Magneto-Optic Recording

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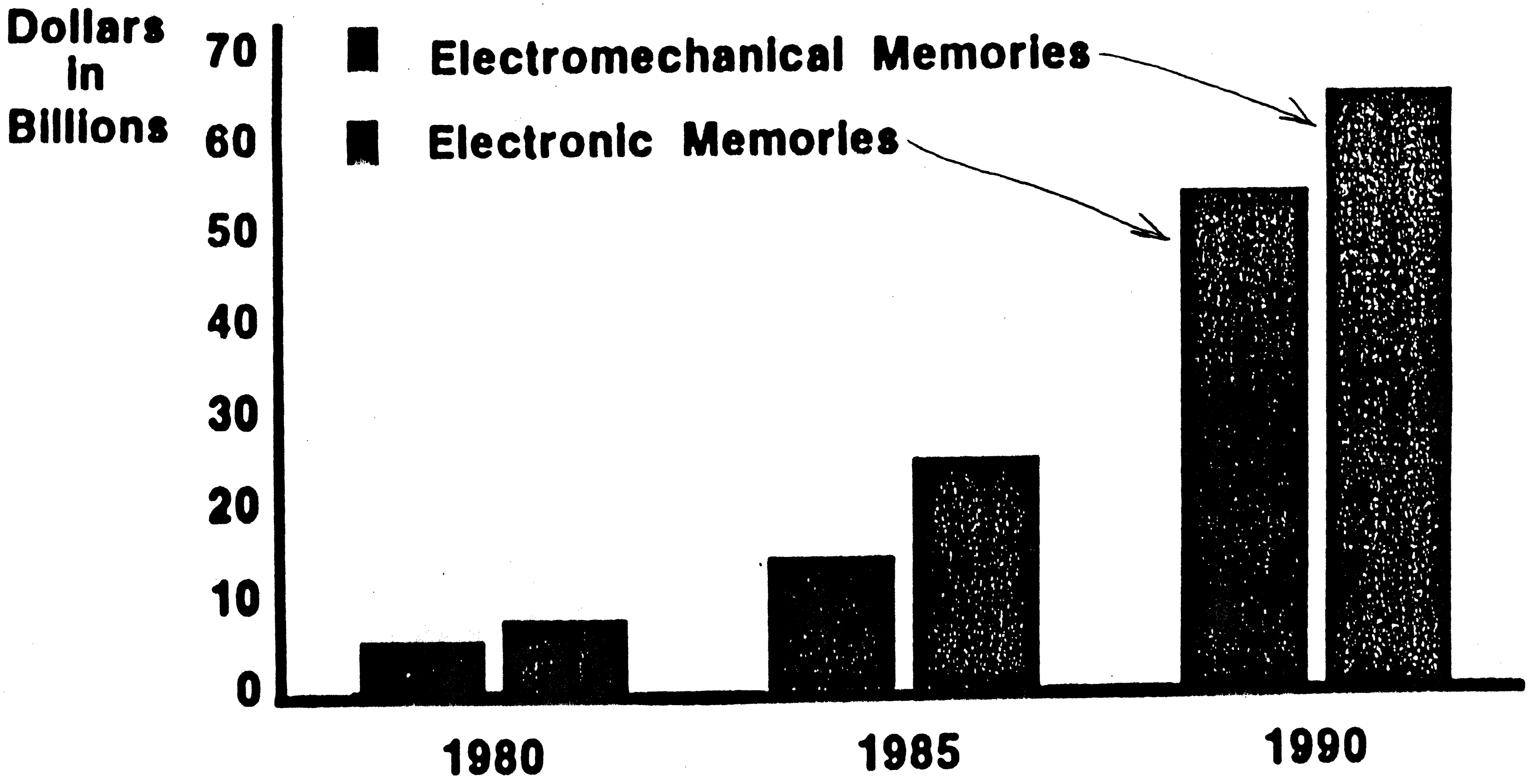
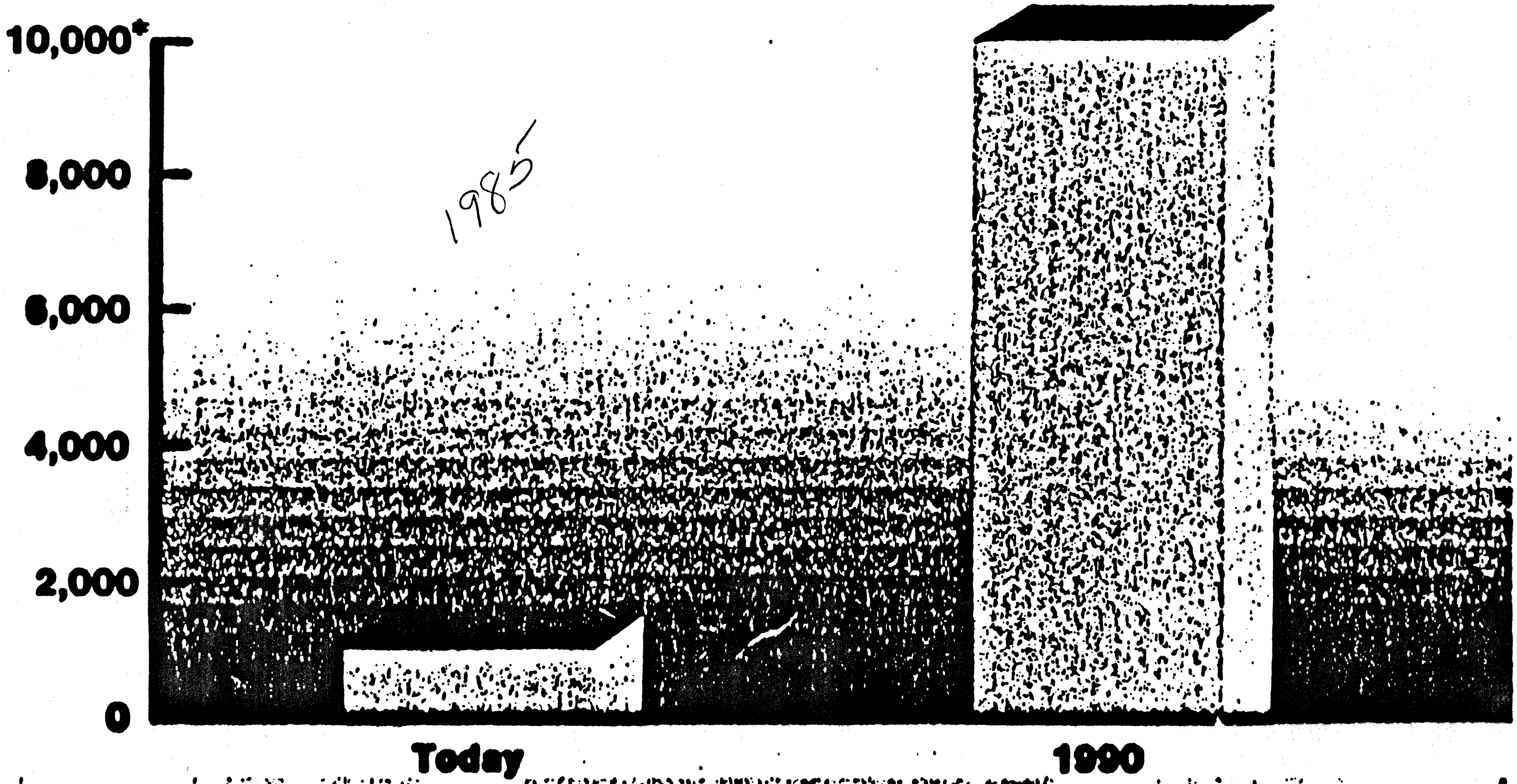
WORLDWIDE SHIPMENT OF MEMORIES



Source: Mackintosh International

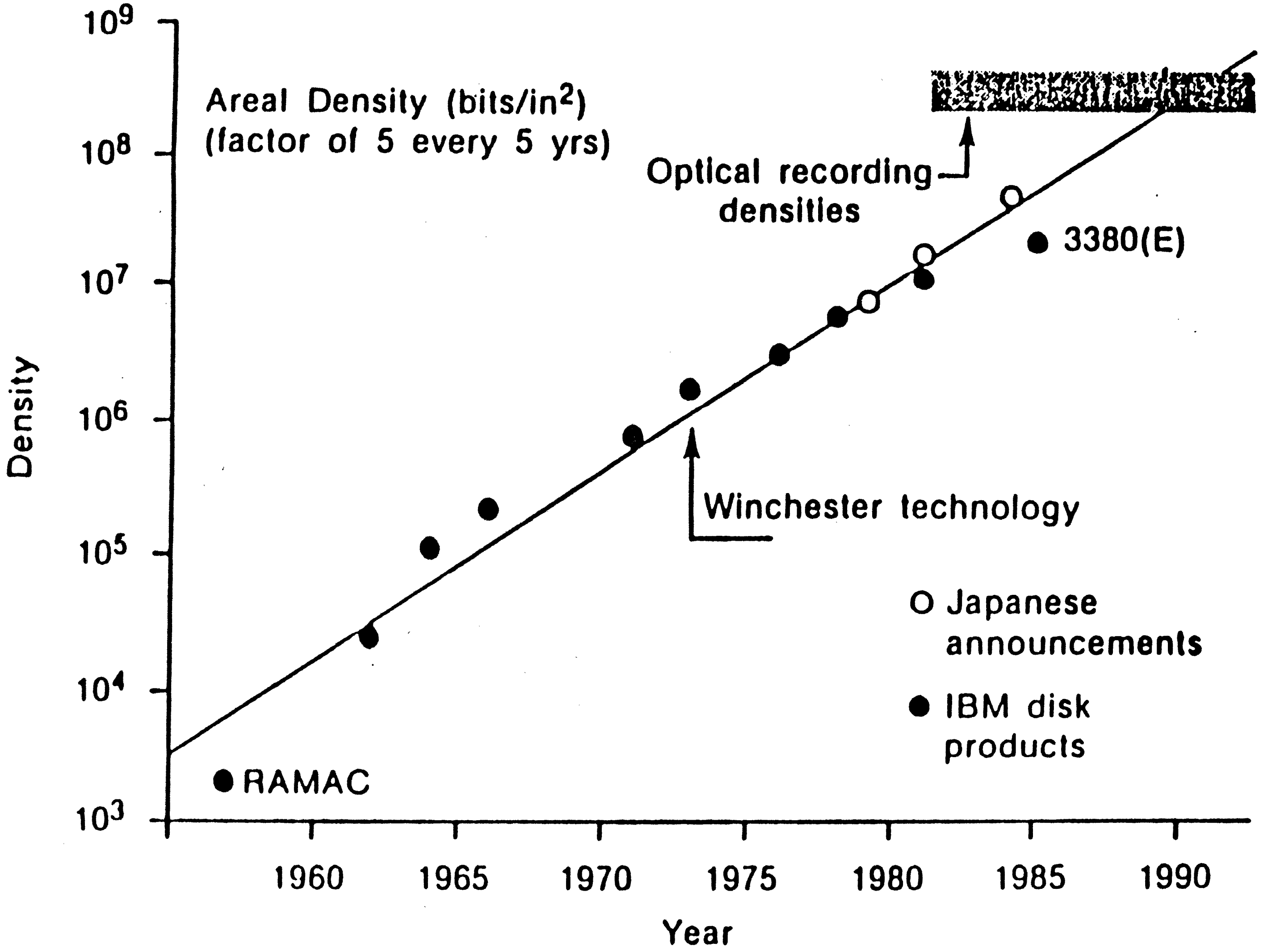
PROJECTED STORAGE GROWTH
(Typical Large System Installation)

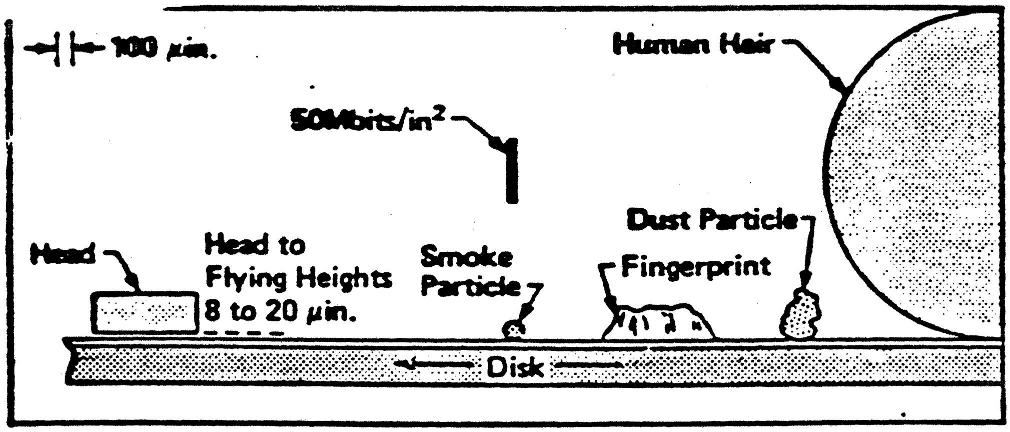


1985

*Gigabytes

Magnetic Disk Storage Density





3. Comparison of typical dimensions encountered in high performance flying-head disk drives.

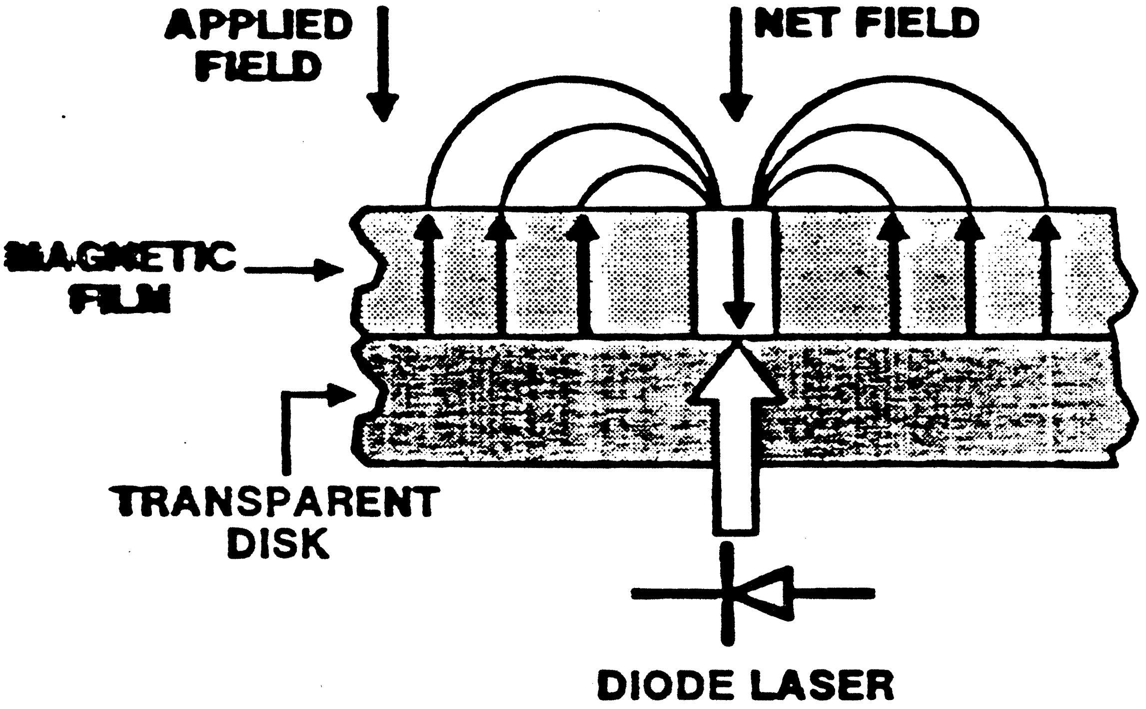


Figure 1. Schematic diagram of the process of thermomagnetic recording a bit. A magnetic field is applied in a direction opposite to the magnetization in the film, as shown by the arrows pointing up. A small micrometer-size spot is heated to reduce the coercive force below the magnitude of the net field. The bit is formed after the laser pulse is turned off, due to the net magnetic field at the site being downward. The recorded bit is a micrometer-size reversed magnetized region.

MAGNETO-OPTIC RECORDING SYSTEMS

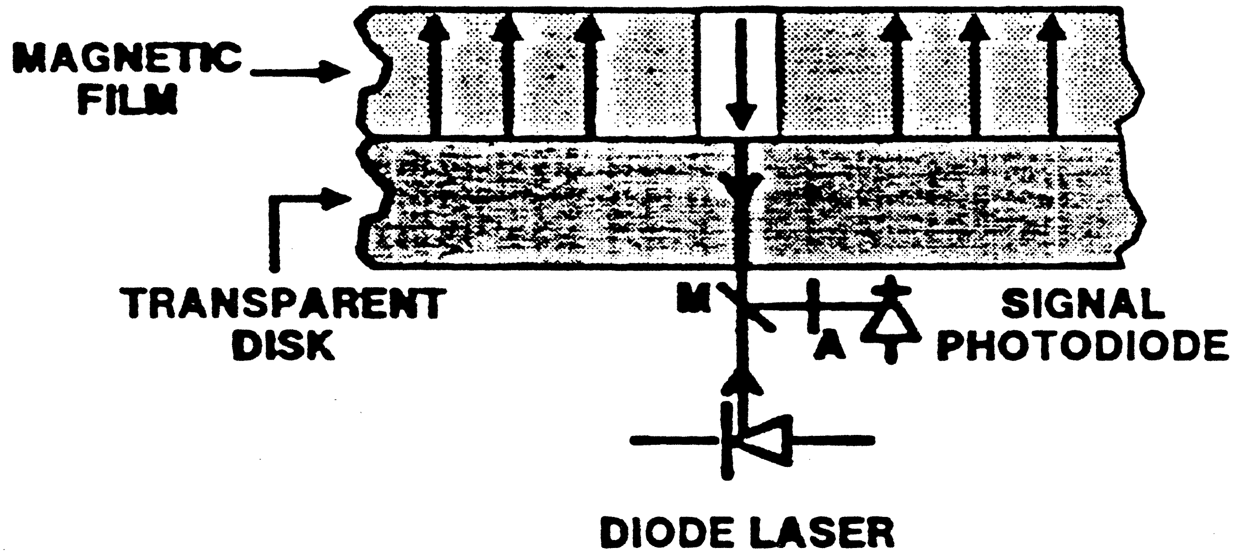


Figure 2. The recorded bit is read by a reduced intensity laser pulse which is reflected from the bit site and from a beam splitter (M) to a signal photo diode. Due to the Kerr magneto-optic effect which causes opposite directions of rotations of a reflected polarized light beam, a reverse magnetized domain can be detected by passing through the analyzer (A) to a signal photo diode.

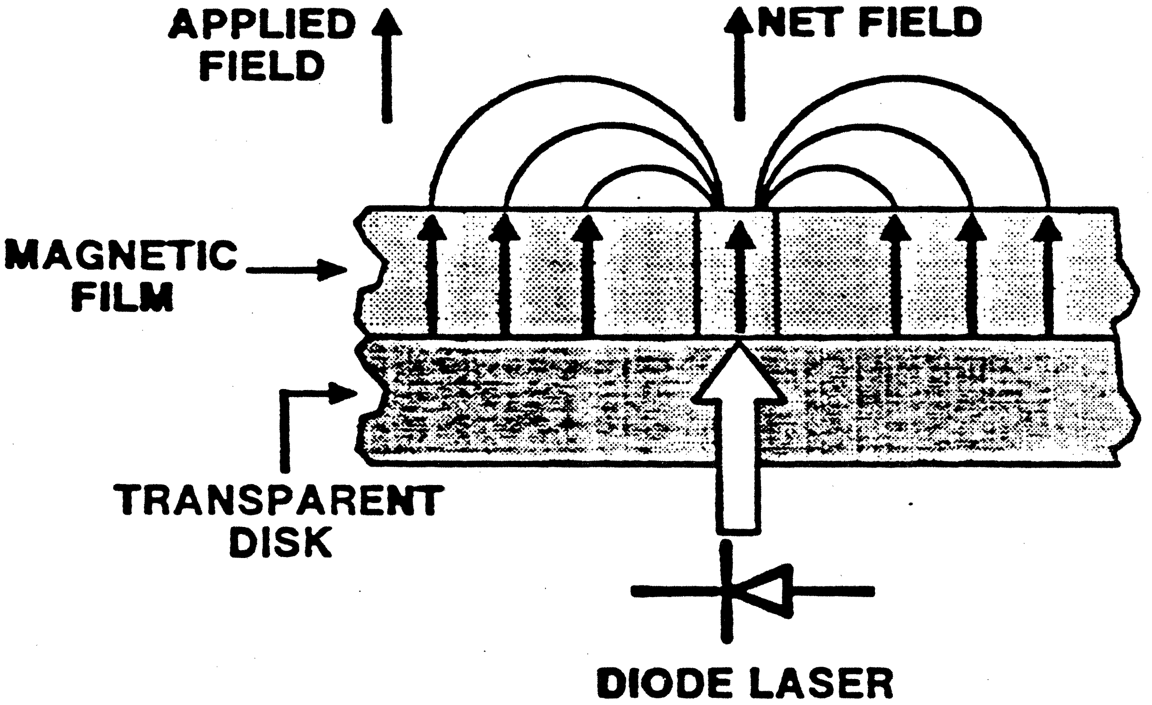
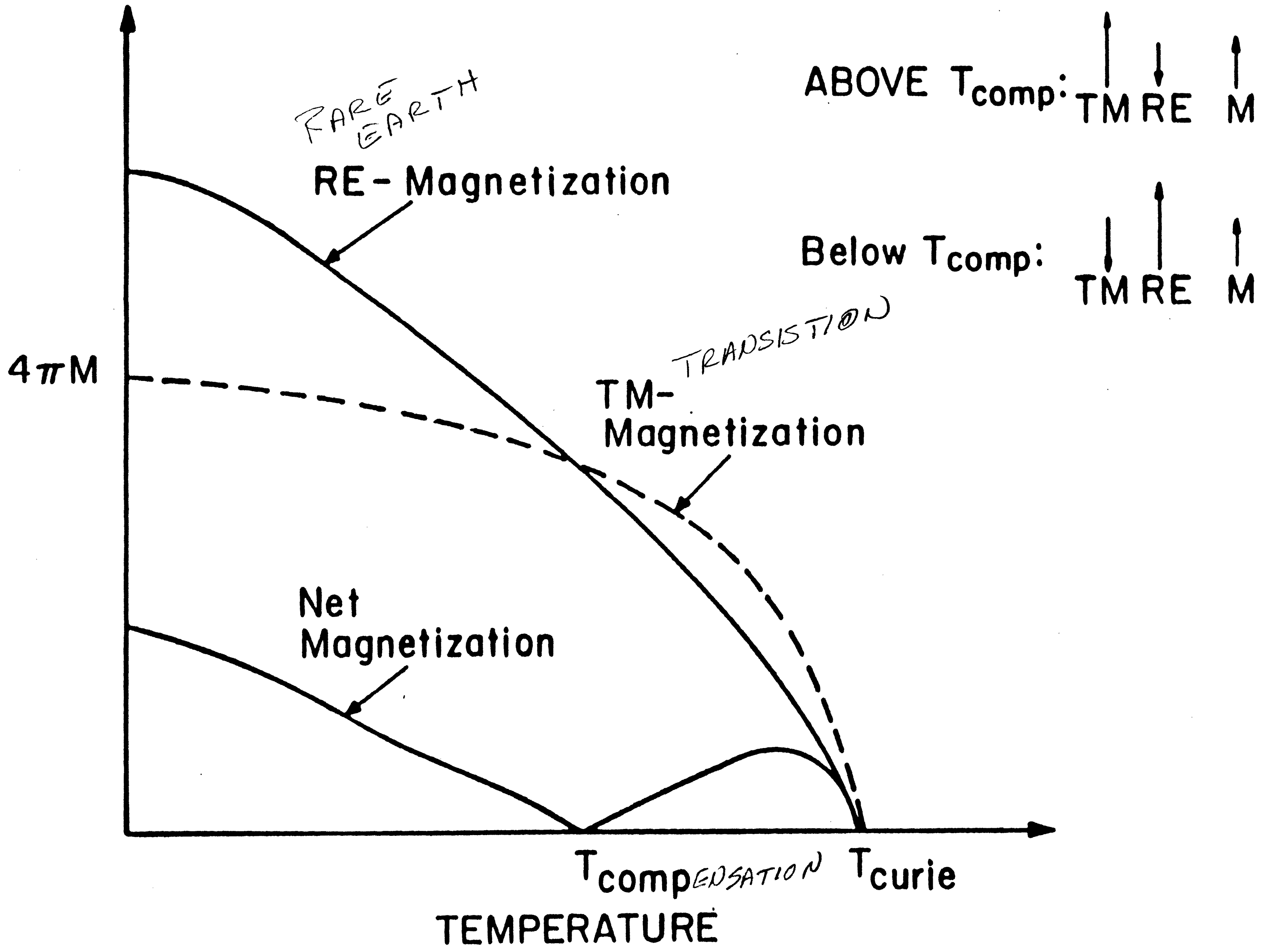
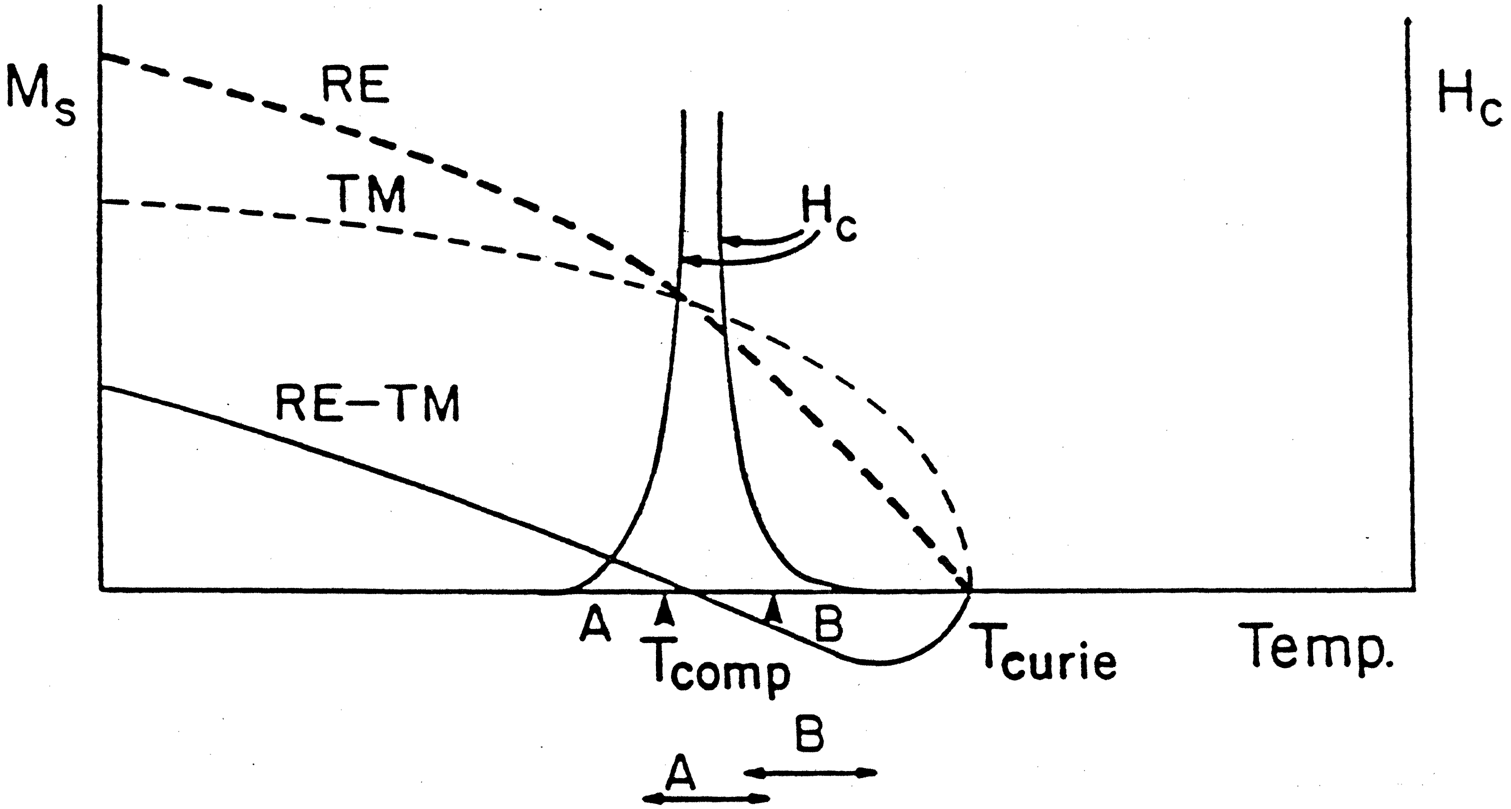


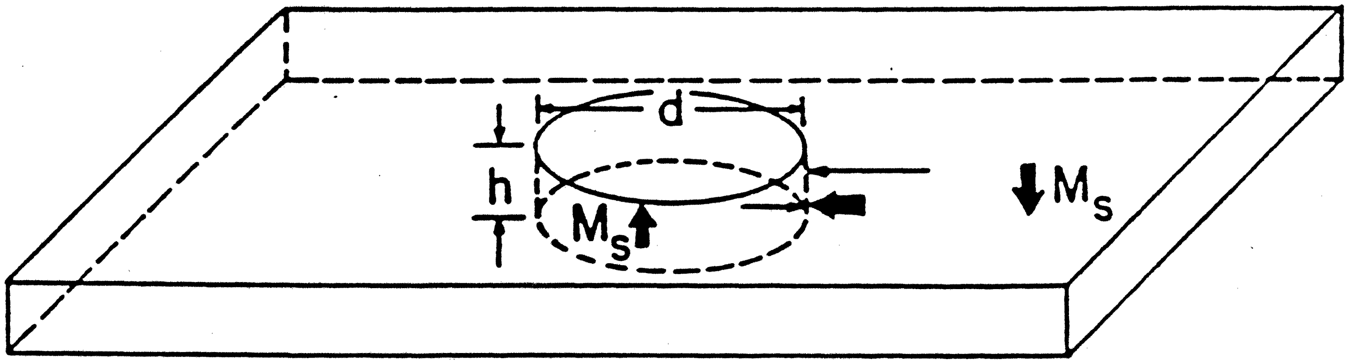
Figure 3. Erasure of a recorded bit is accomplished simply by reversing the applied field used during the writing process, and pulsing the laser. The bit now cools in a magnetic field having the same direction as the neighboring magnetization and, therefore, is annihilated. None of the other neighboring bits are affected by the applied field, since they are not heated by the laser beam.



ABOVE T_{comp}: TM RE M
Below T_{comp}: TM RE M
RARE EARTH
RE- Magnetization
TRANSISTION
TM- Magnetization
$4\pi M$
Net Magnetization
$T_{compensation}$
T_{curie}
TEMPERATURE



Temp. excursion in T-M writing



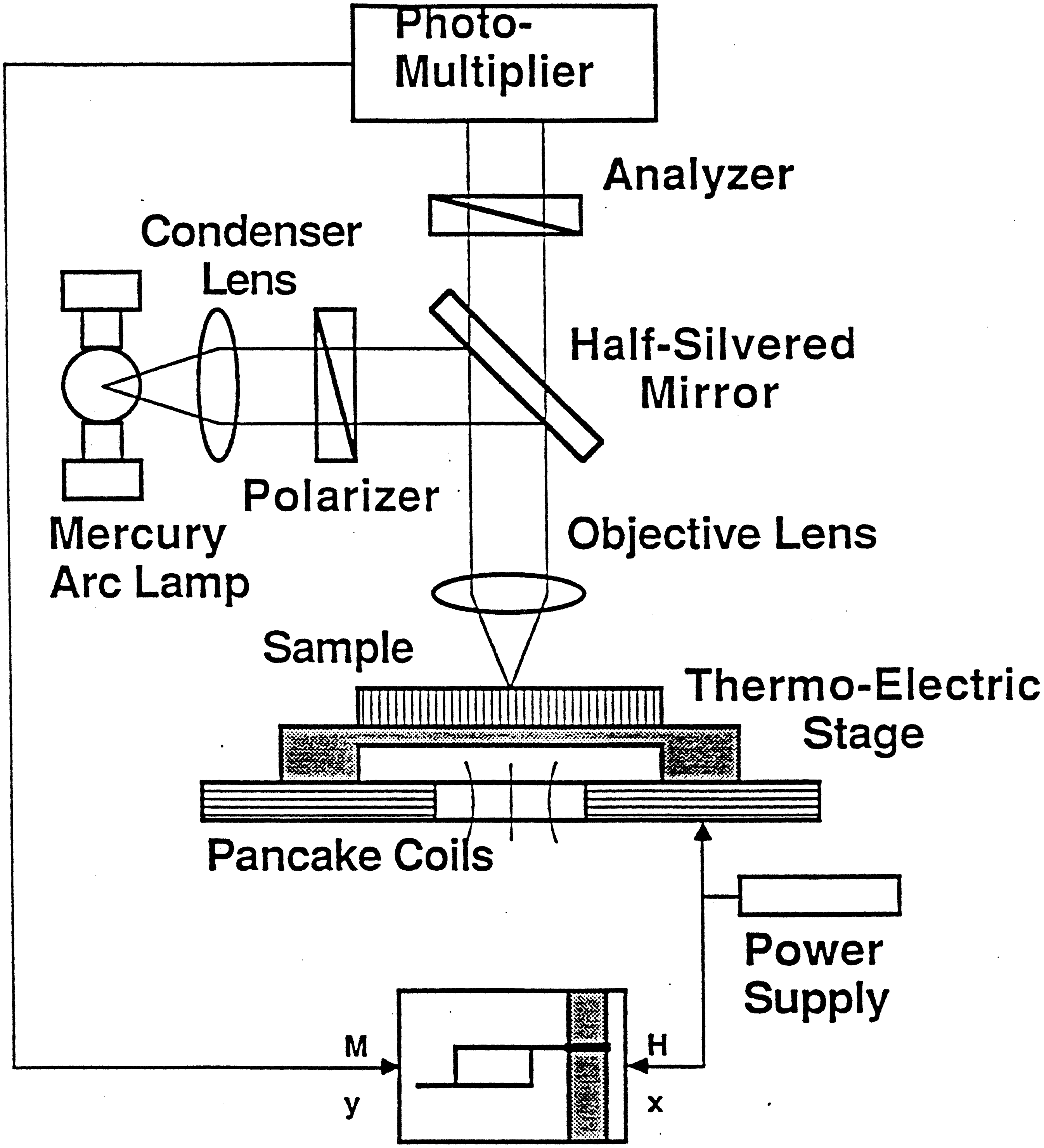
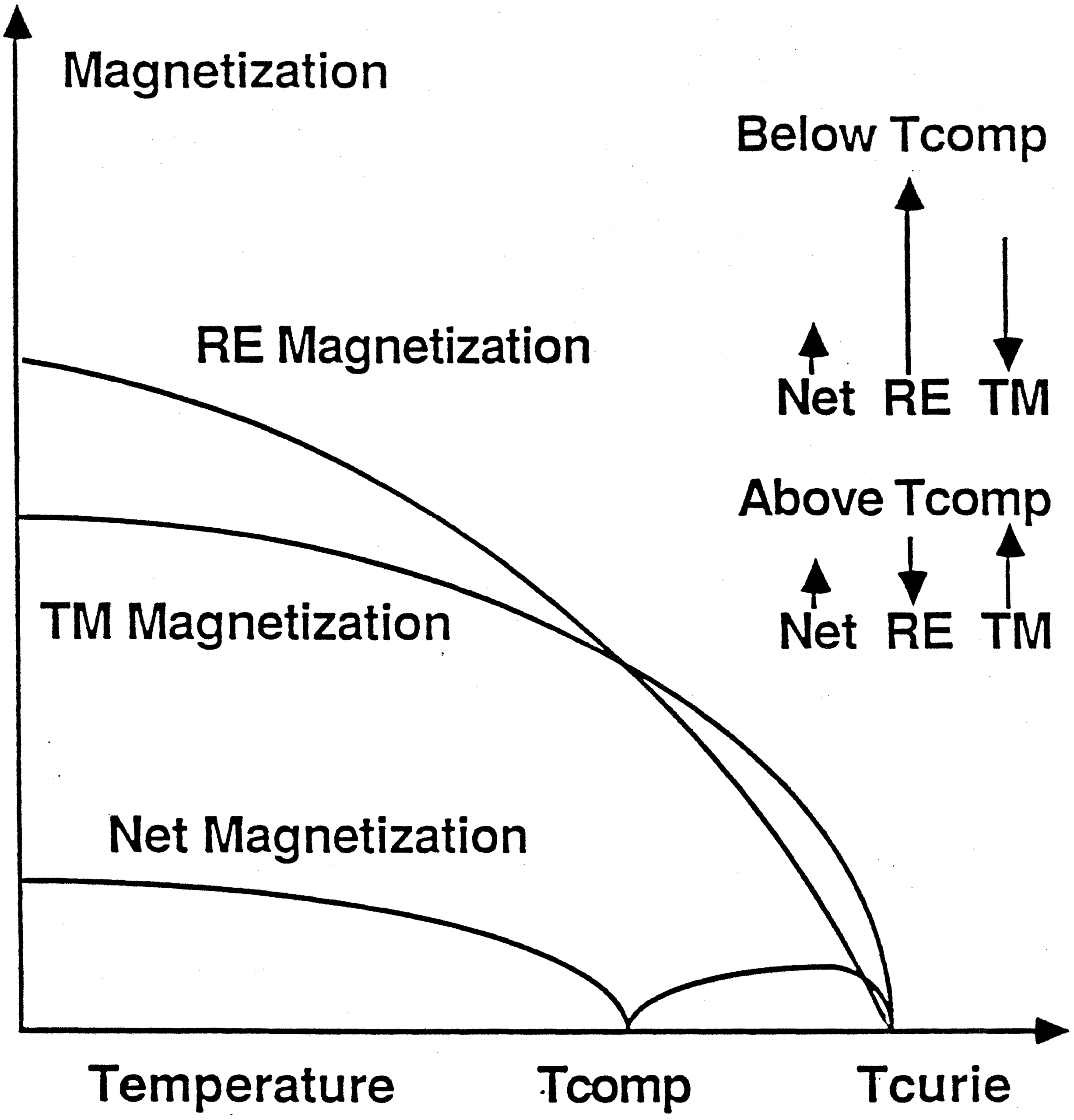


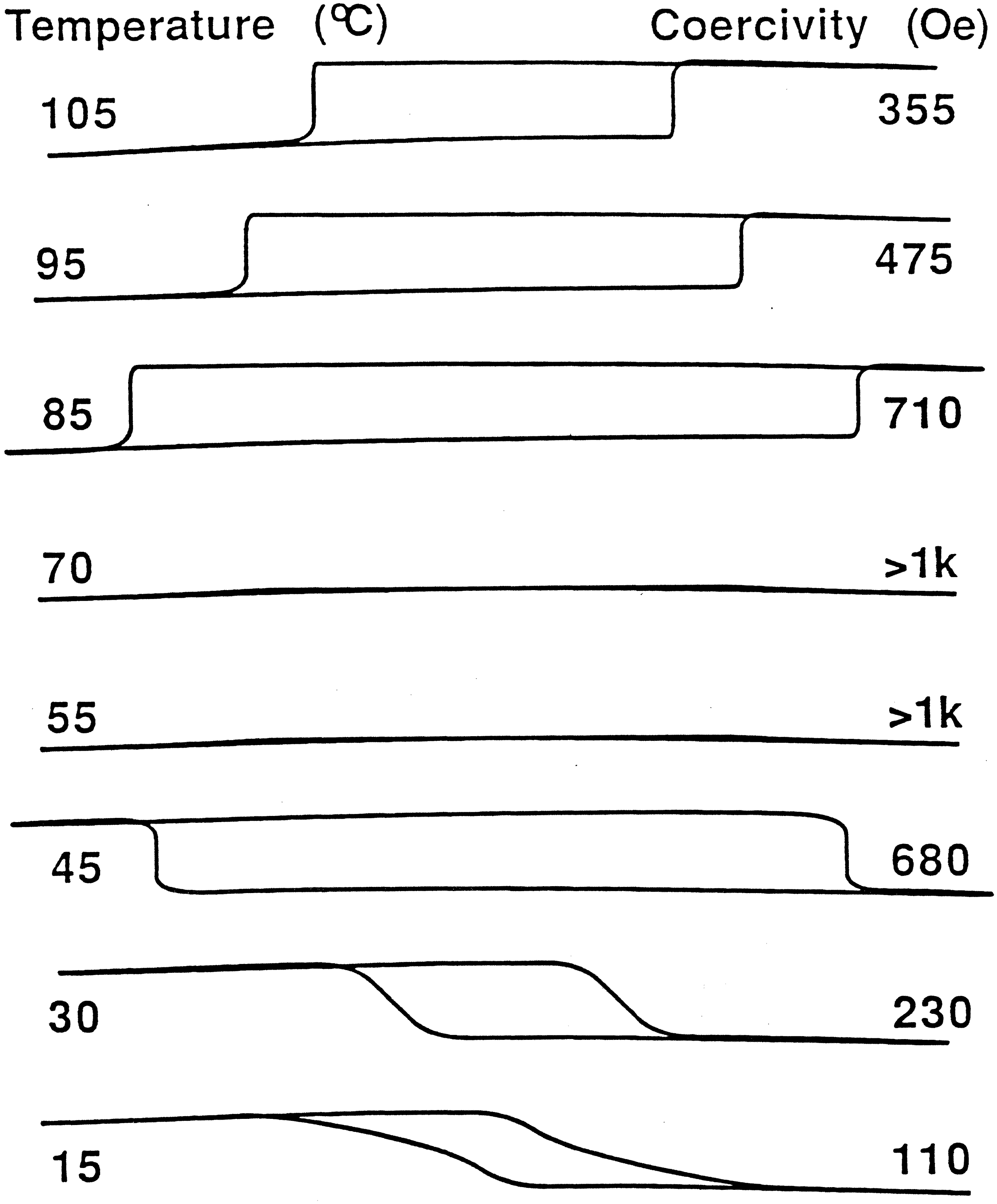
Photo-
Multiplier
Analyzer
Condenser
Lens
Half-Silvered
Mirror
Polarizer
Mercury
Arc Lamp
Objective Lens
Sample
Thermo-Electric
Stage
Pancake Coils
Power
Supply
M
y
H
x

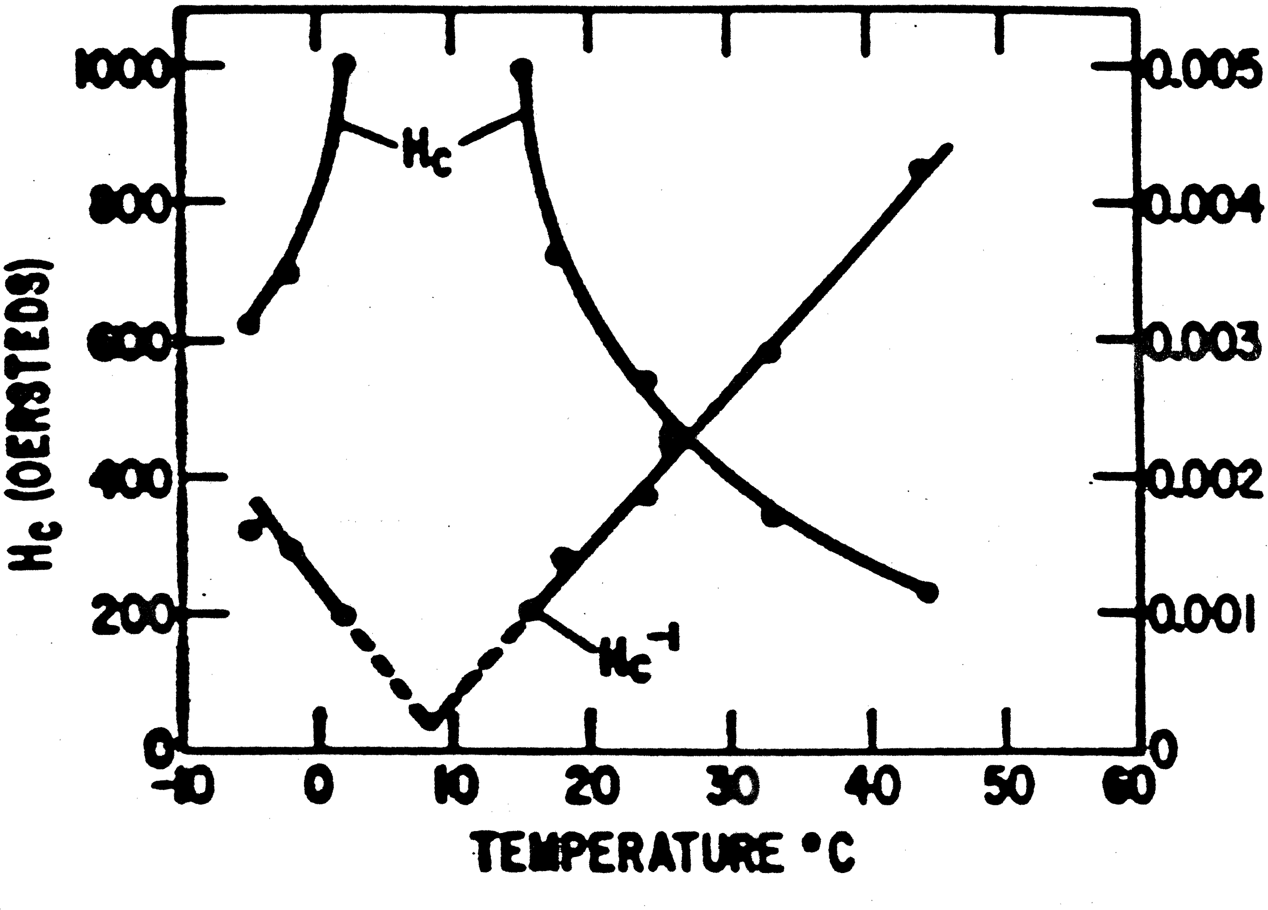


MH Loops

Normal
Above Tcomp

Mirror Imaged
Below Tcomp

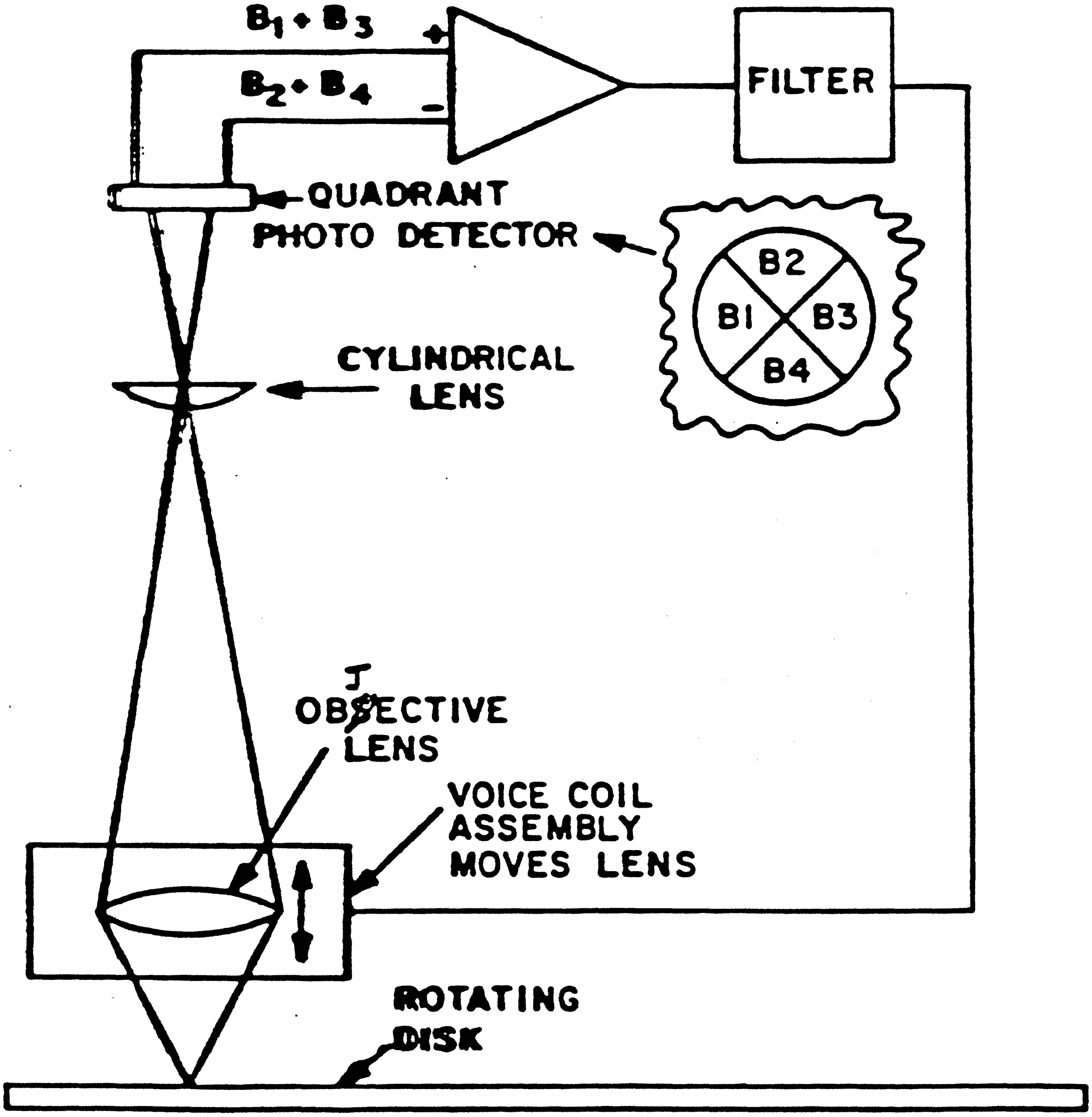

Temperature (°C)
Coercivity (Oe)
105
355
95
475
85
710
70
>1k
55
>1k
45
680
30
230
15
110



Hc (OERSTEDS)
1000
800
600
400
200
0
0.005
0.004
0.003
0.002
0.001
0
H_c^{-1} (OERSTEDS)$^{-1}$
H_c
H_c^{-1}
-10
0
10
20
30
40
50
60
TEMPERATURE °C

Fig. 1

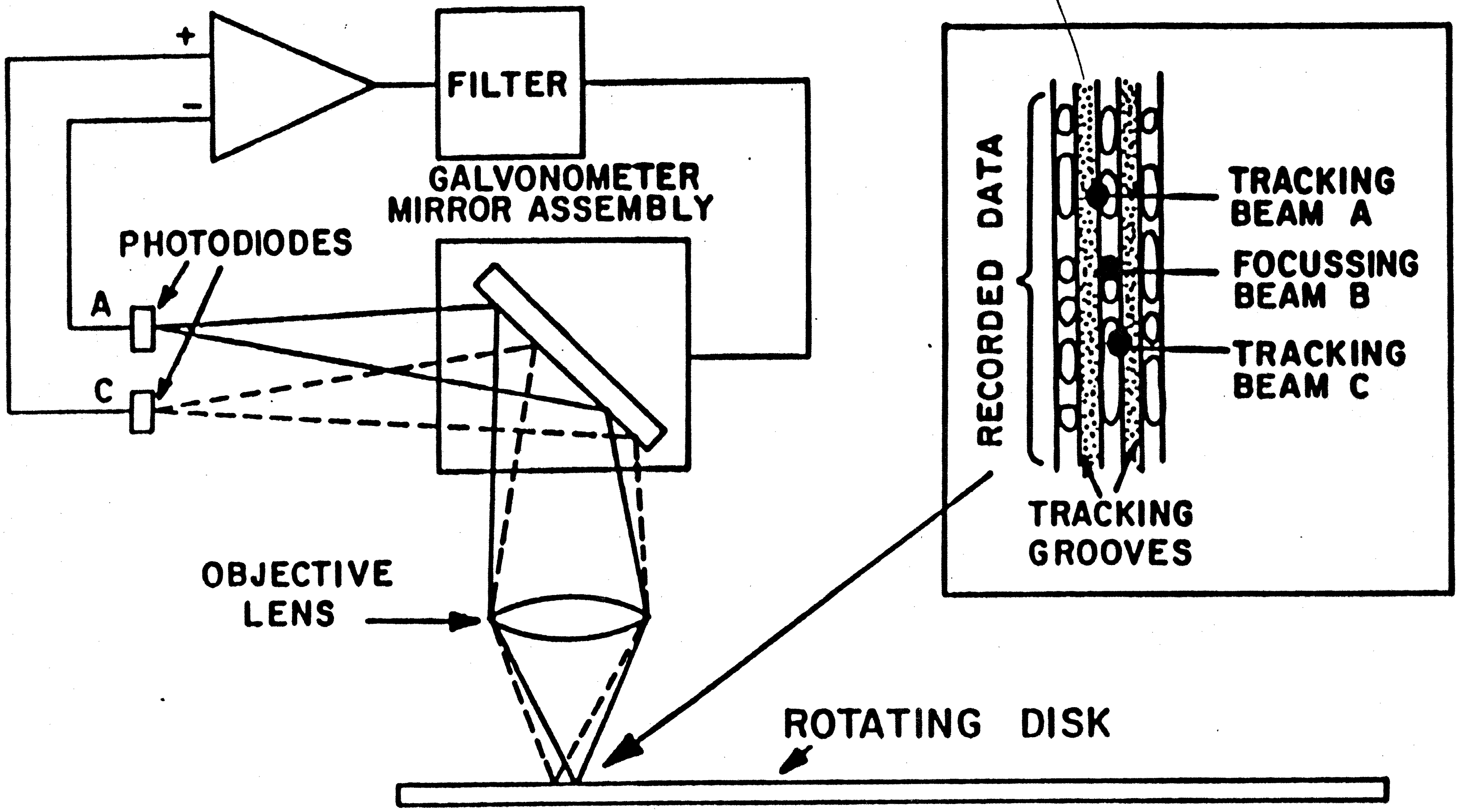
OPTICAL DISK FOCUSSING

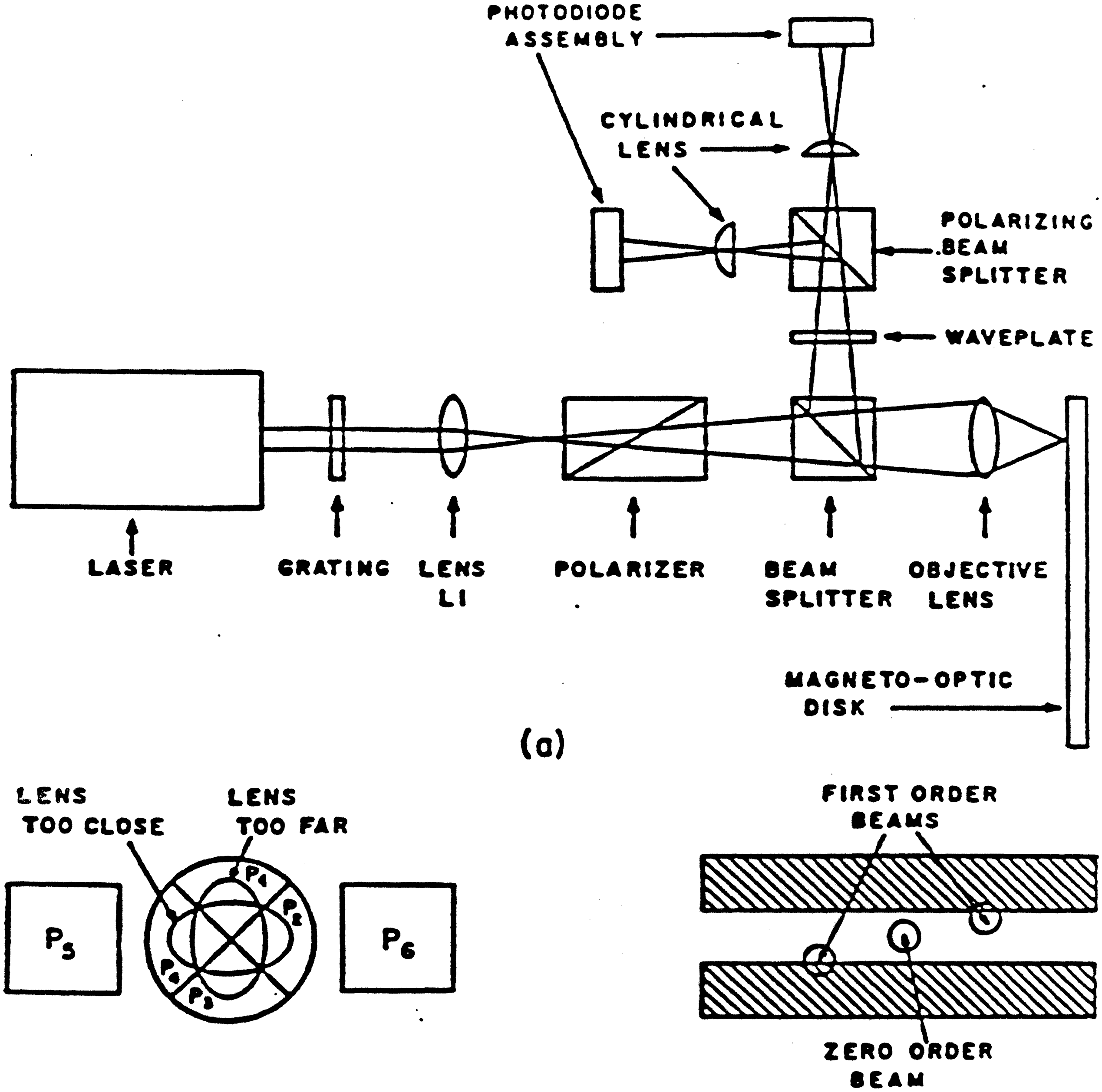


OPTICAL DISK TRACKING

3 BEAM TRACKING

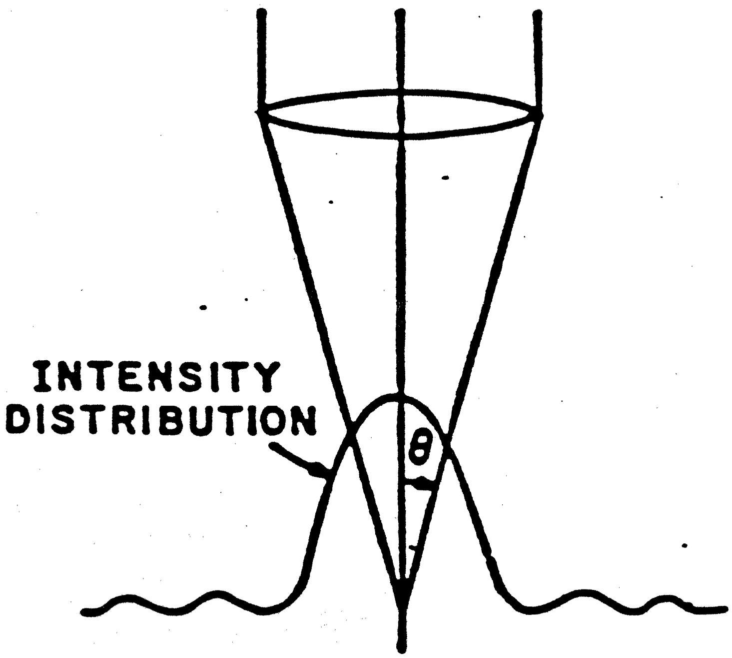
$\frac{1}{4}\lambda$ deep




PHOTODIODE ASSEMBLY
CYLINDRICAL LENS
POLARIZING BEAM SPLITTER
WAVEPLATE
LASER
GRATING
LENS L1
POLARIZER
BEAM SPLITTER
OBJECTIVE LENS
MAGNETO-OPTIC DISK
(a)
LENS TOO CLOSE
LENS TOO FAR
P_1
P_2
P_3
P_4
P_5
P_6
(b)
FIRST ORDER BEAMS
ZERO ORDER BEAM
(c)

OPTICAL RECORDING DENSITY LIMITS

DIFFRACTION LIMIT



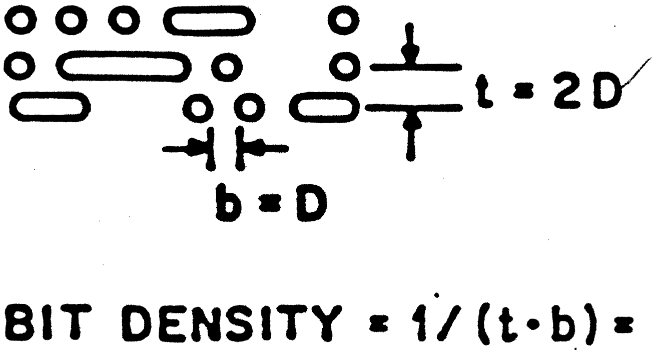
CONSTANT

$$D = \frac{C\lambda}{\sin\theta}$$

$$0.31 \le C \le 0.61$$

FULL MODULATION xfer FUNCTION

BIT DENSITY



BEAM DIAMETER

$\text{BIT DENSITY} = 1/(t \cdot b) = 1/2D^2 \approx 7 \times 10^7/\text{cm}^2$

$C = 0.61,\ \lambda = 820\,\text{nm},\ \sin\theta = 0.6$

DIODE LASER

Magneto-Optic Signal-to-Noise Ratio Using Differential Photodetectors

Shot Noise Current (LIGHT QUANTIZED ELECTRICAL CURRENT QUANTIZED

$$I_N = \sqrt{2eB\eta PR}$$

Signal Current

$$I_s = \eta PR \sin 2\theta$$

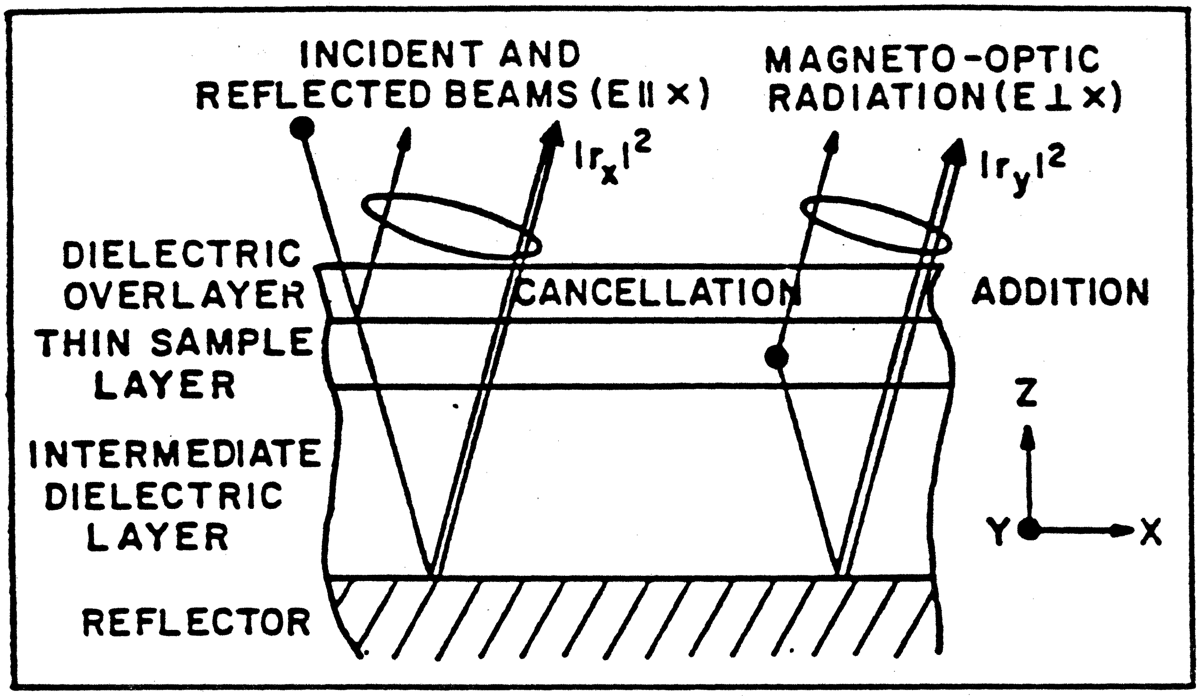
Signal-to-Noise Ratio

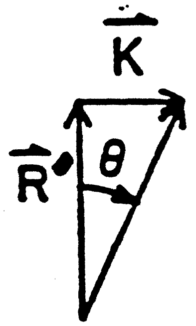
$$\text{SNR (dB)} = 10 \log (2\eta PR \sin^2 \theta / eB)$$

η	Sensitivity of SILICON Photodiodes	0.35 A/W
P	Read Laser Power	1 mW
R	Reflectance (R'^2)	0.6
θ	Kerr Rotation Angle	0.3°
e	Electric Charge	1.6×10^{-19}

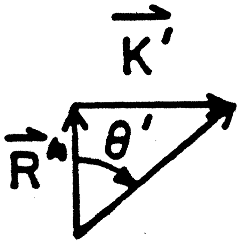
SNR (dB) = 38 dB (B = 10 MHz)

MULTI-LAYER STRUCTURE





UNENHANCED



ENHANCED

$R'' < R'$

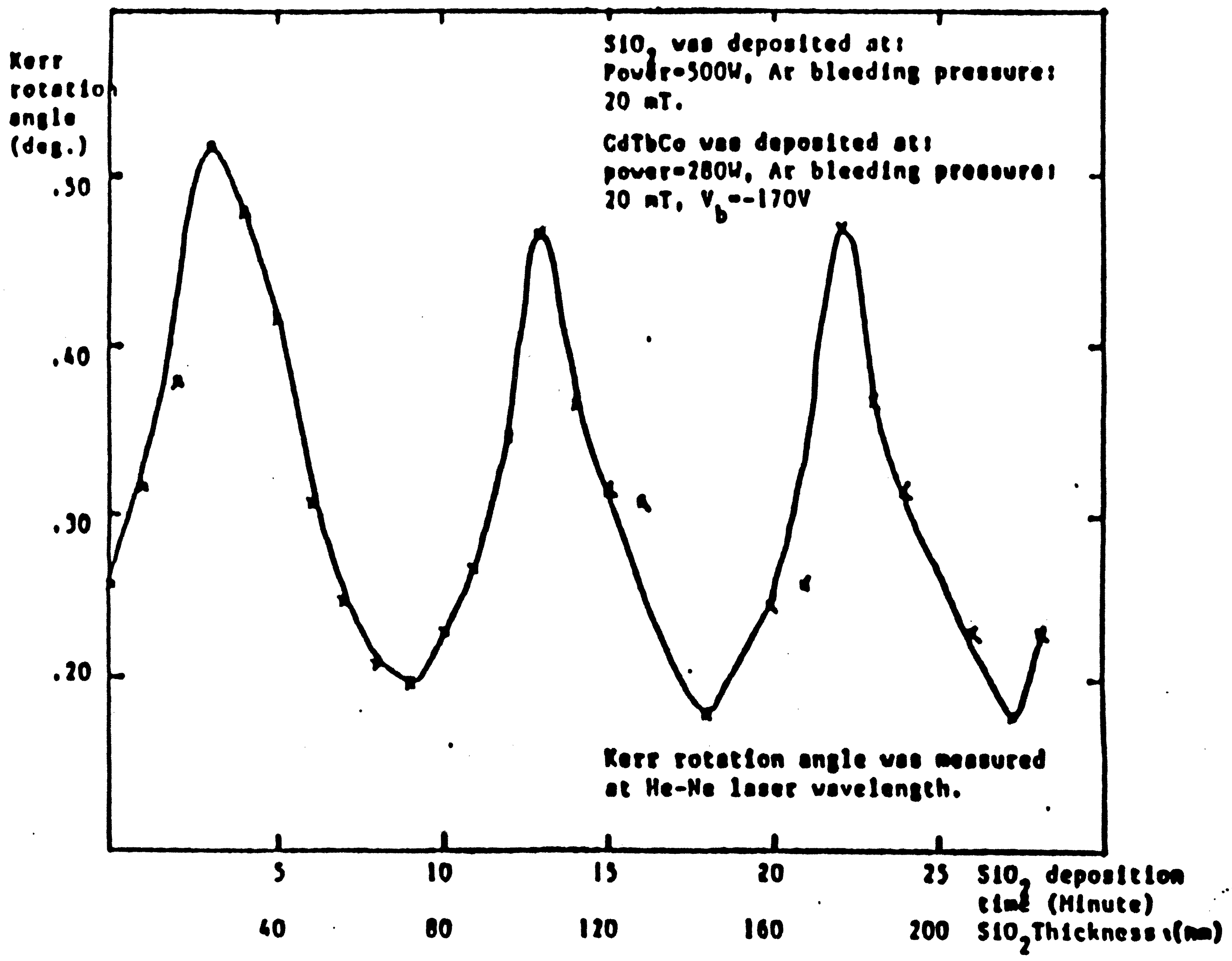
$K' \gtrsim K$

$$\theta' \approx \frac{K'}{R''} \gtrsim \frac{K}{R''}$$

55 dB CNR @ 30 KHz Bandwidths *

Corresponds to 30 dB @ 10 MHz Bandwidths

R. N. Gardiner *et al.*, paper 420-37, SPIE Conference on Optical Mass Data Storage June, 1983



Kerr rotation angle (deg.)
.50
.40
.30
.20
SiO$_2$ was deposited at: Power=500W, Ar bleeding pressure: 20 mT.
GdTbCo was deposited at: power=280W, Ar bleeding pressure: 20 mT, V_b=-170V
Kerr rotation angle was measured at He-Ne laser wavelength.
5
10
15
20
25
SiO$_2$ deposition time (Minute)
40
80
120
160
200
SiO$_2$ Thickness (nm)

F.g 15

ERROR RATE

$$P(SNR) = 1/2 \ \mathrm{erf} \ (\sqrt{SNR})$$

SNR	2.5	4	6.25	10	16	25
SNR (dB)	4	6	8	10	12	14
PROB OF ERROR	10^{-2}	$3X10^{-3}$	$2X10^{-4}$	$4X10^{-6}$	10^{-8}	10^{-12}

↑ TODAY USE REED SOLOMAN CODE

DATA RATE

WRITING

20 NSEC LIGHT PULSE

CORRESPONDS TO:

25 MHz (5×10^7 FLUX CHANGES/SEC)

POSSIBLE SYSTEM:

1.25×10^4 FLUX CHANGES/CM

5000 RPM

12 INCH DISK

READING

MINIMUM SNR (dB) = 20 dB

$\mathrm{SNR} \propto B^{-1}$

55 dB CNR (B = 30 kHz)

$$B\Big|_{20\,\mathrm{dB}} \approx 95\ \mathrm{MHz}$$

CONCLUSION

25 MHz (50 MBPS) DATA RATE SYSTEM

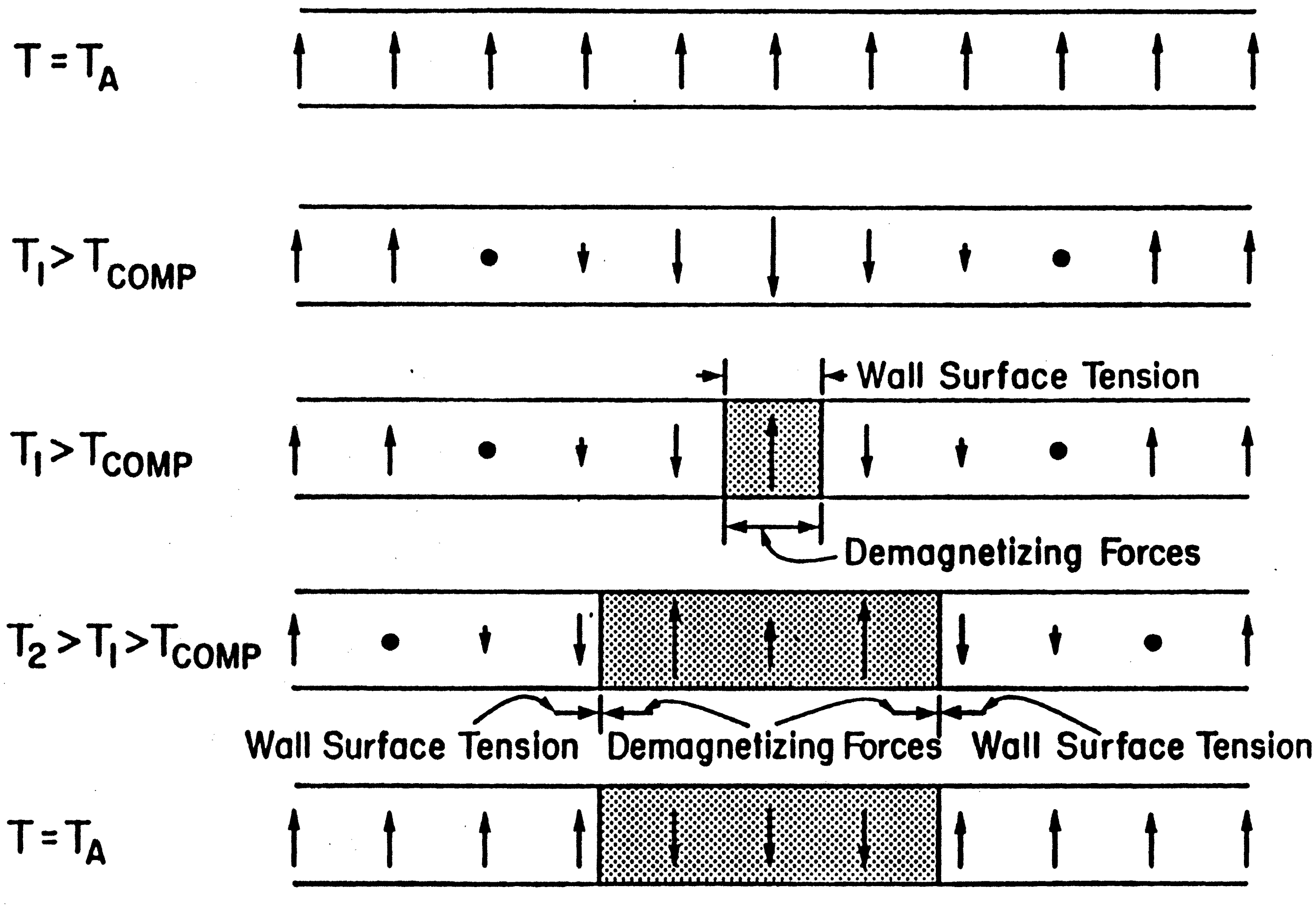
Magneto-Optic Recording Materials with Direct Overwrite Capability

- **Thermomagnetic Writing.**
- **Advantages of Direct Overwrite.**
- **M-O Media with Direct Overwrite Capability.**
- **Direct Overwrite Scheme.**
- **READ-BEFORE-WRITE.**

TODAY – NOT DIRECTLY OVERWRITABLE

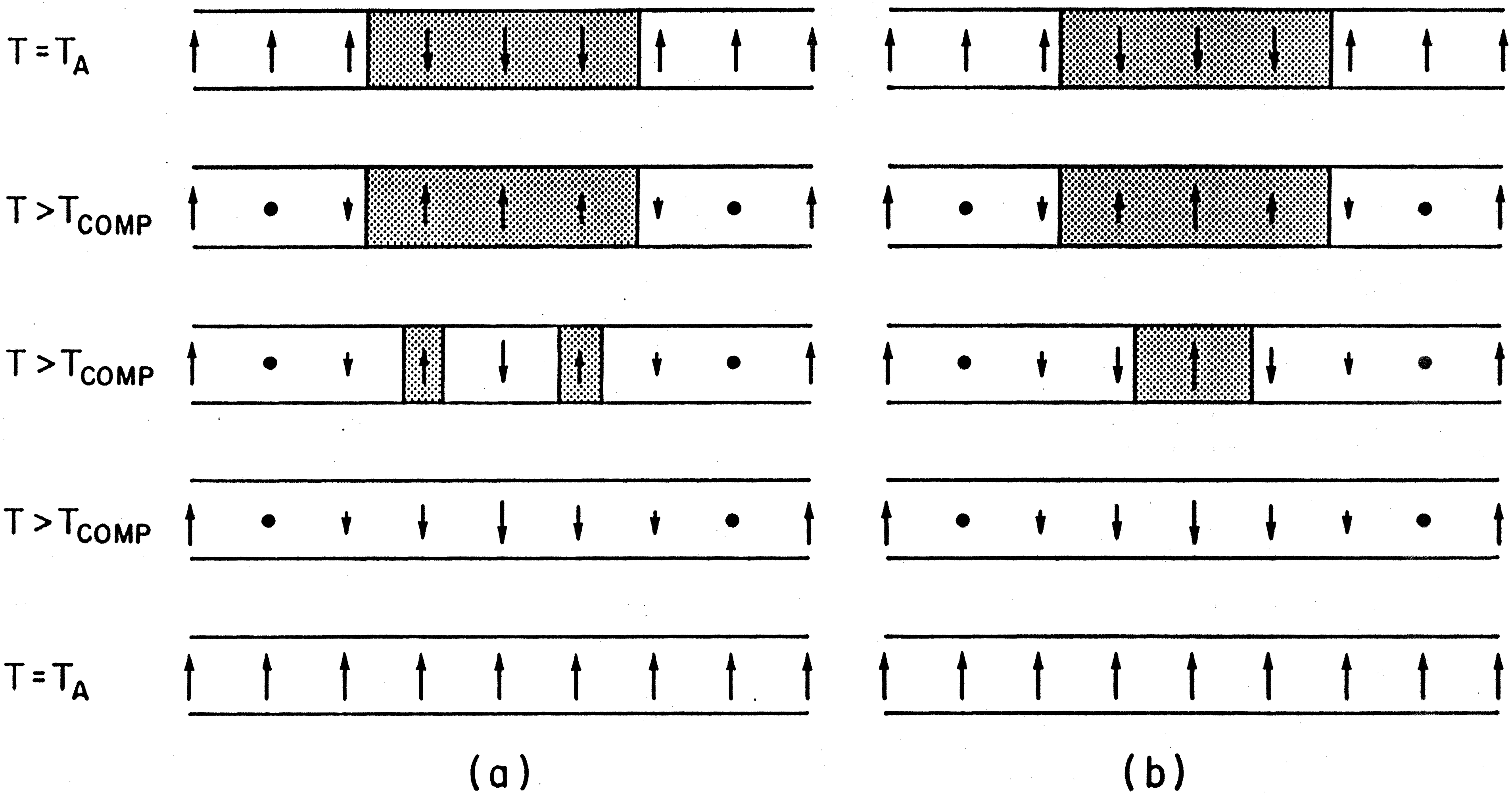
DOMAIN WRITING WITHOUT AN EXTERNAL MAGNETIC FIELD

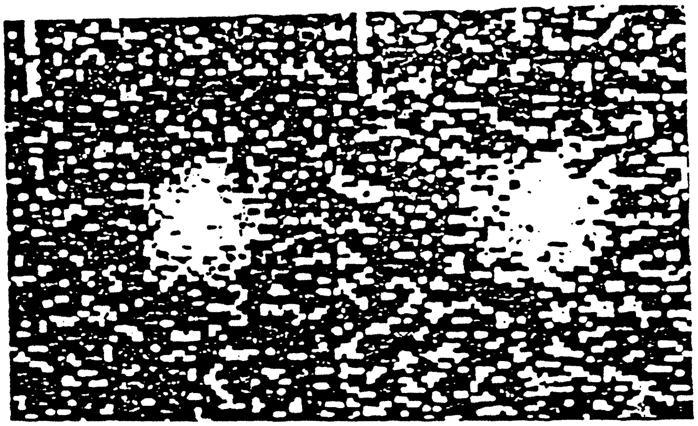
COMPENSATION POINT > ROOM TEMP



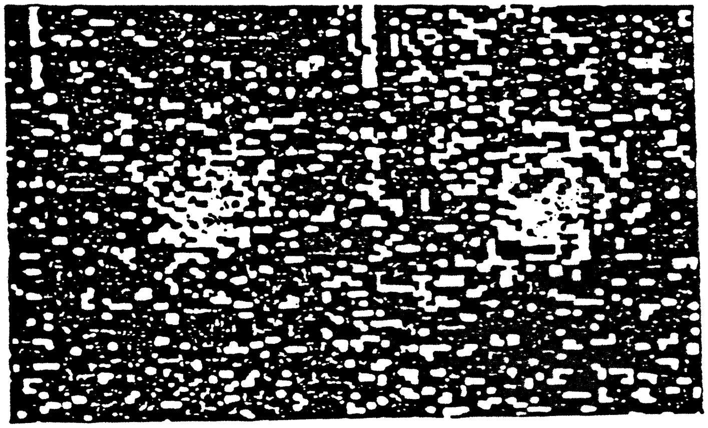
DOMAIN ERASURE WITHOUT AN EXTERNAL MAGNETIC FIELD

Not Right

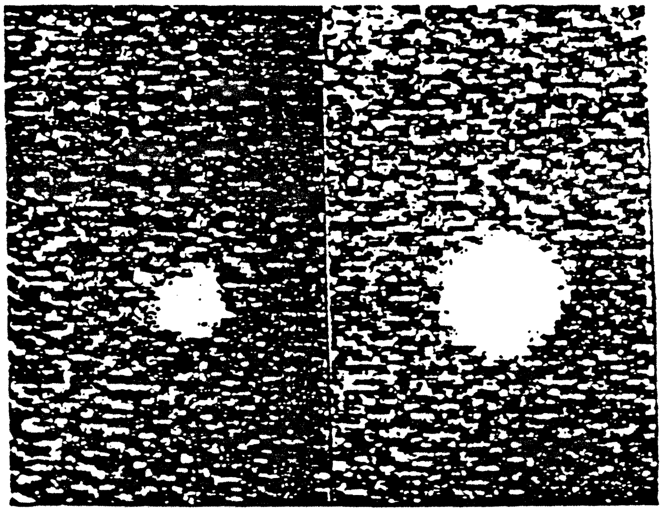




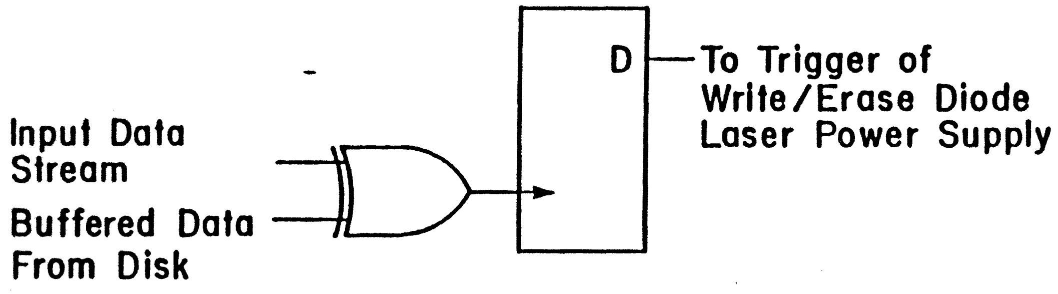
Before erase pulse 30 nsec before EPTE



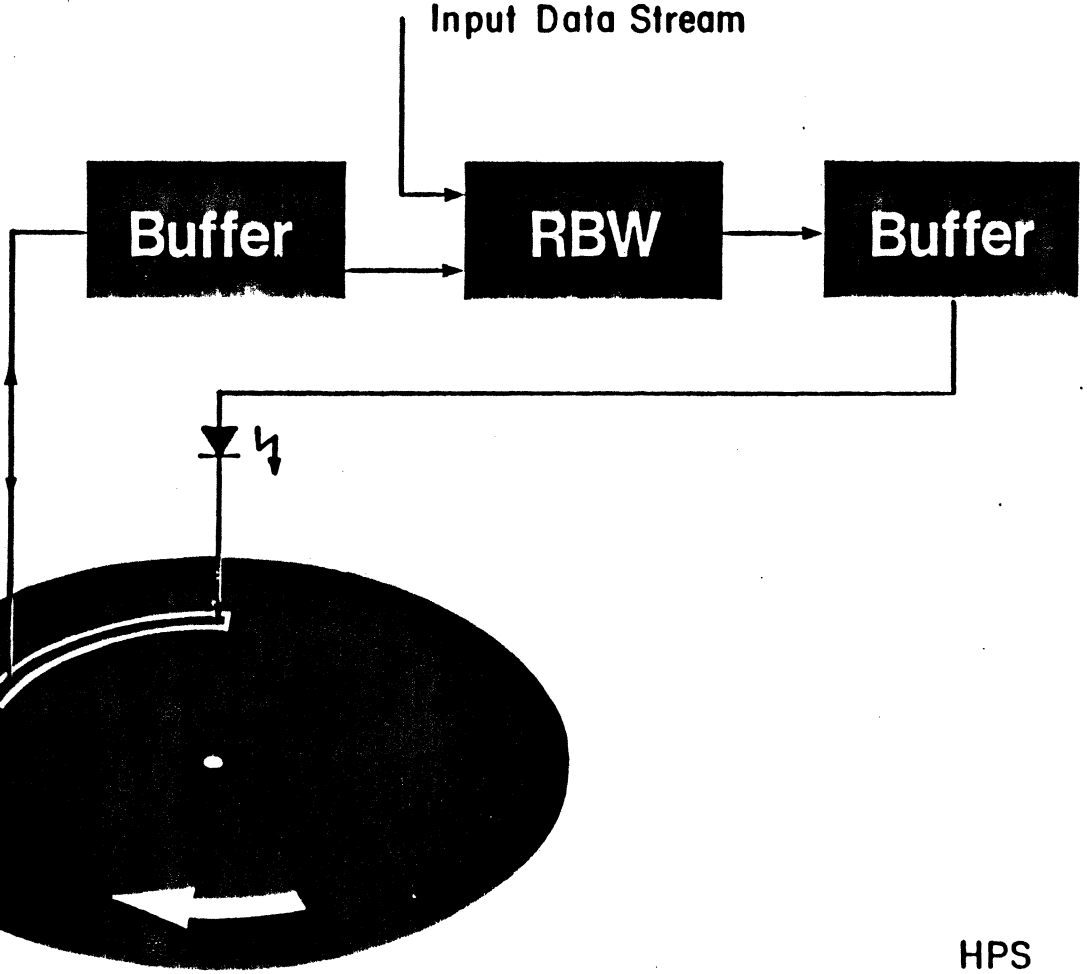
10 nsec after EPTE 30 nsec after EPTE



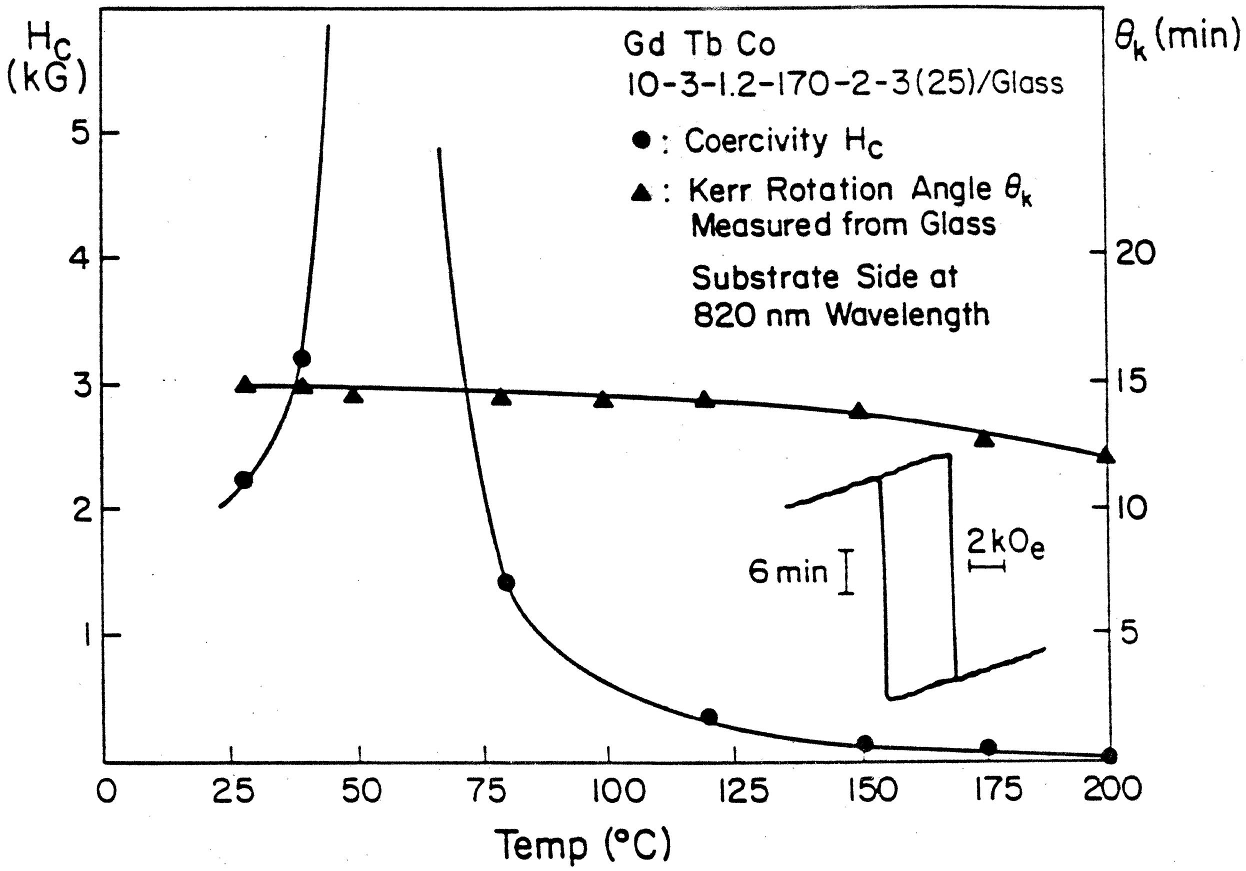
170 nsec erase pulse 150 nsec erase pulse


Input Data Stream
Buffered Data From Disk
D
To Trigger of Write/Erase Diode Laser Power Supply

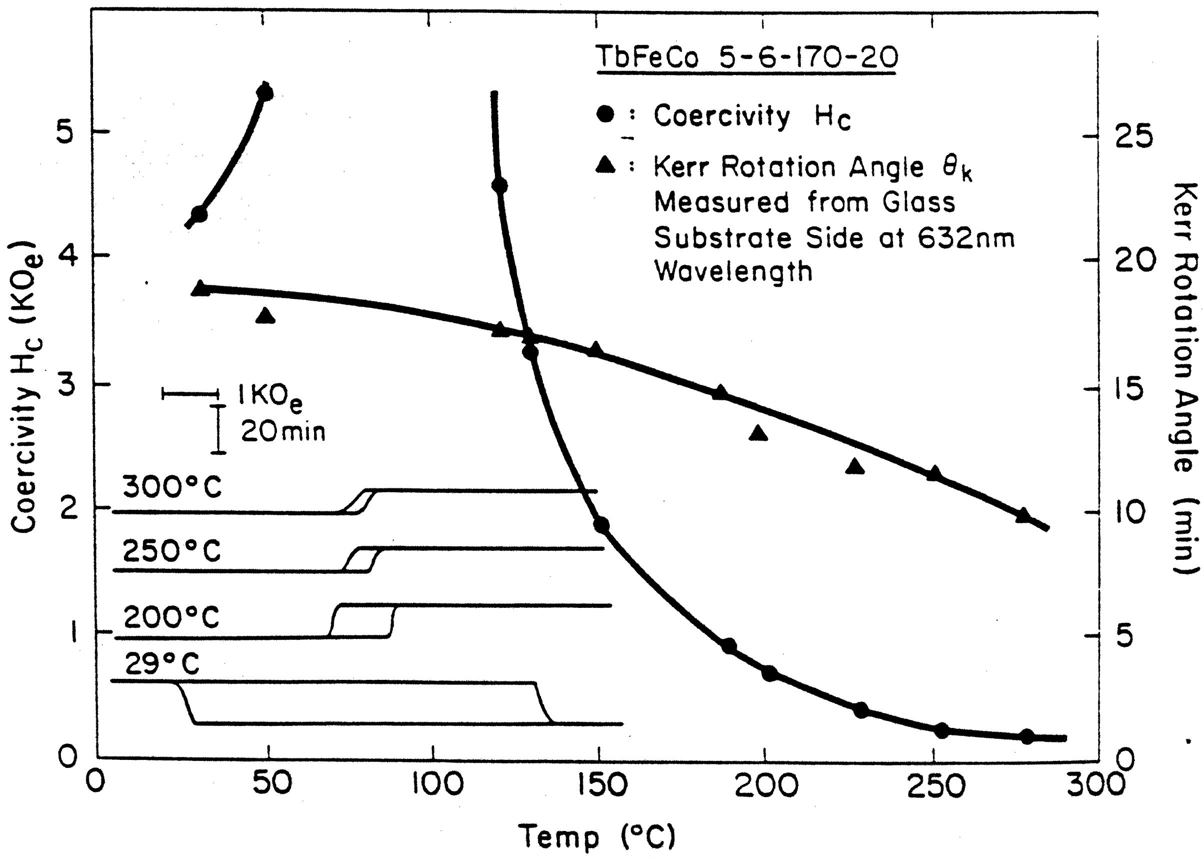
RBW


Input Data Stream
Buffer
RBW
Buffer

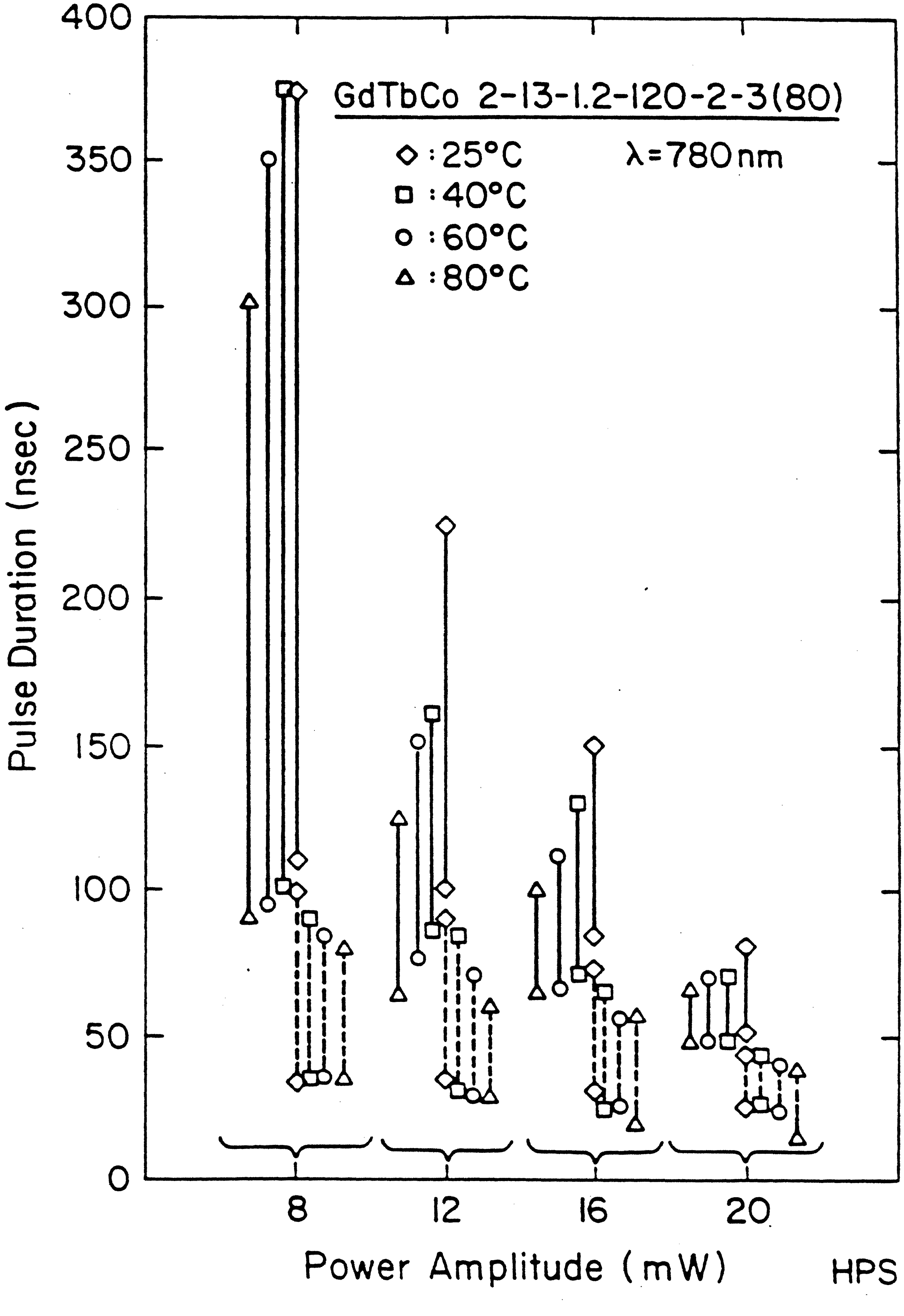
HPS



H_C (kG)
θ_k (min)
Gd Tb Co
10-3-1.2-170-2-3(25)/Glass
● : Coercivity H_C
▲ : Kerr Rotation Angle θ_k Measured from Glass Substrate Side at 820 nm Wavelength
6 min
2 kOe
1
2
3
4
5
5
10
15
20
0
25
50
75
100
125
150
175
200
Temp (°C)

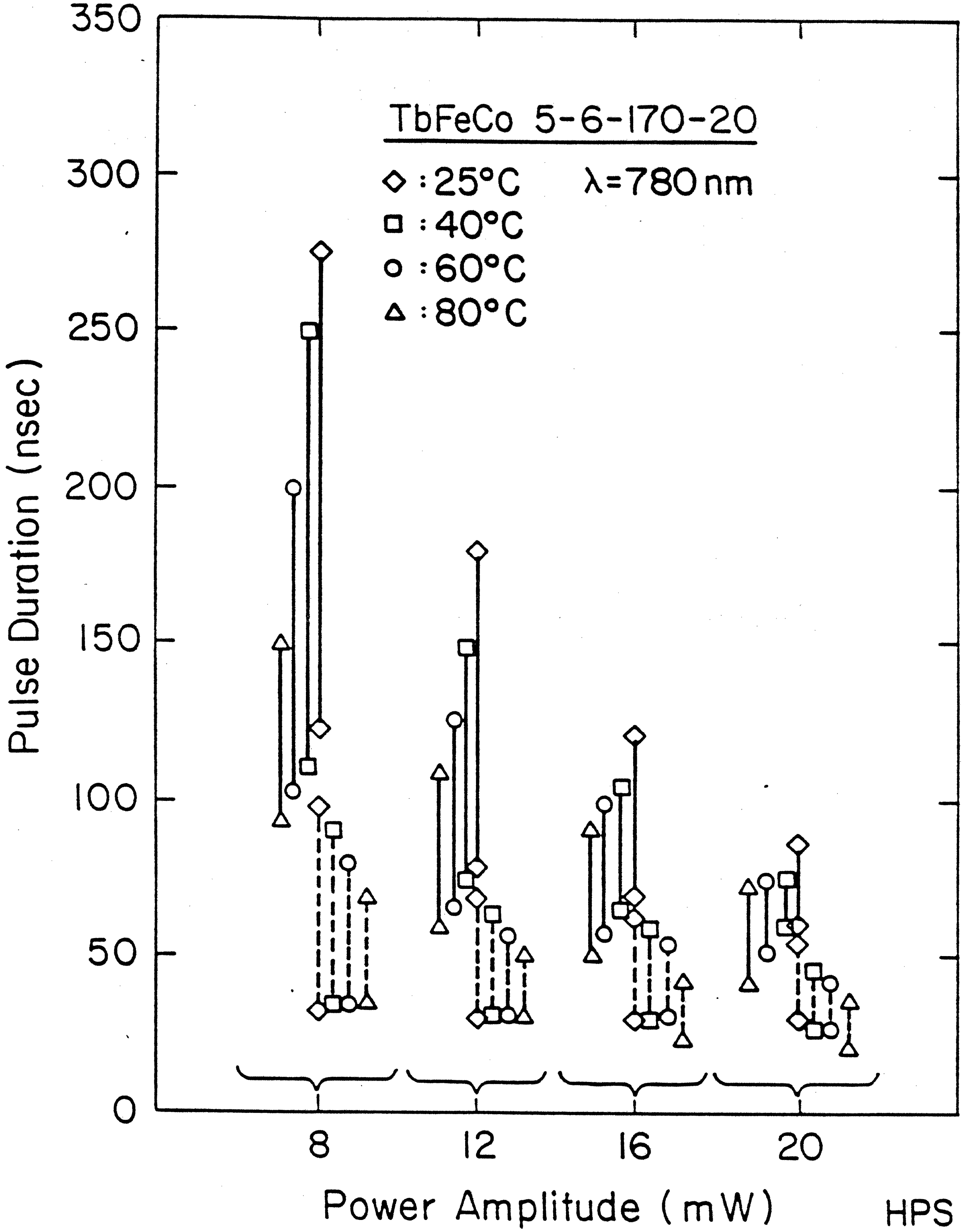


TbFeCo 5-6-170-20
● : Coercivity H_C
▲ : Kerr Rotation Angle θ_k Measured from Glass Substrate Side at 632nm Wavelength
Coercivity H_C (KO_e)
Kerr Rotation Angle (min)
1 KO_e
20 min
300°C
250°C
200°C
29°C
0
1
2
3
4
5
0
5
10
15
20
25
0
50
100
150
200
250
300
Temp (°C)



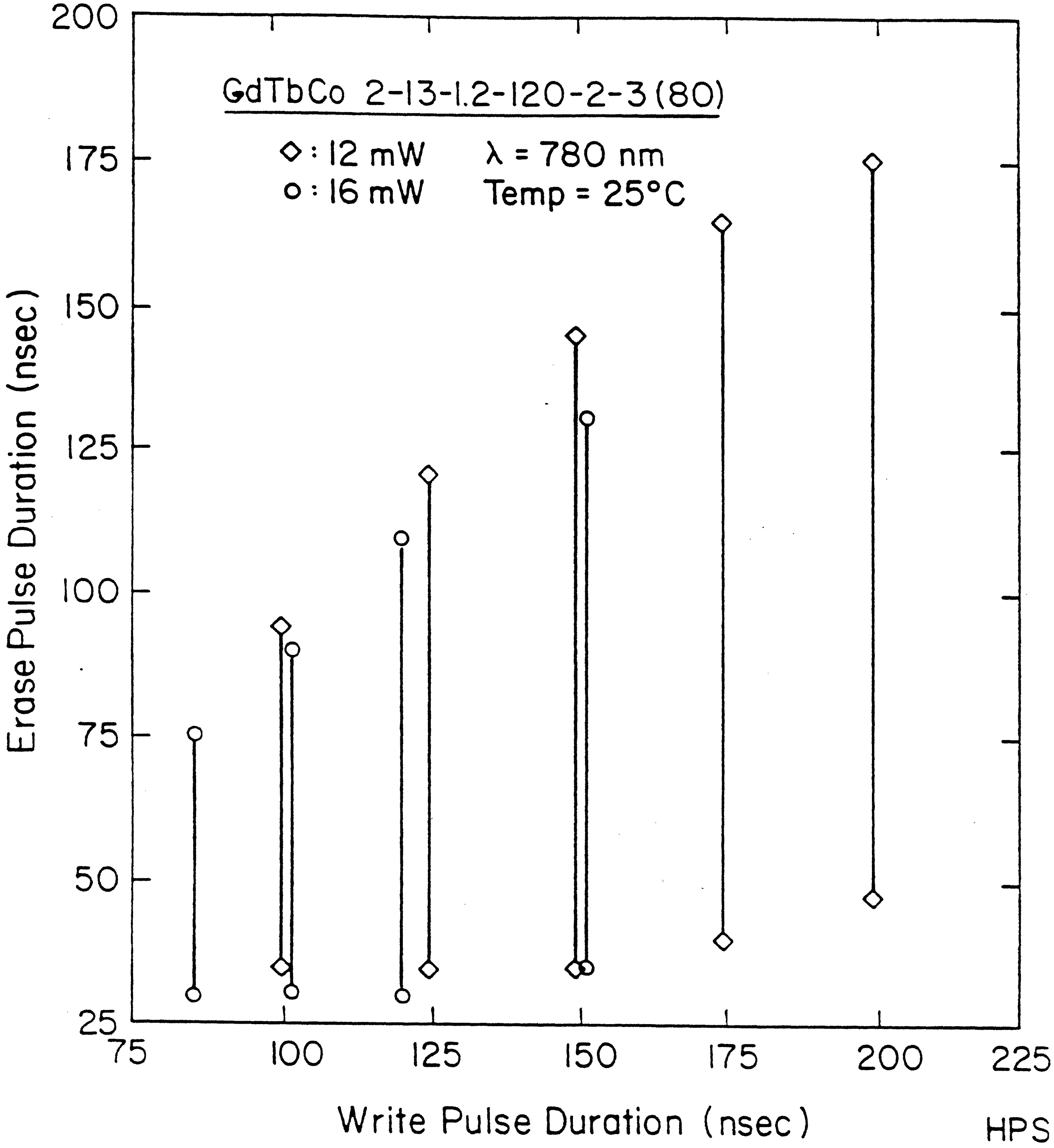
GdTbCo 2-13-1.2-120-2-3(80)
◇ : 25°C
□ : 40°C
○ : 60°C
△ : 80°C
λ=780nm
Pulse Duration (nsec)
0
50
100
150
200
250
300
350
400
8
12
16
20
Power Amplitude (mW)
HPS

Fig. 3(a)



TbFeCo 5-6-170-20
◇ : 25°C
□ : 40°C
○ : 60°C
△ : 80°C
λ=780 nm
Pulse Duration (nsec)
0
50
100
150
200
250
300
350
8
12
16
20
Power Amplitude (mW)

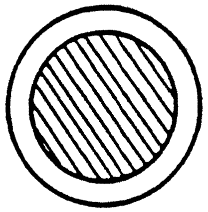
HPS


GdTbCo 2-13-1.2-120-2-3 (80)
◇ : 12 mW
○ : 16 mW
λ = 780 nm
Temp = 25°C
Erase Pulse Duration (nsec)
200
175
150
125
100
75
50
25
75
100
125
150
175
200
225
Write Pulse Duration (nsec)

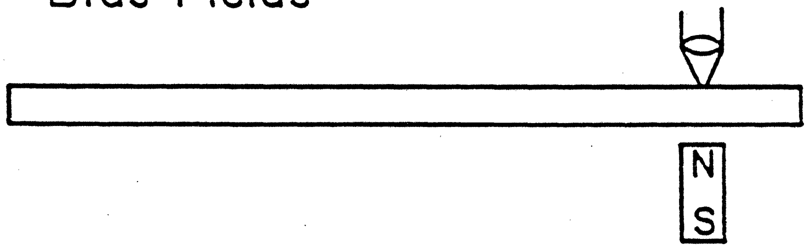
HPS

Performance and Function Research

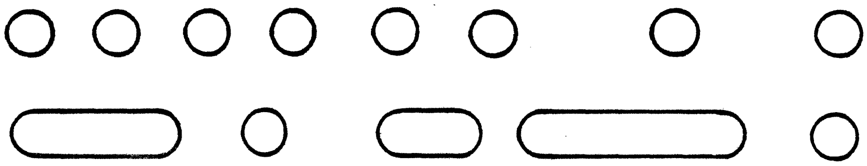
· Erase Error



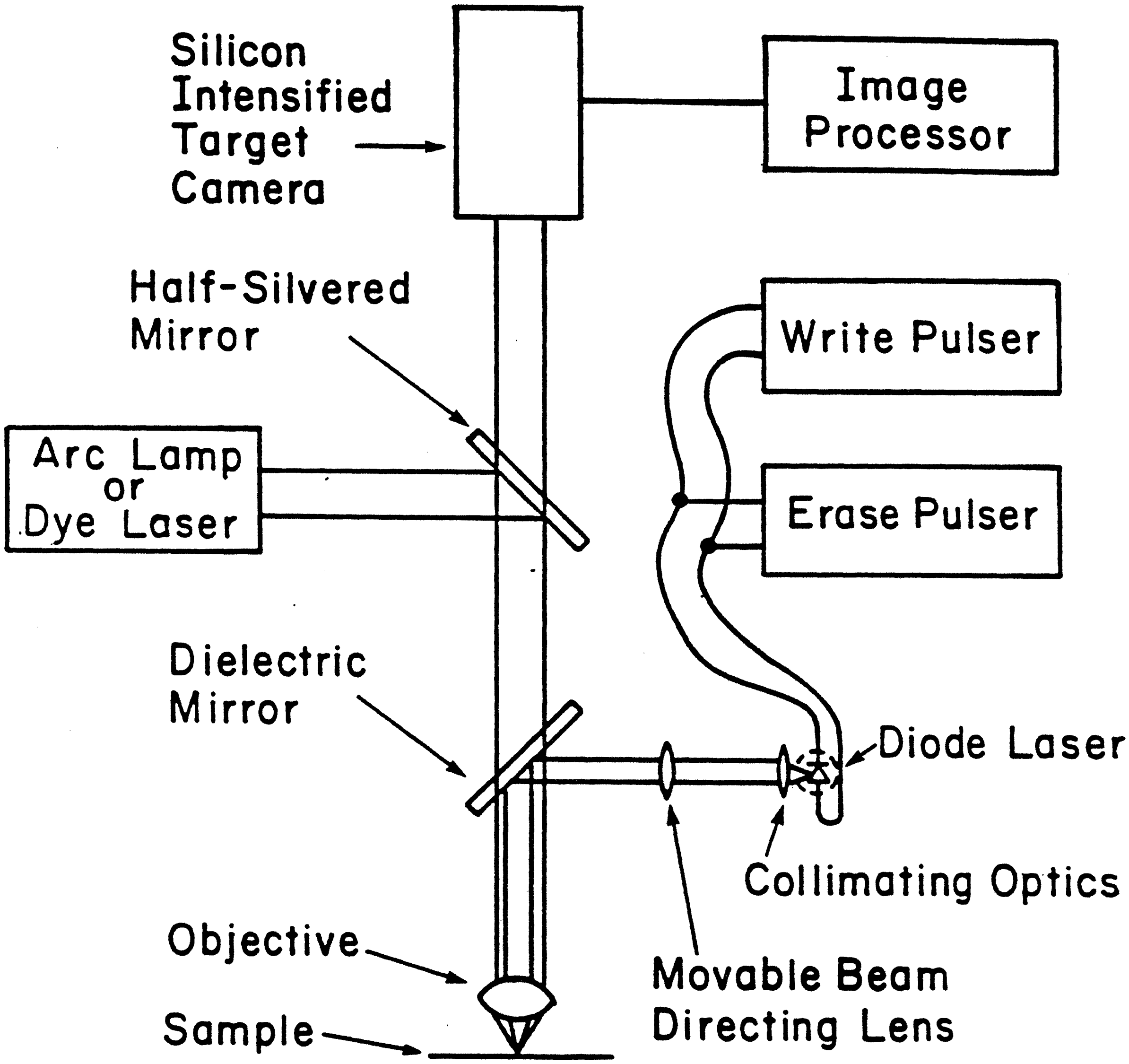
Bias Fields

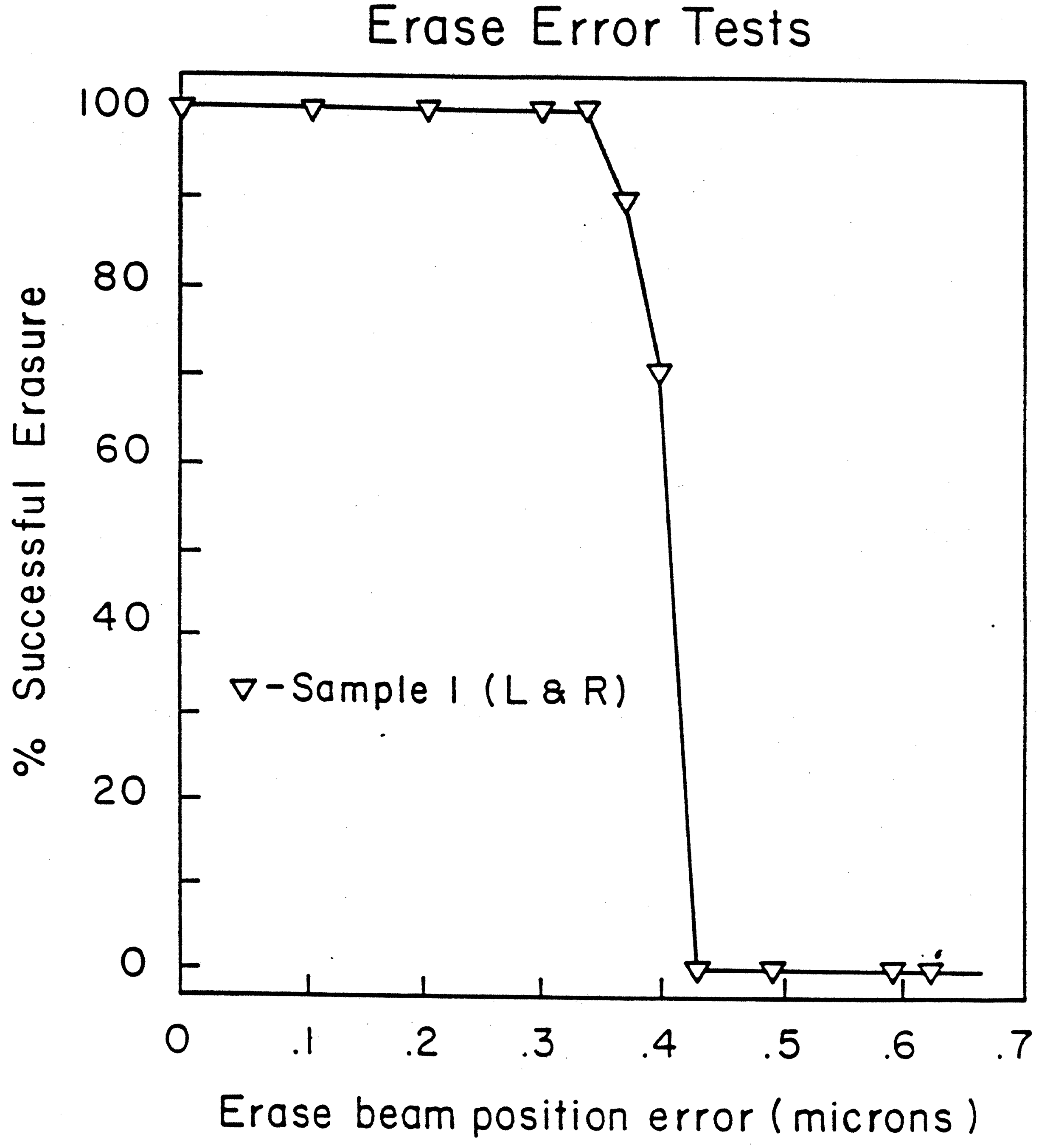


"Stripe" domains

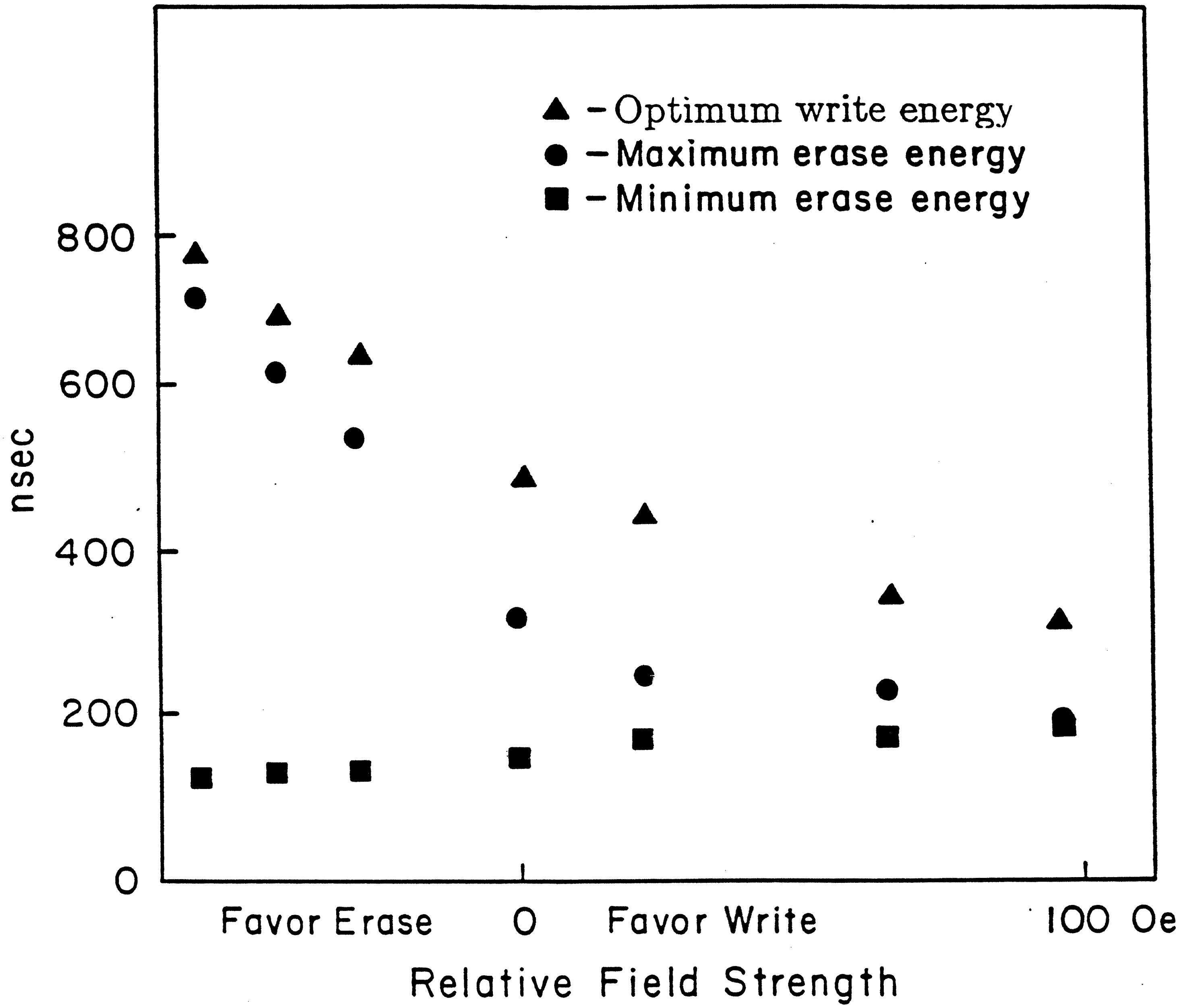


Experimental Equipment



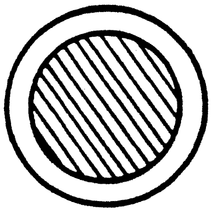


0,8 MICRON
DIAMETER

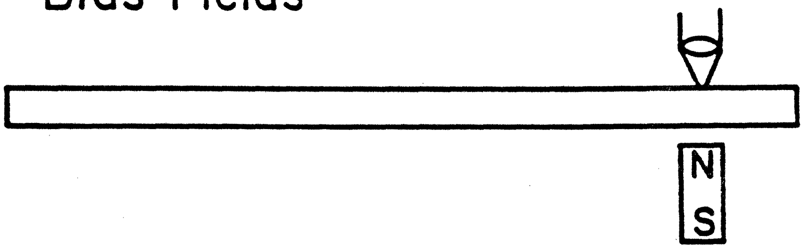

▲ - Optimum write energy
● - Maximum erase energy
■ - Minimum erase energy
800
600
400
200
0
nsec
Favor Erase
0
Favor Write
100 Oe
Relative Field Strength

Performance and Function Research

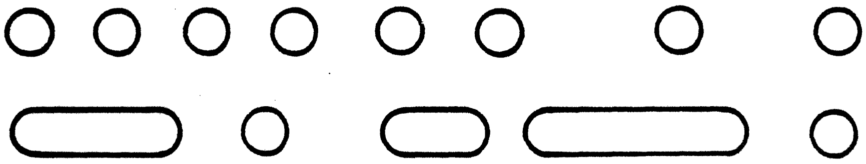
Erase Error



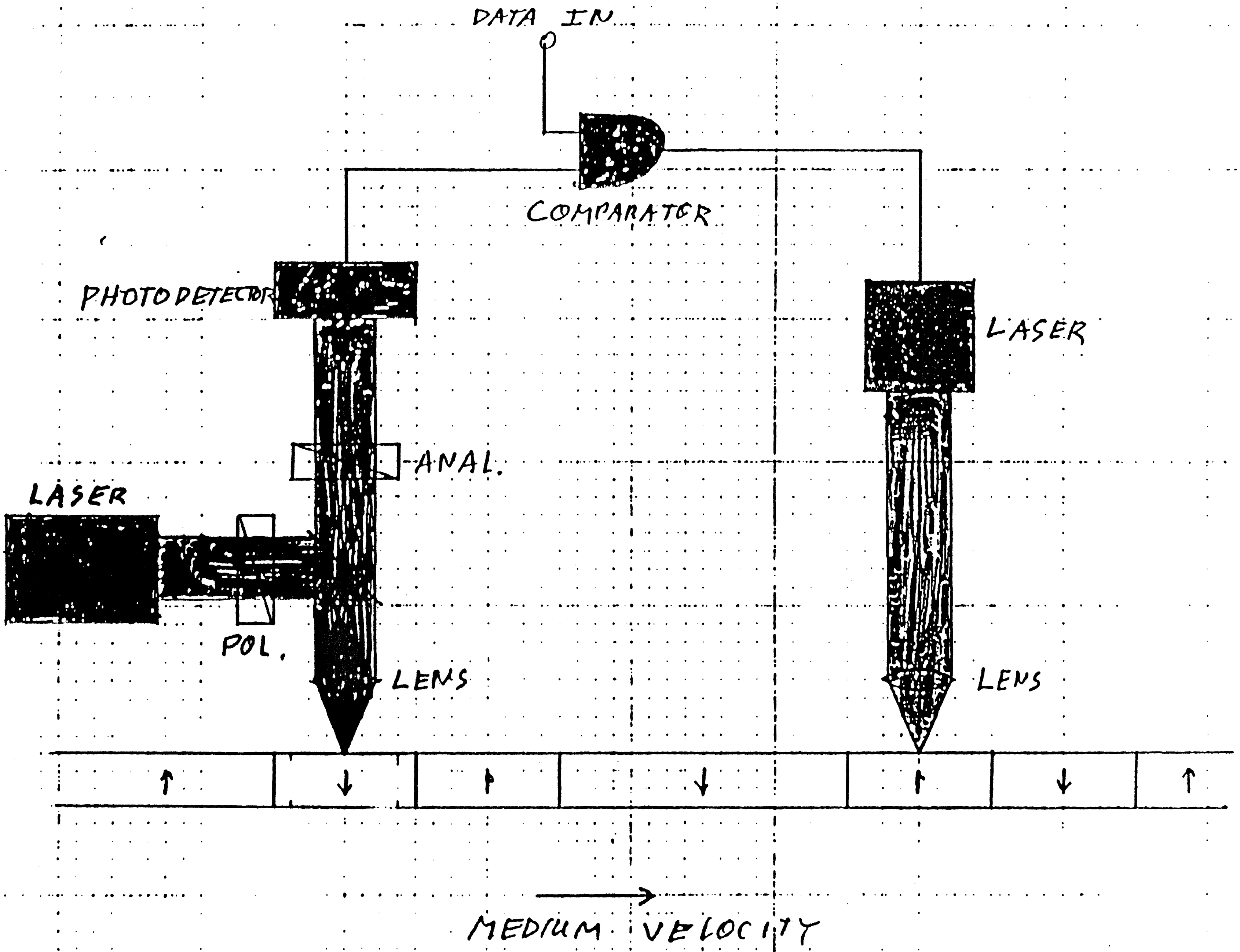
Bias Fields



"Stripe" domains



READ BEFORE WRITE



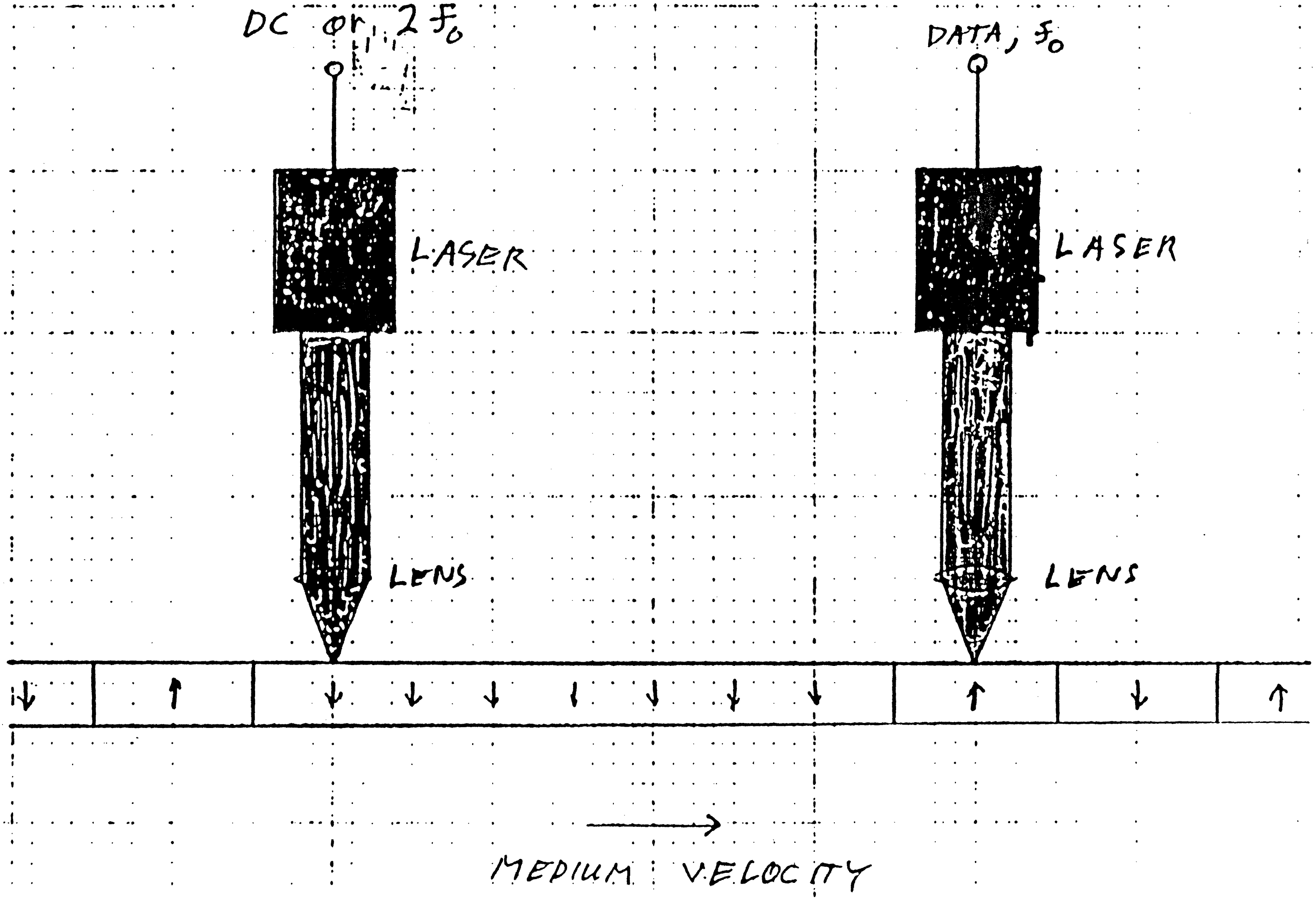
READ BEFORE WRITE

- MUST HIT WITHIN CENTER 75% OF DOMAIN

  +/- 37.5 NSEC TIMING MARGIN AT 10 MHz

- WIDE PULSE DURATION MARGINS
- DC BIAS FIELD CAN BE USED TO IMPROVE DATA RATE
- DC BIAS FIELD MAY ALSO IMPROVE SNR

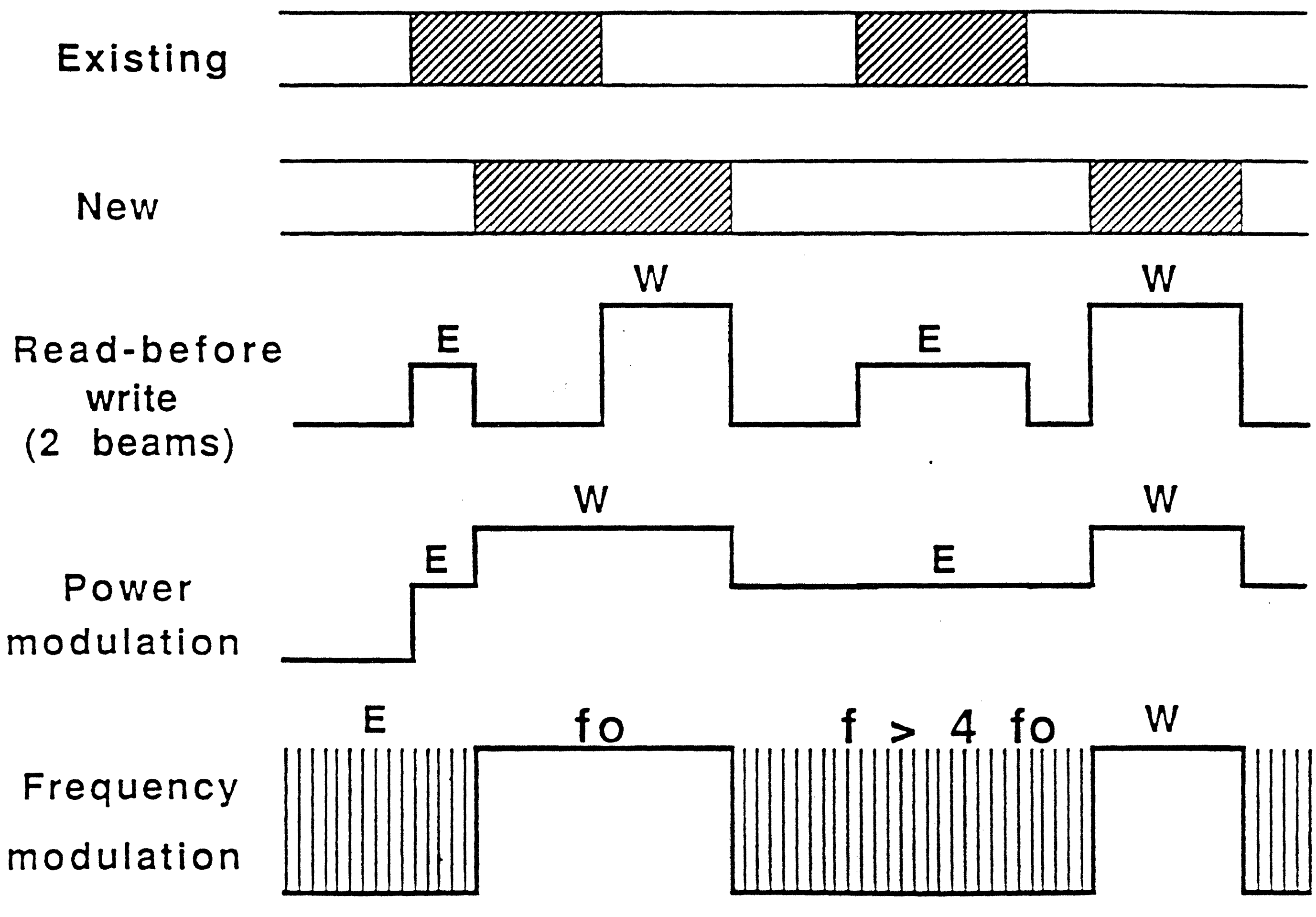
ERASE BEFORE WRITE

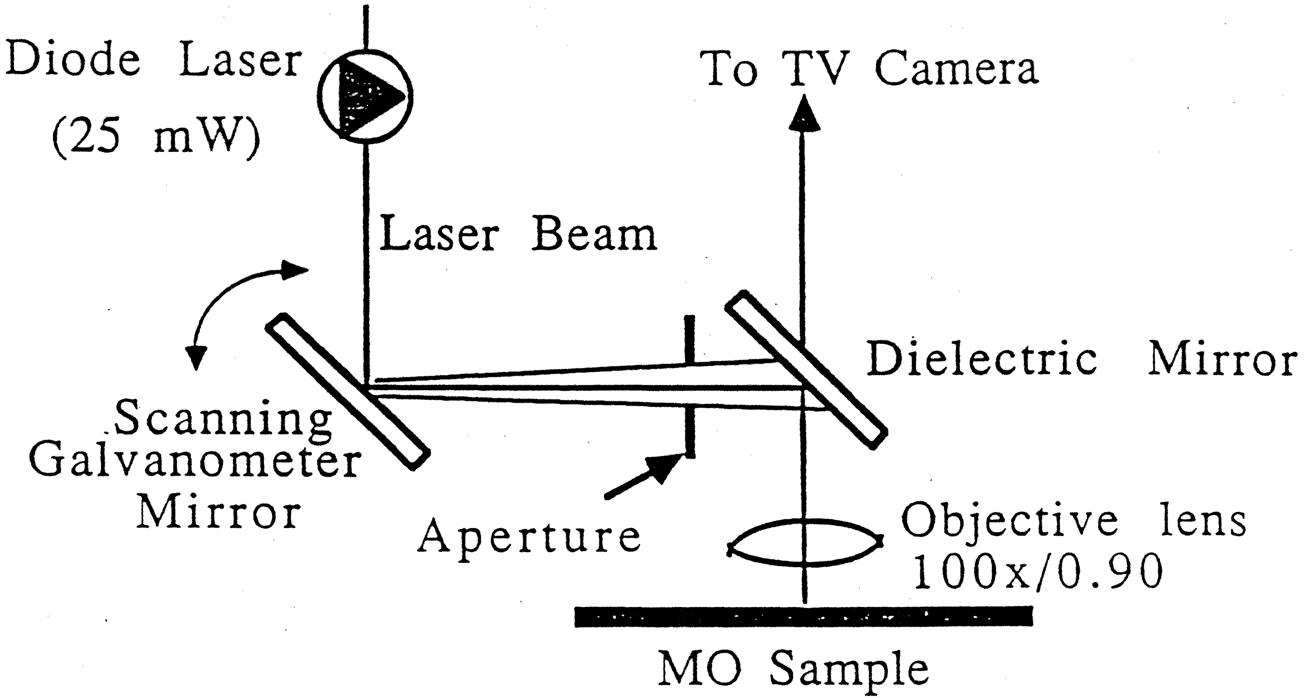


ERASE BEFORE WRITE

- AC (f=2f[$_0$]) INSURES COMPLETE ERASURE WITHOUT CLOCK
- DC WORKS, BUT MAY REQUIRE MORE STRINGENT MEDIA SPECIFICATIONS

SINGLE BEAM
DIRECT OVERWRITE





7.5 m/sec linear speed --> 1432 rpm at 5 cm radius.

CONCLUSIONS

- SINGLE LAYER DIRECT OVERWRITE MAY BE POSSIBLE
- SCANNING RATES UP TO 15 M/SEC
- READ-BEFORE-OVERWRITE
- ERASE-BEFORE-OVERWRITE
- SINGLE BEAM OVERWRITE

MAGNETO-OPTIC RECORDING MATERIALS

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H.P.D. Shieh

Magnetics Technology Center
Carnegie-Mellon University
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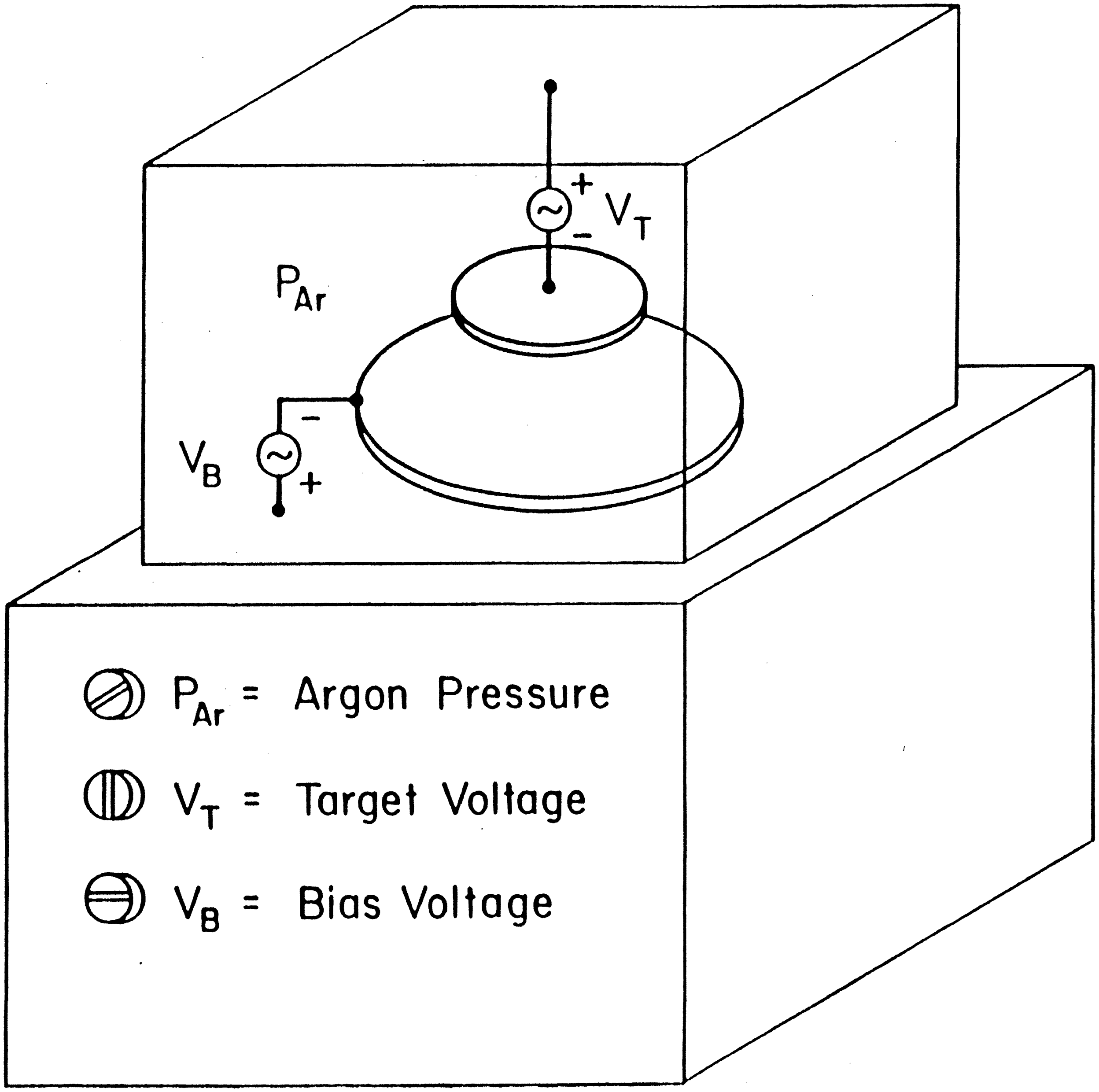
TYPICAL SPUTTERING SYSTEM

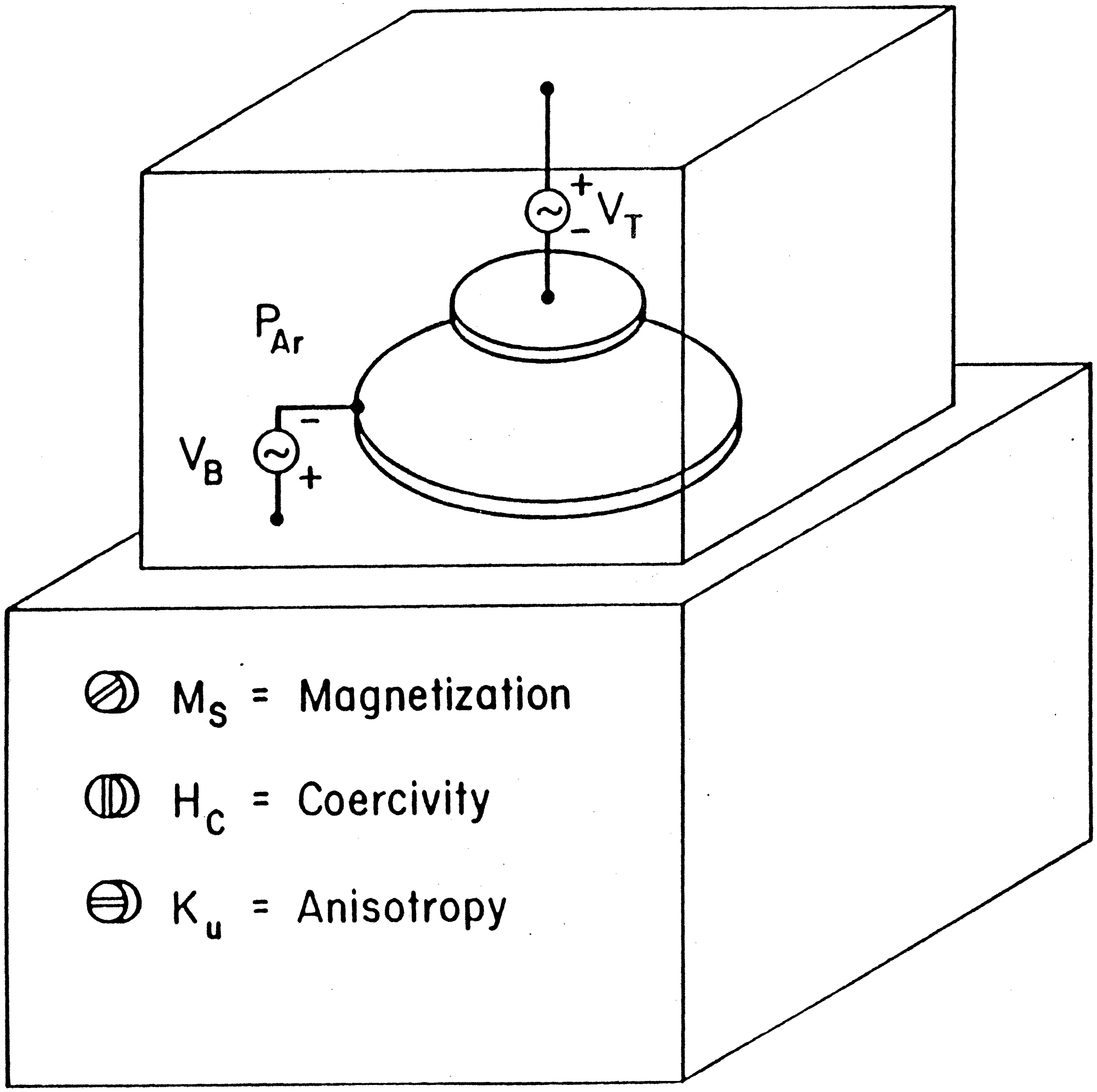


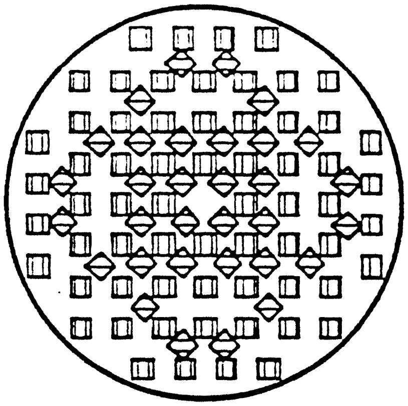
⊘ P_{Ar} = Argon Pressure

⦷ V_T = Target Voltage

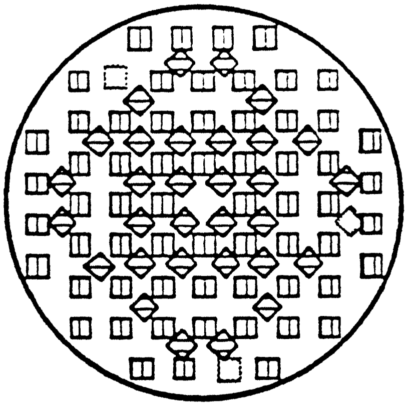
⊖ V_B = Bias Voltage

IDEAL SPUTTERING SYSTEM

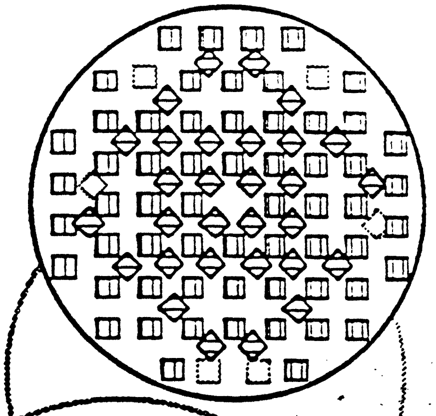




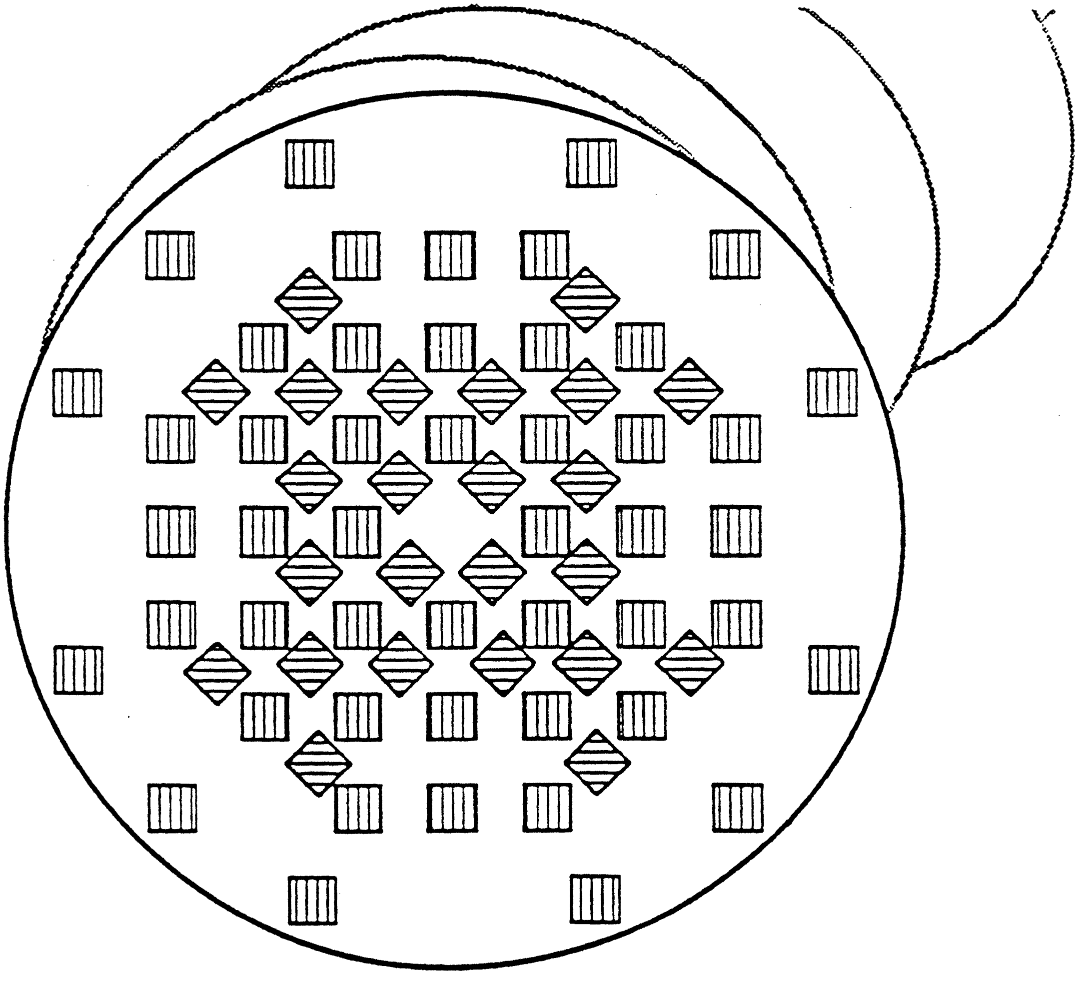
96 RE squares
67% Co



93 RE squares
68% Co

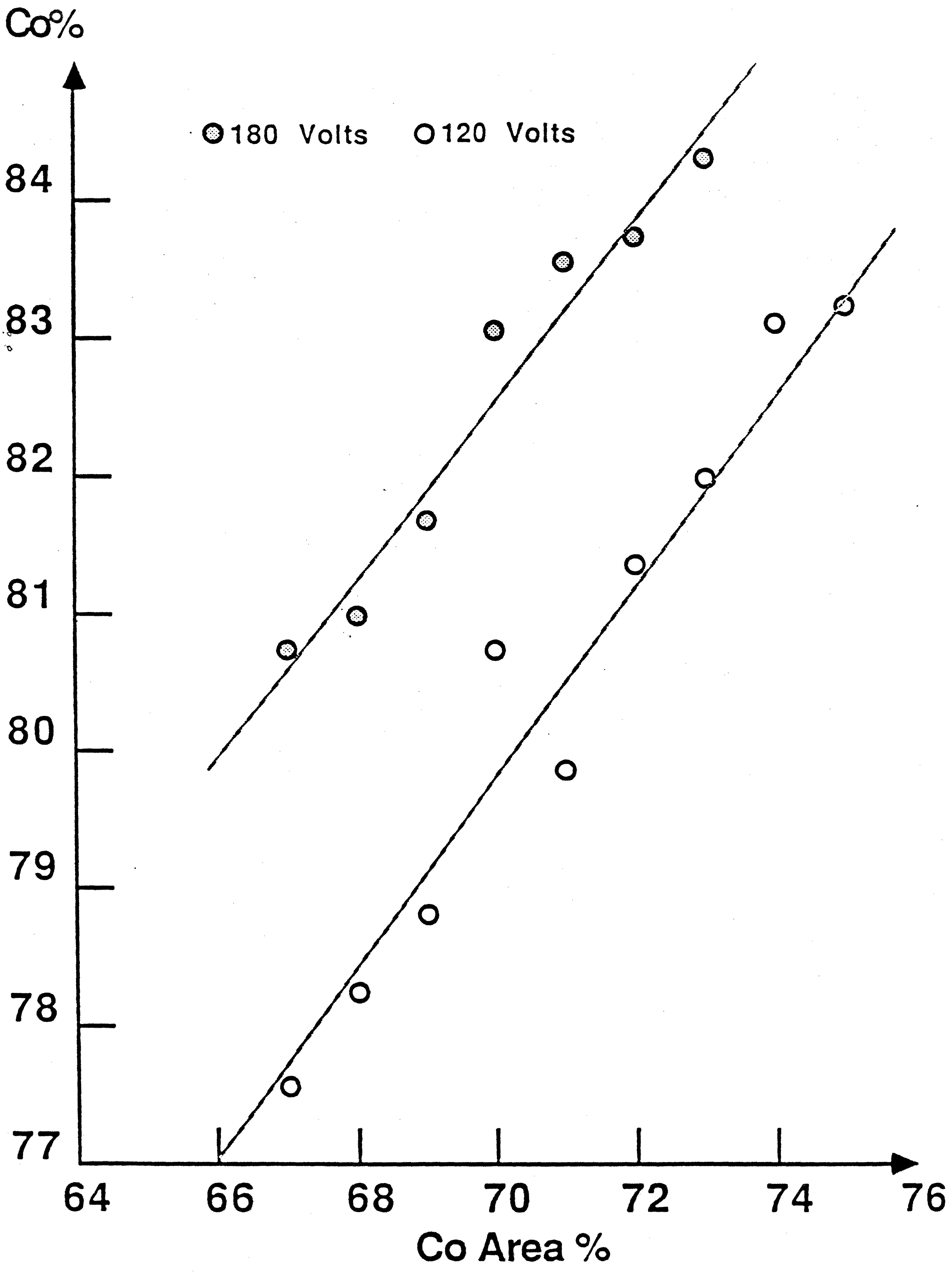


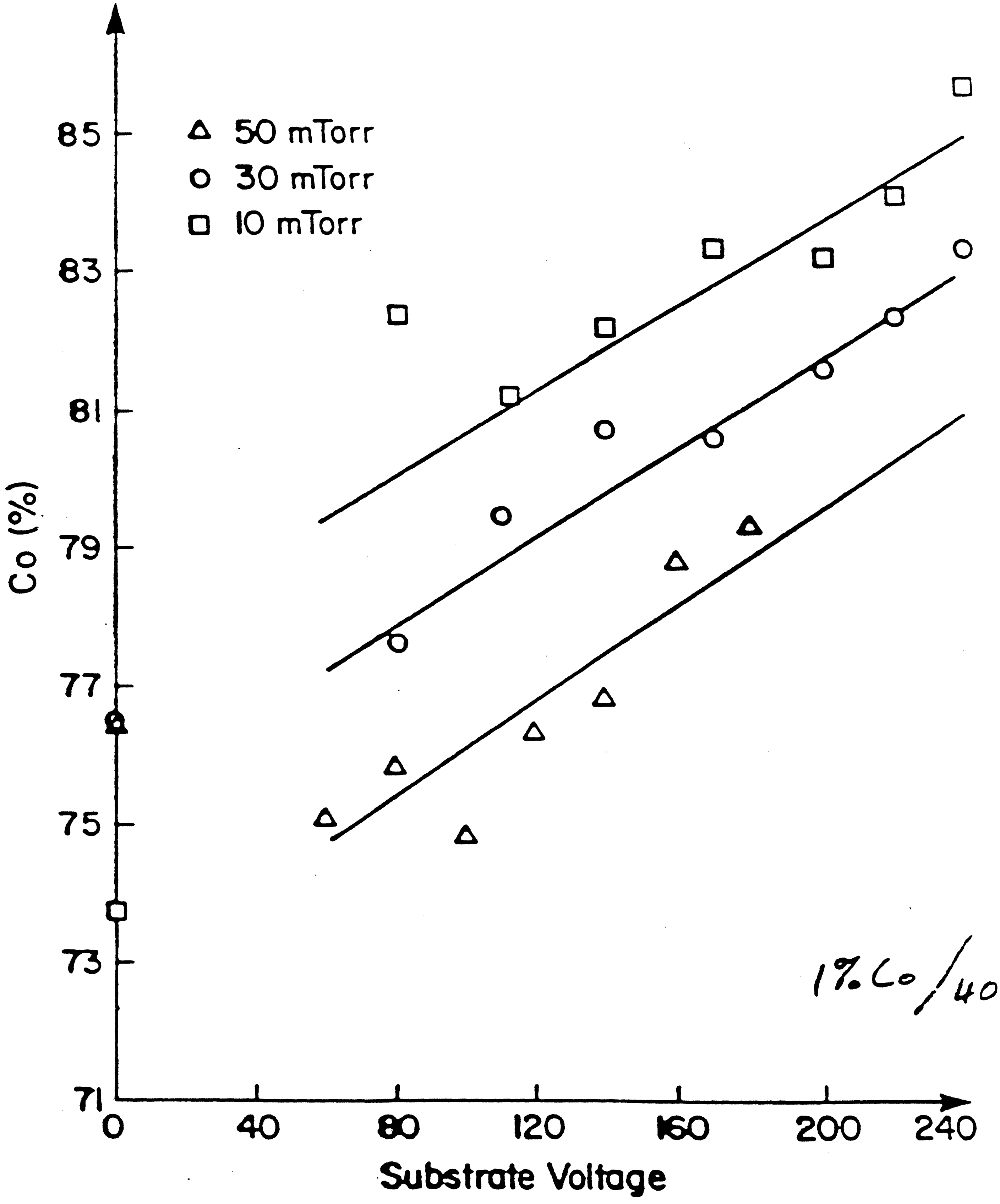
90 RE squares
69% Co



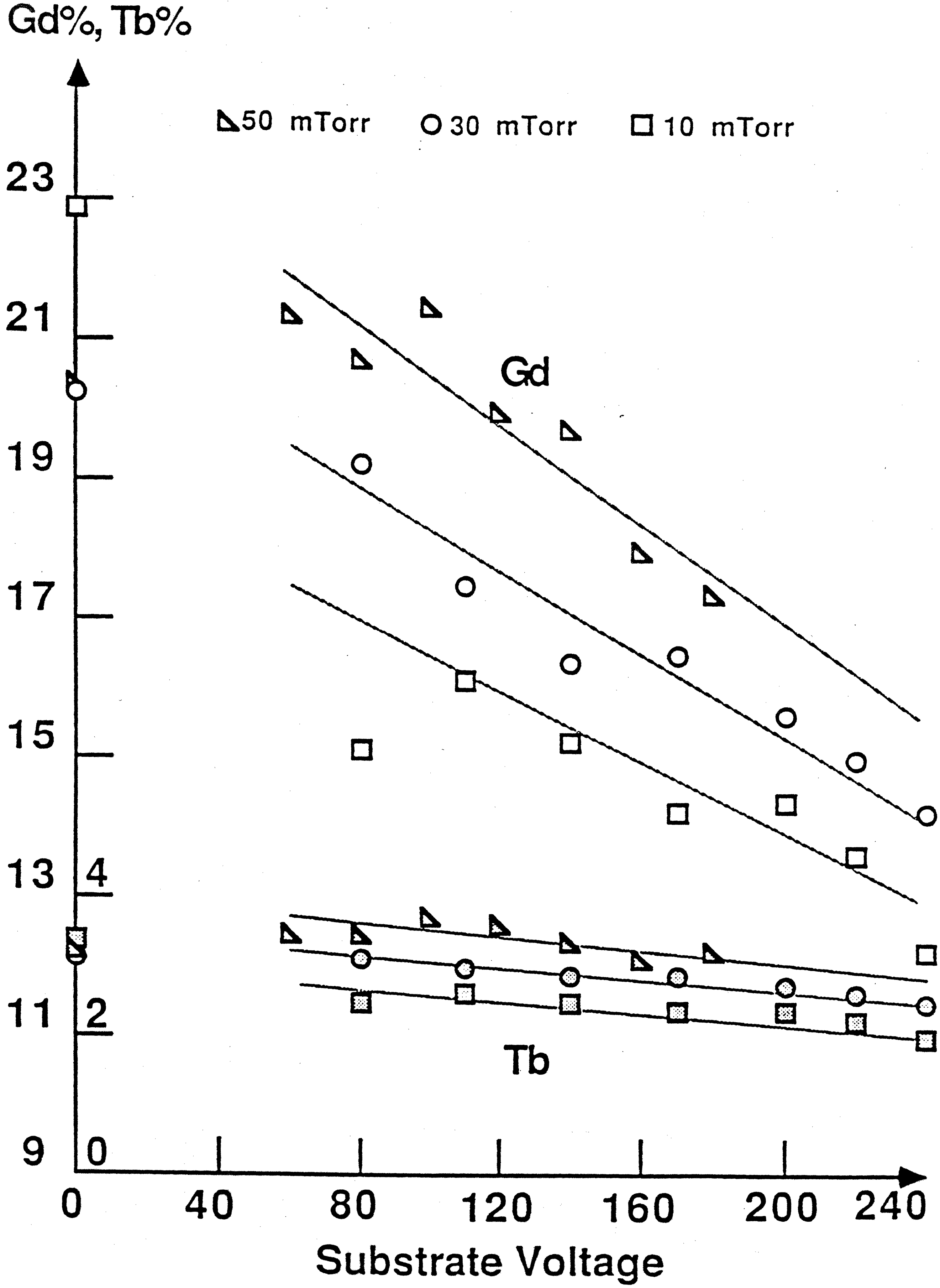
72 RE Squares
75% Co

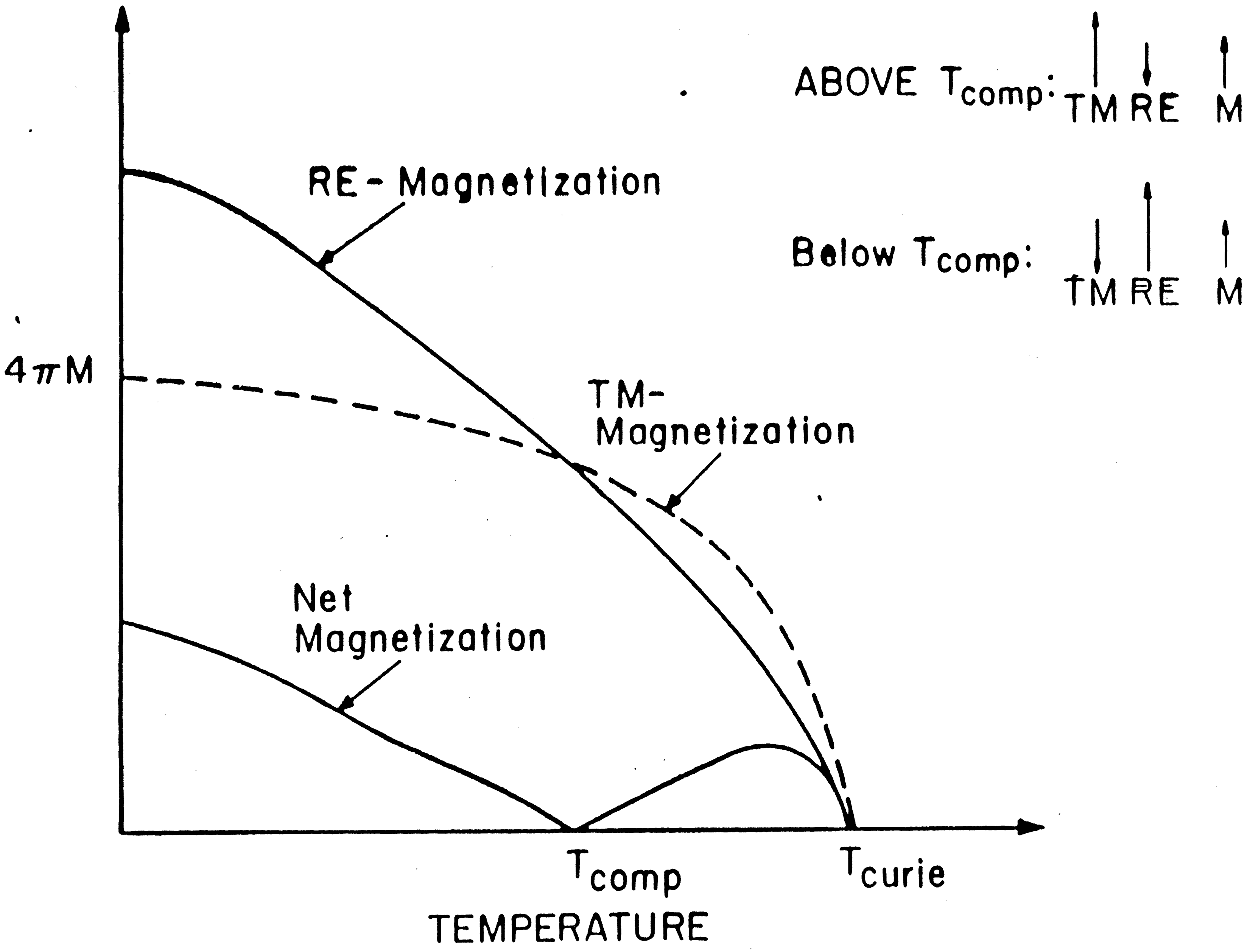
Changing targets [illegible] [illegible]

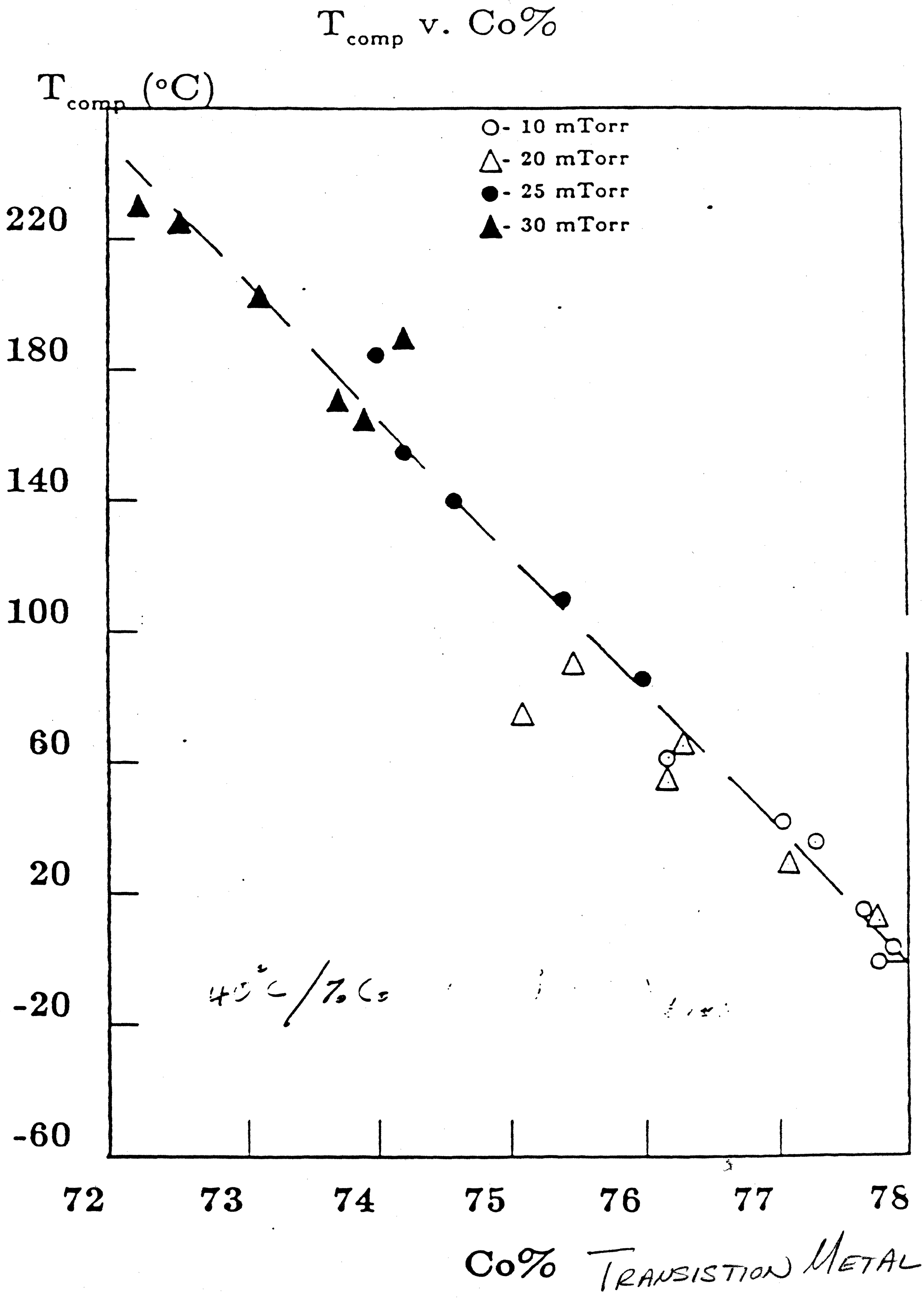

Co%
● 180 Volts
○ 120 Volts
84
83
82
81
80
79
78
77
64
66
68
70
72
74
76
Co Area %


△ 50 mTorr
○ 30 mTorr
□ 10 mTorr
Co (%)
85
83
81
79
77
75
73
71
0
40
80
120
160
200
240
Substrate Voltage

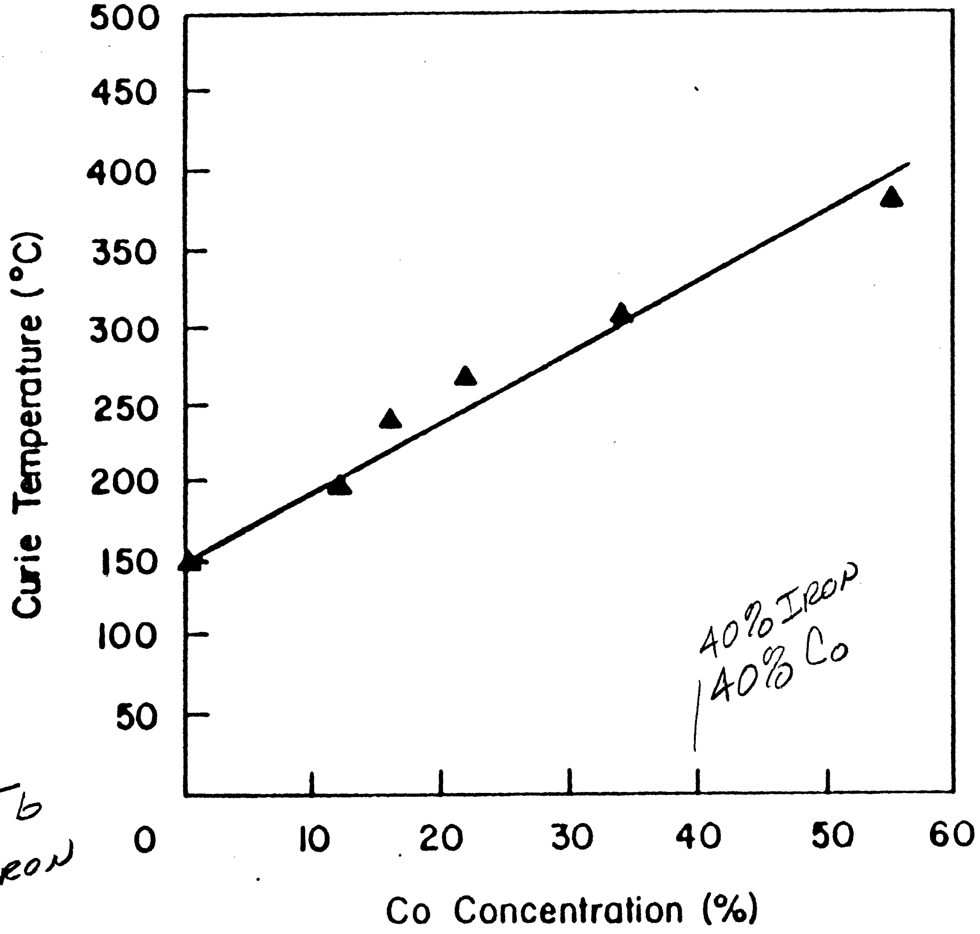
1% Co / 40 V$_{bi}$


Gd%, Tb%
◺50 mTorr
○30 mTorr
□10 mTorr
23
21
19
17
15
13
11
9
4
2
0
Gd
Tb
0
40
80
120
160
200
240
Substrate Voltage


ABOVE T_{comp}: TM RE M
Below T_{comp}: TM RE M
RE- Magnetization
TM- Magnetization
Net Magnetization
$4\pi M$
T_{comp}
T_{curie}
TEMPERATURE



T_{comp} v. Co%
T_{comp} (°C)
○- 10 mTorr
△- 20 mTorr
●- 25 mTorr
▲- 30 mTorr
220
180
140
100
60
20
-20
-60
72
73
74
75
76
77
78
Co% TRANSISTION METAL
40°C/%Co

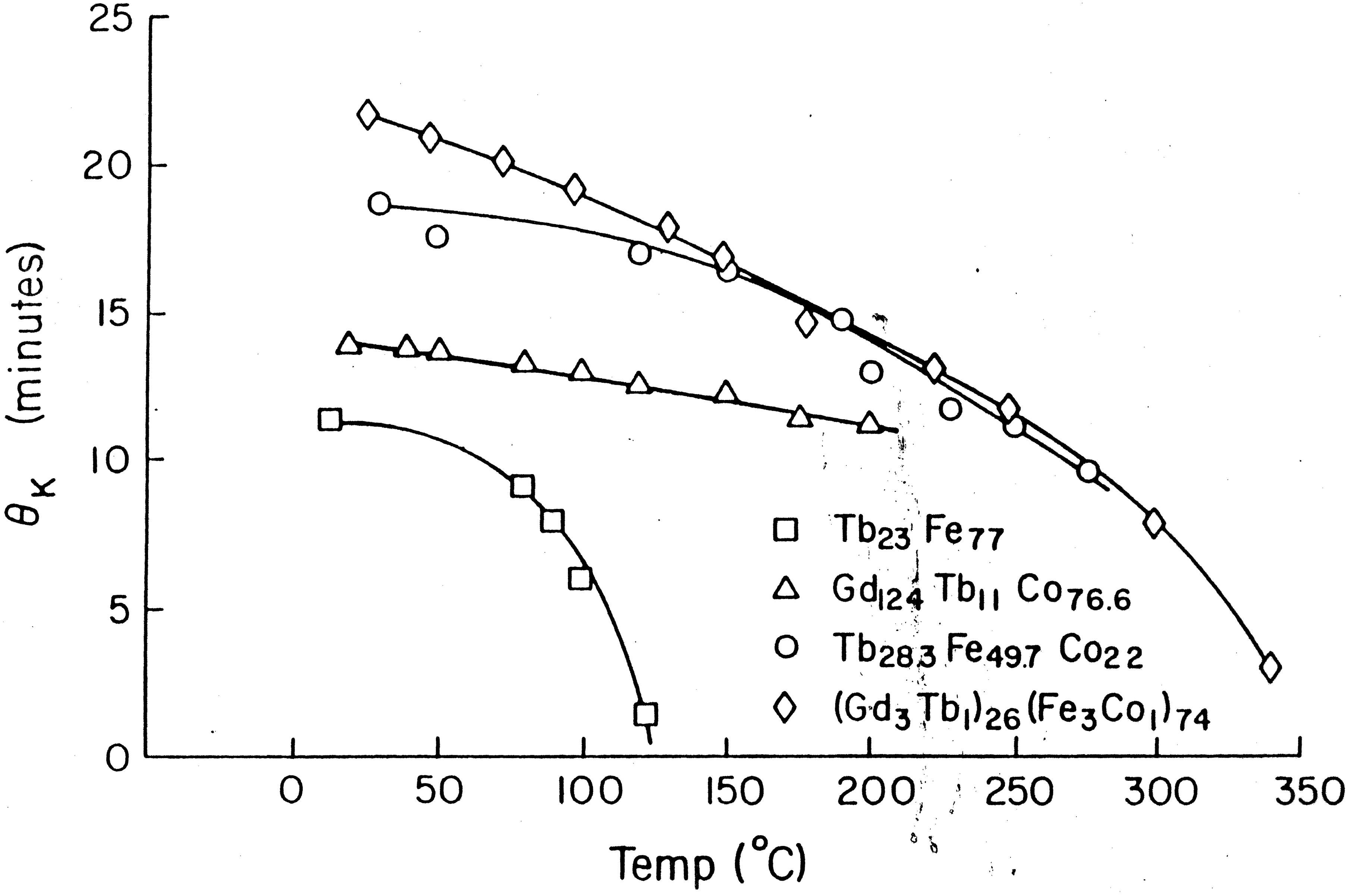


20% Tb
80% Iron

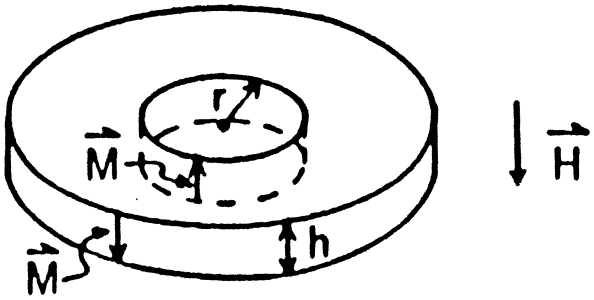
40% Iron
40% Co

Rare Earth
Content Fixed

% of Transition Metal


θ_K (minutes)
25
20
15
10
5
0
0
50
100
150
200
250
300
350
Temp (°C)
□ $Tb_{23}Fe_{77}$
△ $Gd_{12.4}Tb_{11}Co_{76.6}$
○ $Tb_{28.3}Fe_{49.7}Co_{22}$
◇ $(Gd_3Tb_1)_{26}(Fe_3Co_1)_{74}$

DOMAIN STABILITY



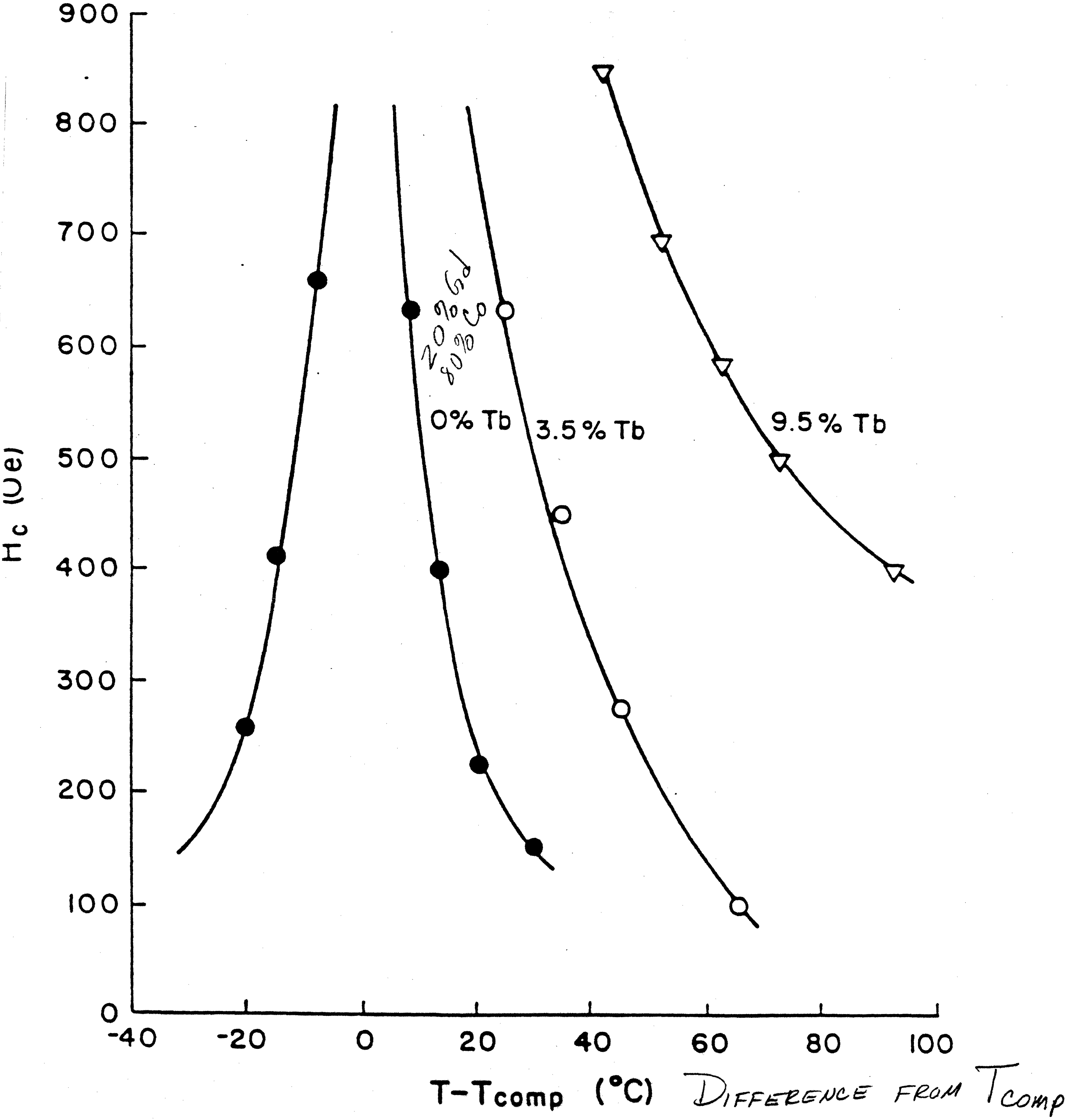
$$\overset{\left(\text{Normalized } \frac{\text{Force}}{\text{Area}}\right)}{\frac{\Delta E}{\Delta r}\cdot\left(\frac{1}{2\pi r h}\right)} = \overset{\left(\text{Wall Surface Tension}\right)}{-\frac{\sigma}{r}} + \overset{\left(\text{Demagnetizing Field}\right)}{4\pi M^2\cdot\frac{h}{r}F\left(\frac{2r}{h}\right)} \overset{\left(\text{Applied Field}\right)}{-2M_s H}$$

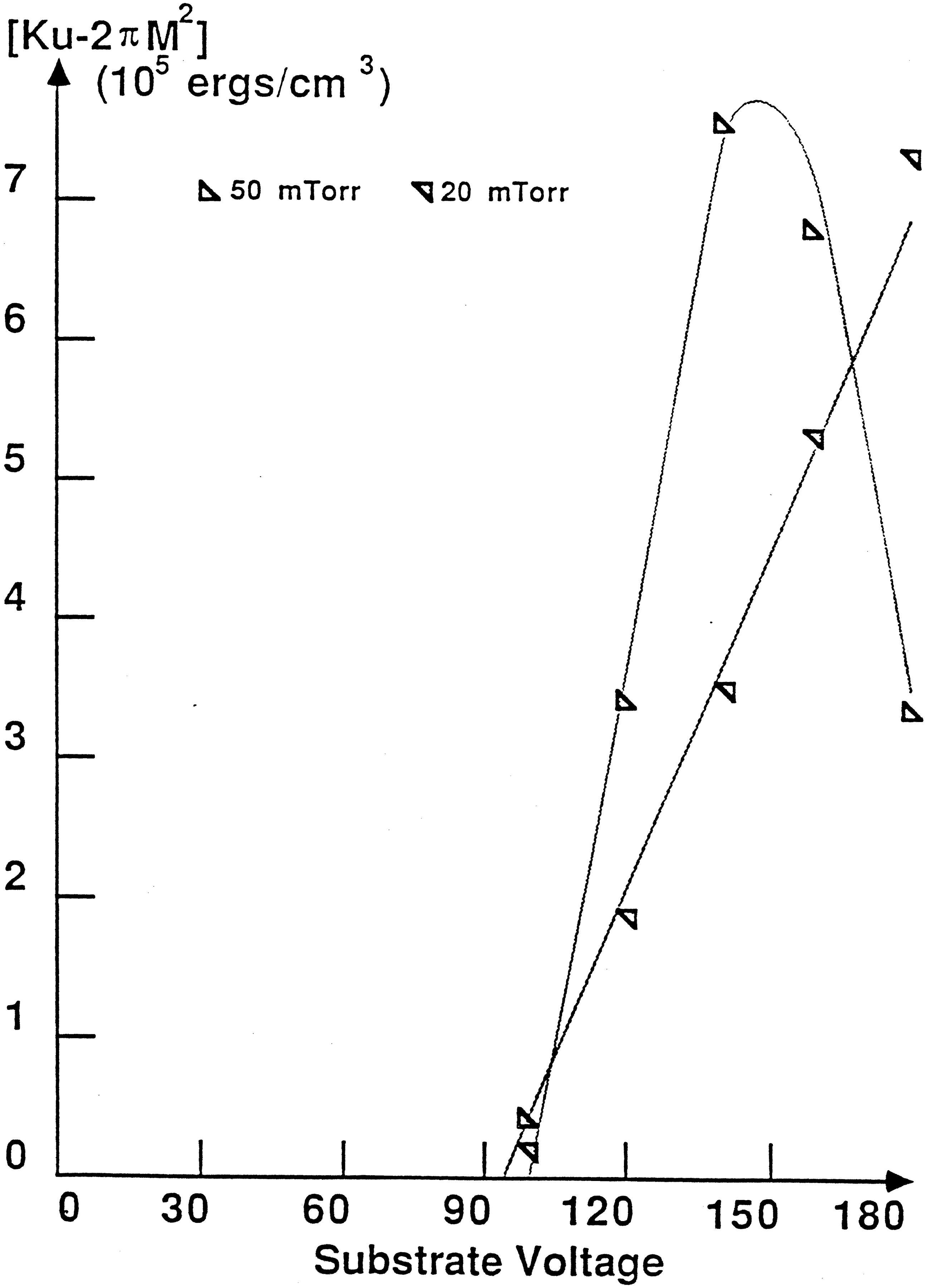
FOR COERCIVE STABILITY:

$$\frac{\Delta E}{\Delta r}\cdot\left(\frac{1}{2\pi r h}\right) > -2MH_c$$

OR:

$$r_{min} = \frac{\sigma}{2M(H_c - H)} \qquad \text{(Small M, thin films)}$$


900
800
700
600
500
400
300
200
100
0
Hc (Oe)
-40
-20
0
20
40
60
80
100
T−Tcomp (°C)
Difference from Tcomp
20% Gd
80% Co
0% Tb
3.5 % Tb
9.5 % Tb



[Ku-2πM^2]
(10^5 ergs/cm^3)
◺ 50 mTorr
◹ 20 mTorr
7
6
5
4
3
2
1
0
0
30
60
90
120
150
180
Substrate Voltage

TAILORING OF GdTbFeCo
FILMS

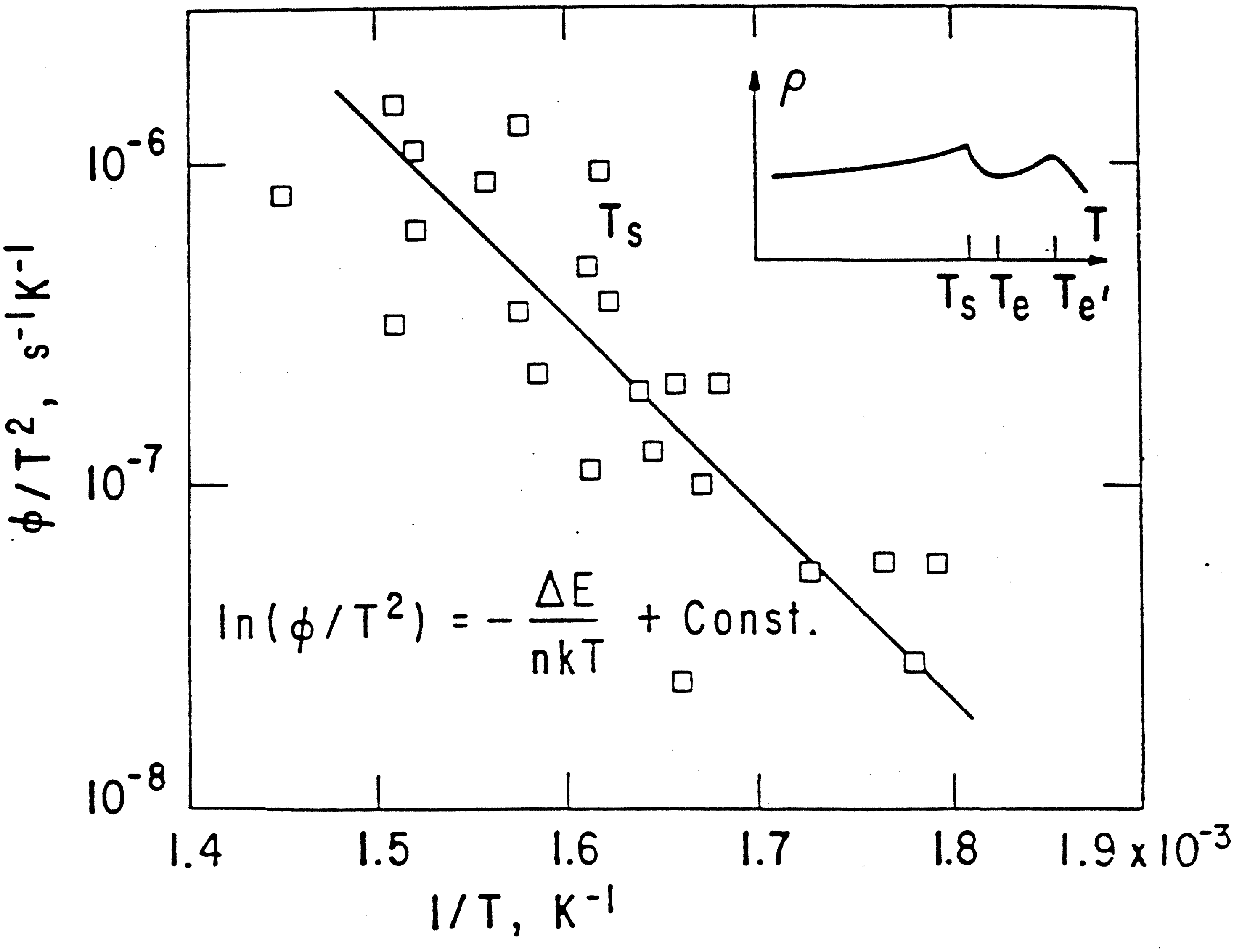
1. SELECT T_{CURIE}
   - Fe/Co RATIO

2. SELECT T_{COMP}
   - RE/TM RATIO

3. SELECT $M_s \cdot H_c$
   - Tb/Gd RATIO

4. PEAK $K_u - 2\pi M_s^2$, θ_K
   - SELECT RE/TM IN TARGET
   - USE BIAS TO ACHIEVE T_{COMP} (1°C/V_{bias})

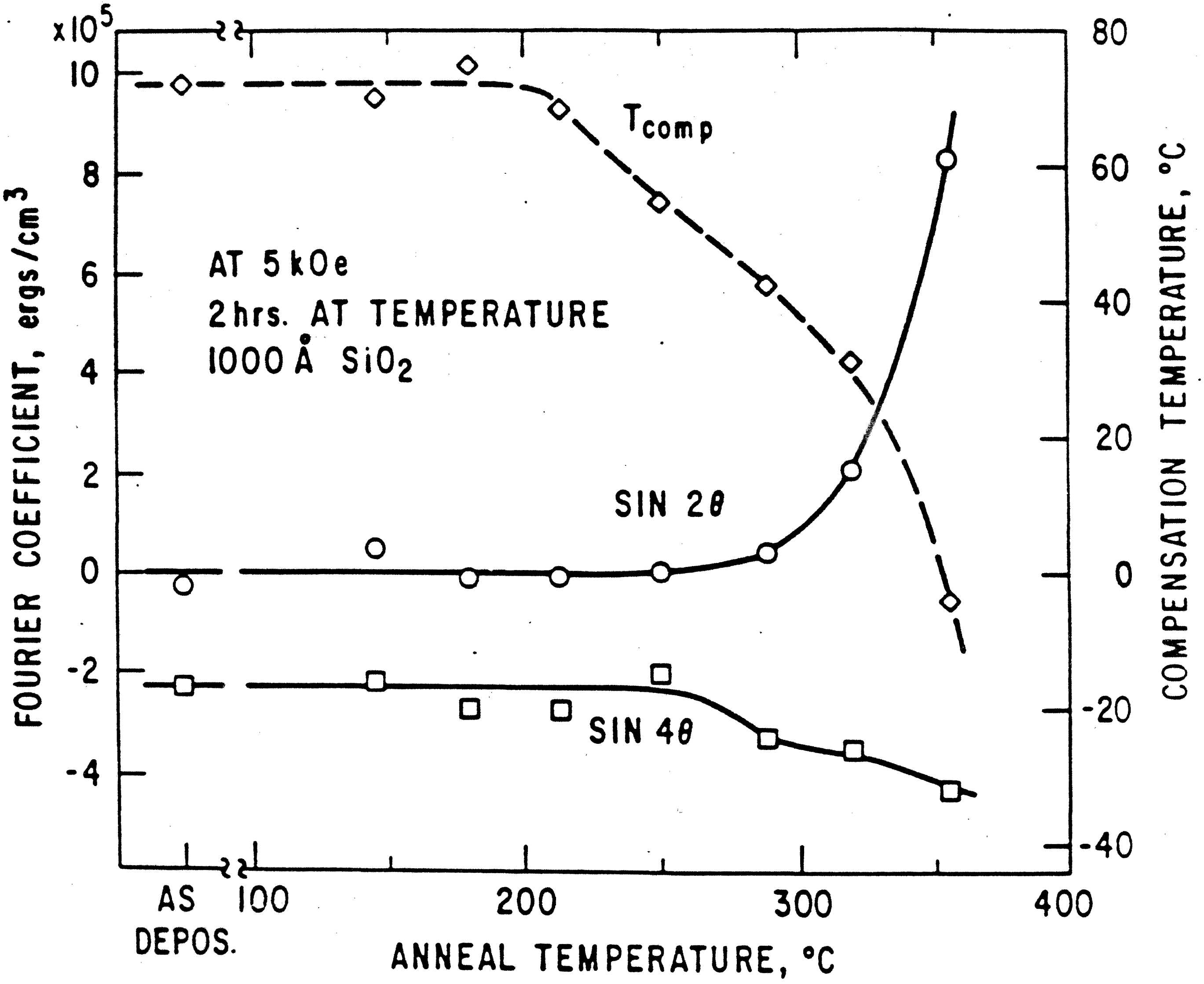
STABILITY AGAINST CRYSTALLIZATION *



TEMPERATURE	LIFETIME
200°C	0.06 YEAR
100°C	100 YEARS

*AFTER F. E. LUBORSKY, J. NON-CRYST. SOL. 61 & 62, 829 (1984)

STABILITY OF ANISOTROPY



LIFETIME FOR 10% CHANGE IN K_u (GdTbCo)*:

$$t = A \exp\left(\frac{\Delta E}{kT}\right) \quad (\Delta E = 1.26\,\text{eV},\ A = 5 \times 10^{-11}\,\text{sec})$$

TEMPERATURE	LIFETIME
100°C	60 DAYS
50°C	70 YEARS
25°C	3000 YEARS

* DATA FROM F.E.LUBORSKY, paper HC-04, Magnetism and Magnetic Materials Conference, San Diego, Nov.27-30, 1984

Tb - SiO_2 PASSIVATION

M. Miyazaki _et al_, Fujitsu

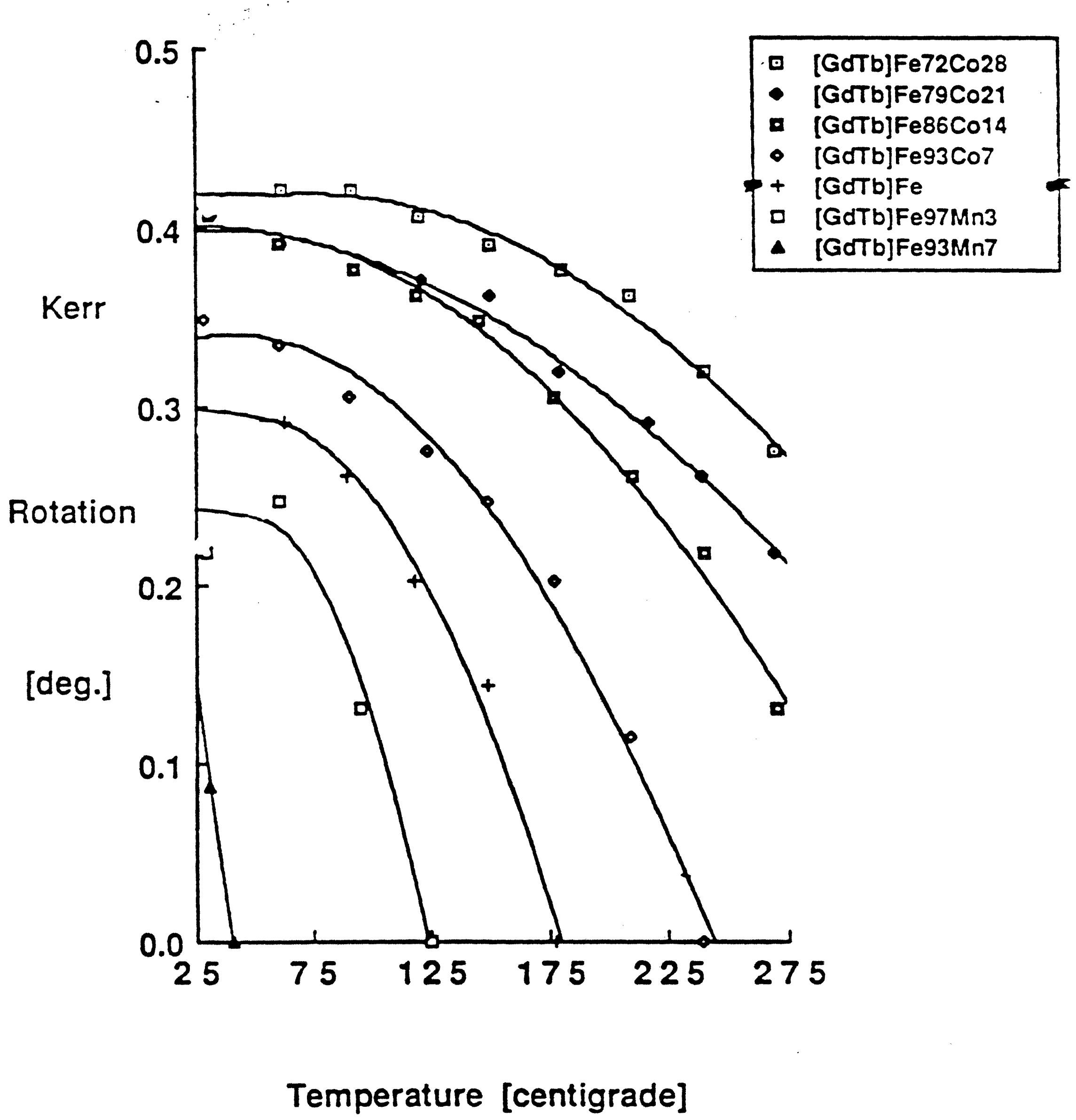
Co-Sputtered T6 & SiO_2

Accelerated Tests at 120°C, 90% RH

Projects lifetime of 20 years
at 40°C, 90% RH.

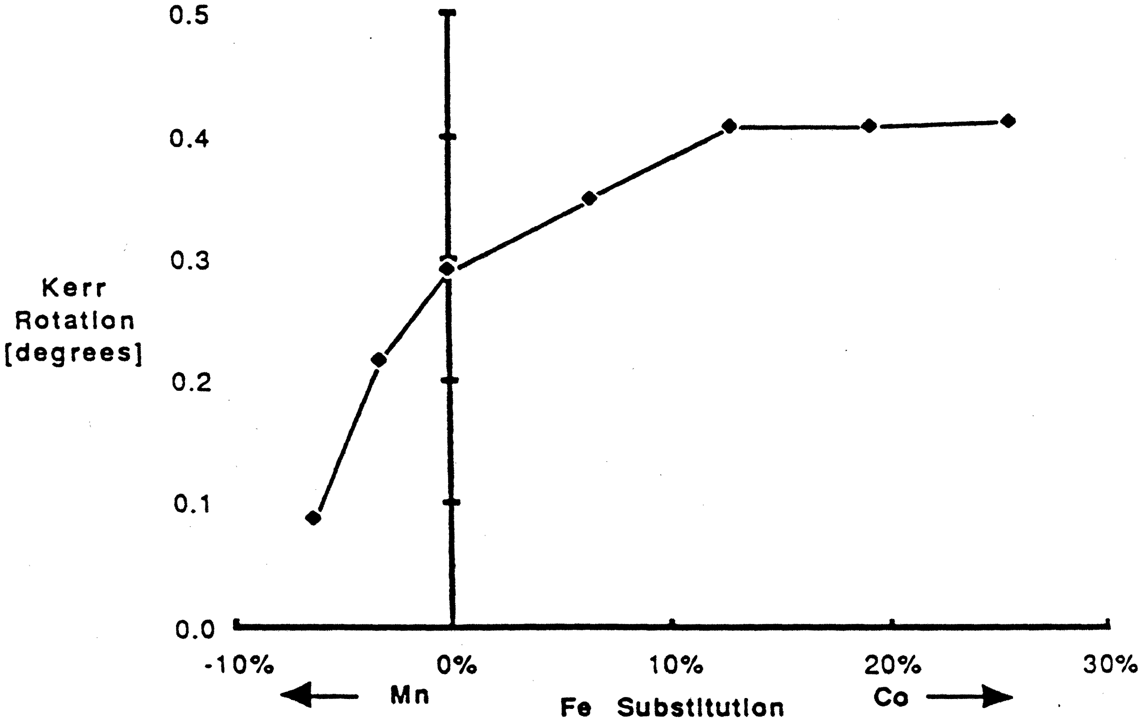
The TM Dependence of the Magneto-Optic Signal in GdTb-TM Thin Films

D.K. Hairston and M.H. Kryder
Carnegie Mellon University

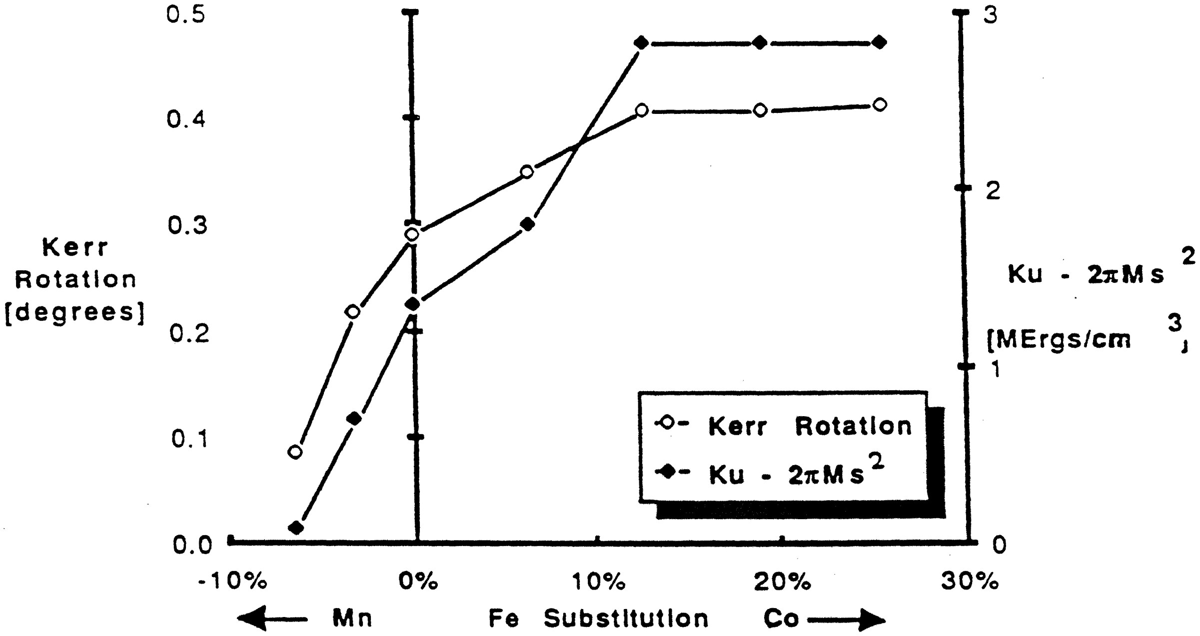


Kerr
Rotation
[deg.]
0.5
0.4
0.3
0.2
0.1
0.0
25
75
125
175
225
275
Temperature [centigrade]
□ [GdTb]Fe72Co28
◆ [GdTb]Fe79Co21
■ [GdTb]Fe86Co14
◇ [GdTb]Fe93Co7
+ [GdTb]Fe
□ [GdTb]Fe97Mn3
▲ [GdTb]Fe93Mn7

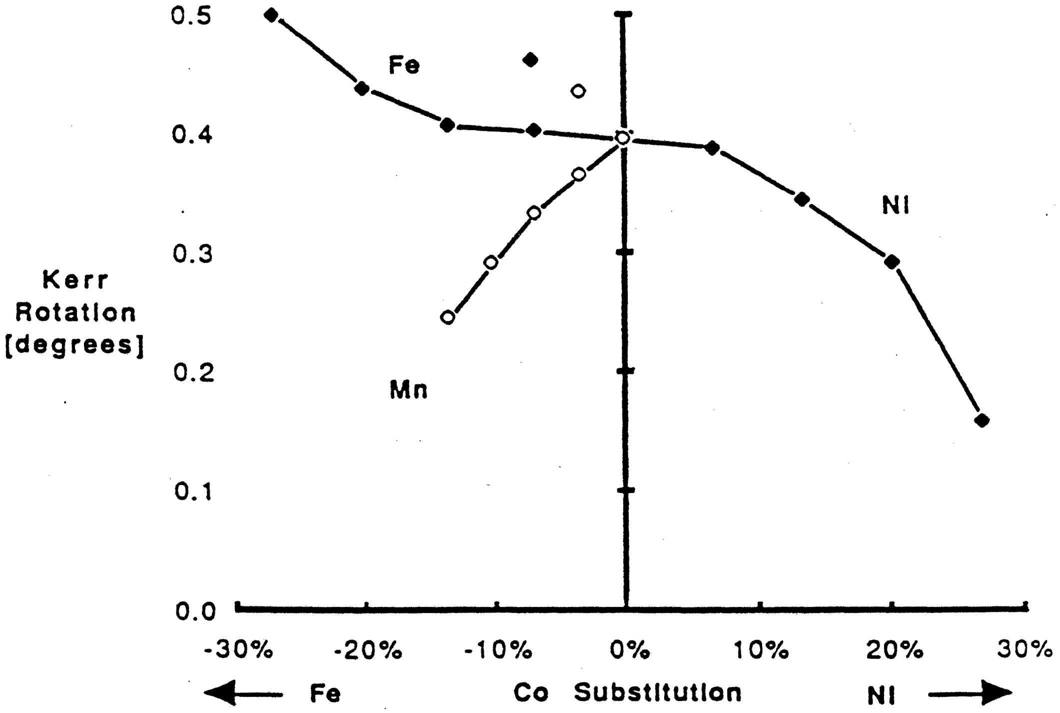
Kerr Rotation vs. Composition for GdTbFeX Films

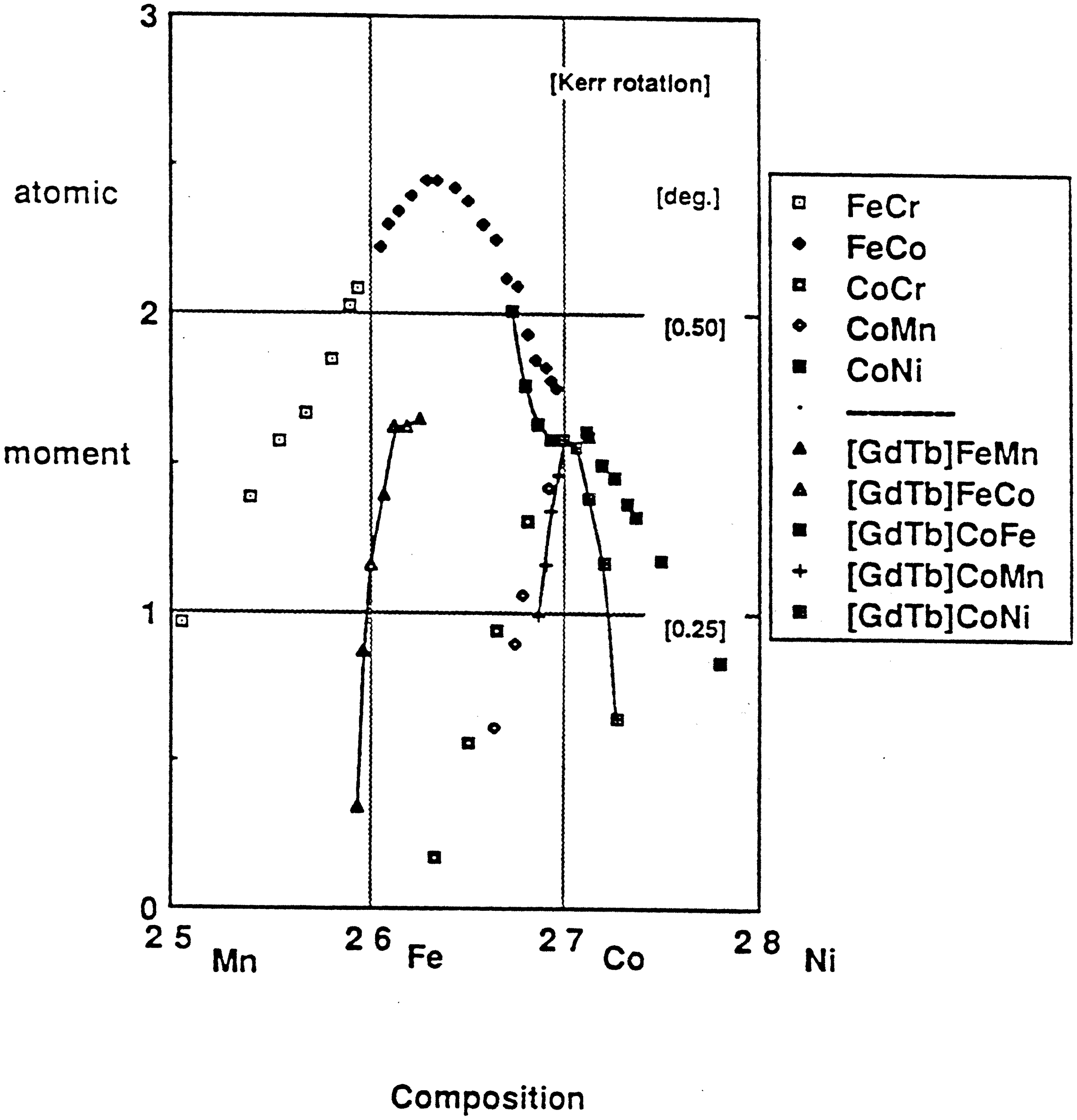


Correlation of Anisotropy and
Kerr Rotation vs. Composition for GdTbFeX Films



Kerr Rotation vs. Composition for GdTbCoX Films





3
2
1
0
atomic
moment
[Kerr rotation]
[deg.]
[0.50]
[0.25]
2 5 Mn
2 6 Fe
2 7 Co
2 8 Ni
Composition
FeCr
FeCo
CoCr
CoMn
CoNi
[GdTb]FeMn
[GdTb]FeCo
[GdTb]CoFe
[GdTb]CoMn
[GdTb]CoNi

Conclusions:

For fixed r.f sputtering conditions the magnetic and optical properties of RE-TM thin films are composition dependent.

The composition dependence of perpendicular anisotropy correlates with the polar Kerr rotation.

The Curie temp. and room temp. MO signal of RE-TM thin films can be changed by the TM composition.

The MO signal of RE-TM thin films qualitatively correlates with the Slater-Pauling curve thus explaining the commonly observed fact:
the MO signal is largest in RE-FeCo alloys.