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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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RESEARCH WORKSHOP ON CONDENSED MATTER PHYSICS
(21 June - 3 September 1993)

WORKING GROUP ON MAGNETIC MULTILAYERS
(9 - 13 August 1993)

MAGNETIC METALLIC MULTILAYERS

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Working Group on Magnetic Multilayers

ICTP, Trieste, Italy

August 9 - 13, 1993

"MAGNETIC METALLIC MULTILAYERS"

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MATERIALS REPORTS

Technical reports giving an overview of progress and challenges in areas of materials research will be included in this section periodically.

Surface, interface, and thin-film magnetism

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OVERVIEW: SYSTEMS

Surfaces and monolayers

Metastable epitaxial films

Semiconductor substrates

Rare Earths

Oxides

Multilayers

TABLE I. Lattice constant (in Å) of representative substrate/film combinations for some magnetic metal films (for further details see Ref. 72). G. A. PRINZ

Substrate		Film	
fcc		fcc	
		Ni	(3.62)
Cu	(3.61)	Co	(3.55)
		Fe	(3.59)
fcc		bcc	
NaCl	(5.64)		
AlAs	(5.62)	Fe	(2.867) × 2
GaAs	(5.65)		
Ge	(5.66)		5.733
ZnSe	(5.67)		
fcc		bcc	
LiF	(4.02)		
Al	(4.05)	Fe	(2.867) $\times \sqrt{2}$
Au	(4.07)		
MgO	(4.31)		4.054
NaF	(4.62)		

TABLE II. Superlattice systems (for further details see Ref. 42, p. 139).

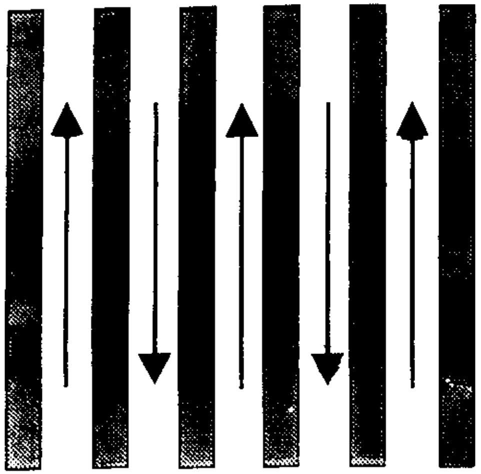
System	Preparation method	System	Preparation method
Ni/Cu	Ev, SpDC	Fe/Mg	Ev
Ni/Mo	SpDC	Fe/V	Ev
Ni/Cr	Ev	Fe/W	SpDC
Ni/C	Ev	Fe/Ta	SpDC
Ni/V	SpDC	Fe/Y	Ev
NiFe/TiN	SpDC	Fe/Pd	Ev, SpDC
Co/Cu	SpRF, Ev	Fe/Cr	Ev
Co/Au	SpRF	Fe/Mn	Ev
Co/Nb	Ev	Fe/FeO	Sp
Co/Sb	Ev	Fe/Nd	SpDC
Co/P	El	Fe/Gd	Ev
Co/Pd	SpRF, Ev	Fe/Tb	Sp
Co/Cr	Ev	FeB/Ag	SpDC
Co/Mn	Ev	FeCo/Si	Sp
Co/Gd	SpDC	FeCo/Tb	Ev
CoNb/CoTi	Sp	Mn/Ag	Ev
CoSiBi/CoTi	Sp	Mn/Sb	Ev
Fe/Cu	SpRF, Sp	Dy/Y	Ev, MBE
Fe/Ag	Ev	Er/Y	MBE
Fe/Au	SpRF	Gd/Y	Ev, MBE
Fe/Sb	Ev	Tm/Lu	Sp
Fe/Sn	Ev		

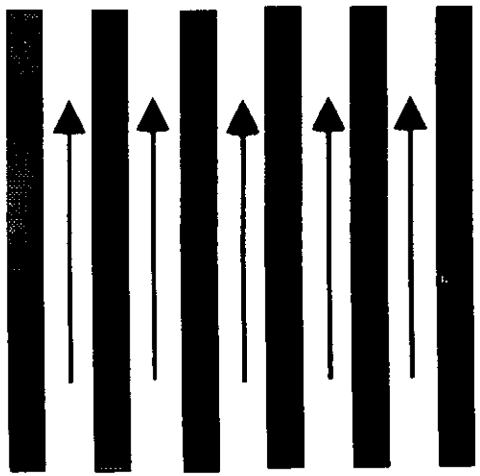
Ev = Evaporation
Sp = Sputtering
El = Electrolytic method
MBE = Molecular Beam Epitaxy

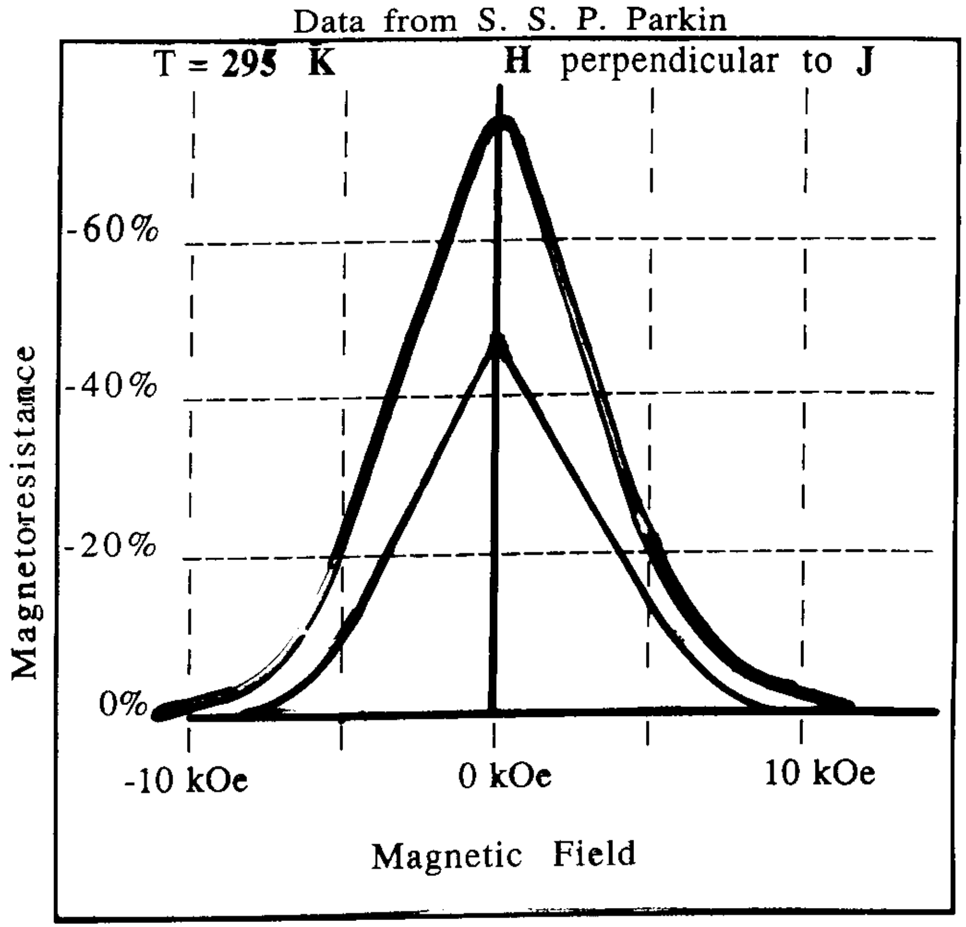
TABLE III. Metal-on-metal growth (for further details see Ref. 73).

Substrate	Overlayer						
	V	Cr	Mn	Fe	Co	Ni	Rare earth
Cu(100)		X		X	X	X	
Cu(110)				X			
Cu(111)				X	X	X	
Ag(100)	X		X	X		X	
Au(100)		X		X			
Pd(100)			X	X			
Pd(111)				X			
Ru(0001)			X	X			
Ru(10$\bar{1}$0)				X			
Re(0001)						X	
W(110)				X			Eu Gd Tb Ce Dy
V(110)							
Fe(100)						X	
Ni(100)							Gd
CuAu(111)				X			
$Cu_3Au(100)$				X			
Y(0001)							Dy Er Gd Ho

S. D. BADER







SiFe(50Å) [8Å Co/8.3Å Cu]$_{60}$Fe(25Å)

SiRu(50Å) [8Å Co/8.3Å Cu]$_{40}$Ru(15Å)

OVERVIEW:

PHYSICAL EFFECTS

Proximity effects

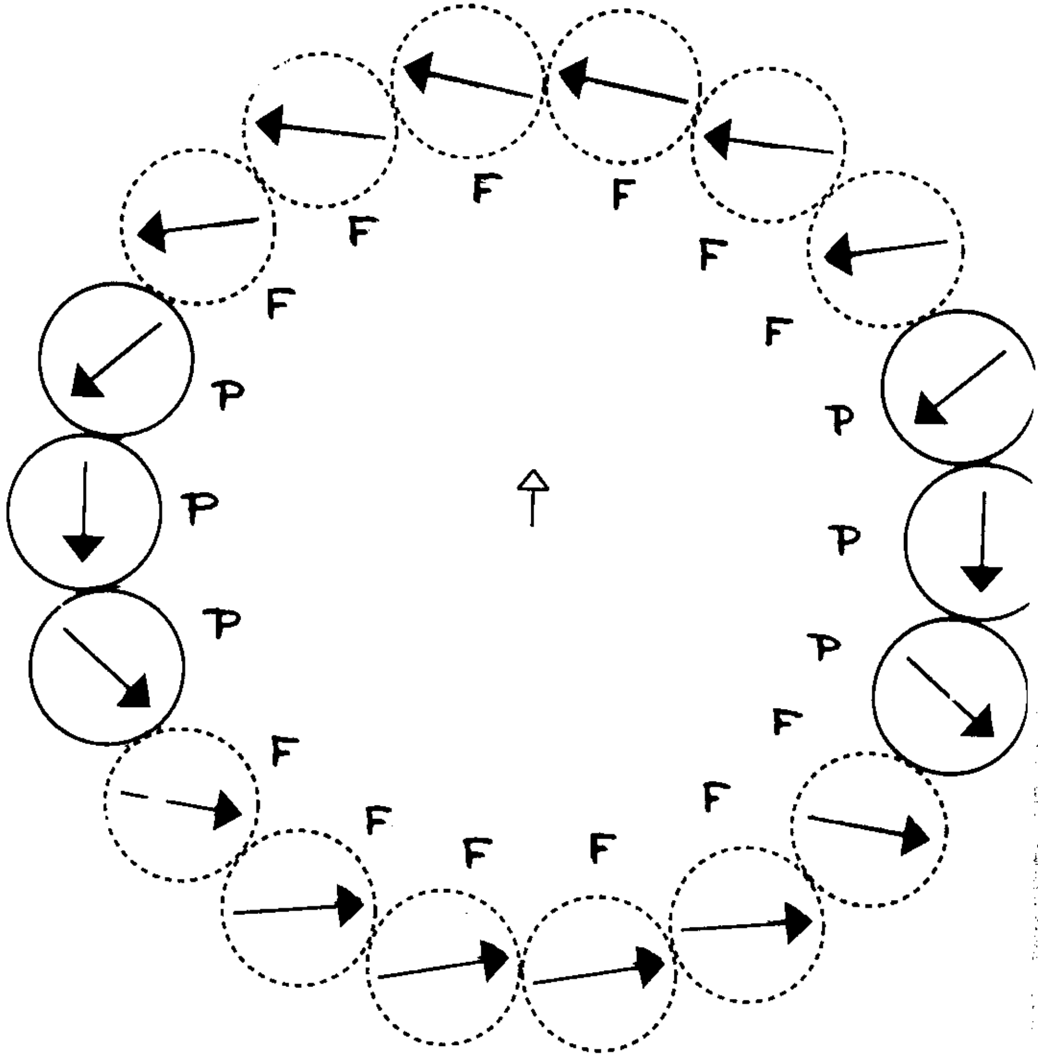
Exchange coupling
across interfaces

RKKY coupling

Coupling through
nonmagnetic layers

Magnetoelasticity

Superlattice effects



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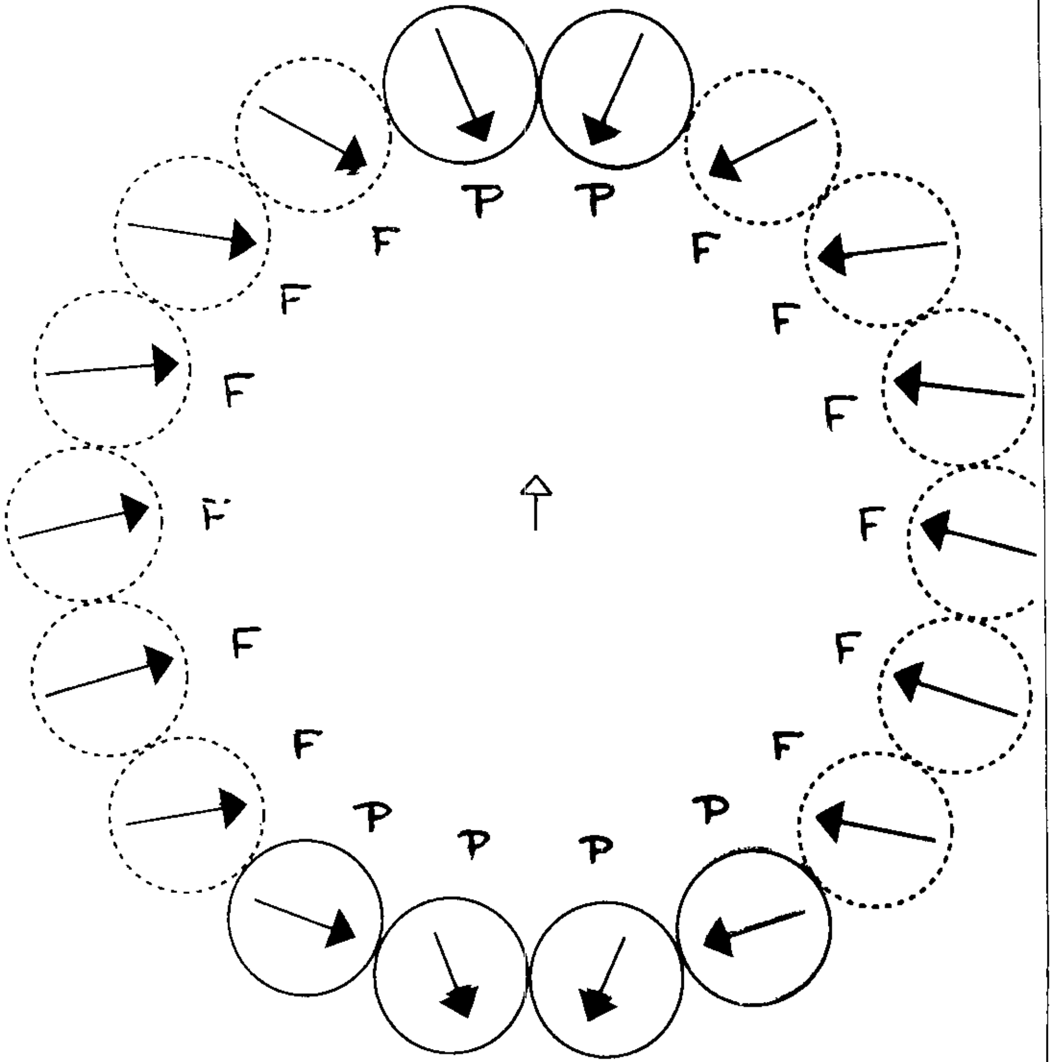

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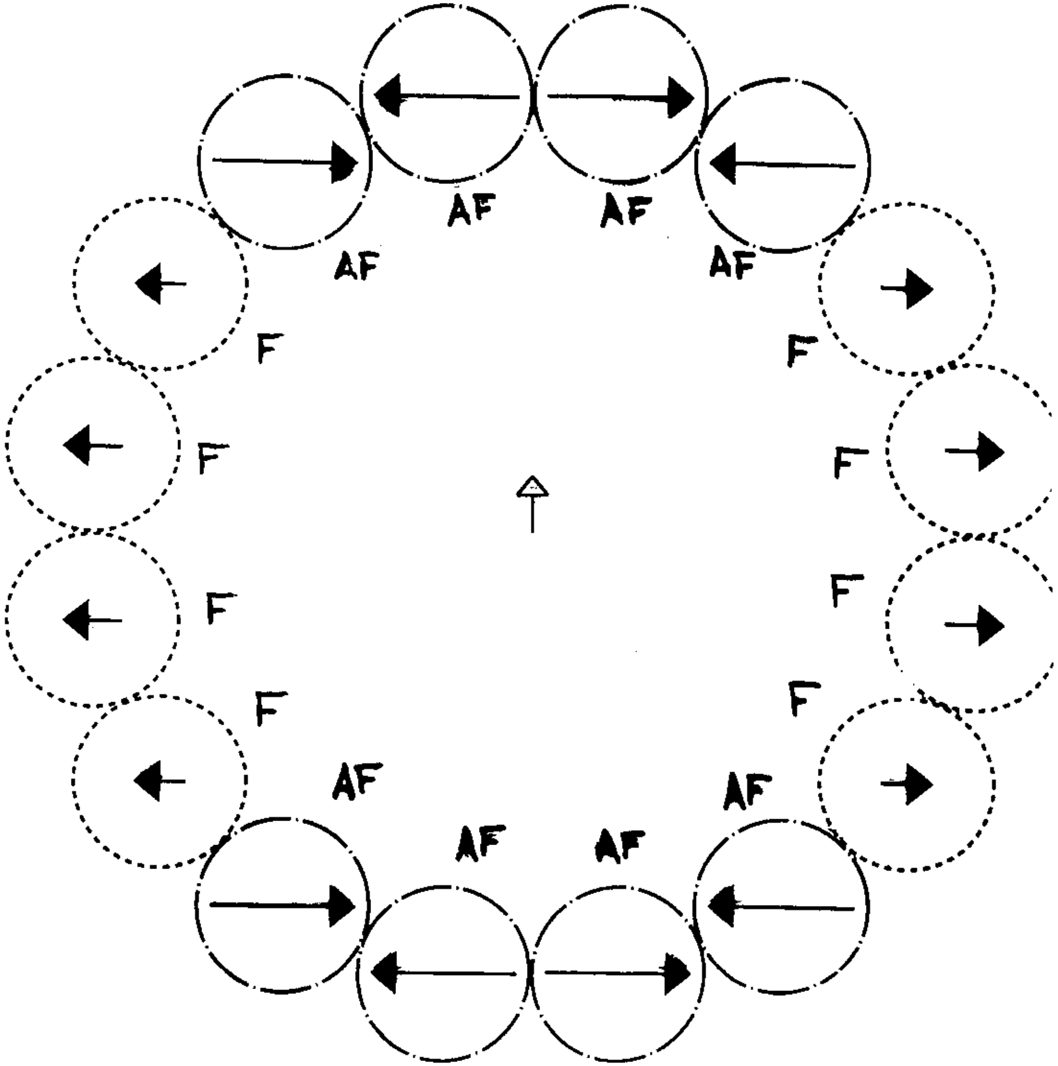
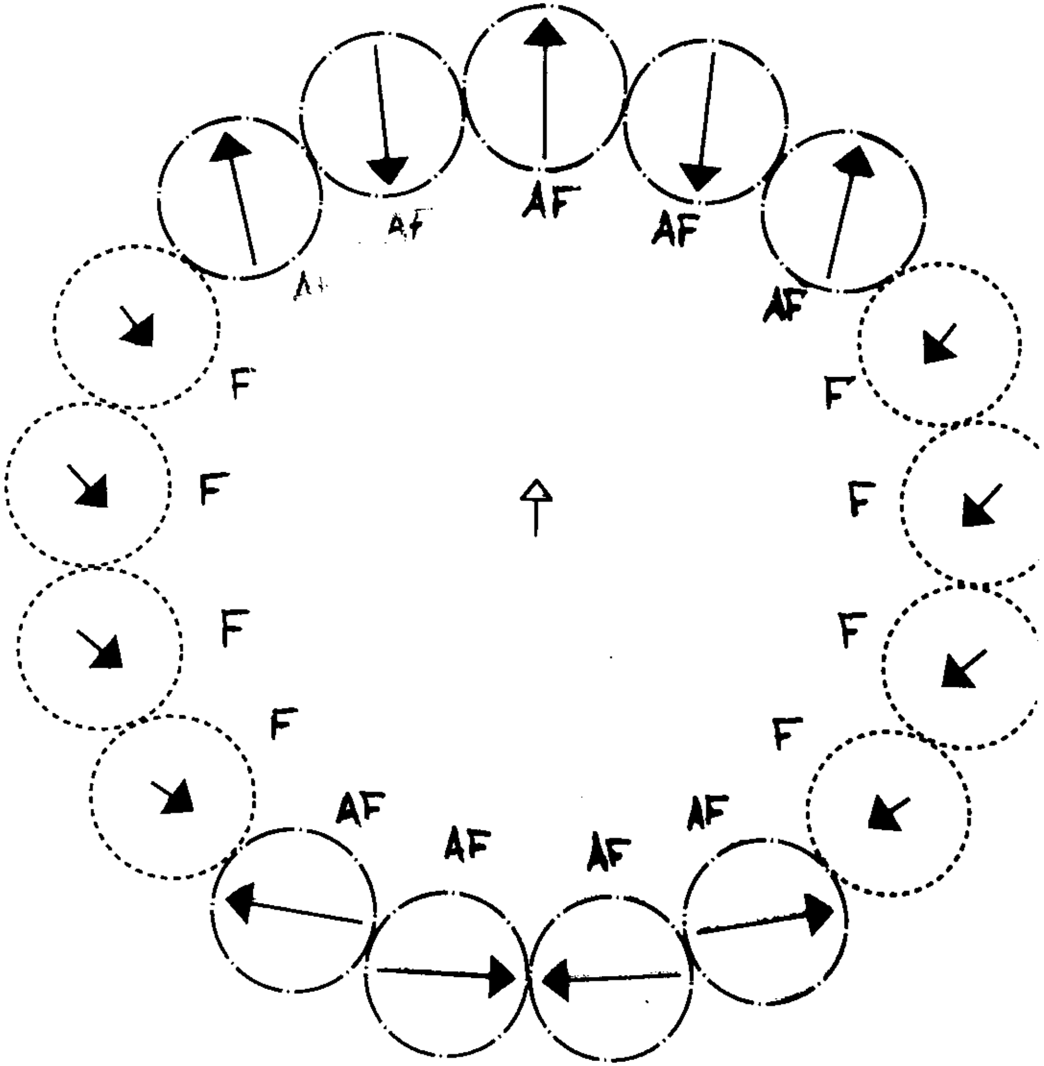
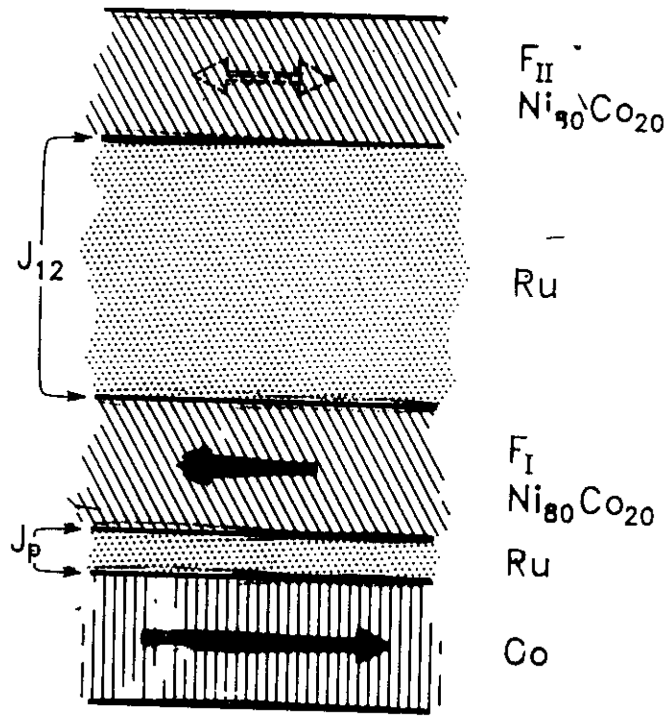




R.Q. HOOD & L.M. FALICOV



PARKIN & MAURI

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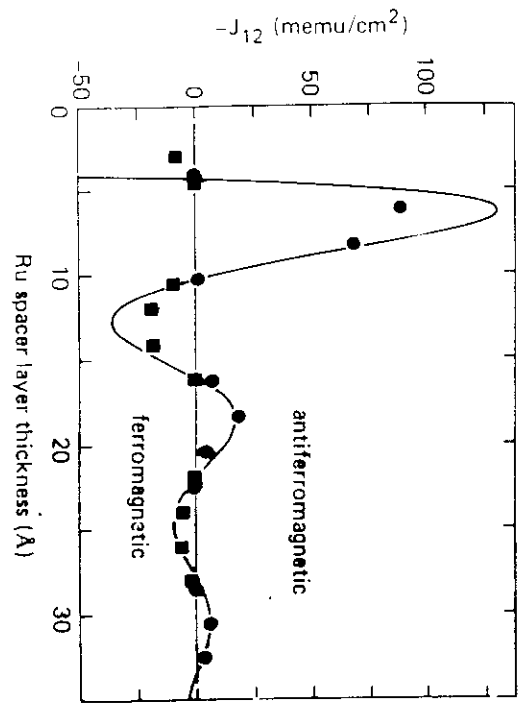

PARKIN 4 MAURI

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METAL

Ti ⬡	V (bcc)	Cr (bcc)	Mn (complex cubic)	Fe (bcc)	Co ⬡	Ni (fcc)	Cu (fcc)
No Coupling	9 | 3 0.1 | 9	7 | 7 .24 | 18		Ferro-Magnet	Ferro-Magnet	Ferro-Magnet	8 | 3 0.3 | 10
2.89	2.62	2.50	2.24	2.48	2.50	2.49	2.56

Zr ⬡	Nb (bcc)	Mo (bcc)	Tc ⬡	Ru ⬡	Rh (fcc)	Pd (fcc)	Ag (fcc)
No Coupling	9.5 | 2.5 .02 | *	5.2 | 3 .12 | 11		3 | 3 5 | 11	7.9 | 3 1.6 | 9	No Coupling	No Coupling
3.17	2.86	2.72	2.71	2.65	2.69	2.75	2.89

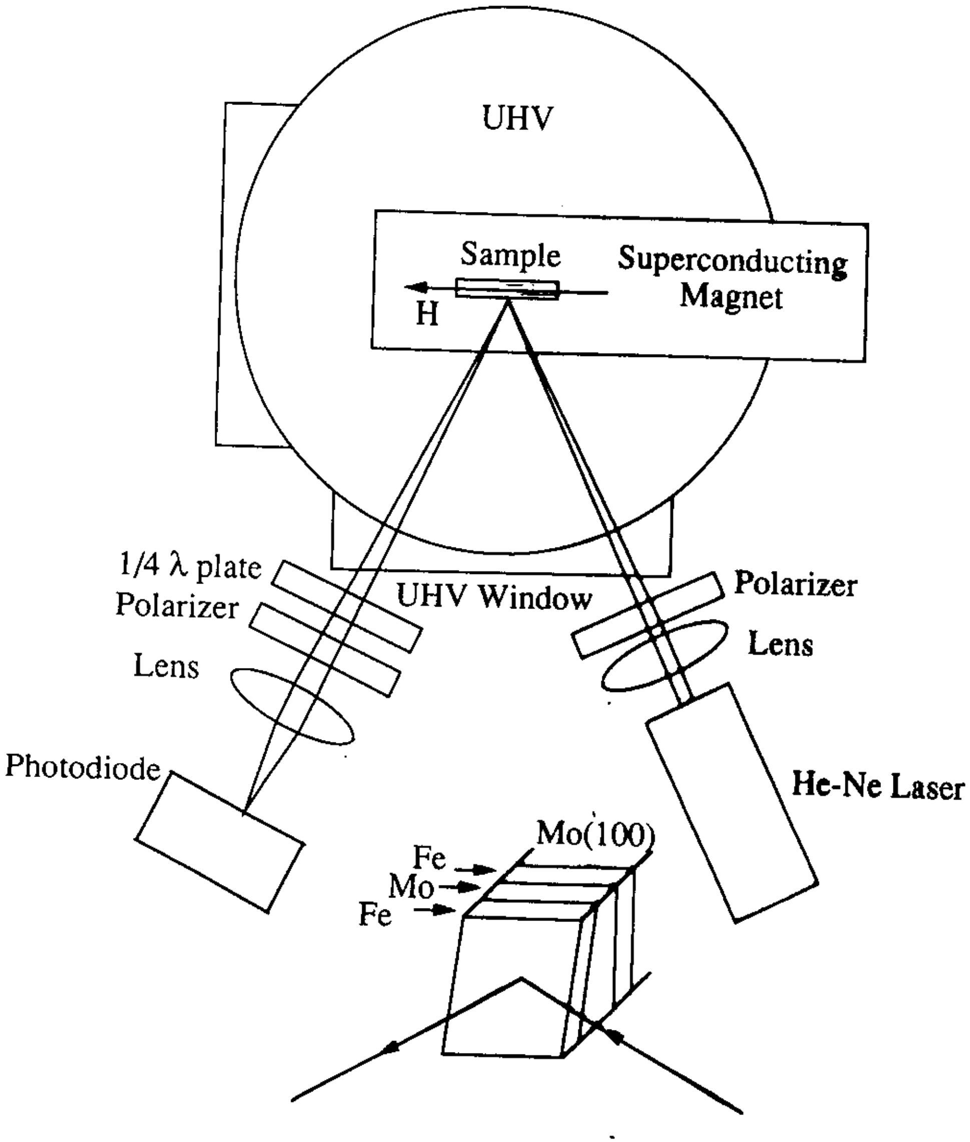
Hf ⬡	Ta (bcc)	W (bcc)	Re ⬡	Os ⬡	Ir (fcc)	Pt (fcc)	Au (fcc)
No Coupling	7 | 2 .01 | *	5.5 | 3 .03 | *	4.2 | 3.5 .41 | 10		4 | 3 1.85 | 9	No Coupling	No Coupling
3.13	2.86	2.74	2.74	2.68	2.71	2.77	2.88

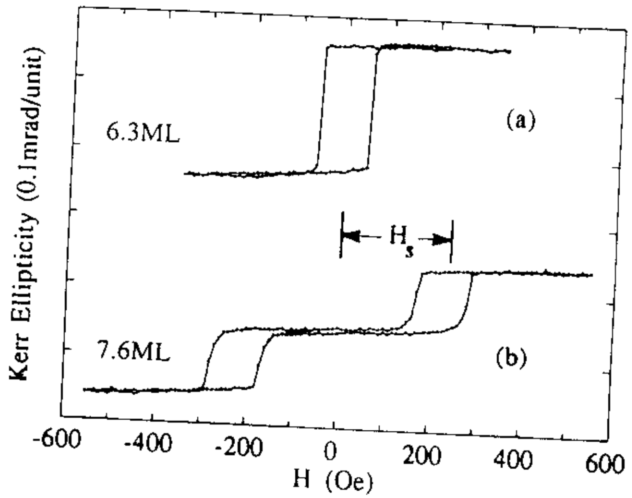
Key:

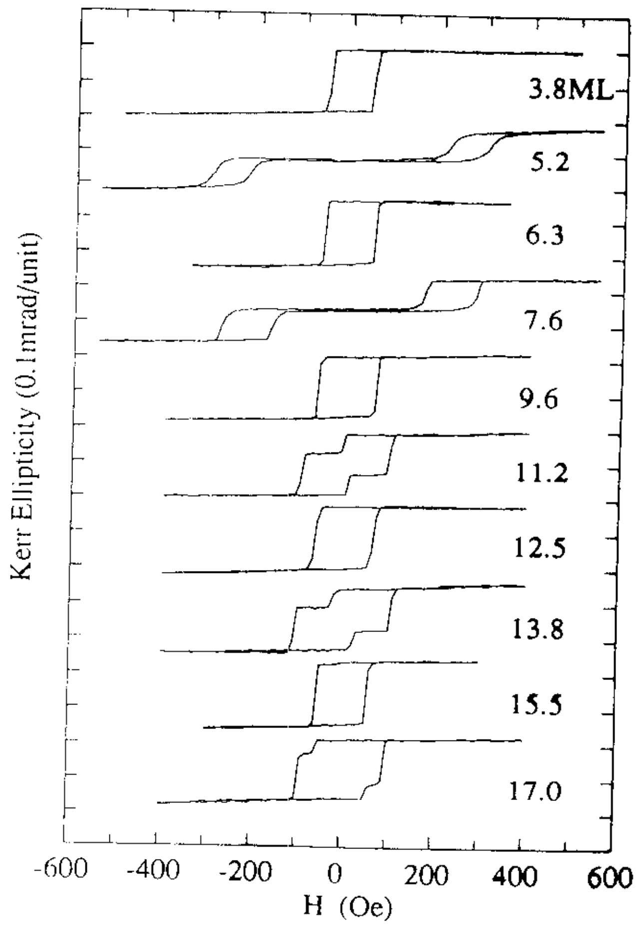
Element	
A_1 (Å)	ΔA_1 (Å)
J_1 (erg/cm^2)	P (Å)
r_{ws} (Å)	

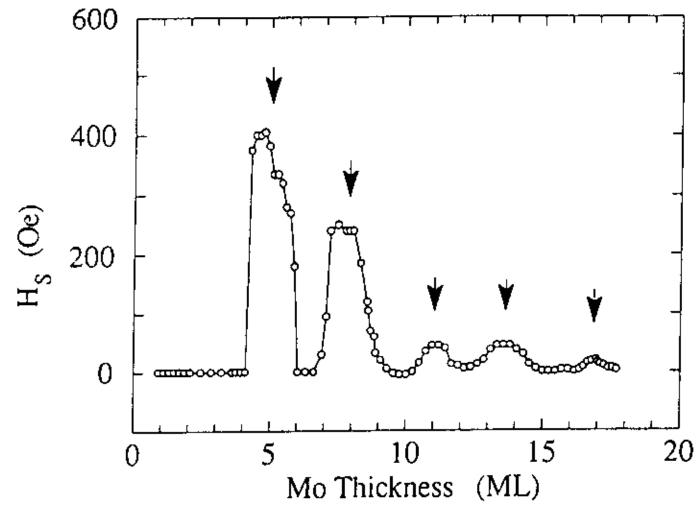
fcc   bcc   ⬡ hcp   complex cubic

S.S.P. PARKIN


UHV
Sample
Superconducting Magnet
H
1/4 λ plate
Polarizer
UHV Window
Polarizer
Lens
Lens
Photodiode
He-Ne Laser
Mo(100)
Fe
Mo
Fe


Kerr Ellipticity (0.1mrad/unit)
6.3ML
(a)
H_s
7.6ML
(b)
-600
-400
-200
0
200
400
600
H (Oe)

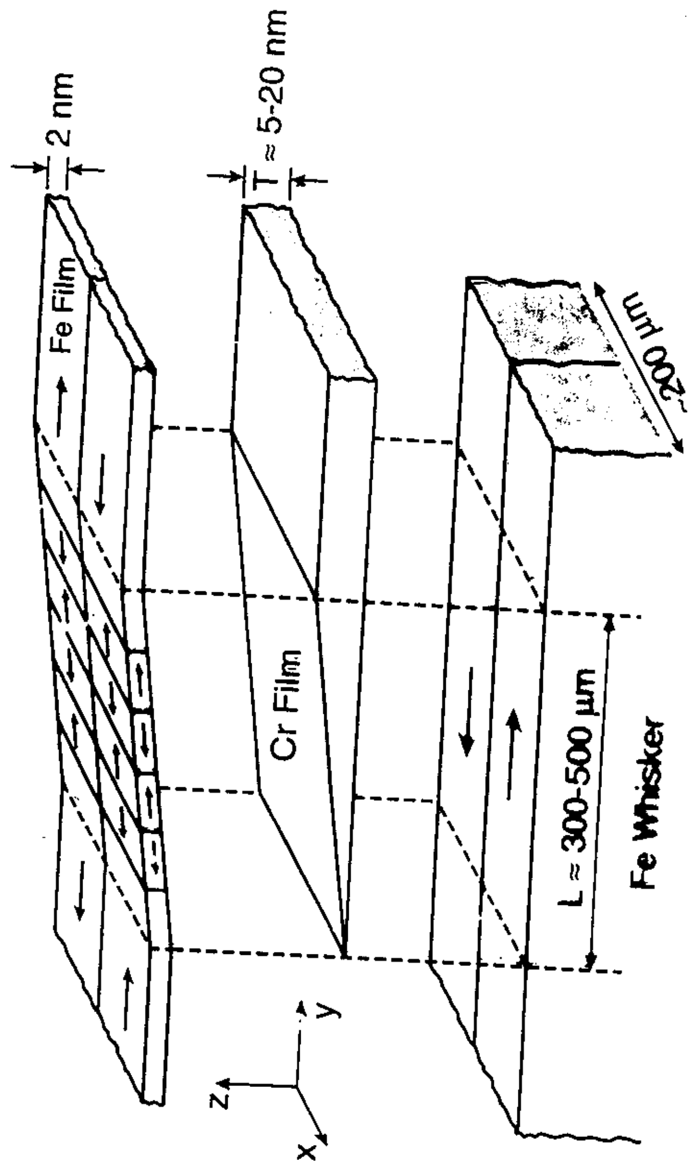

3.8ML
5.2
6.3
7.6
9.6
11.2
12.5
13.8
15.5
17.0
Kerr Ellipticity (0.1mrad/unit)
-600 -400 -200 0 200 400 600
H (Oe)


600
400
200
0
H_S (Oe)
0 5 10 15 20
Mo Thickness (ML)

Scanning Electron Microscopy with Polarization Analysis

FIG. 9. The SEMPA image in (a) shows approximately horizontal light and dark bands corresponding to a written test pattern of magnetic bits, one of which is outlined near the center. In (b) a ten-times-higher magnification magnetization image than in (a) shows the irregularity of the domain boundaries which contribute to the read-back noise and ultimately limit the density of information that can be recorded. The intensity image in (c) shows the surface topography of the same region as in (b).

Pierce, Scheinfein, Unguris & Celotta



Unguris, Celotta & Pierce
Phys. Rev. Lett. 67, 140 (1991)
1 July 1991

SEMPA IMAGES

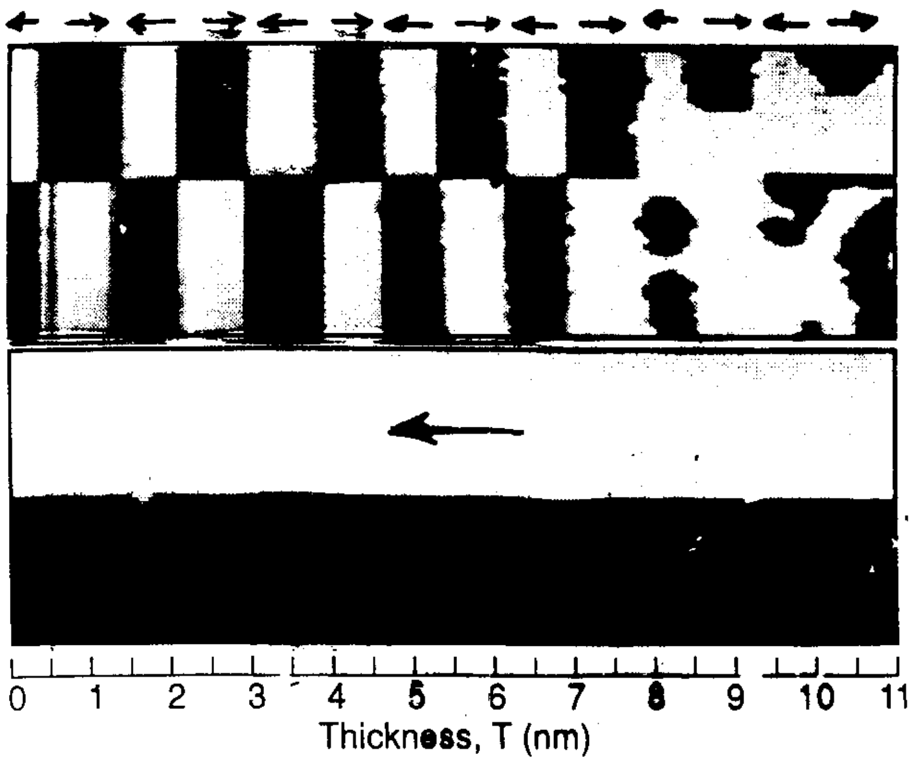


Figure 2.

Unguris
Celotta
+

SEMPA IMAGES

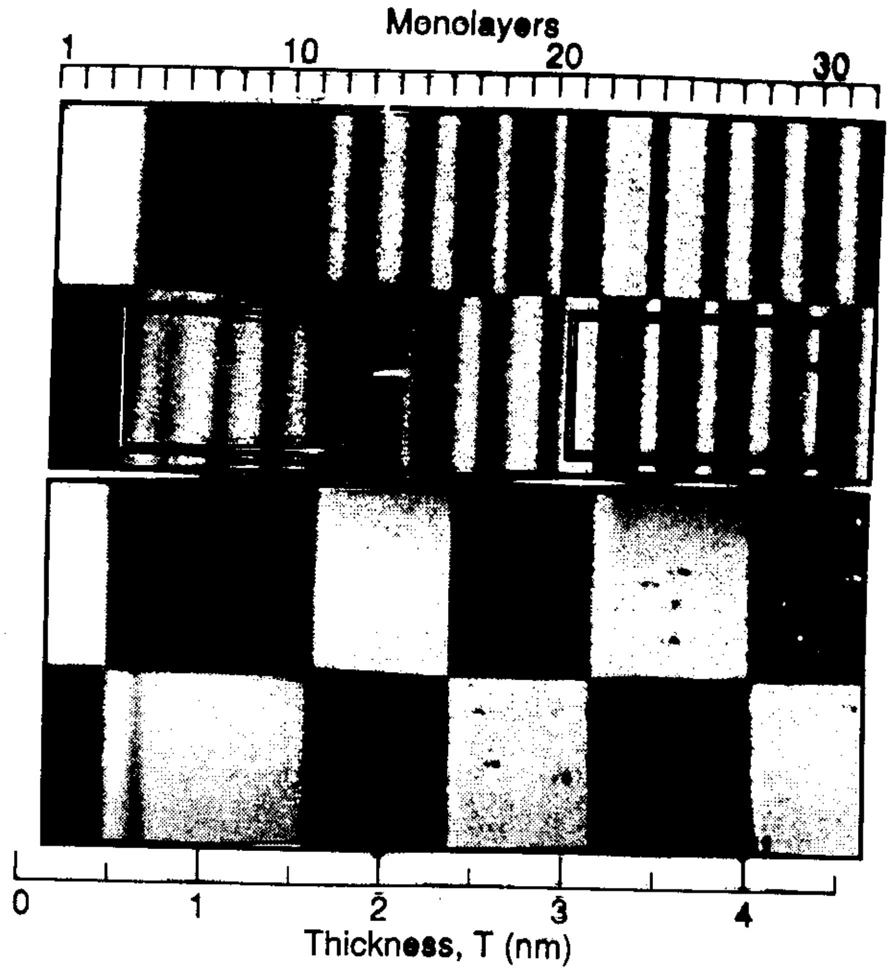
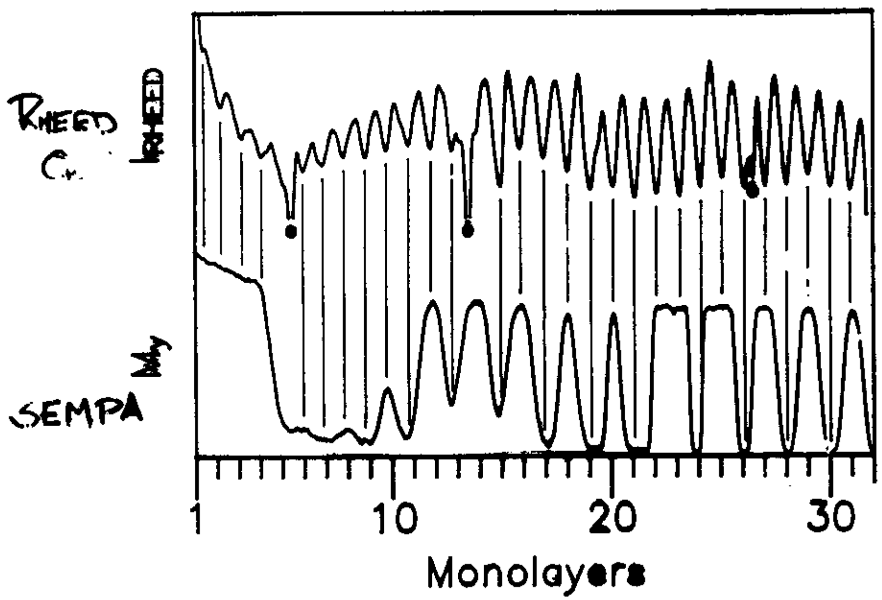


Figure 3.

Unguris, Celotta + Pierce



Unguris, Celotta + Pierce

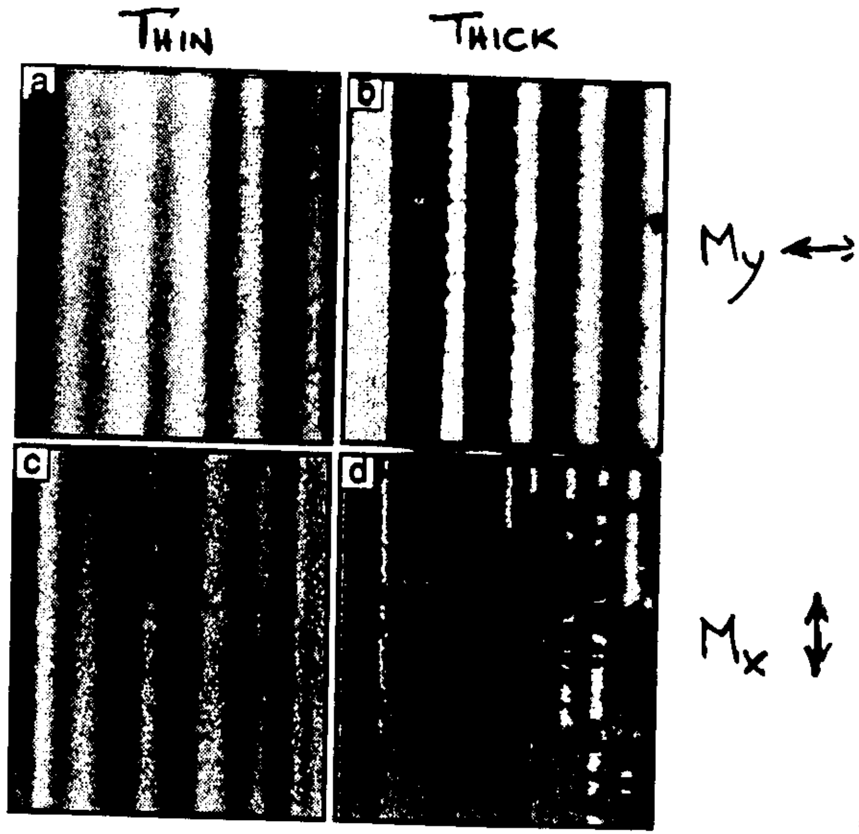


Figure 5.

Unguris, Celotta and Pierce

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OVERVIEW: THEORY

Electronic Calculations

Critical Phenomena

Transport Properties

Micromagnetics

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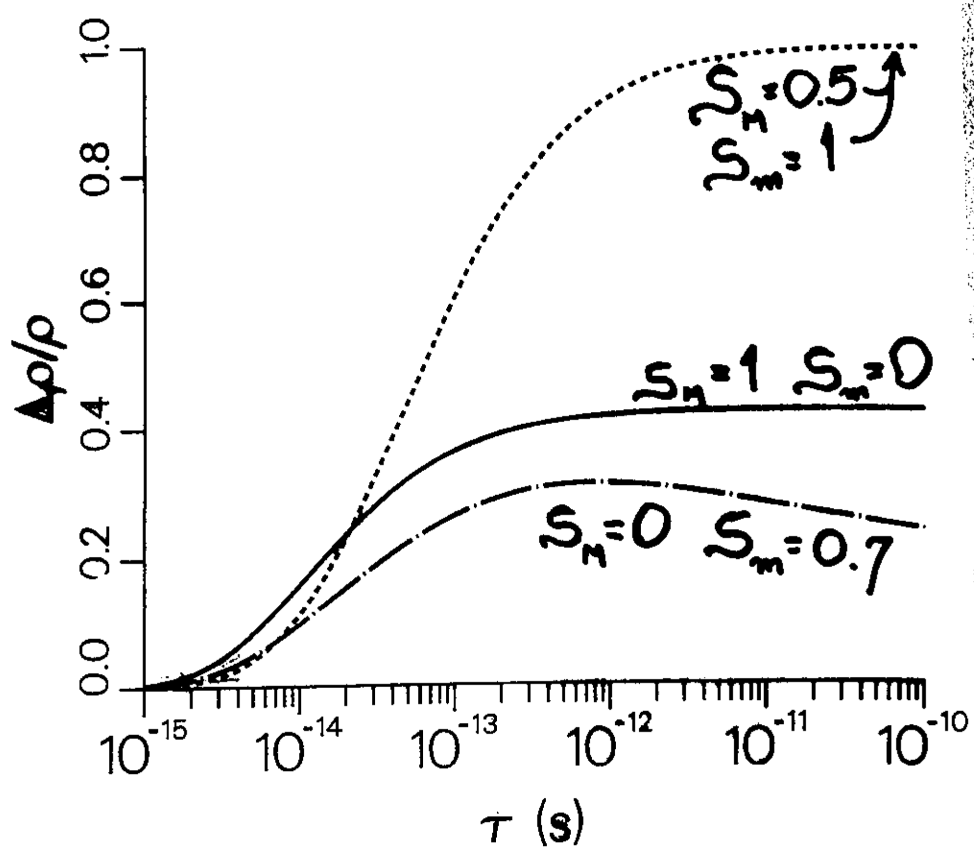

$[Fe/Cr]_n$

$d_{Cr} = d_{Fe} = 10 \text{ Å}$