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Soggetti	Magnetic memory (Computers) Nonvolatile random-access memory
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Nota di contenuto	1. Basic electromagnetism (25 pages) -- 1.1 Introduction -- 1.2 Magnetic force, pole, field, dipole -- 1.3 Magnetic dipole moment, torque and energy -- 1.4 Magnetic flux and magnetic induction -- 1.5 Ampere's circuital law, Biot-Savart law and magnetic field from magnetic material -- 1.5.1 Ampere's Law -- 1.5.2 Biot=Savart's Law -- 1.5.3 Magnetic field from magnetic material -- 1.6 Equations, cgs-SI unit conversion tables -- -- 2 Magnetism and magnetic materials (51 pages) -- 2.1 Introduction -- 2.2 Origin of magnetization -- 2.2.1 From Ampere to Einstein -- 2.2.2 Precession -- 2.2.3 Electron spin -- 2.2.4 Spin-orbit interaction -- 2.2.5 Hund's rules -- 2.3 Classification of magnetisms -- 2.3.1 Diamagnetism -- 2.3.2 Paramagnetism -- 2.3.3 Ferromagnetism -- 2.3.4 Antiferromagnetism -- 2.3.5 Ferrimagnetism -- 2.4 Exchange interactions -- 2.4.1 Direct exchange -- 2.4.2 Indirect exchange: Superexchange -- 2.4.3 Indirect exchange: RKKY interaction -- 2.5 Magnetization in magnetic metals and oxides -- 2.5.1 Slater-Pauling curve -- 2.5.2 Rigid band model -- 2.5.3 Iron oxides and iron garnets -- 2.6 Phenomenology of magnetic anisotropy -- 2.6.1 Uniaxial anisotropy -- 2.6.2 Cubic anisotropy -- 2.7 2Origins of magnetic anisotropy -- 2.7.1 Shape anisotropy -- 2.7.2

Magnetocrystalline anisotropy (MCA) -- 2.7.3 Perpendicular magnetic anisotropy (PMA) -- 2.8 Magnetic domain and domain walls -- 2.8.1 Domain wall -- 2.8.2 Single domain and superparamagnetism -- -- 3 Magnetic thin films -- 3.1 Introduction -- 3.2 Magnetic thin film growth -- 3.2.1 Sputter deposition -- 3.2.2 Molecular beam epitaxy (MBE) -- 3.3 Magnetic thin film characterization -- 3.3.1 Vibrating-sample magnetometer (VSM) -- 3.3.2 Magneto-optical Kerr effect (MOKE) -- -- 4 Magnetoresistance effects (14 pages) -- 4.1 Introduction -- 4.2 Anisotropic magnetoresistance (AMR) -- 4.3 Giant magnetoresistance (GMR) -- 4.4 Tunneling magnetoresistance (TMR) and magnetic tunnel junction (MTJ). 4.5 Contemporary MTJ designs and characterization -- -- 5 Magnetization switching and Field MRAMs (12 pages text + Figs) -- -- 5.1 Introduction -- 5.2 Magnetization reversible rotation and irreversible switching under external field -- 5.2.1 Full film and patterned device -- [homework] -- 5.2.2 Magnetization rotation and switching under a field in easy axis direction -- 5.2.3 Magnetization rotation and switching Under two orthogonal applied fields -- 5.2.4 Magnetization behavior of a Synthetic Anti-Ferromagnetic (SAF) stack -- 5.3 Field MRAMs -- 5.3.1 MTJ of Field MRAM -- 5.3.2 Half select bit disturbance issue -- 5.4 Applications -- references -- -- 6 Spin current and spin dynamics (17 pages) -- 6.1 Introduction to Hall effects -- 6.1.1 Ordinary Hall effect -- 6.1.2 Anomalous Hall effect and spin Hall effect -- 6.2 Spin current -- 6.2.1 Electro spin polarization in NM/FM/NM film stack -- 6.2.2 Non-local spin valve: Spin current injection, diffusion and inverse spin Hall effect -- 6.2.3 Generalized carrier and spin current drift-diffusion equation -- 6.3 Spin dynamics -- 6.3.1 Landau-Lifshitz and Landau-Lifshitz-Gilbert dynamics equation of motion -- 6.3.2 Ferromagnetic resonance -- 6.3.3 Spin pumping and effective damping in FM/NM film stack -- 6.3.4 FM/NM/FM coupling through spin current -- 6.4 Interaction between polarized conduction electron and local magnetization -- 6.4.1 Electron spin torque transfer to local magnetization -- 6.4.2 Macrospin model -- 6.4.3 Spin torque transfer in spin valve -- 6.4.3.1 Switching threshold current density -- 6.4.3.2 Switching time -- 6.4.4 Spin-torque transfer in magnetic tunnel junction -- 6.4.5 Spin-torque ferromagnetic resonance and torque -- 6.5 Spin current interaction with domain wall -- 6.5.1 LLG description of domain wall motion under spin current -- 6.5.2 Threshold current density -- -- 7 Spin-torque-transfer (STT) MRAM engineering (46 pages) -- 7.1 Introduction. 7.2 Thermal stability energy and switching energy -- 7.3 STT switching properties -- 7.3.1 Switching probability and write error rate (WER) -- 7.3.2 Switching current in precession regime -- 7.3.3 Switching delay of a STT-MRAM cell -- 7.3.4 Read disturb rate -- 7.3.5 Switching under a magnetic field - phase diagram -- 7.3.6 MTJ switching abnormality -- 7.3.6.1 Magnetic back hopping -- 7.3.6.2 Bifurcation switching (Ballooning in WER) -- 7.3.6.3 Domain mediated magnetic reversal -- 7.4 The integrity of MTJ tunnel barrier -- 7.4.1 Write current stress -- 7.4.2 MgO degradation model -- 7.5 Data retention -- 7.5.1 Energy barrier extraction based on bit switching probability -- 7.5.2 Energy barrier extraction based on aiding field -- 7.5.3 Energy barrier extraction with retention bake at chip level -- 7.5.4 Data retention at chip level -- 7.6 The cell design consideration and scaling -- 7.6.1 MRAM bit cell and array -- 7.6.2 CMOS options -- 7.6.3 Cell switching efficiency -- 7.6.4 The cell design considerations -- 7.6.4.1 Write current and cell size -- 7.6.4.2 Read access performance -- 7.6.4.3 READ and WRITE margin -- 7.6.4.4 Stray field control for perpendicular MTJ -- 7.6.4.5 Suppression of stochastic switching time variation ideas

-- 7.6.5 The scaling of MTJ for memory -- 7.6.5.1 In-plane MTJ -- 7.6.5.2 Out-of-plane (perpendicular) MTJ -- 7.7 MRAM cell SPICE model -- 7.7.1 Introduction -- 7.7.2 MTJ SPICE model embedded with Macrospin calculator -- 7.8 Test chip and chip level weak bit screening methodology -- 7.8.1 READ margin bits -- 7.8.2 WRITE margin bits -- 7.8.3 Weak retention bits -- 7.8.4 Low endurance bits -- -- 8 Advanced switching MRAM modes -- -- 8.1 Introduction -- 8.2 Current Induced-Domain-wall-motion (CIDM) memory -- 8.2.1 Single-bit cell -- 8.2.2 Multi-bit cell: Racetrack -- 8.3 Spin-orbit Torque (SOT) Memory -- 8.3.1 Introduction -- 8.3.2 Spin-orbit-Torque (SOT) MRAM cells -- 8.3.2.1 In-plane SOT cell. in-plane SOT cell structure and switching behavior -- Device engineering and Cell scaling -- 8.3.2.2 Perpendicular SOT Cell -- 8.3.3 Materials choice for SOT-MRAM cell -- 8.3.3.1 Transition metals and their alloys -- 8.3.3.2 Emergent materials systems -- 8.3.3.3 Benchmarking of SOT switching efficiency -- 8.4 Magneto-electric effects and voltage-control magnetic anisotropy (VCMA) MRAM -- 8.4.1 Magneto-electric effects -- 8.4.2 VCMA-assisted MRAMS -- 8.4.2.1 VCMA-assisted Field-MRAM -- 8.4.2.2 VCMA-assisted multi-bit-word SOT-MRAM -- 8.4.2.3 VCMA-assisted Precession-toggle MRAM -- 8.5 Relative Merit of advanced switching mode MRAMs -- -- 9 MRAM applications, market position and production (31 pages) -- 9.1 Introduction -- 9.2 Intrinsic properties and product attributes of emerging non-volatile memories -- 9.2.1 Intrinsic properties -- 9.2.2 Product attributes -- 9.3 Memory landscape and MRAM opportunity -- 9.3.1 MRAM as embedded memory in logic SoC chips -- MTJ process integration issue of embedded MRAM -- MRAM as embedded FLASH in micro-controller -- embedded MRAM cell size -- MRAM as cache memory in processor -- improvement of access latency -- 9.3.2 High-density discrete MRAM -- 9.3.2.1 Technology status -- 9.3.2.2 Ideal CMOS technology for high-density MRAM -- 9.3.3 Applications and market opportunity -- 9.3.3.1 Battery-back memory applications -- 9.3.3.2 Internet -of-things (IoT), Cybersecurity applications -- 9.3.3.3 Applications to in-memory computing, artificial intelligence (AI) -- 9.3.3.4 MRAM based Memory-driven computing -- 9.4 MRAM production -- 9.4.1 MRAM product ecosystem -- 9.4.2 MRAM production history -- 9.4.2.1 1st generation MRAM - Field MRAM -- 9.4.2.2 2nd generation MRAM - STT MRAM -- 9.4.2.3 Potential 3rd generation MRAM -SOT MRAM -- Appendix -- A. Retention bake (include two-way flip) (1 pages) -- B. Memory Functionality-based scaling (10 pages) -- C. High-bandwidth MRAM architecture (6 pages).

Sommario/riassunto

"This book first provides the basics of magnetism that electrical engineering students in the semiconductor curriculum can easily understand. Then, it goes one step forward to discuss electron spin. Following the above background discussion, readers are taught the physics of magnetic tunnel junction device (MTJ), the work horse of MRAM, for memory applications. At the end of this book, the author gives a comparison of emerging non-volatile memories (PCM, ReRAM, FeRAM and MRAM). The author also explores MRAM's unique quality among emerging memories, in that is the only one in which the atoms in the device do not move when switching states. This property makes it the most reliable and low power"--