

Contents

1	Introduction	1
1.1	Introduction to Nanotechnology.	1
1.2	Introduction to Nanoelectronics.	3
1.2.1	Information Technology: Current Limits	3
1.2.2	GMR Heads: Impact on the Information Storage	4
1.3	Comparison of the Nanostructures Studied in the Thesis from a Dimensional Point of View	7
1.4	Epitaxial Fe_3O_4 Thin Films.	8
1.5	Dual Beam System for the Fabrication of Nanostructures.	11
1.5.1	Focused Electron Beam (or SEM).	12
1.5.2	Focused Ion Beam	13
1.5.3	Focused Electron/Ion Beam Induced Deposition	13
1.6	Atomic-Sized Nanoconstrictions	16
1.6.1	Theoretical Background for Atomic-Sized Constrictions	16
1.6.2	Atomic Constrictions in Magnetic Materials.	19
1.7	Functional Nanowires Created by FEBID/FIBID.	21
1.7.1	Pt-C NWs Created by FEBID/FIBID.	21
1.7.2	Superconducting W-based NWs Created by FIBID	22
1.7.3	Magnetic Co NWs Created by FEBID.	23
1.8	Structure of the Thesis	24
1.9	Reproduction of Material	25
	References	27
2	Experimental Techniques	33
2.1	Lithography Techniques	33
2.1.1	Optical Lithography	34
2.1.2	Dual Beam System	38

2.2	Electrical Measurements	40
2.2.1	Magnetotransport Measurements as a Function of Temperature	40
2.2.2	“In situ” Electrical Measurements	41
2.3	Spectroscopic Techniques	42
2.3.1	Energy Dispersive X-Ray Spectroscopy	42
2.3.2	X-Ray Photoelectron Spectroscopy	43
2.4	Spatially Resolved MOKE Magnetometry	44
2.5	Atomic Force Microscopy	46
2.6	High Static Magnetic Fields	47
2.7	Other Techniques	47
	References	49
3	Magnetotransport Properties of Epitaxial Fe_3O_4 Thin Films	51
3.1	Introduction	51
3.1.1	General Properties of Fe_3O_4	51
3.1.2	Properties of Epitaxial Fe_3O_4 Thin Films	53
3.2	Experimental Details	54
3.2.1	Growth of the Films	54
3.2.2	Types of Electrical Measurement: Van Der Pauw and Optical Lithography	54
3.3	Structural and Magnetic Characterization	54
3.4	Resistivity	57
3.4.1	Resistivity as a Function of Film Thickness (Room Temperature)	57
3.4.2	Resistivity as a Function of Temperature	57
3.5	Magnetoresistance and Anisotropic Magnetoresistance	58
3.5.1	Geometries for MR Measurements	58
3.5.2	MR as a Function of Film Thickness (Room Temperature)	59
3.5.3	MR as a Function of Temperature	61
3.6	Planar Hall Effect	63
3.6.1	Introduction to the Planar Hall Effect	63
3.6.2	PHE as a Function of Film Thickness (Room Temperature)	64
3.6.3	PHE as a Function of Temperature	66
3.7	Anomalous Hall Effect	68
3.7.1	Introduction to the Anomalous Hall Effect	68
3.7.2	AHE as a Function of the Film Thickness (Room Temperature)	70
3.7.3	AHE as a Function of the Temperature	71
3.7.4	AHE in Fe_3O_4 : Universal Behavior	72

3.7.5	Fe ₃ O ₄ Inside the AHE Dirty Regime of Conductivities.	74
3.8	Ordinary Hall Effect	74
3.8.1	OHE as a Function of Film Thickness (Room Temperature)	76
3.8.2	OHE as a Function of Temperature.	77
3.9	Conclusions	78
	References	79
4	Conduction in Atomic-Sized Magnetic Metallic Constrictions Created by FIB	83
4.1	Introduction	83
4.2	Experimental Procedure. Example for a Non-Magnetic Material: Chromium.	84
4.3	Iron Nanocontacts	90
4.3.1	Creation of Fe Nanoconstrictions Inside the Chamber.	90
4.3.2	Measurements of One Constriction in the Tunneling Regime of Conduction.	91
4.4	Conclusions	95
	References	96
5	Pt-C Nanowires Created by FIBID and FEBID	99
5.1	Nanowires Created by Focused-Ion-Beam- Induced-Deposition	99
5.1.1	Previous Results in Pt-C Nanodeposits Grown by FIBID.	99
5.1.2	Experimental Details	100
5.1.3	Results.	104
5.1.4	Discussion of the Results.	114
5.2	Comparison of NWs Created by FEBID and FIBID.	118
5.2.1	Experimental Details	118
5.2.2	Results.	119
5.3	Conclusions	124
	References	125
6	Superconductor W-based Nanowires Created by FIBID	129
6.1	Introduction	129
6.1.1	Previous Results in FIBID-W.	129
6.1.2	Transition Superconductor Temperatures in W Species	130
6.2	Experimental Details	130
6.2.1	HRTEM Analysis	131
6.2.2	XPS Measurements	131

6.2.3	Electrical Measurement in Rectangular (Micro- and Nano-) Wires	131
6.3	HRTEM Analysis of FIBID-W	131
6.4	XPS Study of FIBID-W	132
6.5	Superconducting Electrical Properties of Micro- and Nano-Wires	134
6.5.1	Critical Temperature of the Wires	134
6.5.2	Critical Field of the Nanowires	137
6.5.3	Critical Current of the Nanowires	138
6.6	Study of FIBID-W by Scanning-Tunneling-Spectroscopy	138
6.7	Conclusions	140
	References	141
7	Magnetic Cobalt Nanowires Created by FEBID	143
7.1	Previous Results for Local Deposition of Magnetic Materials Using Focused Beams	143
7.2	Experimental Details	144
7.2.1	Compositional Analysis by EDX.	144
7.2.2	HRTEM.	144
7.2.3	Electrical Measurements of Wires.	145
7.2.4	Spatially-Resolved MOKE Measurements	145
7.2.5	AFM Measurements	145
7.3	Compositional (EDX) and Microstructural (HRTEM) Characterization	145
7.4	Magnetotransport Measurements of FEBID-Co Nanowires	147
7.4.1	Magnetotransport Properties of Cobalt NWs Grown at High Currents.	148
7.4.2	Magnetotransport Properties of Cobalt NWs Grown at Low Currents	151
7.5	Systematic Study of Rectangular Nanowires	152
7.5.1	Types of Structures Grown. Maximum Resolution Obtained	153
7.5.2	AFM Investigation of the NWs Topography.	154
7.5.3	Magnetization Hysteresis Loops	156
7.5.4	Micromagnetic Study in FEBID-Co NWs	160
7.6	Domain Wall Conduit Behavior in FEBID-Co	163
7.6.1	Domain Wall Conduit: The Concept	163
7.6.2	Creation of L-Shaped Nanowires	164
7.6.3	MOKE Measurements and Field Routines	165
7.7	Conclusions	170
	References	171
8	Conclusions and Outlook	175
8.1	General Conclusions	175

8.2	Fe_3O_4 Epitaxial Thin Films.	176
8.3	Creation of Atomic-Sized Constrictions in Metals Using a Focused-Ion-Beam.	177
8.4	Nanowires Created by Focused Electron/Ion Beam Induced Deposition	178
	Curriculum Vitae	181

Studies of Nanoconstrictions, Nanowires and Fe₃O₄

Thin Films

Electrical Conduction and Magnetic Properties.

Fabrication by Focused Electron/Ion Beam

Fernandez-Pacheco, A.

2011, XVI, 188 p., Hardcover

ISBN: 978-3-642-15800-1