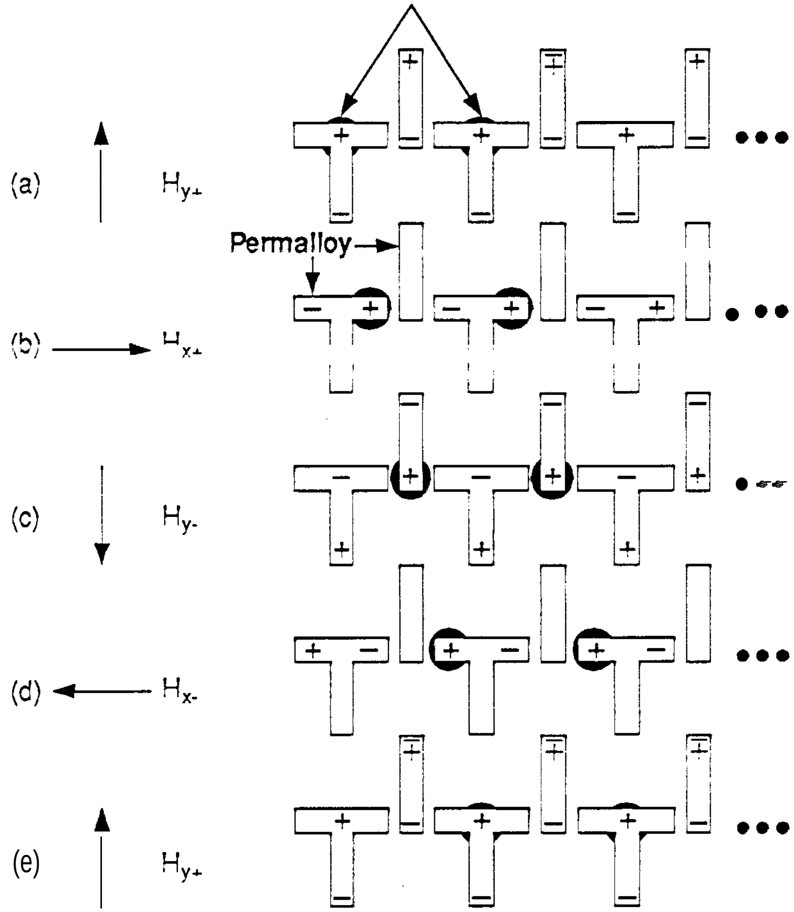
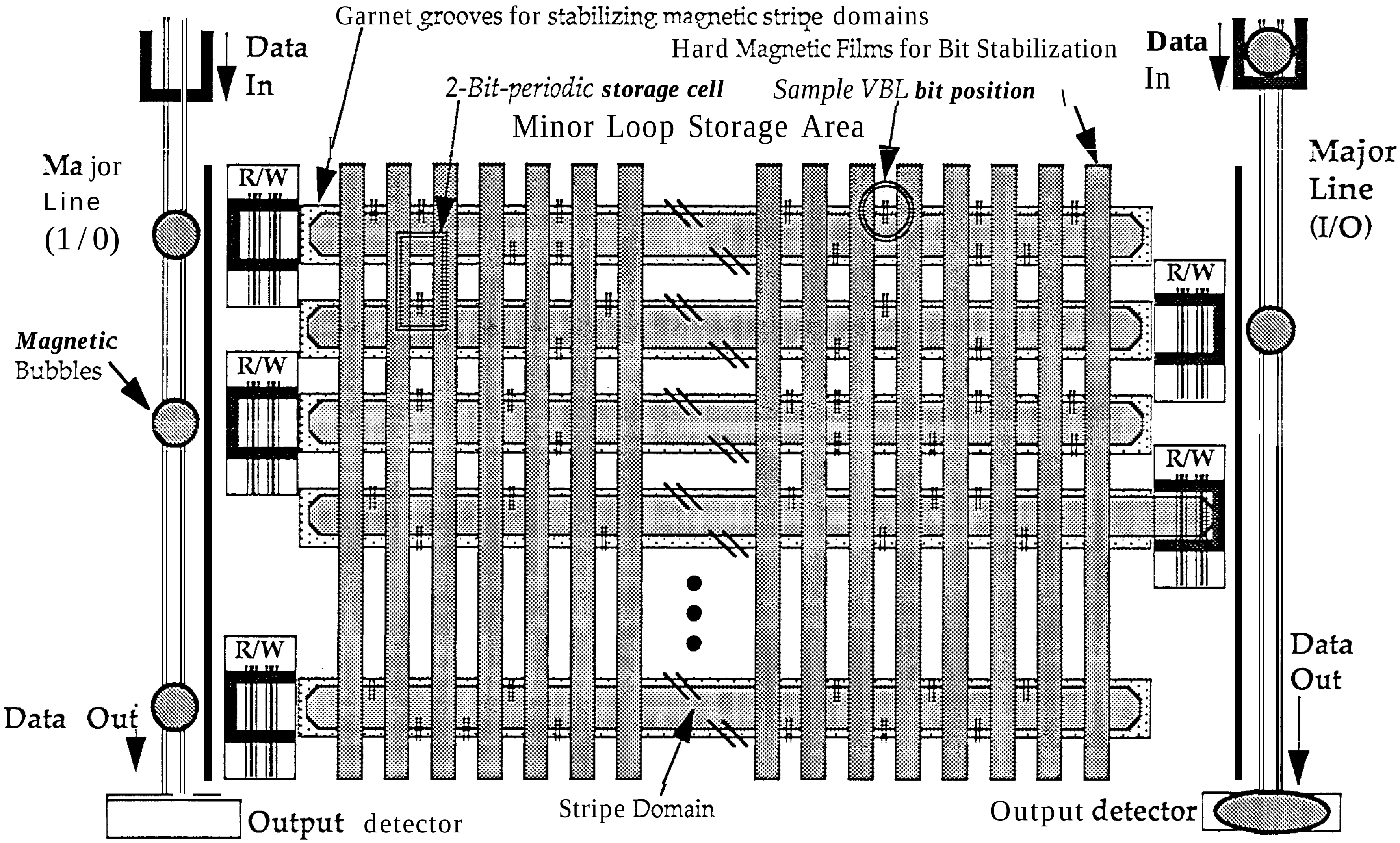
Propagation of bubbles with field-accessed T-bar overlay **elements. The drive field rotates clockwise in the x-y plane, causing the bubble pattern to move to the right.** *Source: 'Watson, J.K. 1980.* Applications of Magnetism. *John Wiley and Sons, New York.*



A schematic areal layout of a VBL chip.

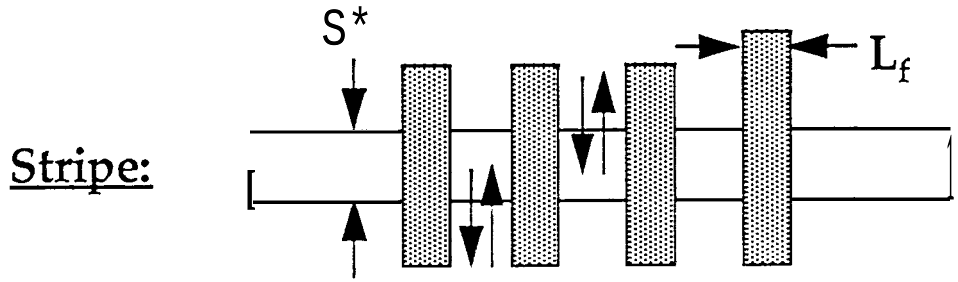


VBL Storage Chips: Areal Storage Density Performance

	L_f = 1 μm	L_f = 0.5 μm	L_f = 0.1 urn
S_w = 5 μm	10 Mbits/cm^2	20 Mbits/cm^2	100 Mbits/cm^2
S* = 2 μm	25 Mbits/cm^2	50 Mbits/cm^2	250 Mbits/cm^2
S_w = 1 urn	50 Mbits/cm^2	100 Mbits/cm^2	500 Mbits/cm^2
S* = 0.5 μm	100 Mbits/cm^2	200 Mbits/cm^2	1,000 Mbits/cm^2
S* = 0.25 urn	200 Mbits/cm^2	400 Mbits/cm^2	2,000 Mbits/cm^2

VBL Memory areal storage density is proportional **to:**

$$I / ((S_w) \times (L_f))$$



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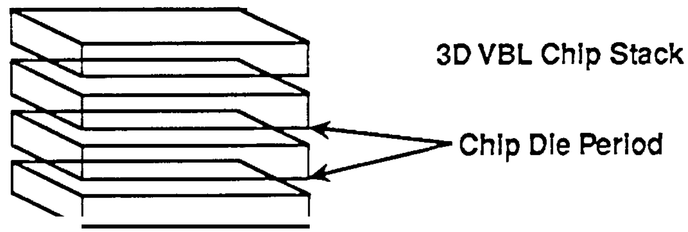
VBL volumetric storage performance.

VBL Storage Chips: Volumetric Storage Performance

Areal Storage Density	Chip Die Density: 16 die/cm (25 mils/die) (625 μm/die)	40 die/cm (10 mils/die) (250 μm/die)	200 die/cm (2 mils/die) (50 μm/die)	400 die/cm (1 mil/die) (25 μm/die)
25 Mbits/cm2	0.4 Gbits/cc	1 Gbit/cc	5 Gbits/cc	10 Gbits/cc
100 Mbits/cm2	1.6 Gbits/cc	4 Gbits/cc	20 Gbits/cc	40 Gbits/cc
200 Mbits/cm2	3.2 Gbits/cc	8 Gbits/cc	40 Gbits/cc	80 Gbits/cc
1,000 Mbits/cm2	16 Gbits/cc	40 Gbits/cc	200 Gbits/cc	400 Gbits/cc
10,000 Mbits/cm2	160 Gbits/cc	400 Gbits/cc	2,000 Gbits/cc	4,000 Gbits/cc



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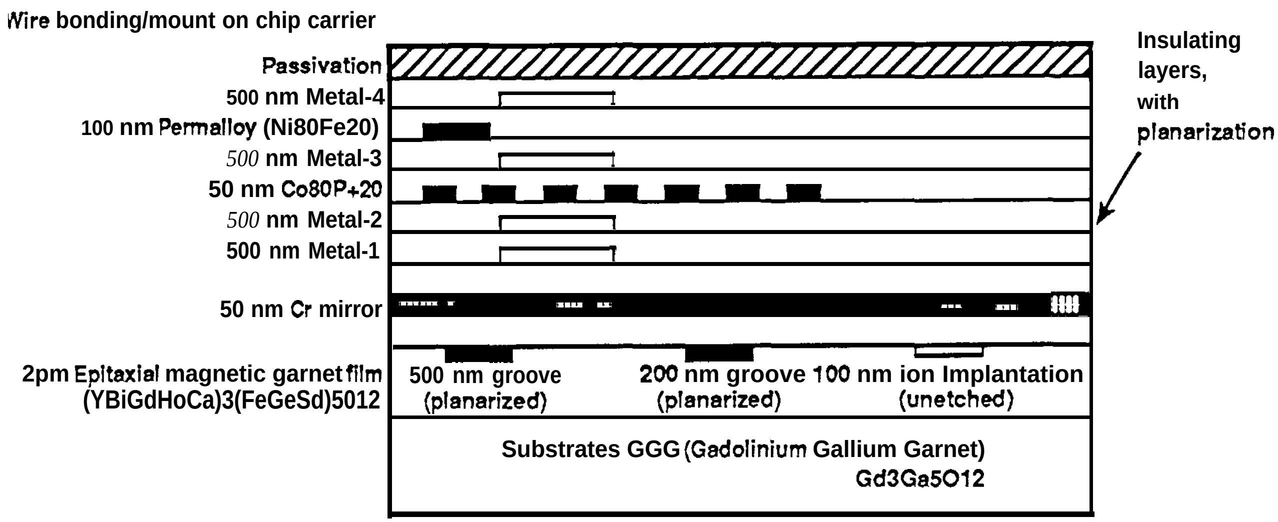
VBL device cross section.

VBL Storage Device Cross-Section



Grooves are formed through ion implantation, and wet etching.
Ion implantation conditions, 1st groove: Ne+, 300 keV, 10^15 ions/cm2.
ion implantation conditions, 2nd groove: Ne+, 150 keV, 10-15 ions/cm2.
Ion implantation conditions, hard bubble suppression layer: 80 keV, 10-15 ions/cm2.

Grooves and deposited layers should be planarized.

Layer period is approximately 1 µm.

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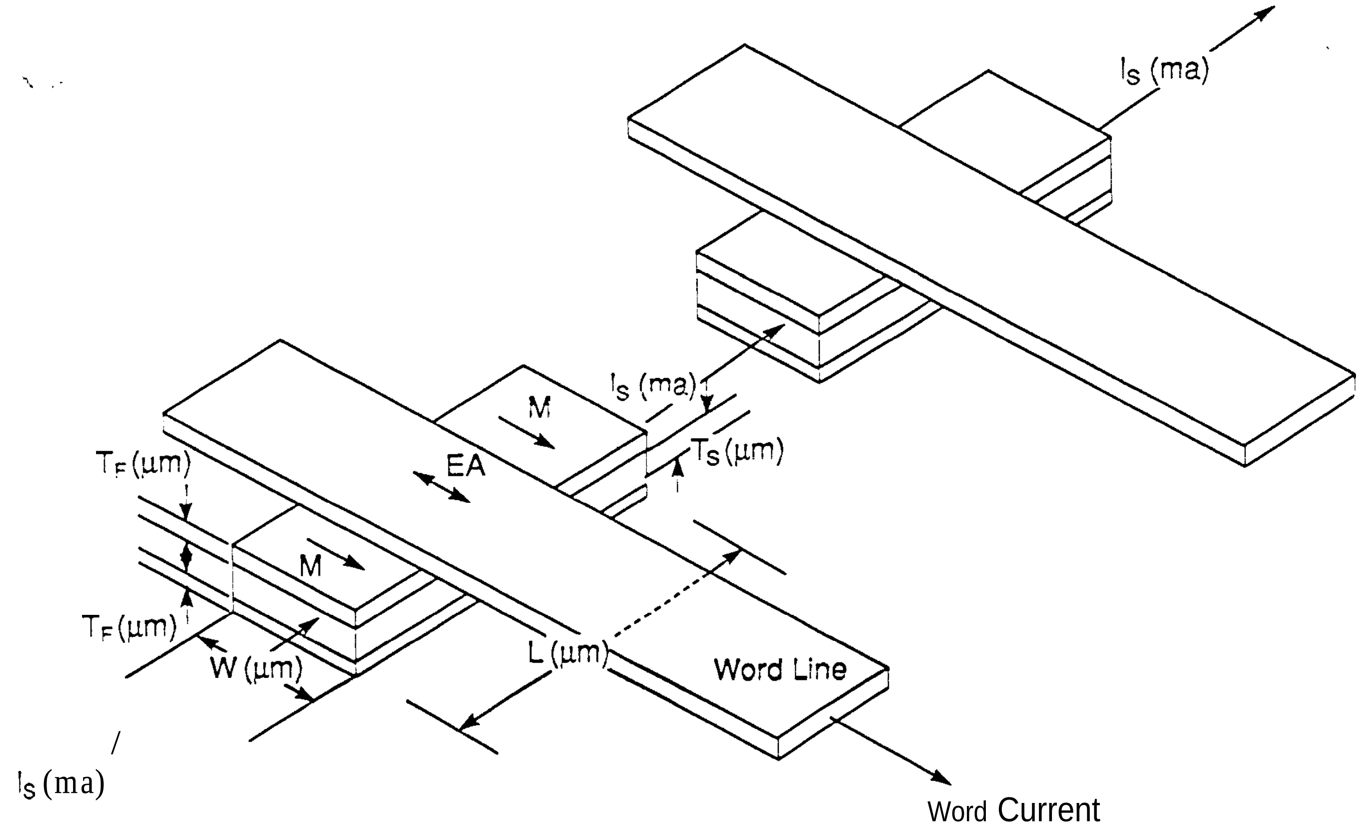
MRAM memory cell. *Source: Daughton, J.M. 1992. Magnetoresistive memory technology.* Thin Solid Films 216,162.



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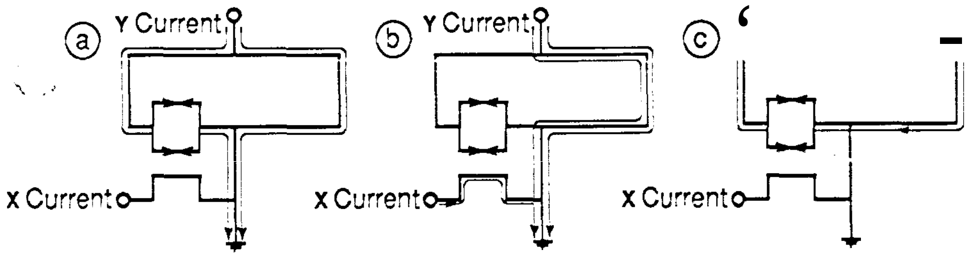
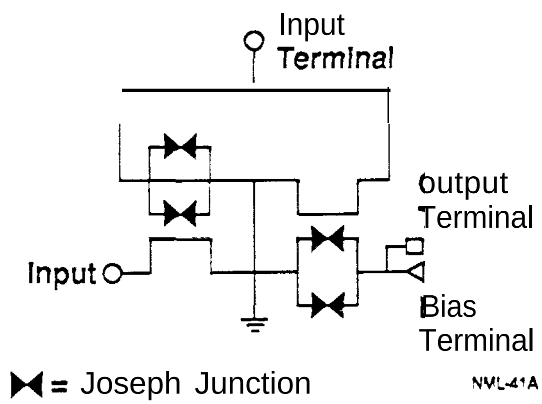
Superconducting memory operation. *Source: McDonald, Donald G. February 1981.* Physics Today *37.*



Operation of a memory cell consisting of a super conducting loop with an inserted SQUID.



Memory compatible with high "speed logic utilizes the quantized flux state of a superconductor.

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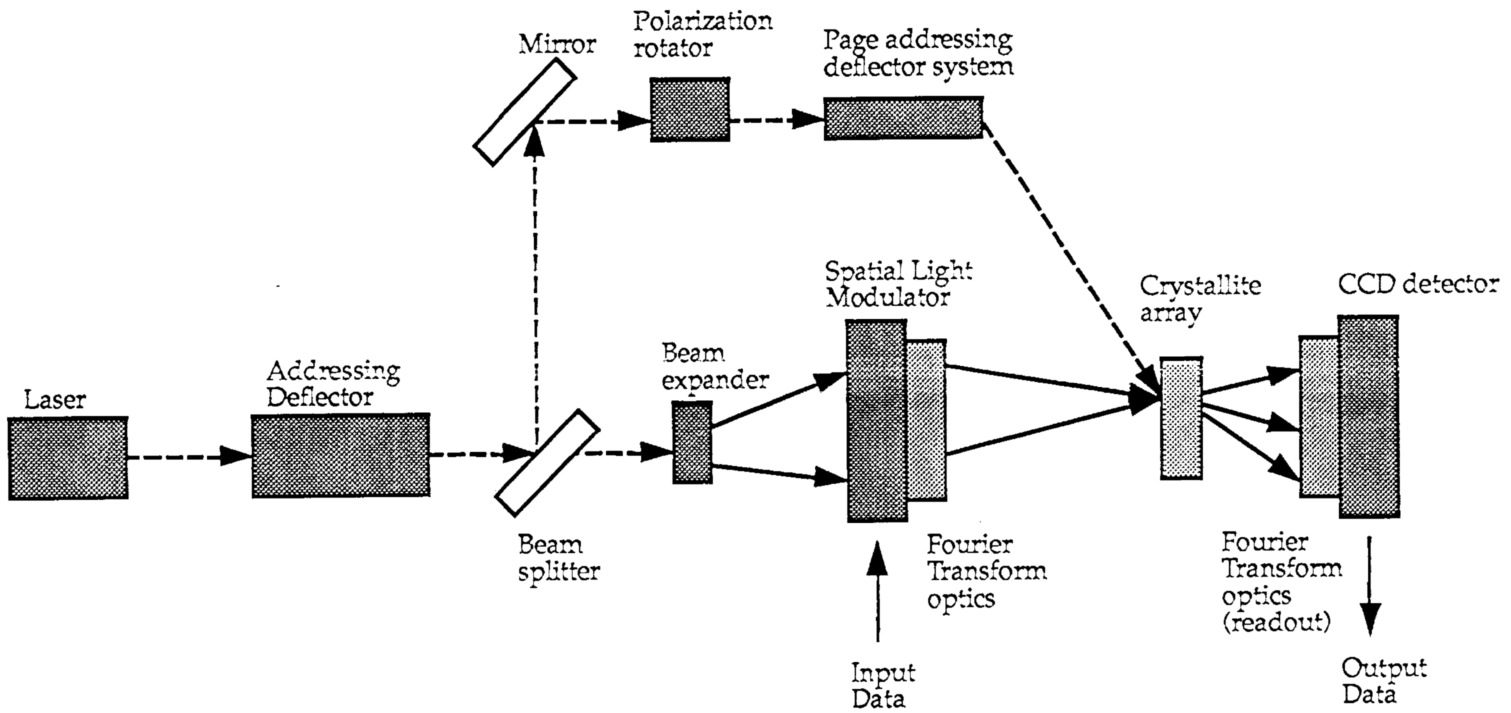
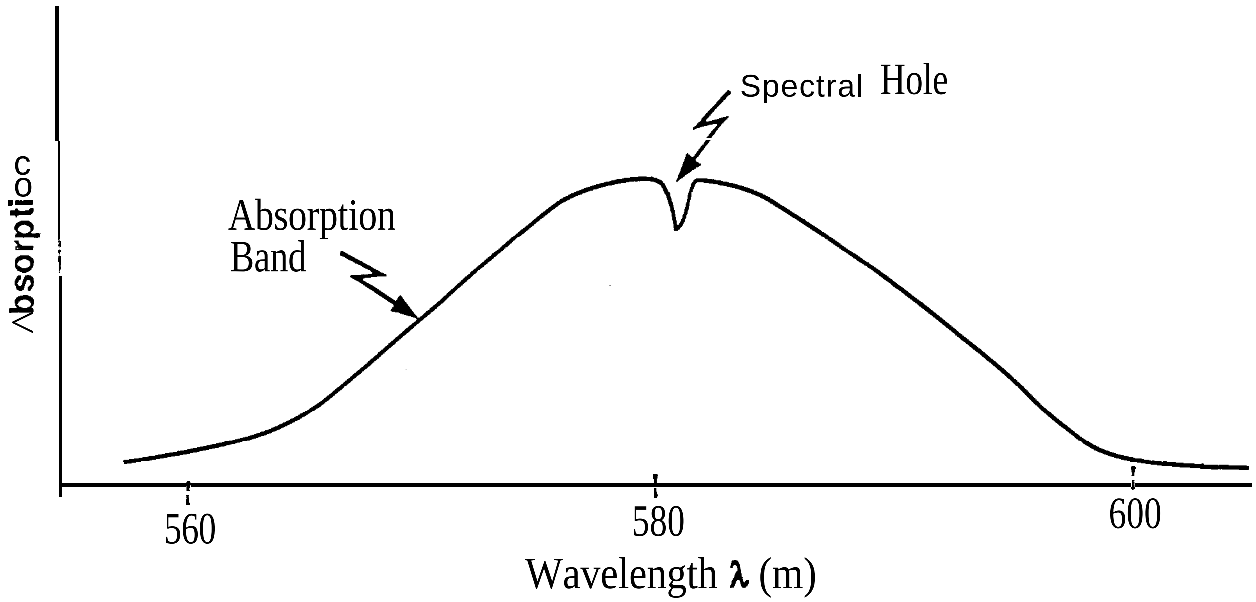
Holographic Storage Technology.



If a narrow beam of light from a tuned laser is made incident onto a small region of the polymer, a resulting change in the electronic states of those molecules absorbing at that wavelength modifies the absorptivity at the laser wavelength producing a hole in the absorption band.



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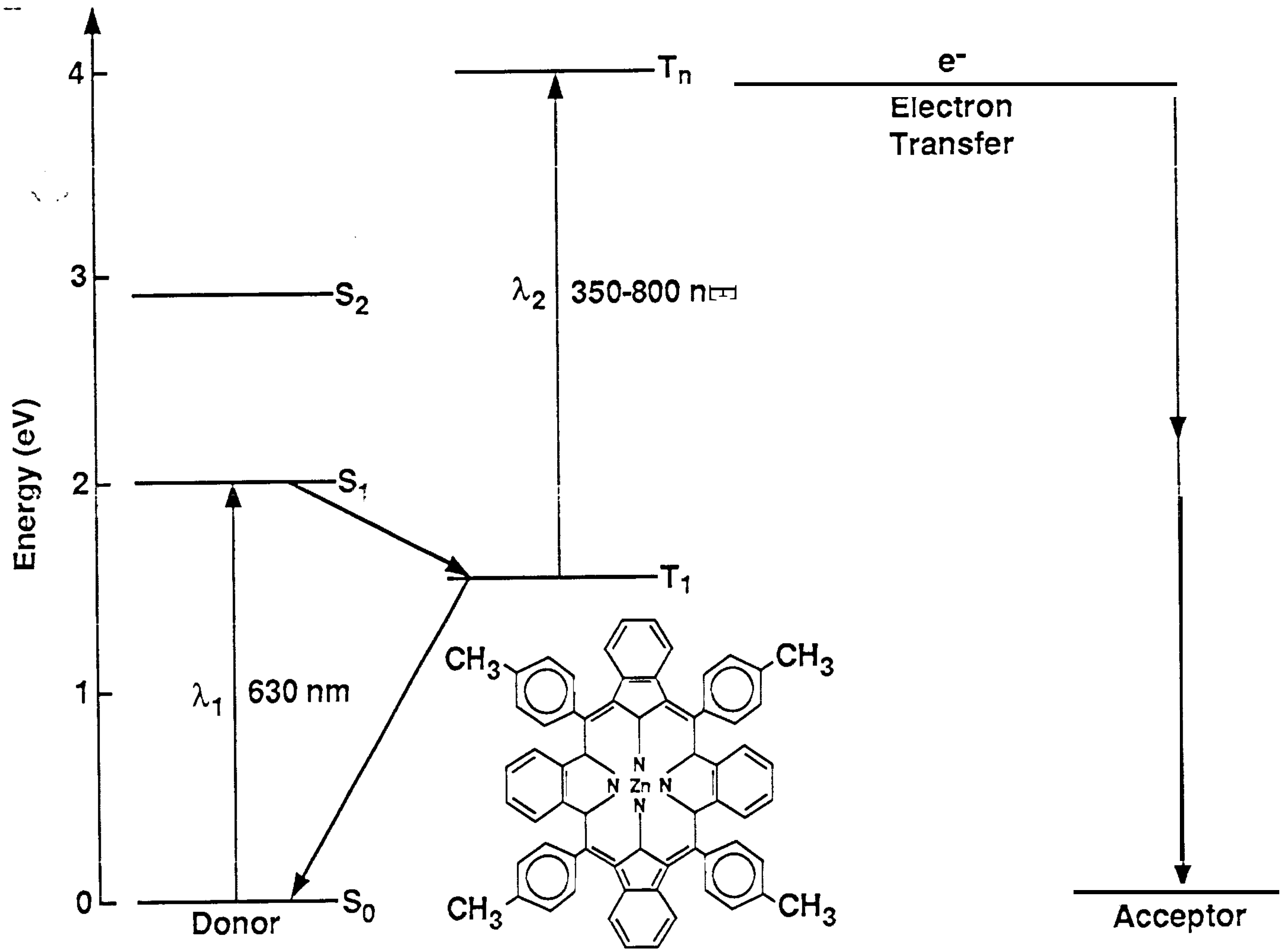
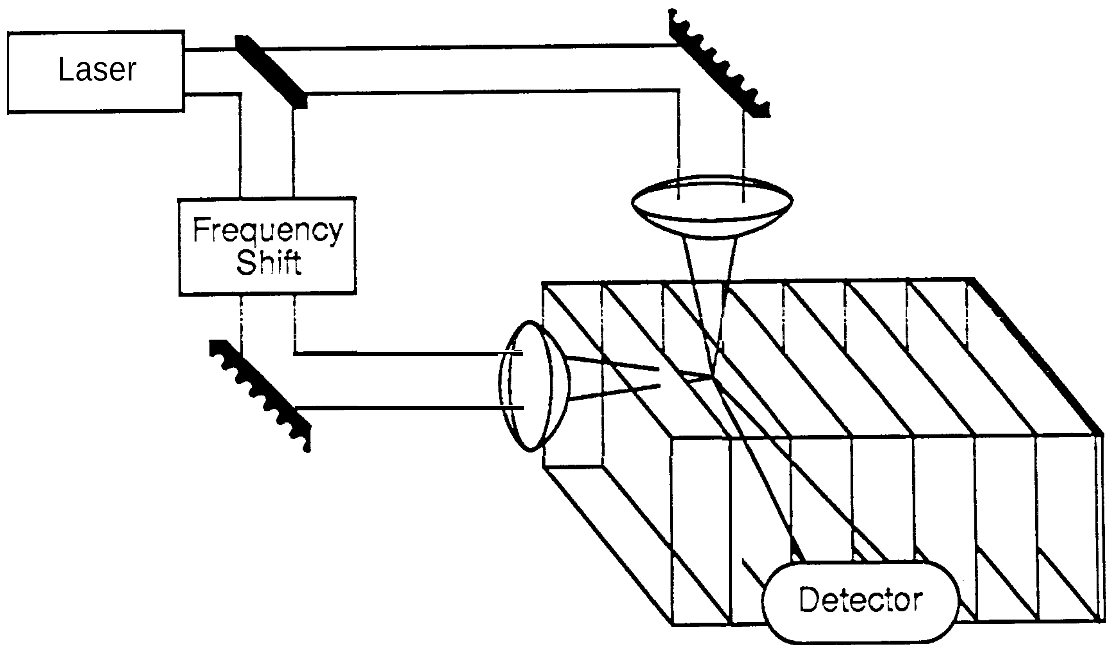
A photon gated process. *Source: Moerner, W.E. 1988. Persistent Spectral Hole Burning: Science and Applications. Springer, Berlin.*



Schematic diagram of a 3D-memory device. Source: *Dvornikov, A. S. and P. M. Rentzepis.* **1992.** Studies on 3D Volume Memory. *SPIE* ***1662, Image Storage and Retrieval Systems,*** 197.



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Technical publication activity for 1988 to 1993 by year.

	1988	1989	1990	1991	1992	1993	Totals
DRAM or SRAM	403	459	477	572	477	237	2625
Holographic	63	107	108	110	129	102	619
EEPROM	92	93	70	92	79	68	494
VBL	70	45	40	65	19	9	248
Hash	29	20	33	38	31	23	174
Magnetic Bubble	53	30	29	43	13	1	169
FRAM	16	15	28	33	41	9	142
Josephson Junction	14	30	15	33	16	19	127
Magnetic Core	12	18	13	26	20	3	92
Spectral Hole Burning	8	7	16	18	24	11	84
Biological or Molecular	9	8	6	12	6	7	48
MRAM	5	4	8	11	12	2	42
Two Photon Three Dimensional	0	2	13	7	4	14	40
Single Electron Transistor	1	1	0	5	12	9	28
Hall Effect	1	3	5	6	0	5	20
Magnetic Cross Tie	3	3	2	2	4	4	18
Plated Wire	3	1	1	0	0	0	5

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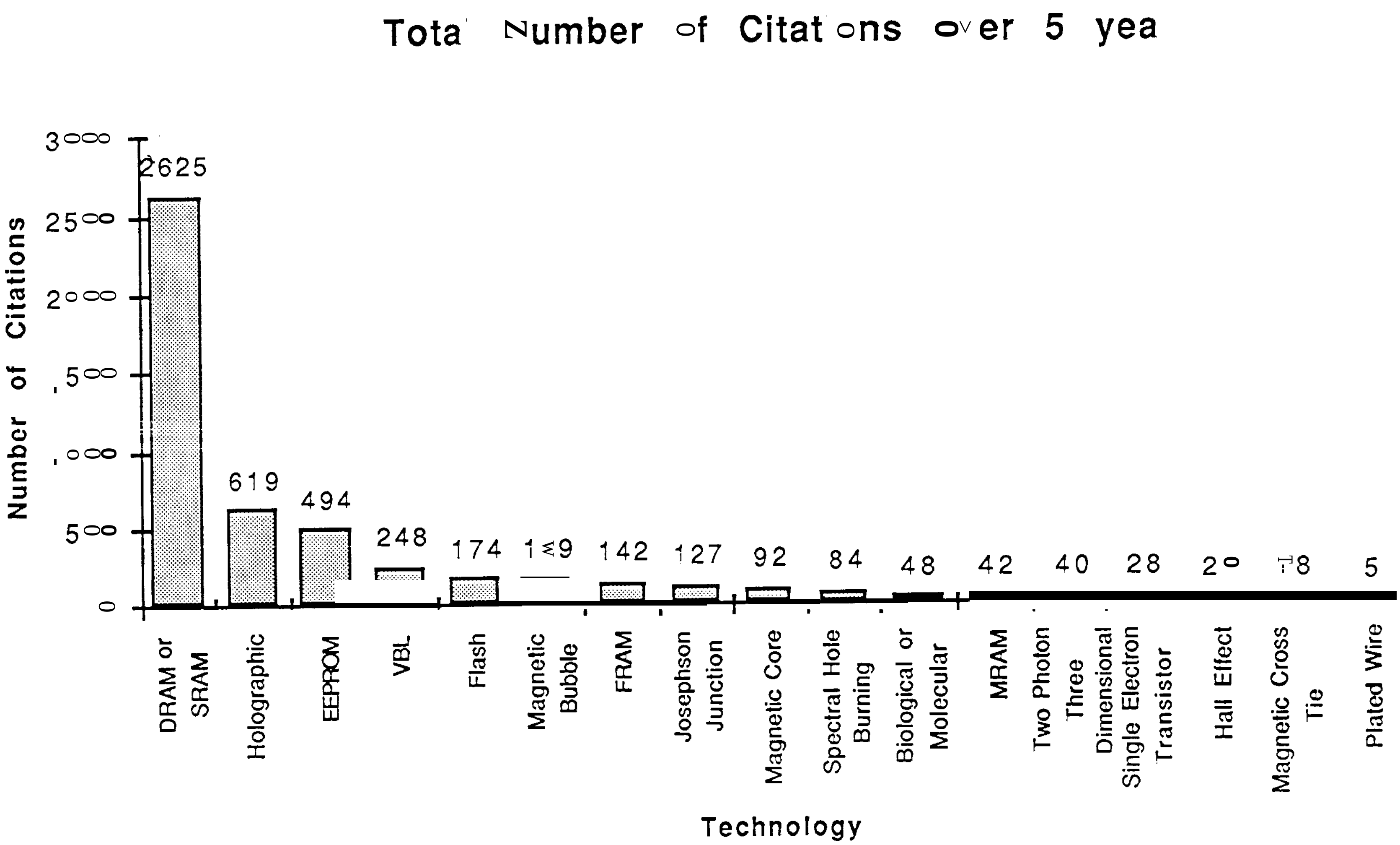
Total technical publication activity for 1988 to 1993.



Technology classifications.

Industrial Commercial	Government Commercial	Functioning Prototype	Research and Developement
EEPROM	Magnetic Core	MRAM	Single Electron
FLASH	Plated Wire	FRAM	Josephson Junction
RONI	Cross-Tie	VBL	Photon Echo
SRAM	Magnetic Bubble	Holographic	Spectral Hole Burning
DRAM	NVSRAM		Molecular or Chemical
			2 Photon 3D

Increasing Cost, Time to Availability, Program Risk →

Decreasing Number of Units Produced

Reasons for technical activity levels.

Technology	**Category**	**Location** in Product Life Cycle	Anticipated Activity Level
Magnetic Core, Plated Wire, Cross-Tie, Magnetic Bubble	Government Commercial	Old	Small and Decreasing
EEPROM. ROM, SRAM, DRAM,	Industrial Commercial	Middle Aged	Large and Steady
Flash	Industrial Commercial	Young	Moderate and Increasing
NVSRAM	Government Commercial	Young	Small
MRAM, FRAM, VBL, Holographic	Prototype	Young	Small and Increasing
Single Electron, Josephson Junction, Photon Echo, Spectral Hole Burning, Molecular or Chemical, Two Photon Three Dimensional	Research and Development	Never a product	Small

Technology Comparison Matrix

Type of Memory	Cost per MByte ($)	Years to Maturity	Development Cost ($)	Risk (minuses)	Benefit (Pfuses)	Density (MByte/cc)	Power
Magnetic Bubble	100	Zero	Zero	Power use, speed. limited density	Known technology, radiation hard	0.008 to 0.005	1-1oo W/Mbit/sec
VBL	0.01 to 5	5 to 10	5 to 15M	Losing bubble technology base	Dense, radiation hard, few fabrication steps	1 to 100	0.01 to 1 W/Mbit/sec
Magnetic Core	100 to 1000	Zero	Zero	Size, power, cost, speed	Robust, reliable, radiation hard	0.0002 to0.001	1 to 60 W/Mbit/sec
Optical Holographic	0.06 :00.10	5 to 10	>25M	Media, optics, lasers	High speed, parallel read	16.5	Less than 15 watts
MRAM	10.00	5 to 10	100M	Speed/density tradeoff, Materials development	Few fabrication steps, radiation hard, NDRO, nonvolatile, fast write, infinite durability, high density	$1x10^9$ bytes/cc (10^8/cm2)	0.025 W/Mbit/sec read or write
GMRAM	10.00	5 to 10	100M	Materials development	Few fabrication steps, radiation hard, NDRO, nonvolatile, fast writek infinite durability, high density	1 xl 0^9 bytes/cc (10^8/cm2)	0.025 W/Mbit/sec read or write
Josephson Junction	10.00	10	IB	Low temperature operation	Extremely high speed (picosec)	1 x1 0^9bytes/cc (108/cm2)	0.001 W/Mbit/sec
Single Electron Transistors	? 0.00	15	10B	Low temperature operation, extreme lithographic needs, some volatility	Extremely high density/high speed (picosec)	1X:O12 bytes/cc (10^{11} /cm2)	0.0001 W/Mbit/see
Flash EEPROM	30-55 Now Follows Semiconductor Trends	2	Enormous (industry dominated)	Slow write cycle, Number of read/write cycles	Known technology, commercially driven	1.7-2.6 PCMCIA Card, Follows Semiconductor Trends	125-35o mW operating: 2 mW sleep
FRAM	2000 Now Follows Semiconductor Trends	3 to 5	Large, industry driven	Low density, Number of read /write cycles, Ferroelectric materials	Low power, individual'y addressable bits	340 KByte/cc in chip package, Follows Semiconductor Trends	0.5 mW operating, 0.?2 mW sleep

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Technology Comparison Matrix- *Continued*

Conclusions

- **A variety of physical effects, which can be generally characterized as electronic, magnetic, or optical, can be used to store and access information.**

- **The selection of the appropriate technology for various applications is dependent on many considerations which relate to performance and cost.**