GMR and TMR devices; read heads, MRAMS, and sensors

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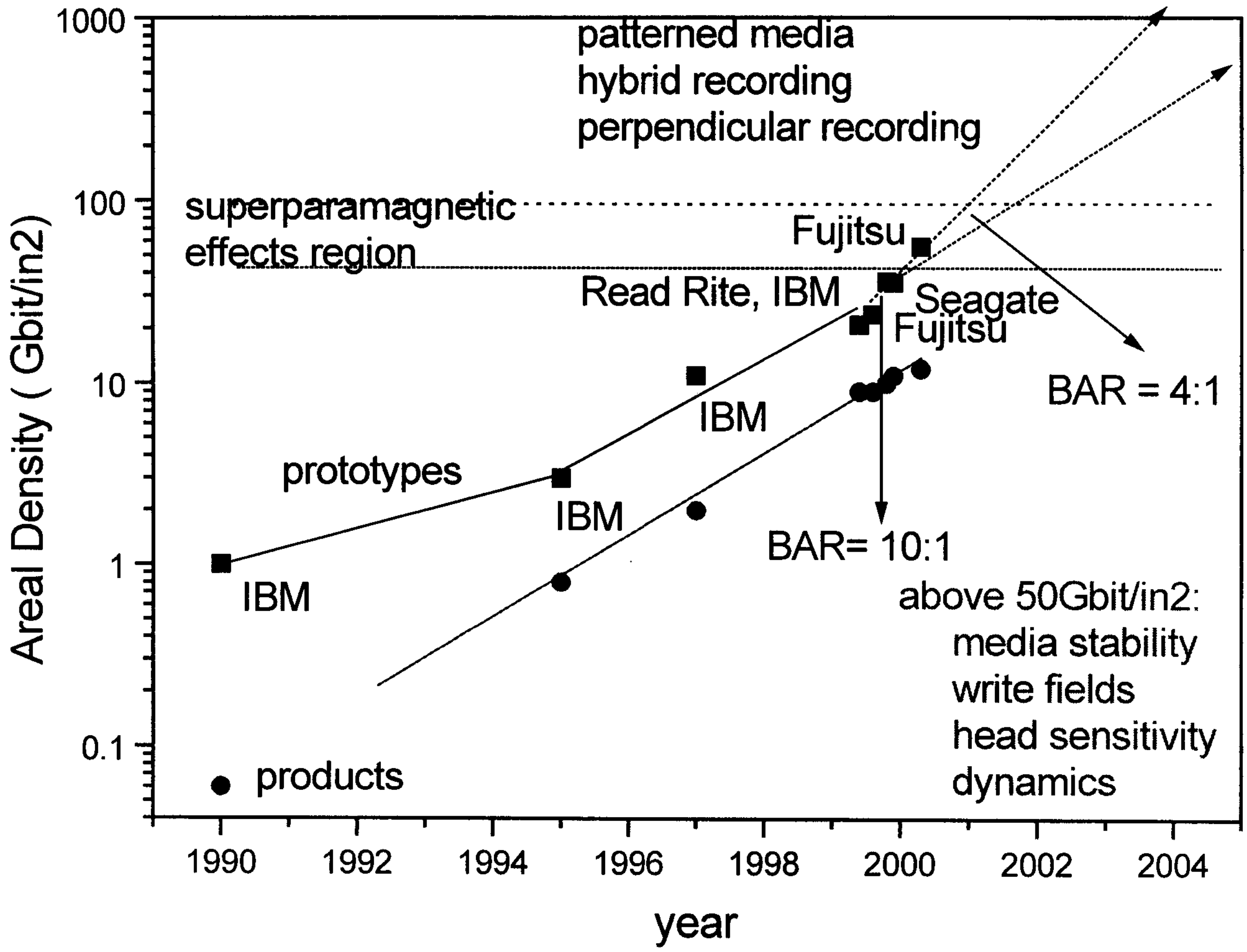
outline

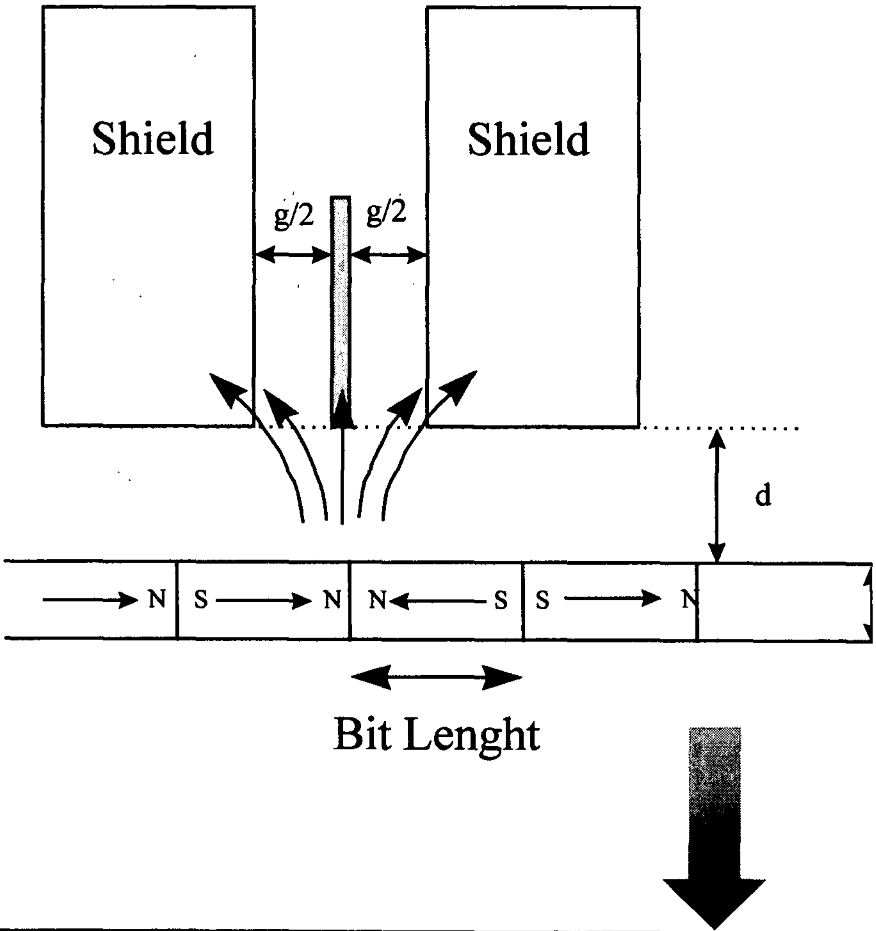
1- Read heads
. Specular spin valves
. Tunnel junction read heads
2- MRAMS
. Improving the thermal stability beyond 350C with FeOx interfacial layers
. Effect of ion damage on switching properties of MRAM cells
3- SENSORS
.application of GMR and SV bridge sensors in robotics, power control, biochip.

AREAL DENSITY ROADMAP



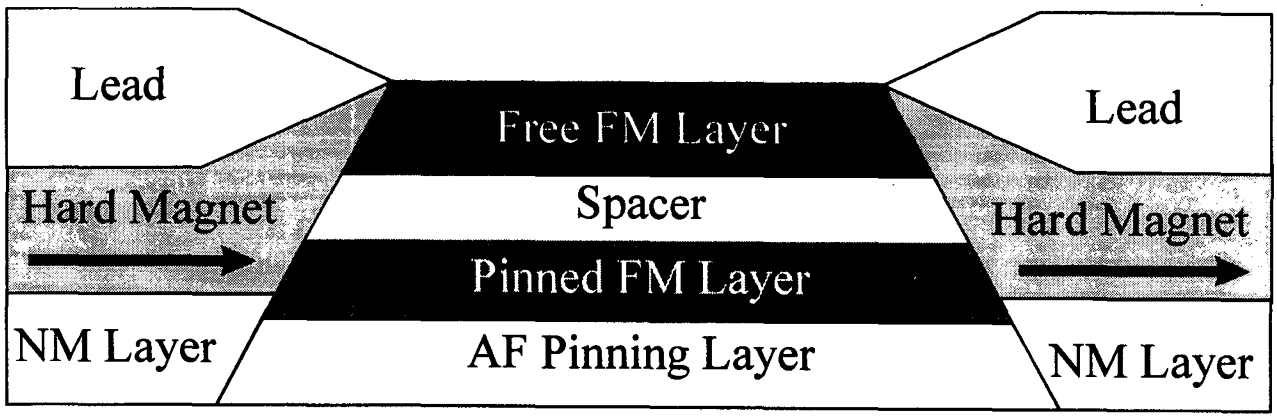
34 billion US$ market (HDD)
100% cgr

Shielded MR sensor



year	density (Gbit/in²)	w (μm)	2.g_R (nm)	t (nm)	ΔR/R (%)	sensor type
1998	5	1.5-0.8	200	12-9	1.8-1.5	AMR
2000	10	0.5	140	5.0	8	sv
2003	40	0.25	70	2.5	12	sv
2005	80	0.18	50	1.8	18	sv or TJ

Standard spin valve sensor



AF: PtMn/CoFe/Ru/CoFe,
MnIr/CoFe/Ru/CoFe
MR ~8 to 10 %
(~ in production)

How to increase head sensitivity?

- **Increase MR signal**
  - **Specular Spin Valves** — **13~25%**
  - **Dual Spin Valves** — **15~25%**
  - **Low R Tunnel Tunction** — **10~20%**

- **Reduce free layer thickness**
  - **Synthetic free layers** — **< 1 nm**
  - **Spin Filter spin valves** — **?**
  - **Low R Tunnel Tunction** — **< 2 nm**

... keeping good thermal stability

Increase Blocking Temperature and Exchange coupling

- **Synthetic anti-ferromagnets**

  AF/SAF

- **Improved AF exchange layers**

T_B > 300-400°C

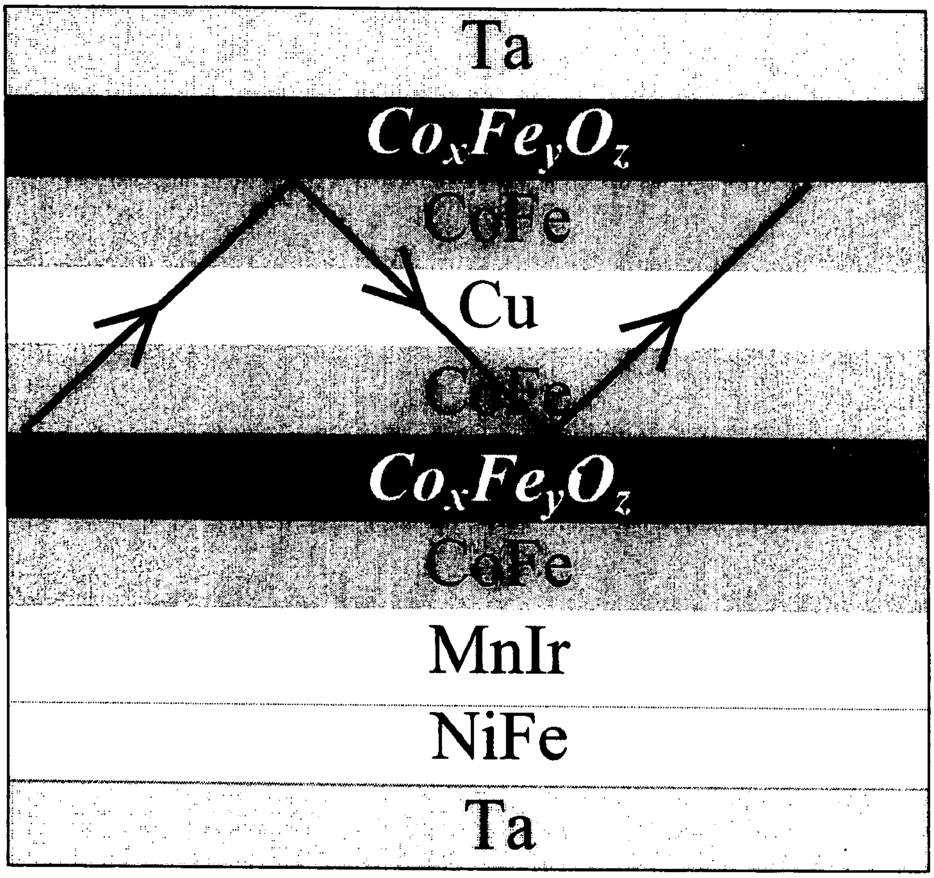
J_{ex} > 0.3-0.4 erg/cm²

Advanced spin valve architectures for 100 Gbit/in^2 recording

1-Enhanced MR signal

SPECULAR SPIN VALVES WITH NANO OXIDE LAYERS

Goal:
- MR ~20% and...
- state of the art exchange materials
- good thermal stability
- low switching fields

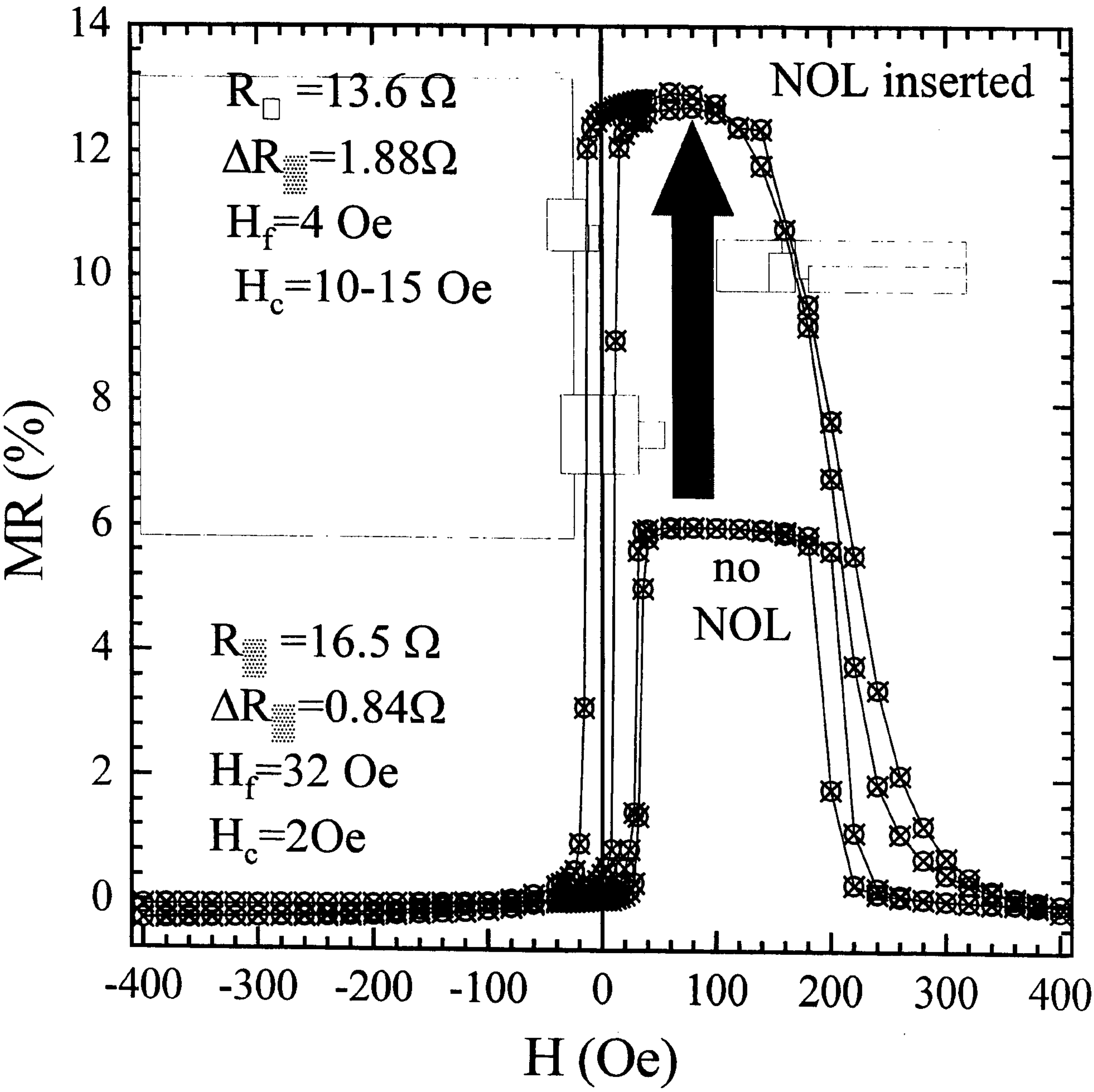


27% MR signal obtained in NiO/Co/Cu/Co/NiO structures but with low exchange, high switching field, low T_B

Advanced spin valve materials and architectures for 100Gbit/in^2 recording

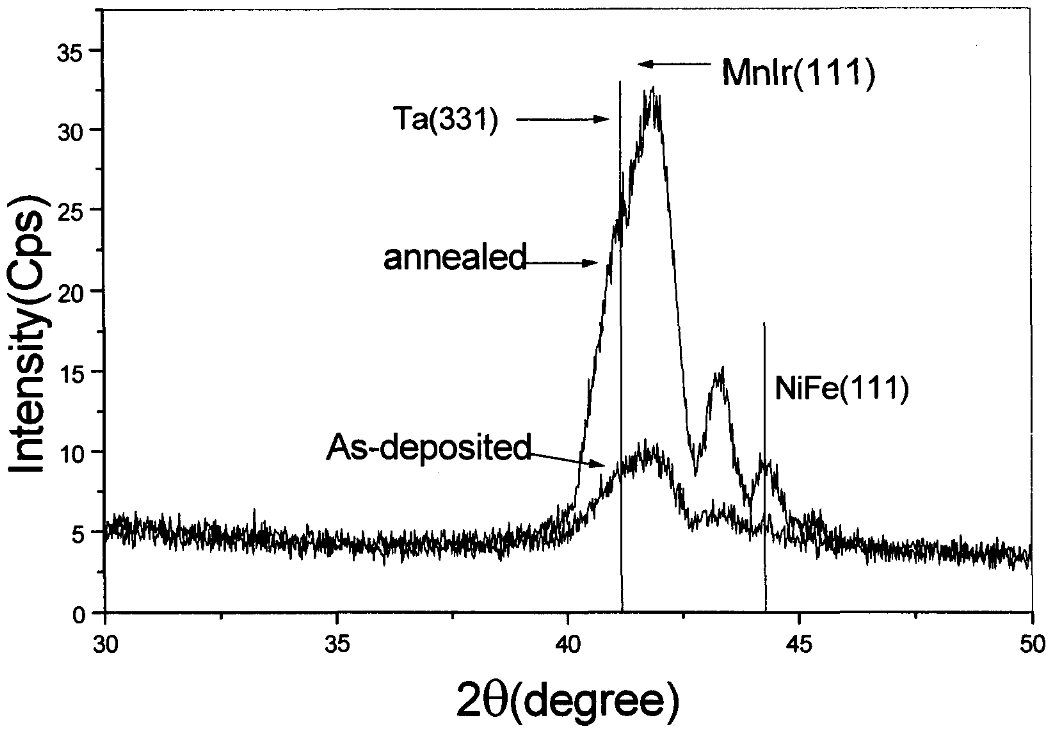
1- Enhanced MR signal

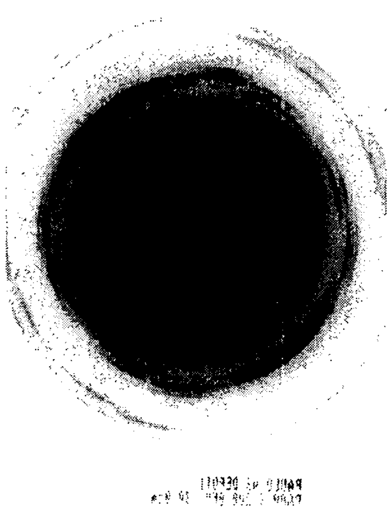
PVD spin valves

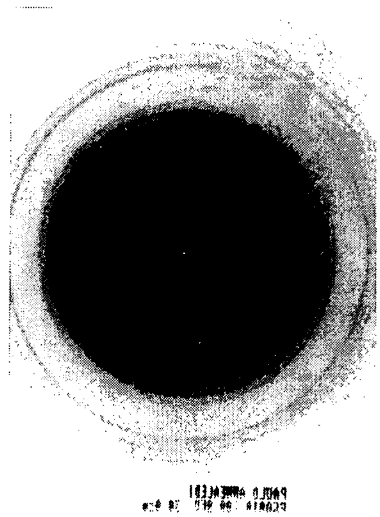


HOW WAS THE EXCHANGE FIELD SET?

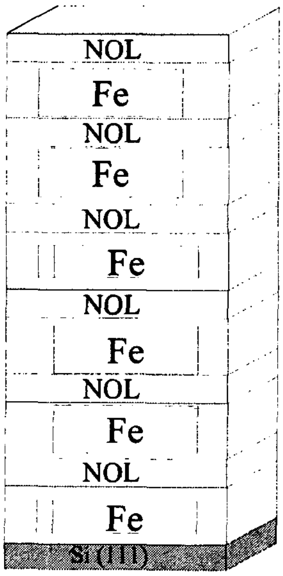
Bottom pinned MnIr SVs require 10min anneal at 270C to enhance 111 texture



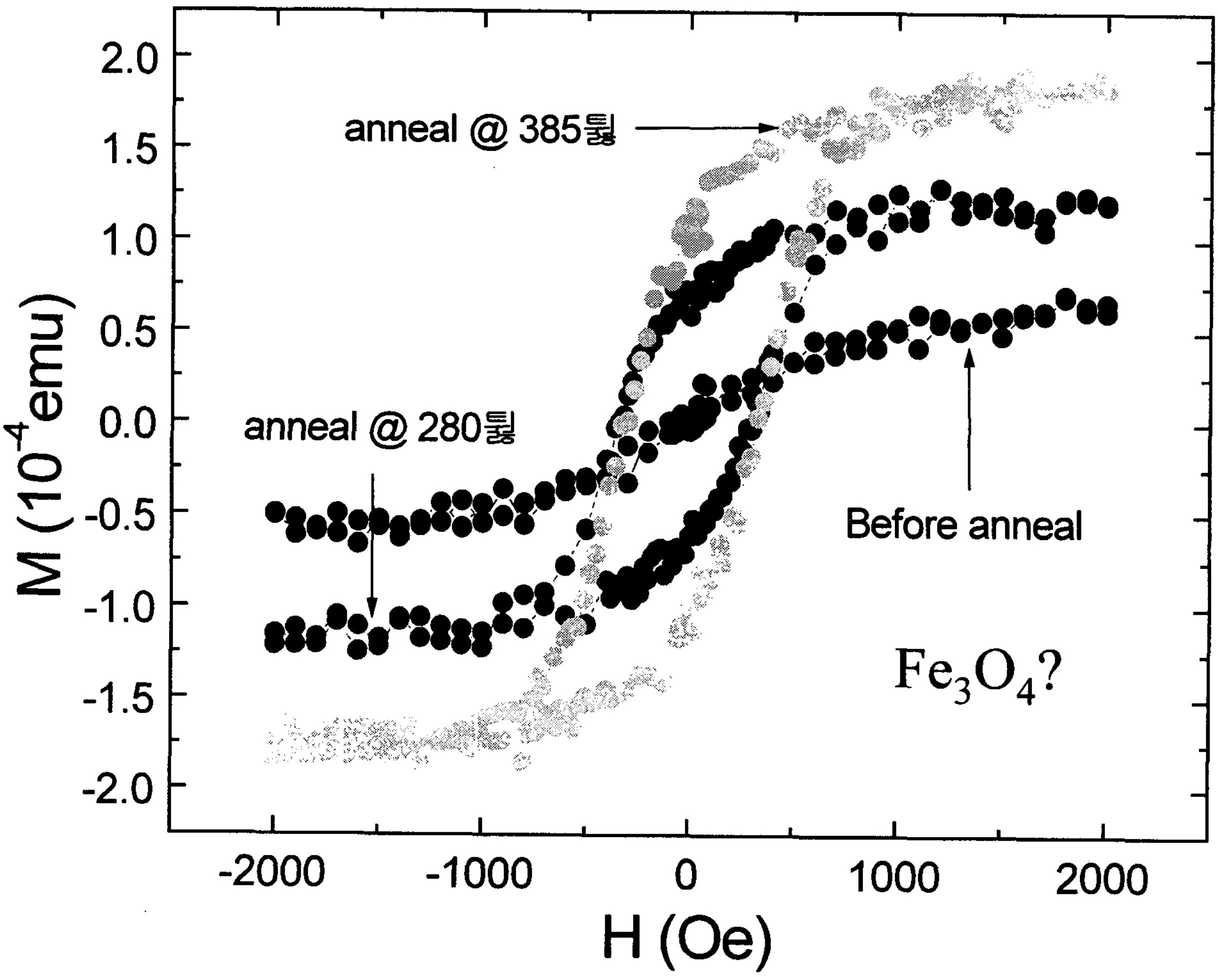




Does this annealing step affect the NOL layer?

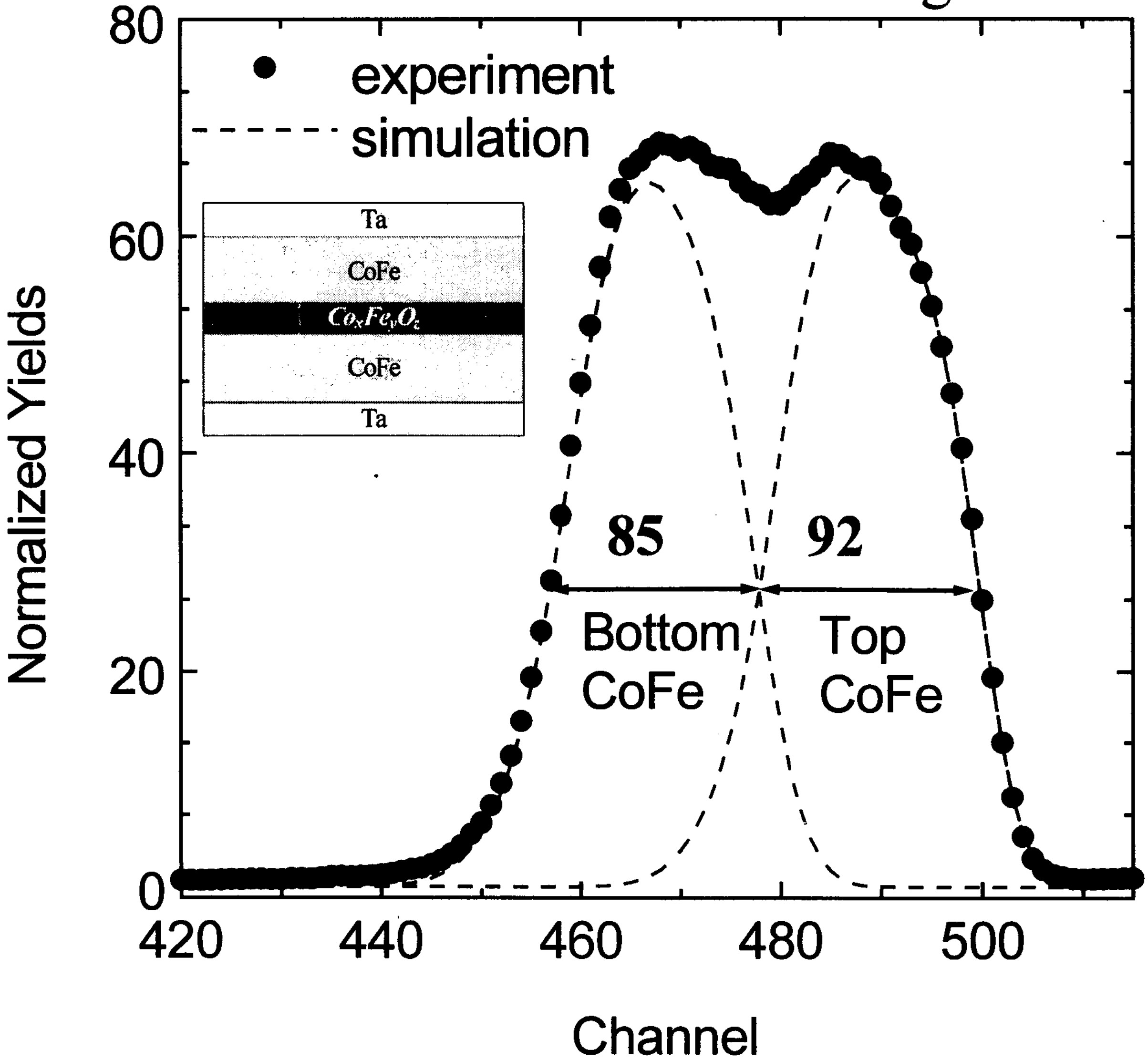


(Fe20A/ox.10")$_{x8}$



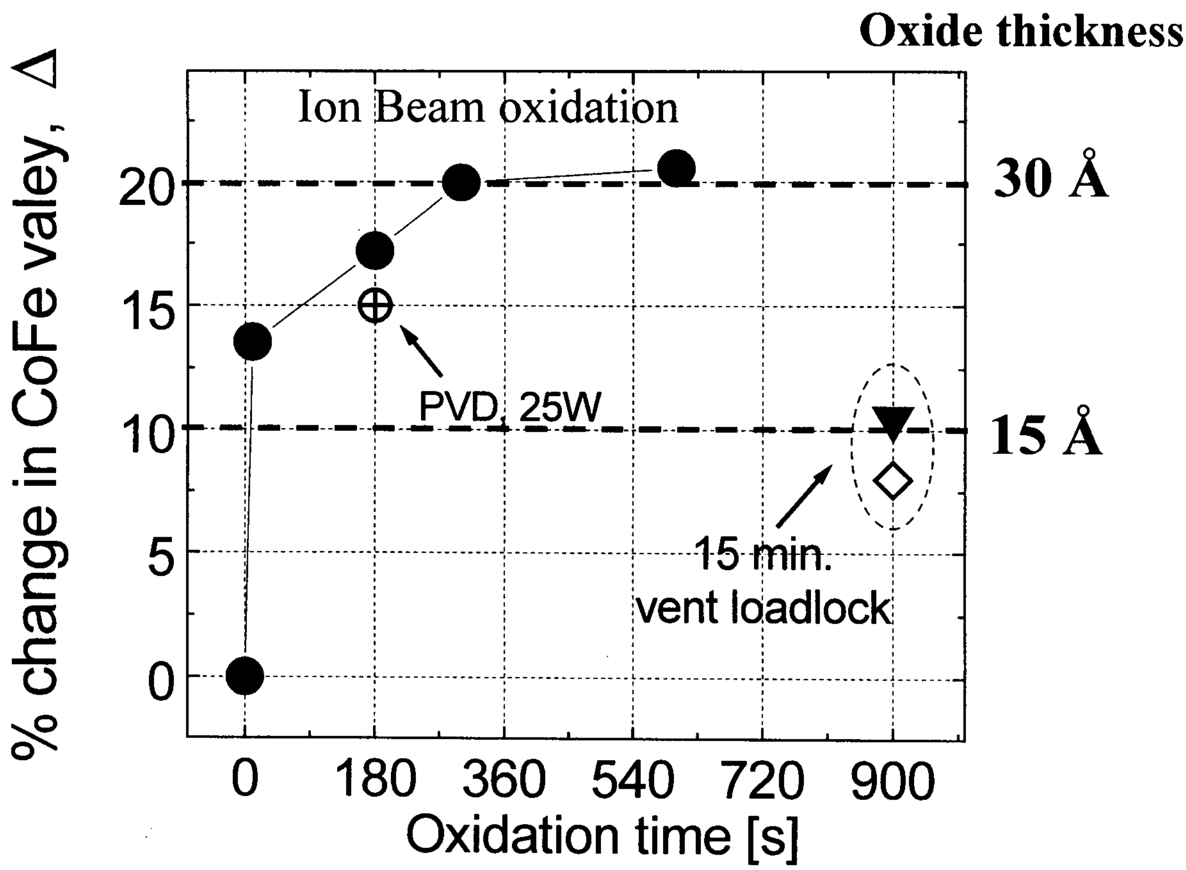
Nano-oxide layers characterization

Rutherford Backscattering



		RBS	X-rays
	NOL thickness (Å)	18	15
Density (g/cm^3)	NOL	6.31423	6.11852
	CoFe	8.706	8.3694

Nano-oxide layers characterization



Which oxide?

Thermal stability ~270°-300C

Advanced spin valve materials and architectures for 100Gbit/in^2 recording

2-Exchange bias materials

Comparison of exchange bias materials

	materials	Tb (°C)	Exchange energy (erg/cm2)	corrosion resistance	requires aneal?
	FeMn[17]	150	0.13	bad	no
	NiO[17]	190	<0.1	[redacted]	no
DIS.AF	Mn78Rh22[17]	235	0.2	reasonable	no
DIS.AF	Mn80Ir20[25]	[redacted]	0.2-[redacted] * (bottom sv, after anneal)	reasonable	yes (bottom spin valves)
ORD.AF	MnNi[15,17]	[redacted]	[redacted]	reasonable/good	yes
ORD.AF	MnPt, MnPdPt[15.32]	[redacted]	[redacted]	good	yes
AF/SAF	(MnIr, MnPdPt, NiO)/Co/Ru/Co	[redacted]	[redacted]	good/reasonable	yes (because of MnPt and MnIr layers)

For a general reference see:

M.Lederman, IEEE Trans.Magn, vol.35, p.794-799, March 1999

Exchange Materials goals:

$T_{Blocking}$ > 300-350°C

J_{exch} > 0.4 erg/cm2

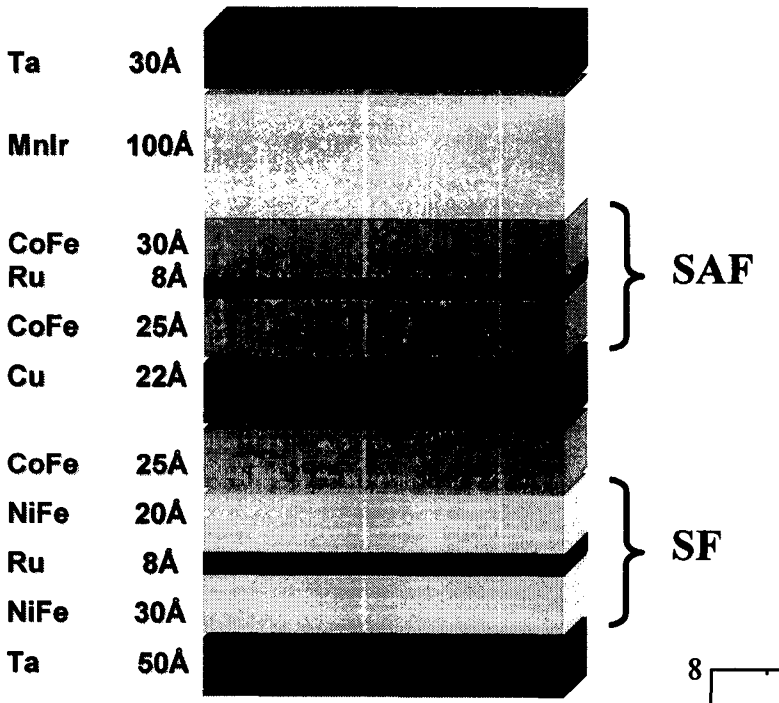
Thickness < 10 nm

Good corrosion resistance

Advanced spin valve materials and architectures for 100Gbit/in^2 recording

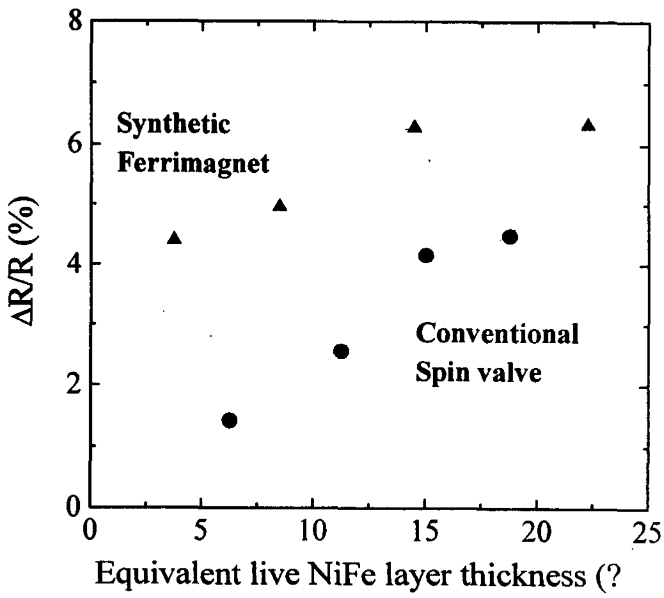
3-Thin free layers

Synthetic free layers

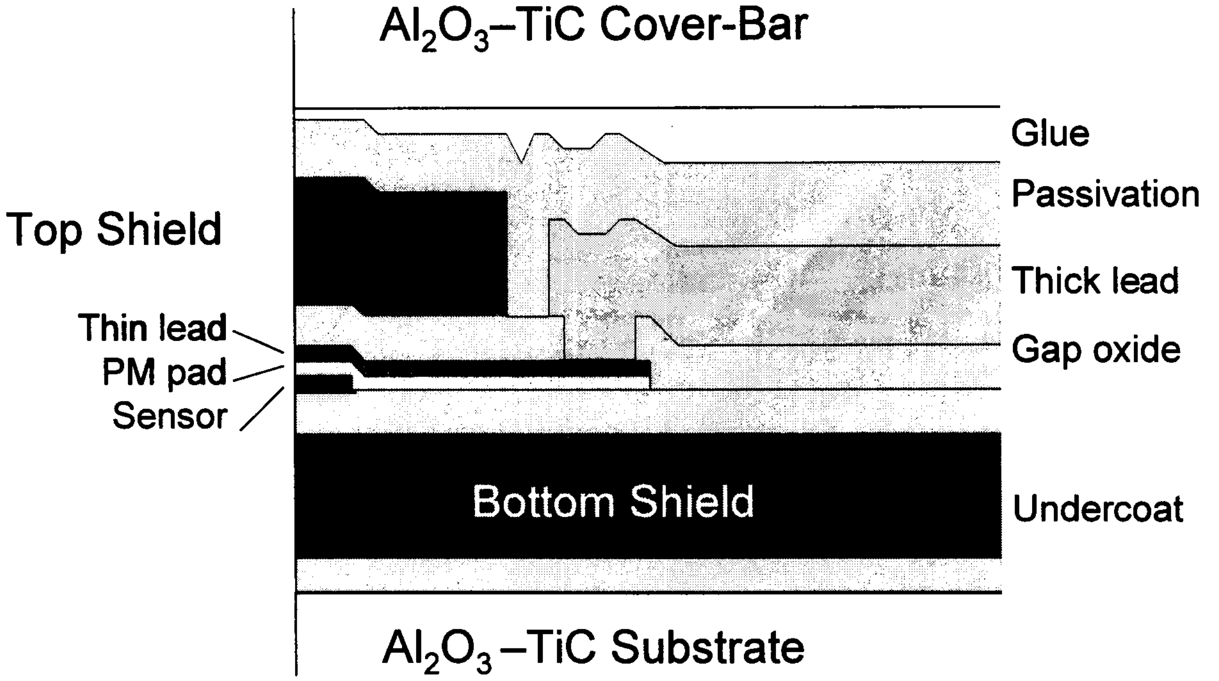


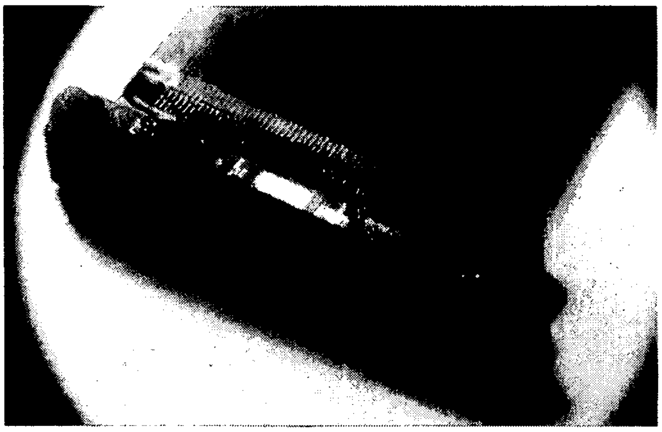
Smaller effective magnetic thickness[2]

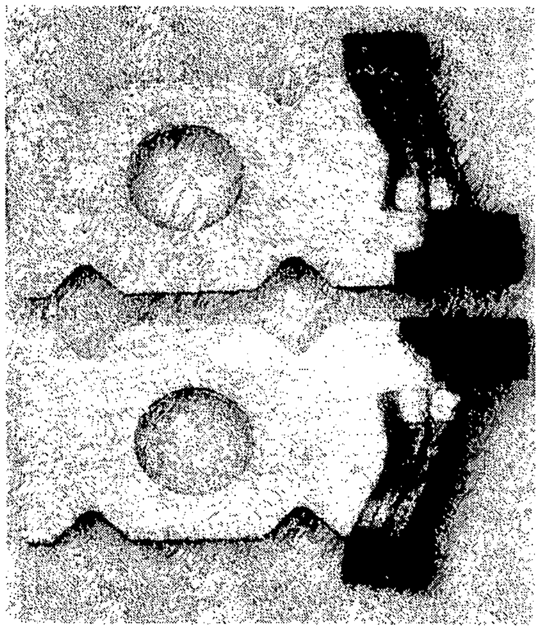
$t_{eff}^{f} = (M_a t_a - M_b t_b)/M_{NiFe}$



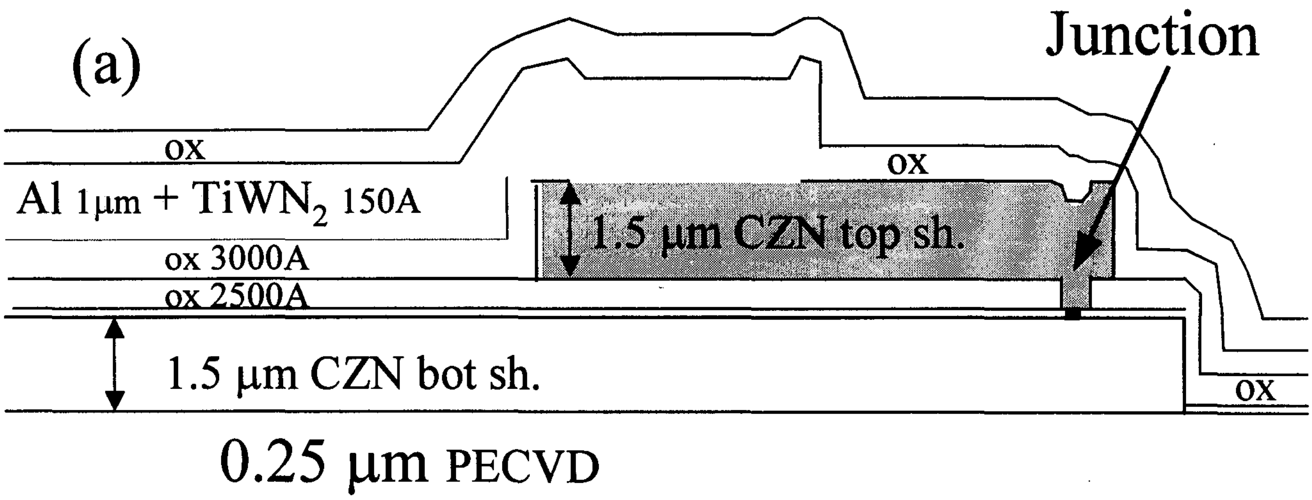
Multitrack spin valve tape heads

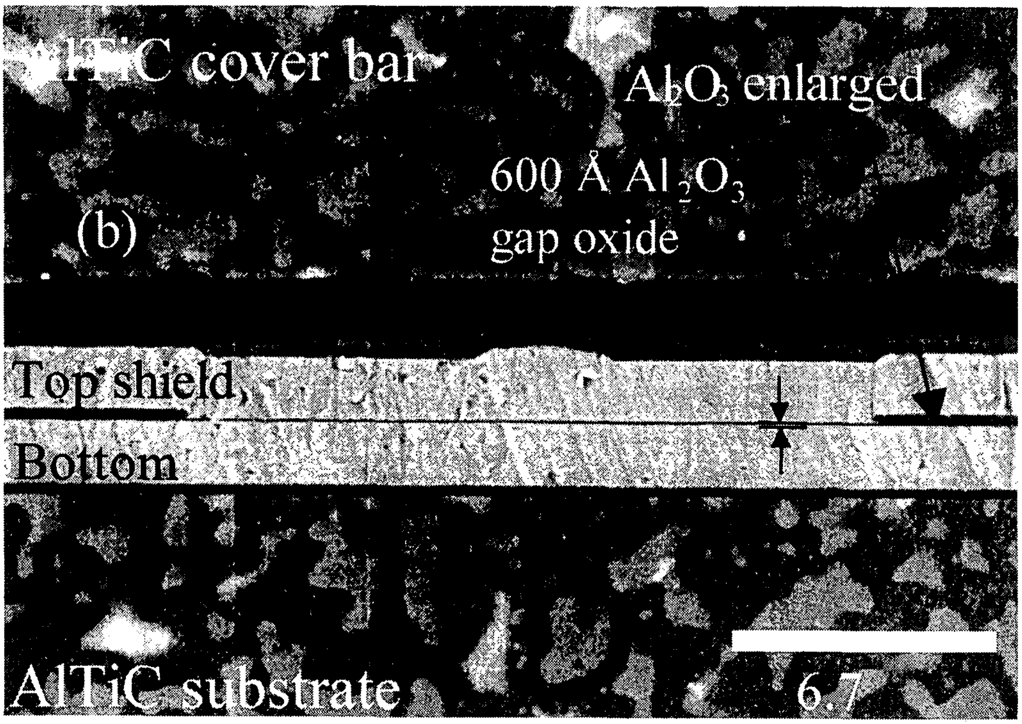






Spin Tunnel Junction-Read Heads for 100 Gbit/in^2 recording





SPIN VALVE AND TUNNEL JUNCTION SHIELDED HEAD PARAMETERS FOR 100 $Gbit/in^2$

Head Parameters	Spin Valve	Tunnel Junction
MR(%)	20	40
Read gap (A)	550	550
Read trackwidth (um)	0.15	0.15
Sensor heigth(um)	0.2	0.2
Rsq or RxA	20 ohm/square	3 Ohm x um^2
Sensor resistance (ohms)	15	100
Free layer thickness (A)	15	15
sense current (mA)	2	0.2
Head output (V 0-p)	750 uV	1.1mV

$$V_N\,(sv) = (\,4\,K_B\,T\,R\,sv\,\Delta f\,)^{1/2}$$

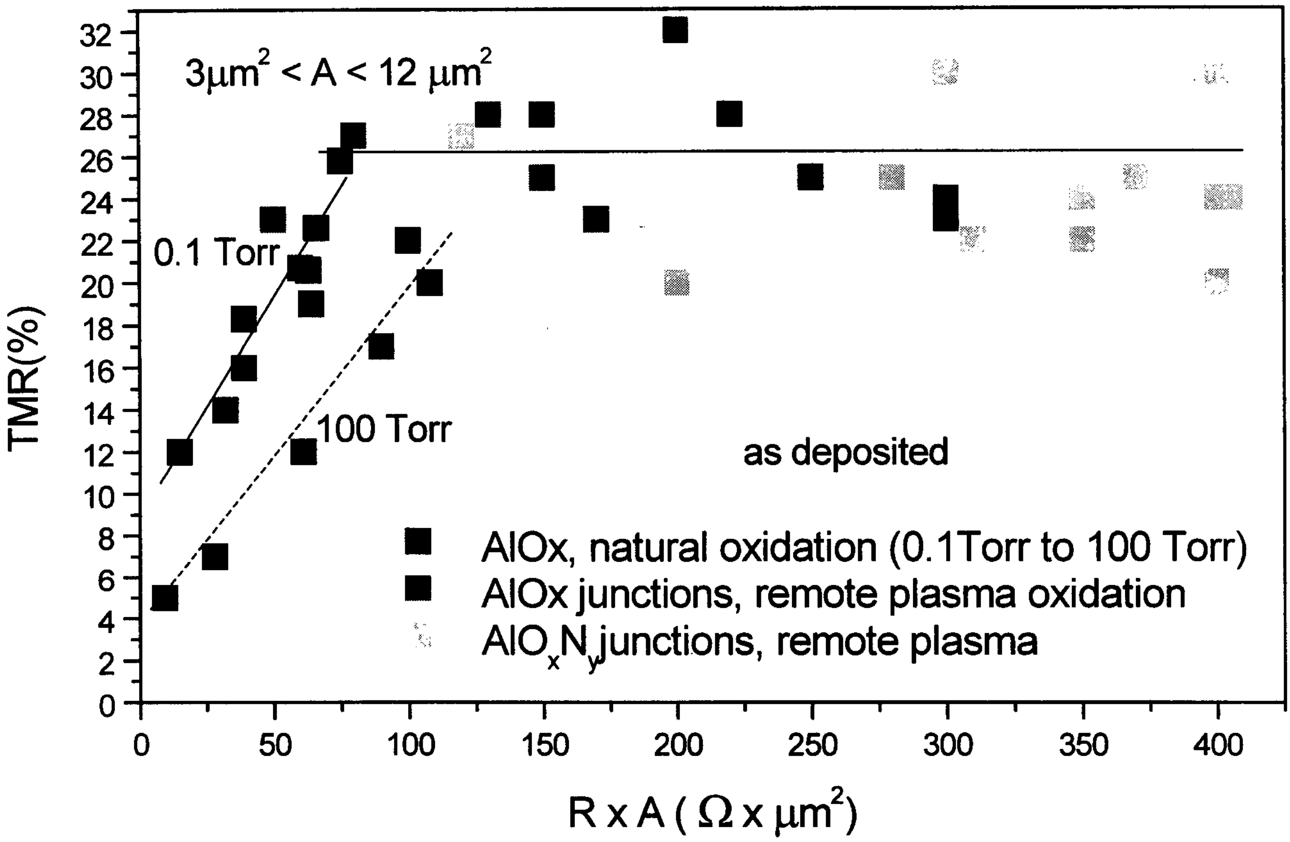
$$V_N\,(tj) = (\,2\,e\,Vb\,Rtj\,\Delta f\,)$$

$$Vs\,(sv) = I\,Rsq\,(w/h)\,(MR/2)\,E_f\,\phi_{ABS} / (\mu_o\,Ms\,t\,w)$$

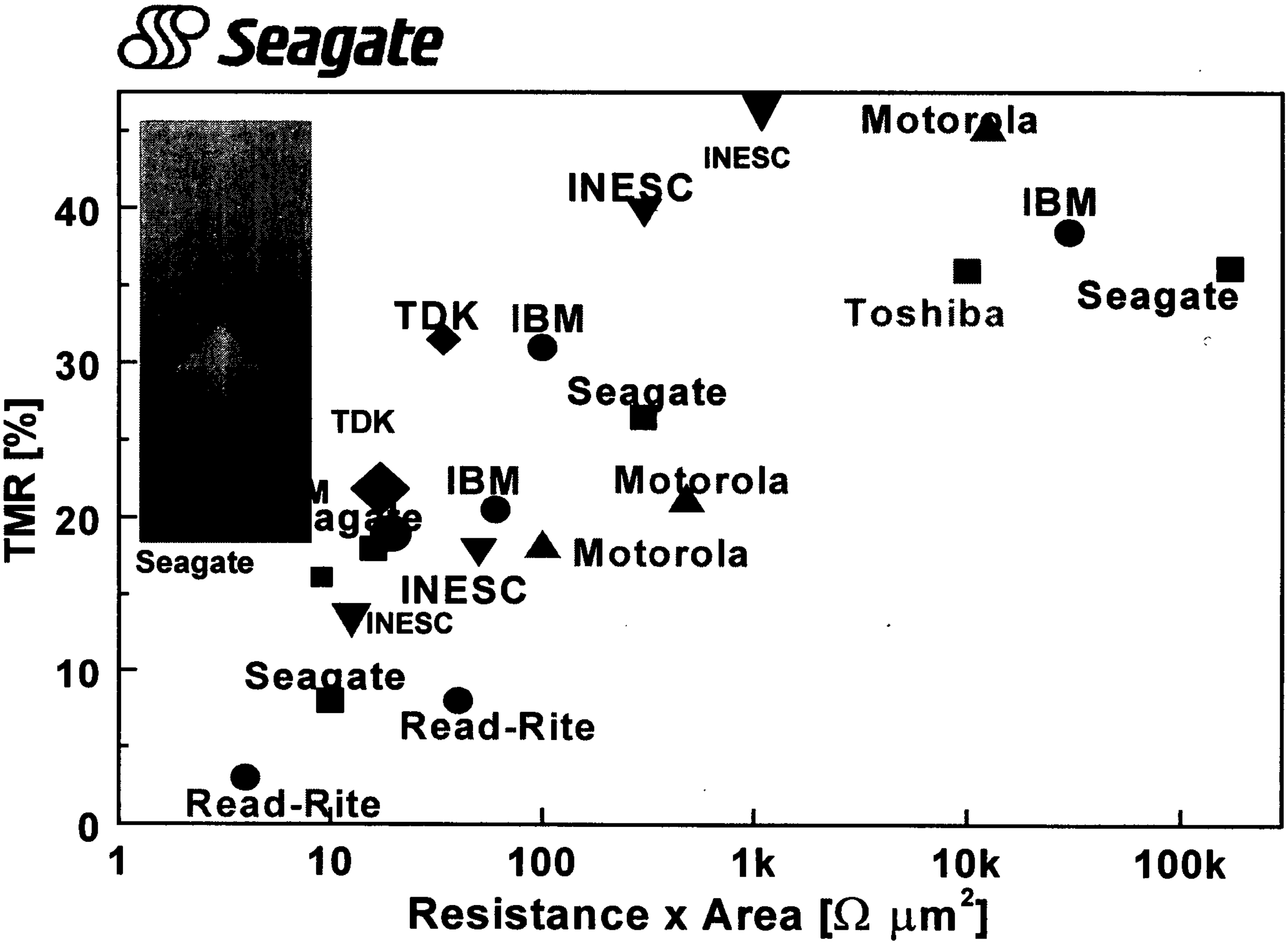
$$Vs\,(tj) = I\,((RxA)/(w.h))\,.\,(MR/2)\,E_f\,\phi_{ABS} / (\mu_o\,Ms\,t\,w)$$

$$SNR\,(tj) / SNR\,(sv) = (Vs\,(tj) / Vs\,(sv)) * (V_N\,(sv) / V_N\,(tj)) = 1.46 * 0.62 = 0.91$$

Low resistance junctions

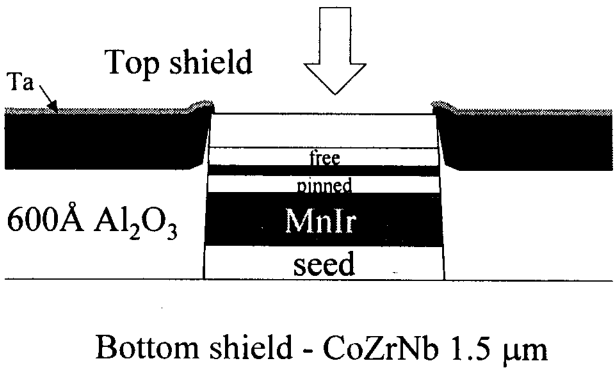


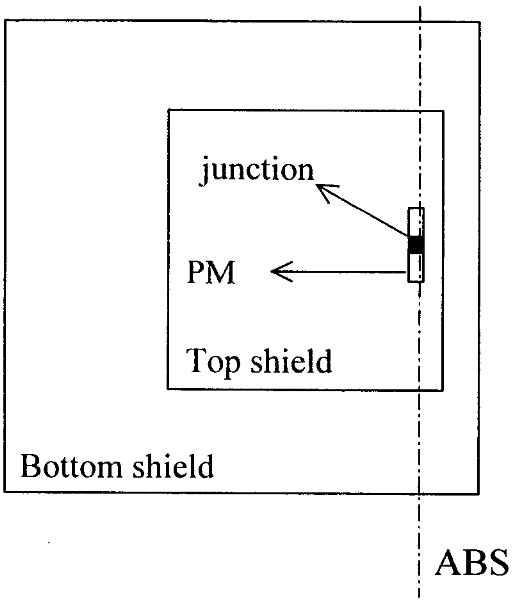
High TMR + low RxA ?



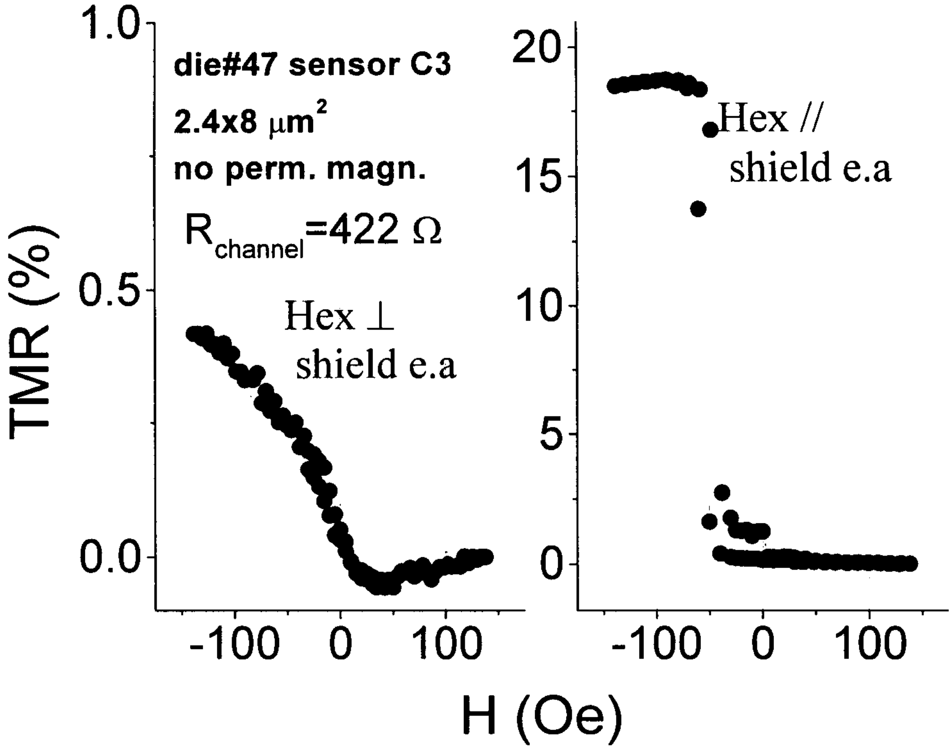
Courtesy of Dian Song (Seagate)

Tunnel junction read head

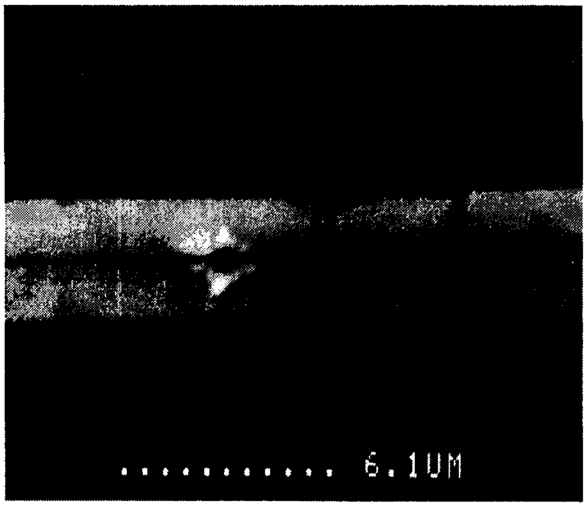




[1]*P.P.Freitas, S. Cardoso, R.Sousa, W.Ku, R.Ferreira, INTERMAG 2000*



(a)



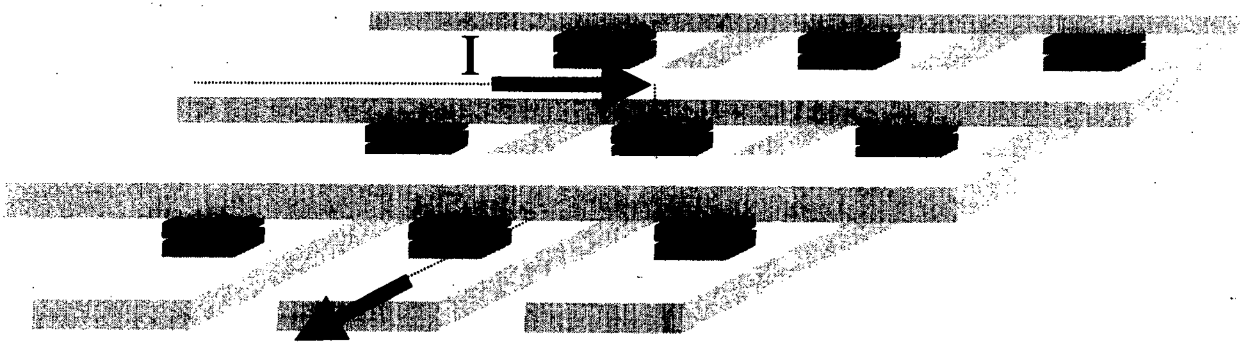
(b)

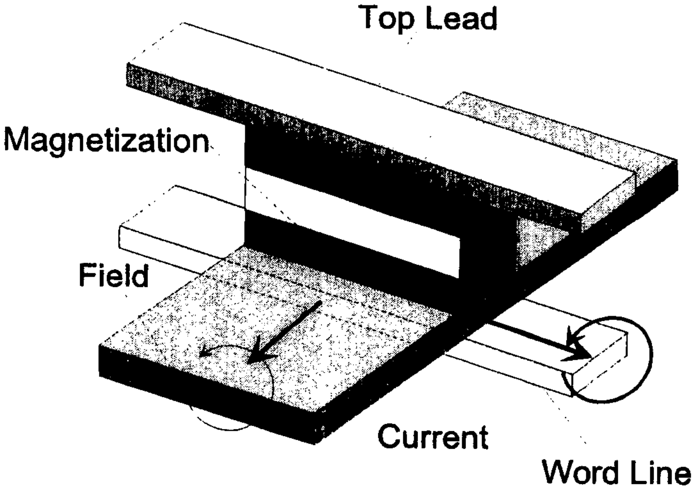
Major remaining problems:

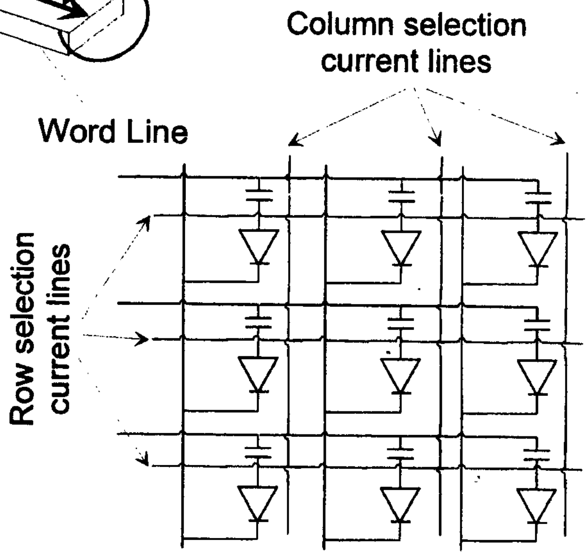
1-lower junction resistance to < 5 Ohm x um^2

2-control gap smearing, leading to head shorts

Tunnel junction MRAM

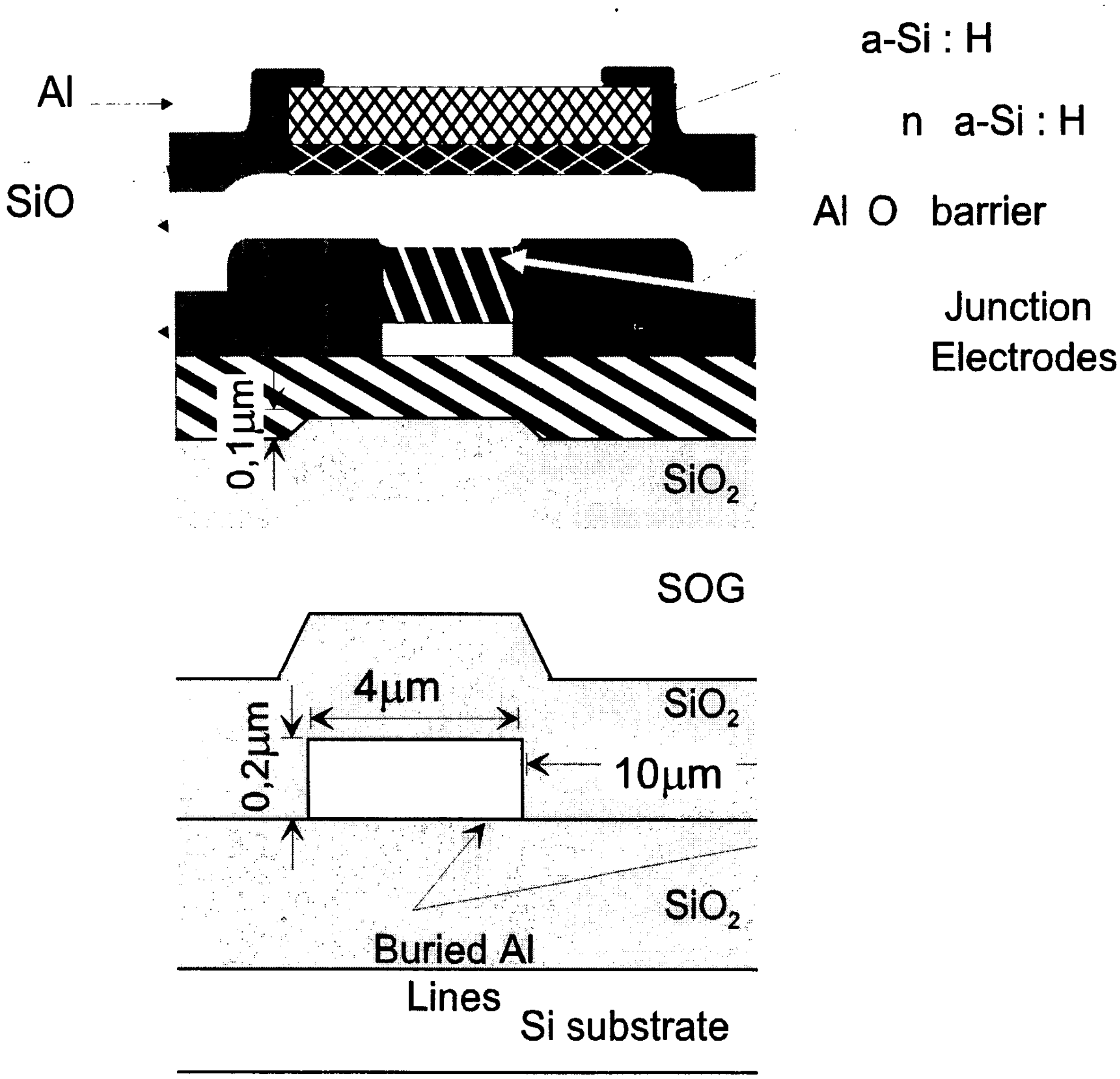




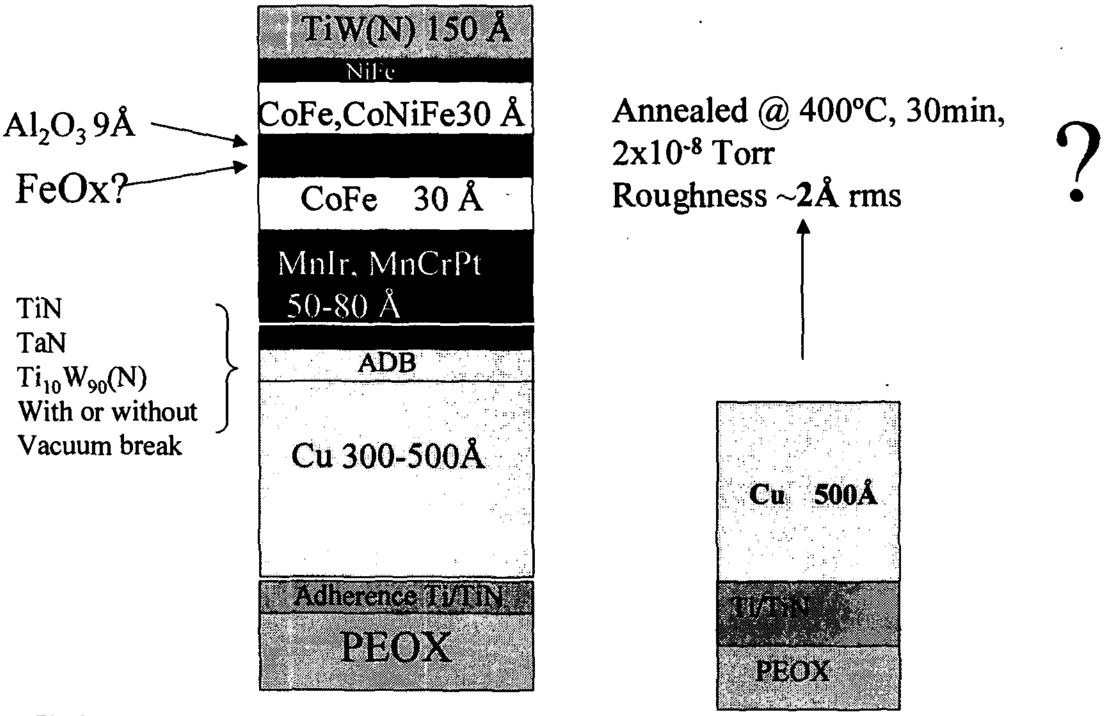


Write operation

TJ +a:Si diode vertical integration over buried word lines



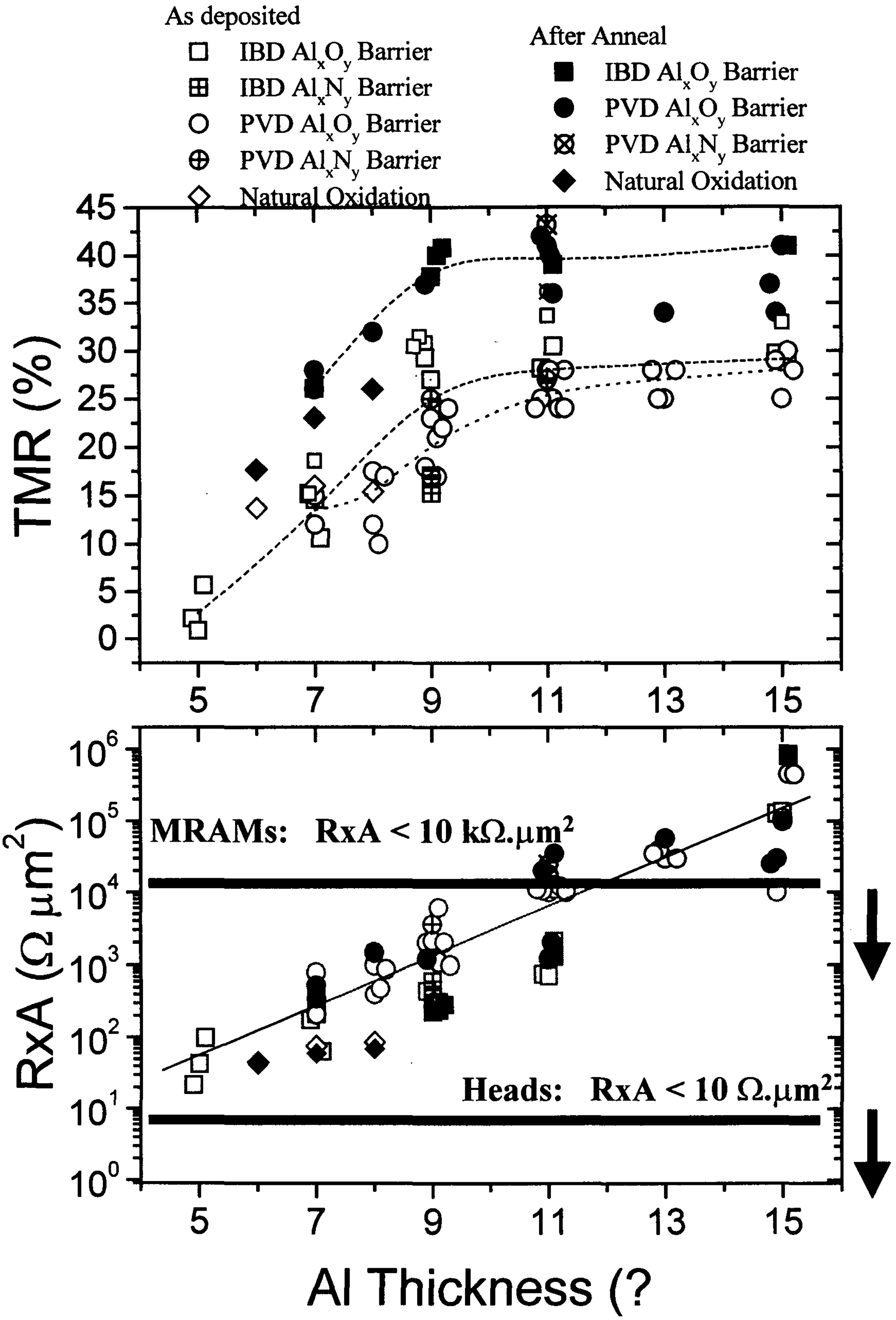
New junction structures under study for MRAMS



$Ti_{10}W_{90}$(N), 150uOhm.cm(PVD)
TaN, 300-600 uOhm.cm(PVD,IBD)
TiN, 80-200 uOhm.cm(PVD,IBD)

- Free layer switching control
- Increase TJ stack thermal stability for BEOL compatibility (400 to 450C)

Low R×A + high TMR tunnel junctions



Oxidation methods

Plasma oxidation

RF substrate bias

t_{Al} = 9-11 Å
RxA ~ 0.5-20 kΩ.μm^2
TMR ~ 40 %

IBD oxidation

Ion beam or remote plasma

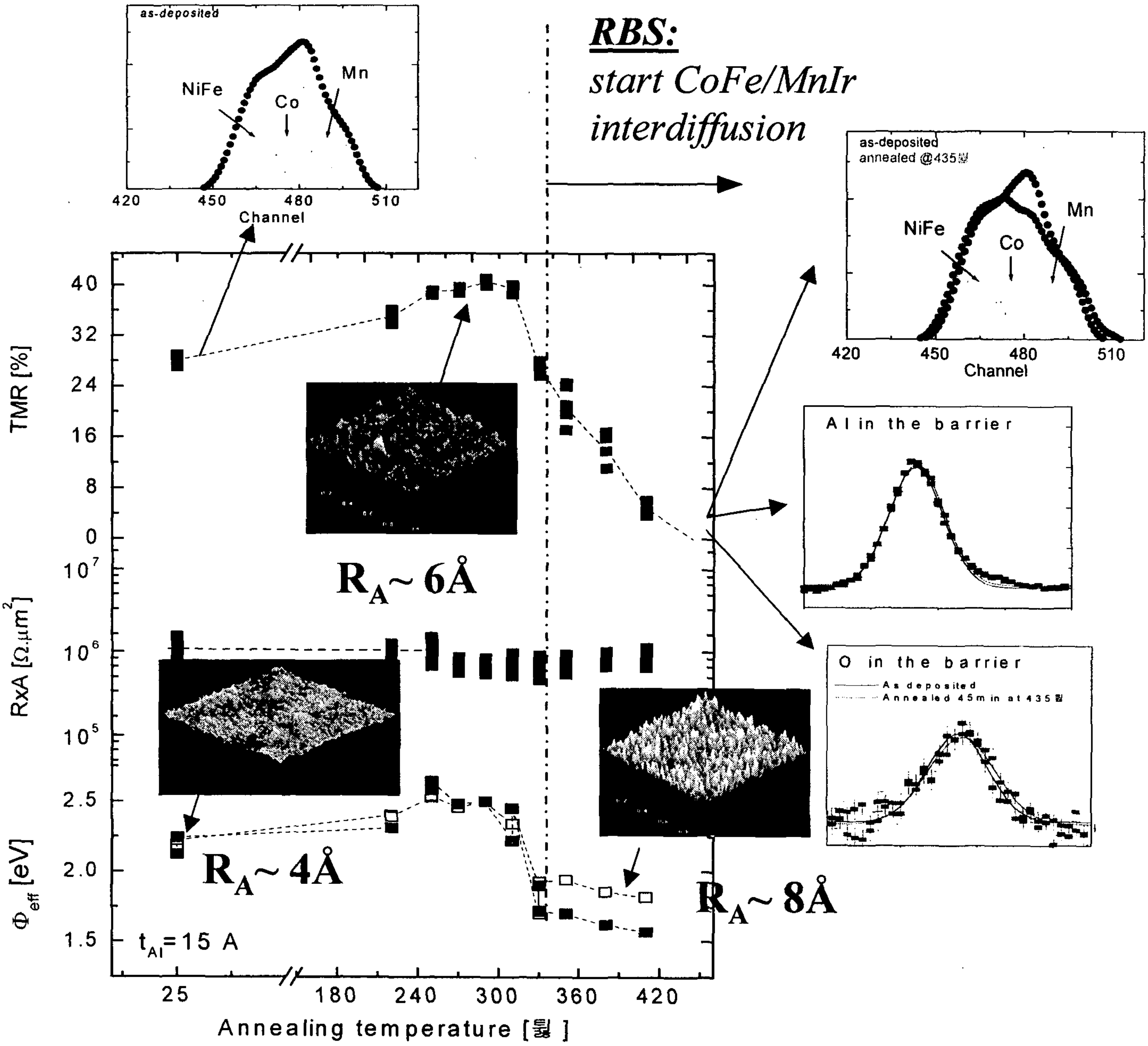
t_{Al} = 9 Å
RxA ~ 200-500 Ω.μm^2
TMR ~ 40 %

Natural oxidation

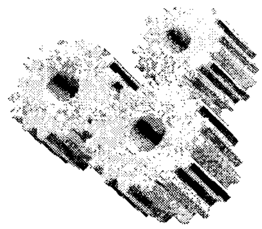
100 mTorr oxygen atmosphere

t_{Al} = 6-8 Å
RxA ~ 40-60 Ω.μm^2
TMR ~ 18-26 %

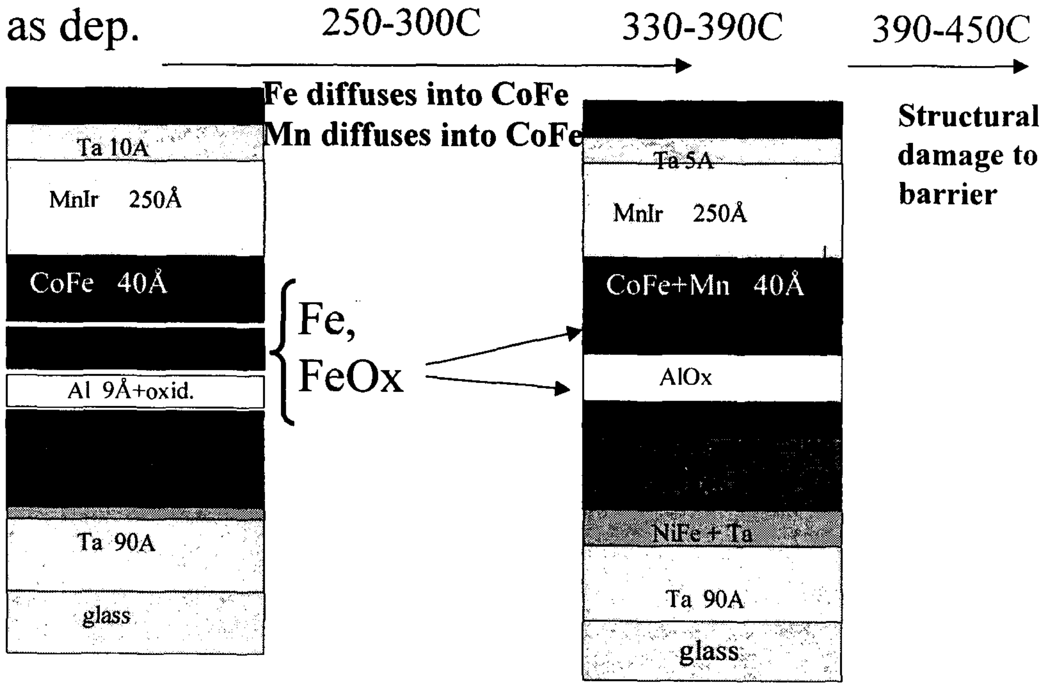
Review of main mechanisms leading to loss of TMR above 300-350C



How to improve thermal stability?

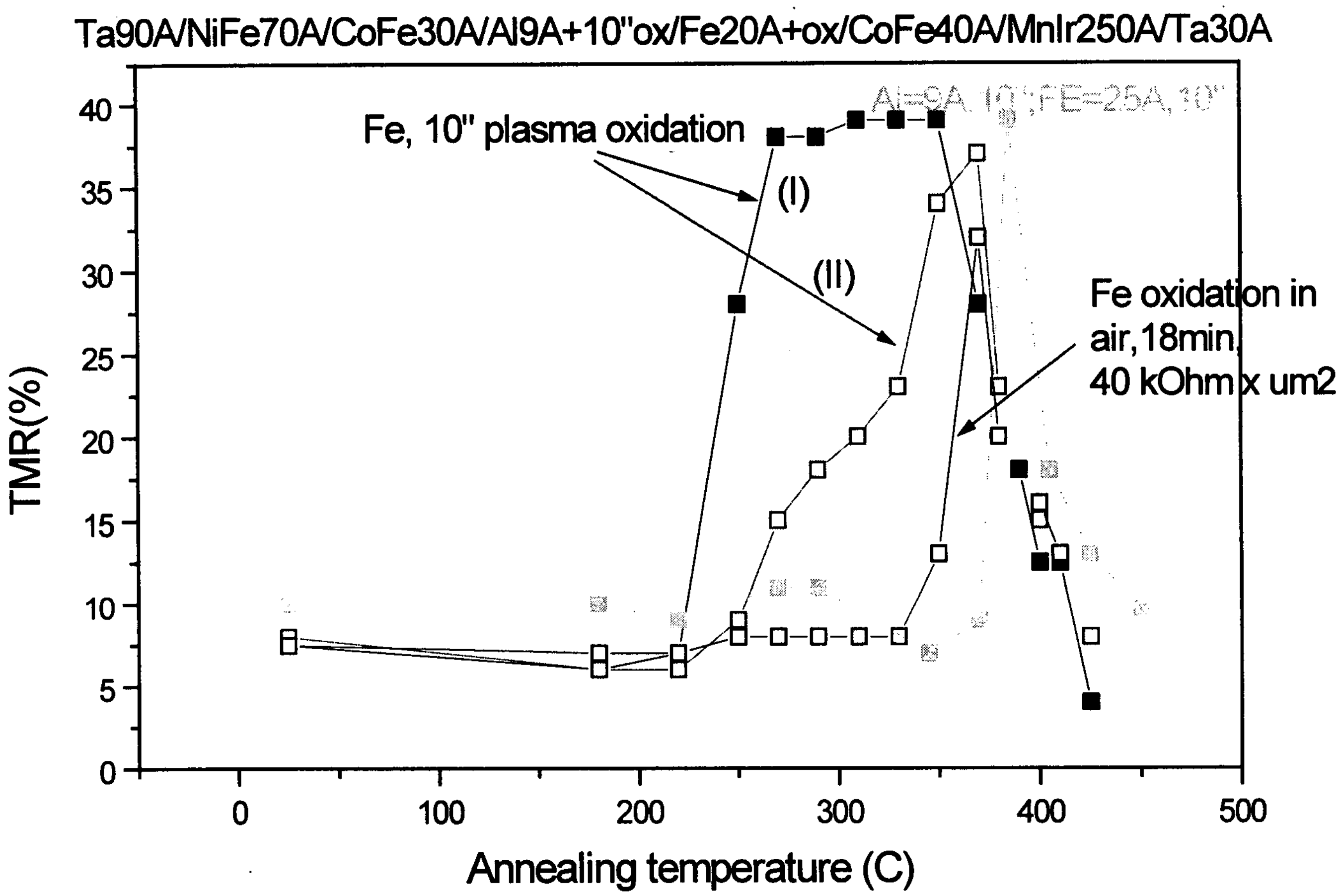


Tunnel Junctions with FeOx interfacial layer

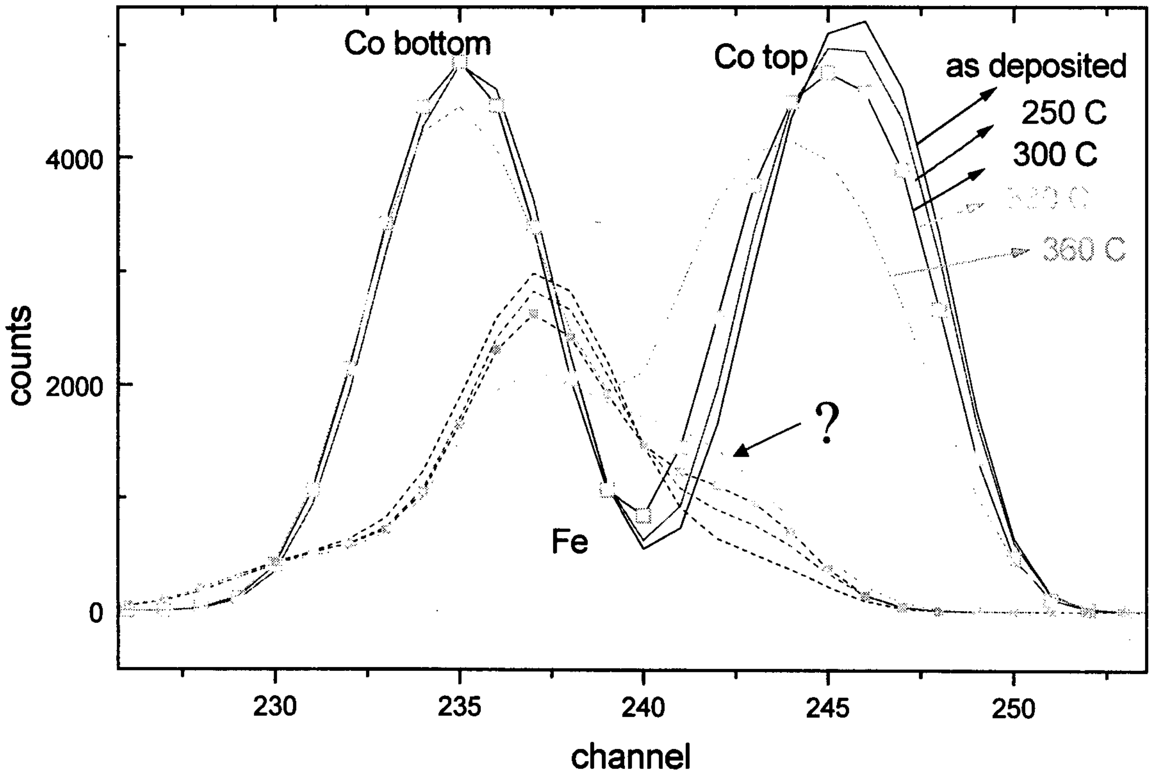


Maintaining full polarization at the barrier/electrode interface at 350 to 390 C,
Leads to 35 to 40% TMR in this temperature range.

Insertion of FeOx layer allows high TMR maintained after anneal between 350 and 385C



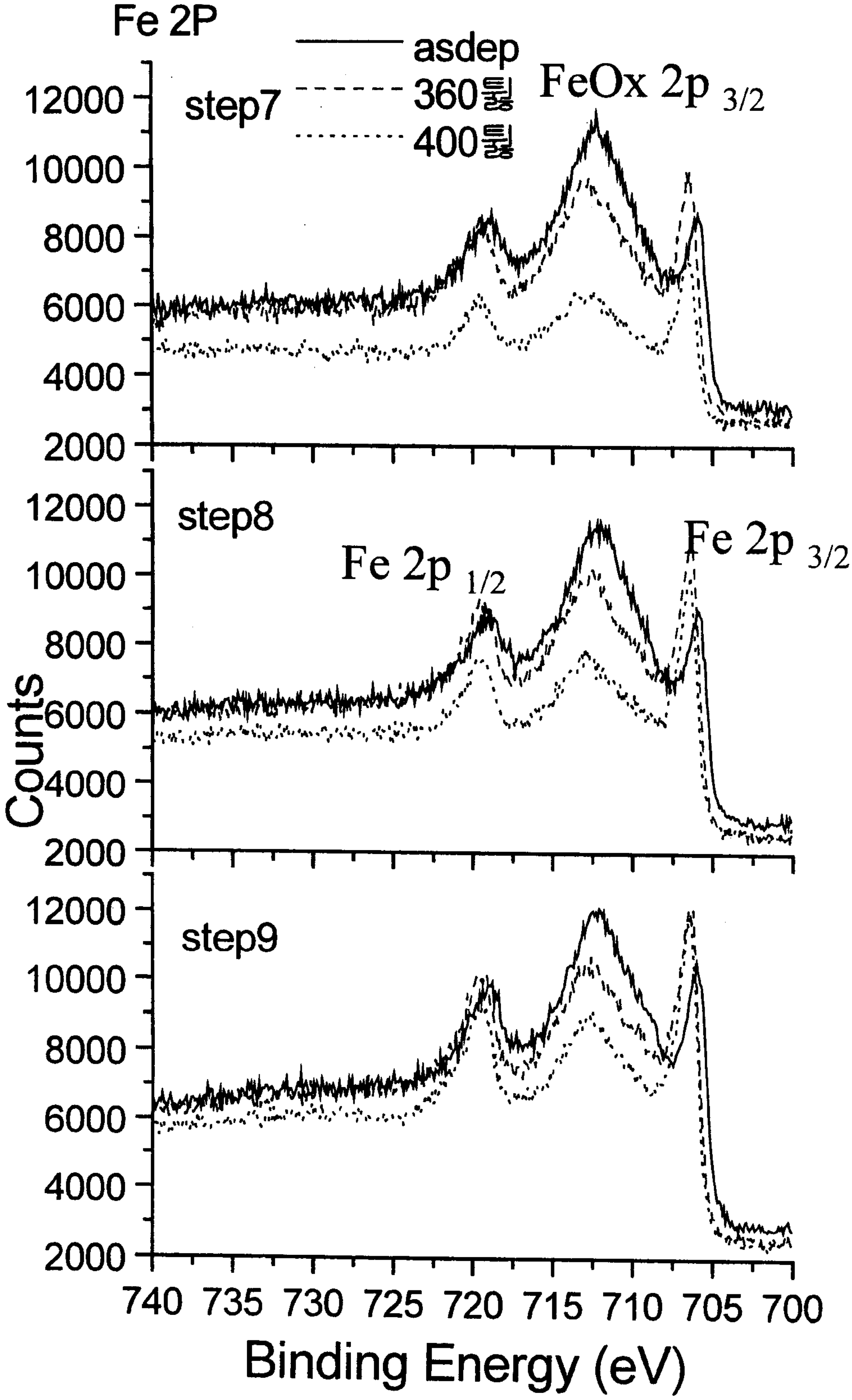
Co and Fe distribution as a function of anneal temperature: NDF* fits to the data



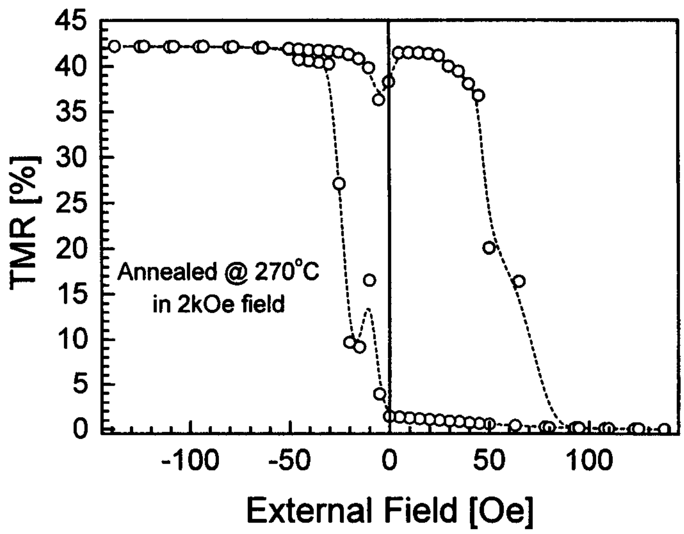
*N.P. Barradas, C. Jeynes, R.P. Webb, Appl. Phys. Lett. 71 (1997) 291

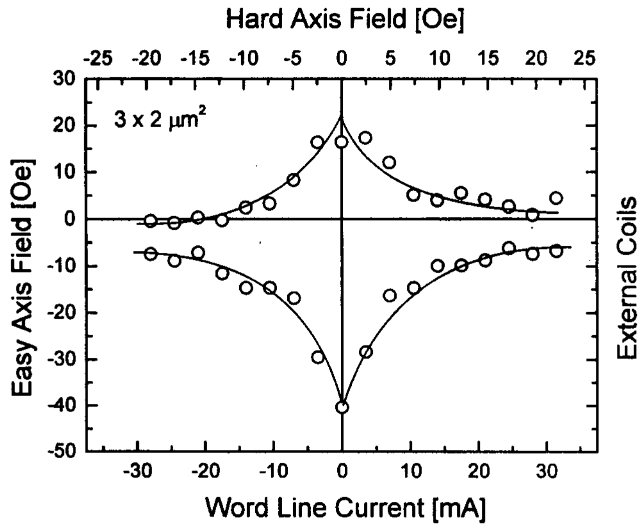
XPS analysis of Fe-Feox

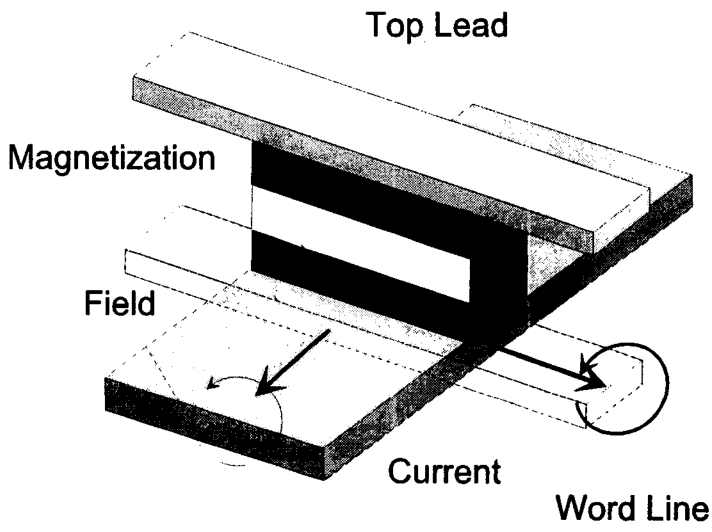
Si/Al2O3/CoFe30/AL9+ox./Fe20+ox./CoFe40/Ta30

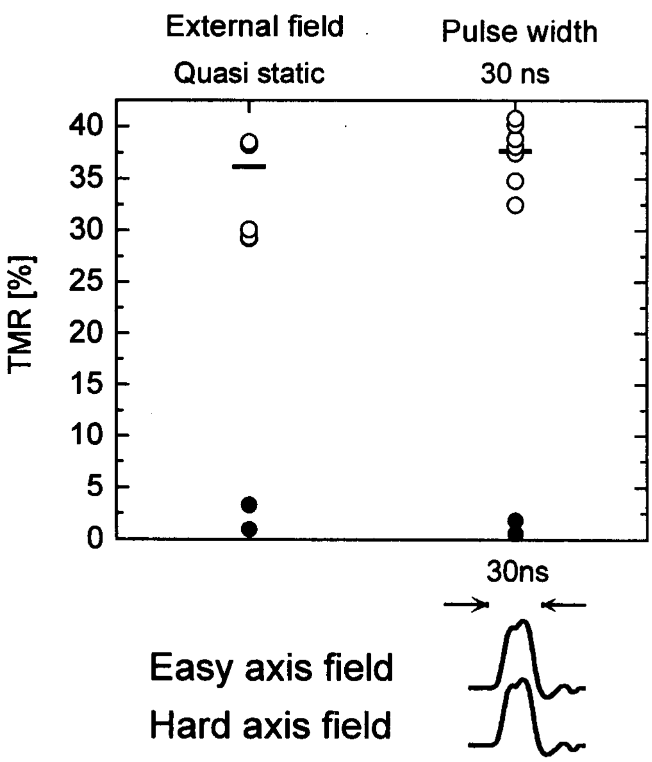


Dinamic switching of TJ

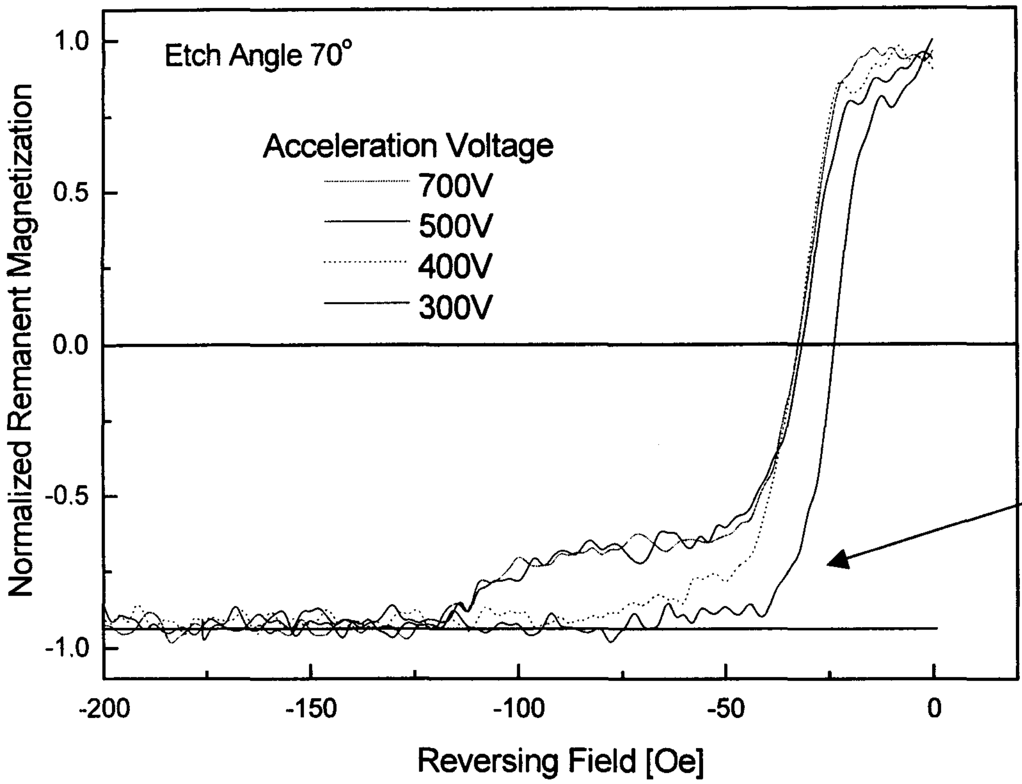




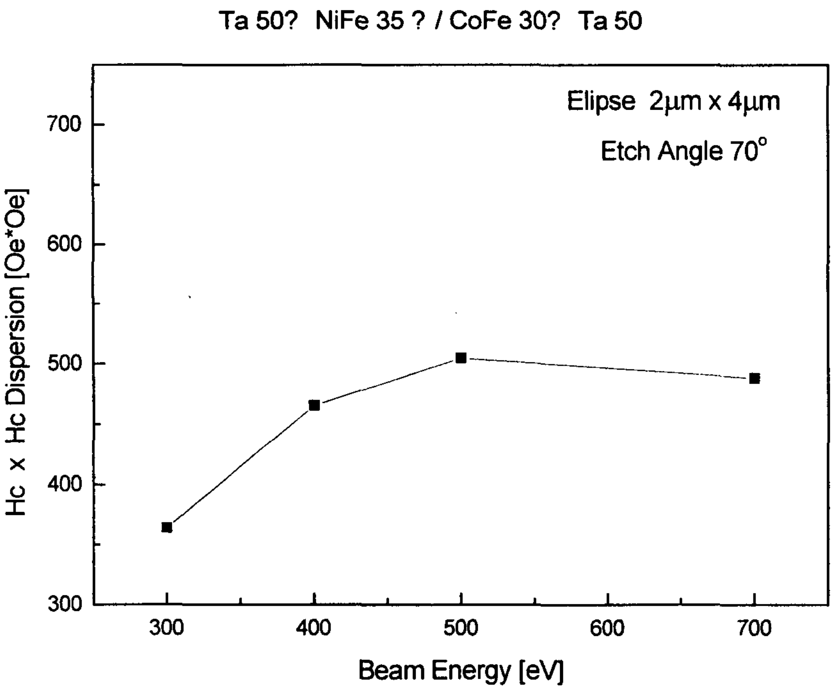




Milling Ion Energy Influence



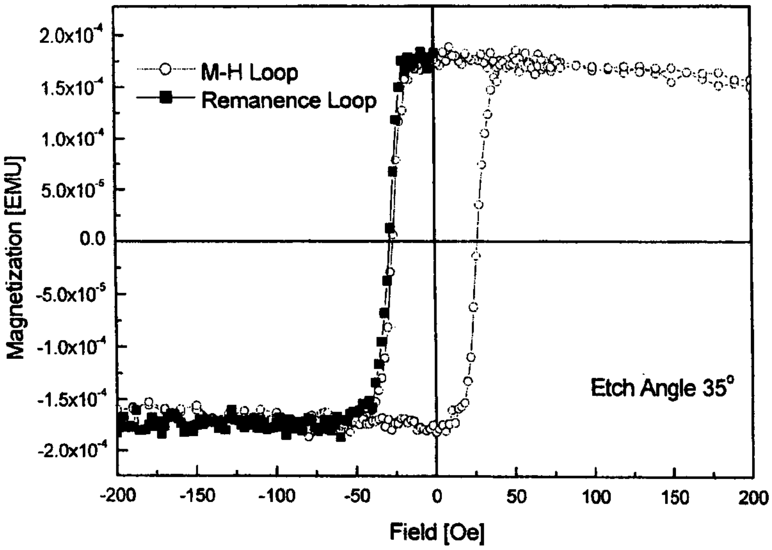
Low ion energy milling reduces the field for complete reversal.



Low ion energy also results in lower coercivity and steeper reversal of the patterned free layer.

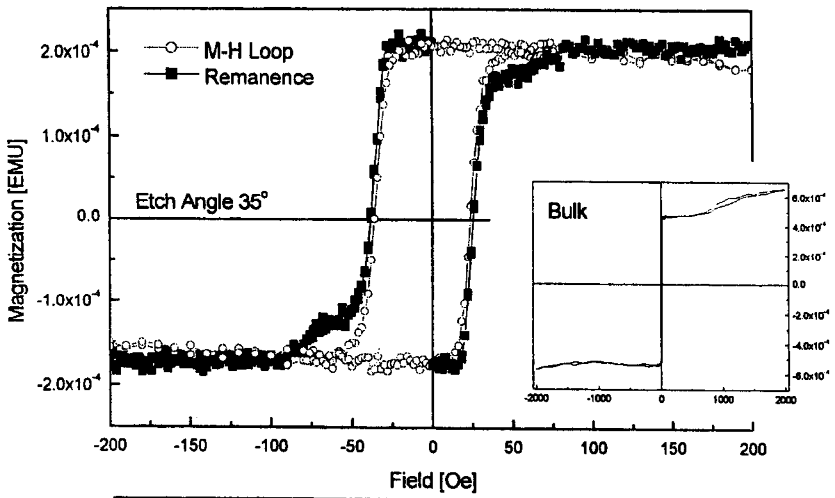
Patterning Full Junction Structures

Structure



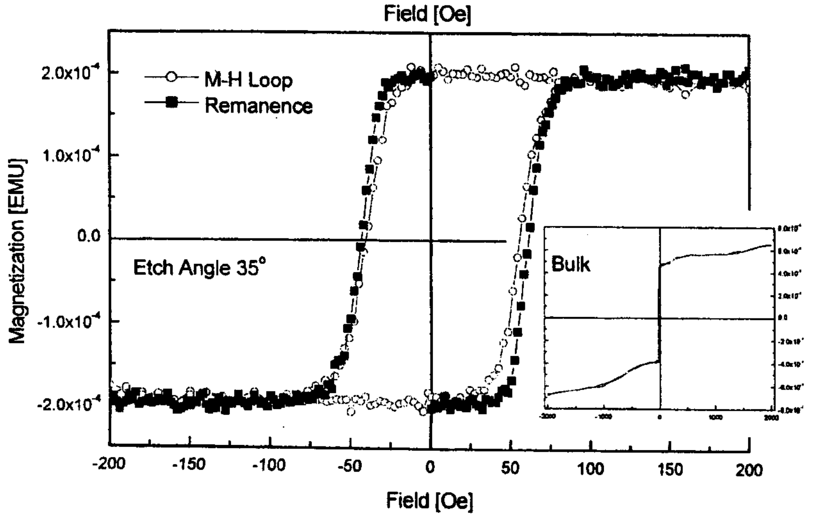
Free Layer

Ta 50 Å / NiFe 35 /
CoFe 30 / Ta 50 Å



Top Pinned Junction

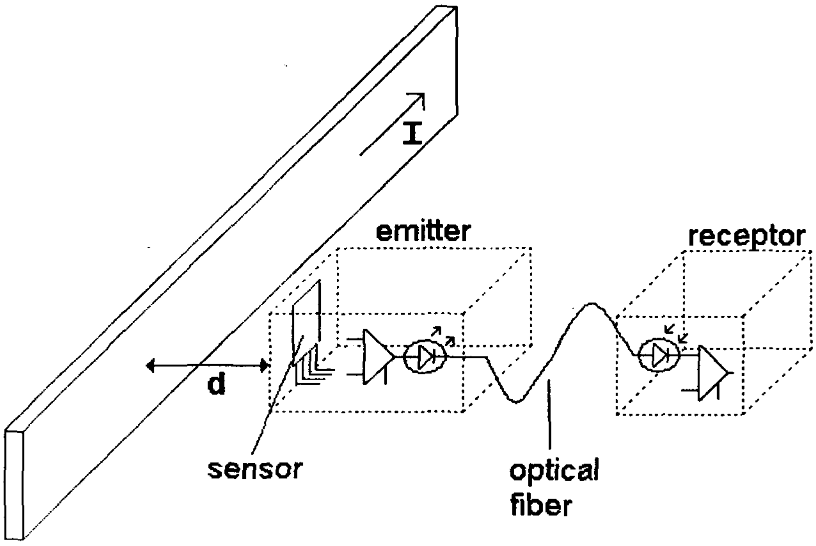
Ta 50 Å / NiFe 30 / CoFe 2
/ Al_2O_3 11 / CoFe 27 / Ru 6
CoFe 25 / MnIr 80 / Ta 50

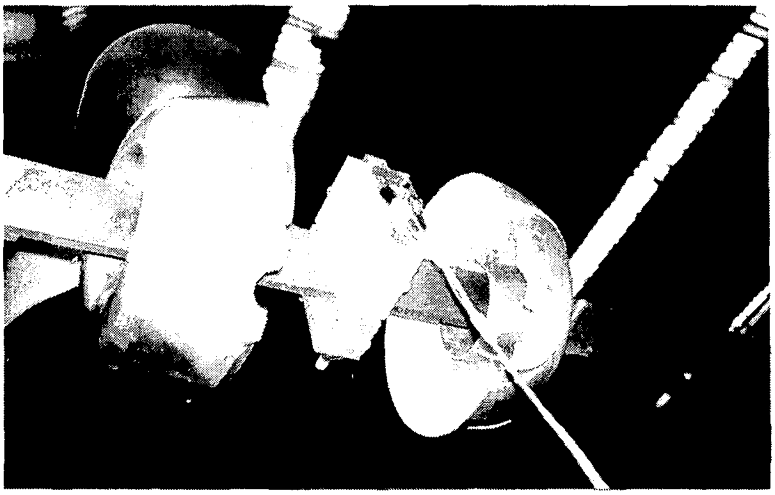


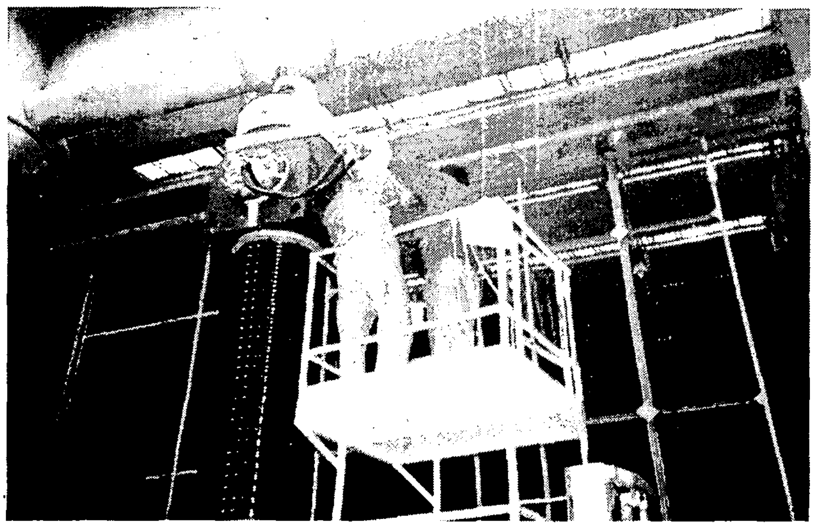
Bottom Pinned Junctior

Ta 50 Å / NiFe 2
/ MnIro80 / CoFe 25 / Ru (
CoFe 27 / Al_2O_3 11 / CoFeo2
/ NiFe 30 / Ta 5

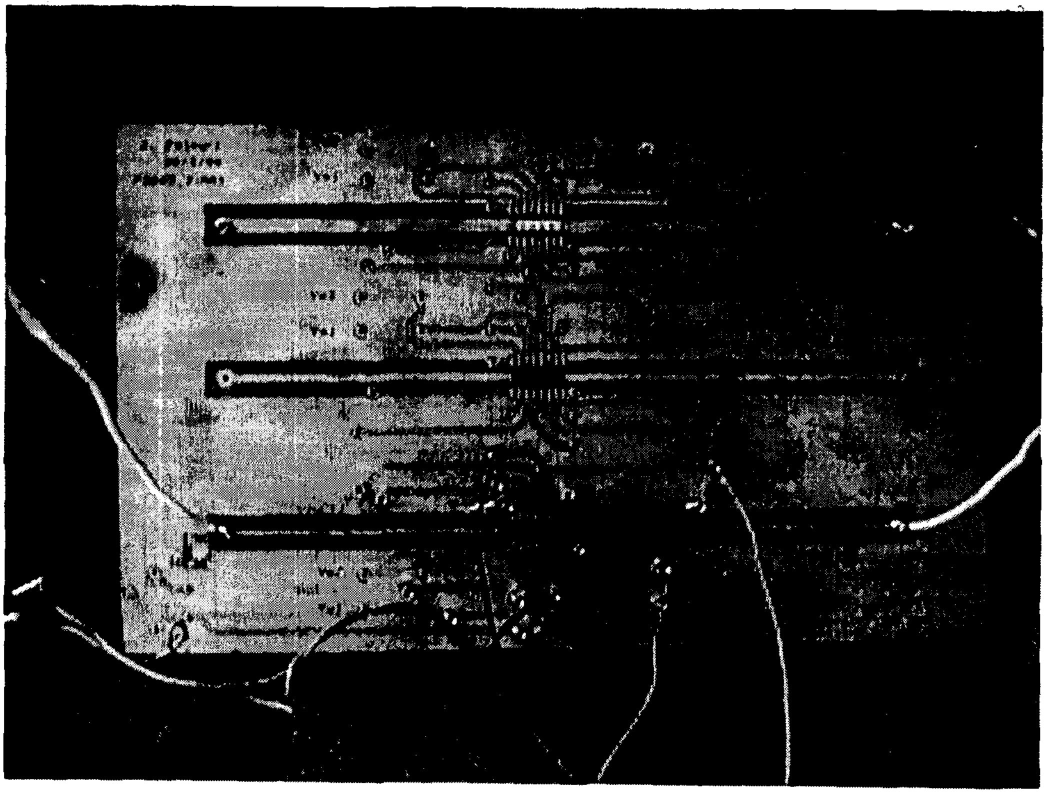
Power line (10.000A, 400 kV) monitoring







Incorporation of a GMR bridge sensor over a current line for high frequency measurements



X-Y precision robotic object handling using integrated dual GMR sensor