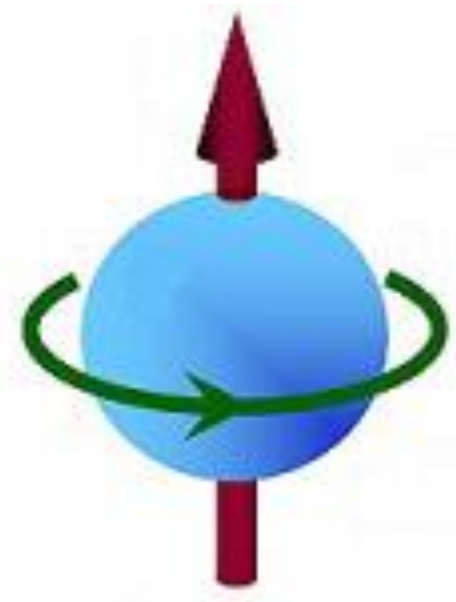




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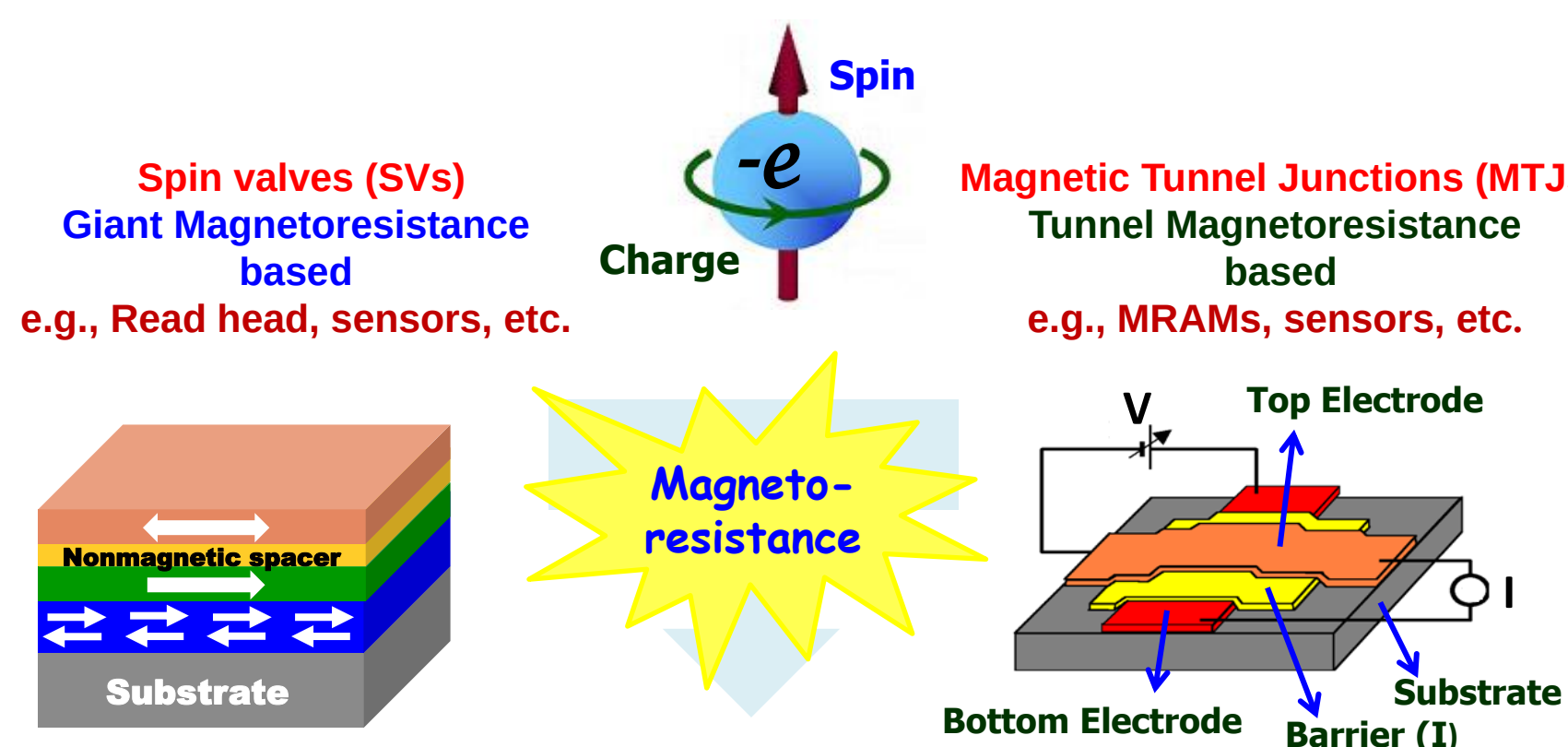
Exchange Bias effect in Antiferromagnetic/Ferromagnetic (AF/FM) systems for Spintronics

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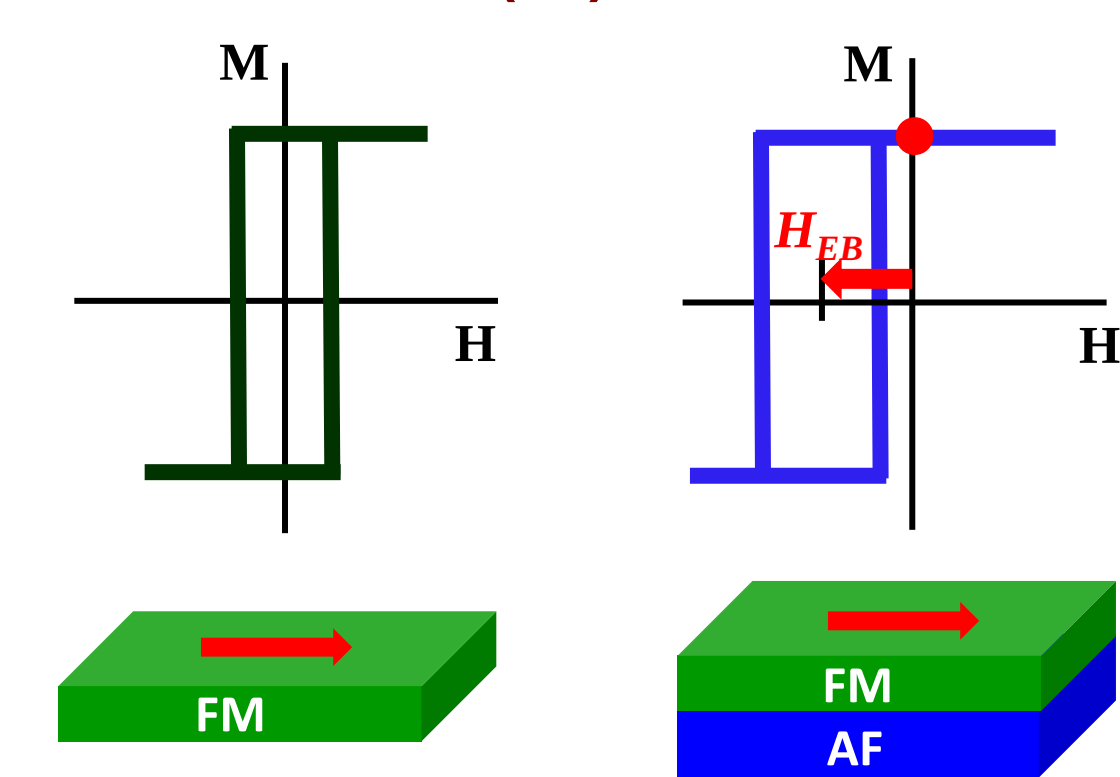
SPINTRONICS Amalgamating magnetism with electronics



ADVANTAGES Fast switching speed Low power consumption Non-volatility Scalability at low dimensions

What is Exchange Bias (EB) ?

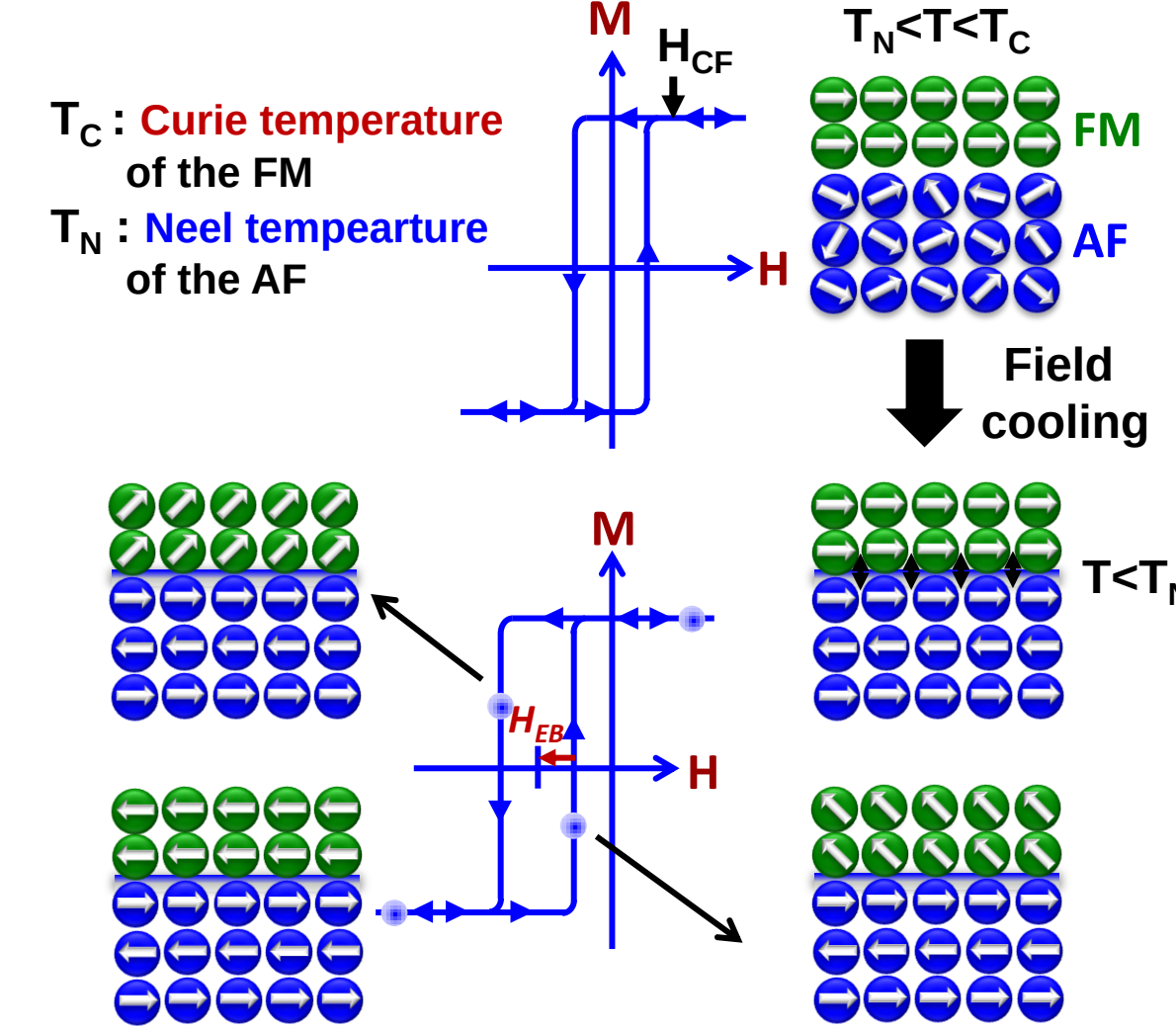
EXCHANGE BIAS (EB) – An Interface Effect !



Exchange Bias characteristics:

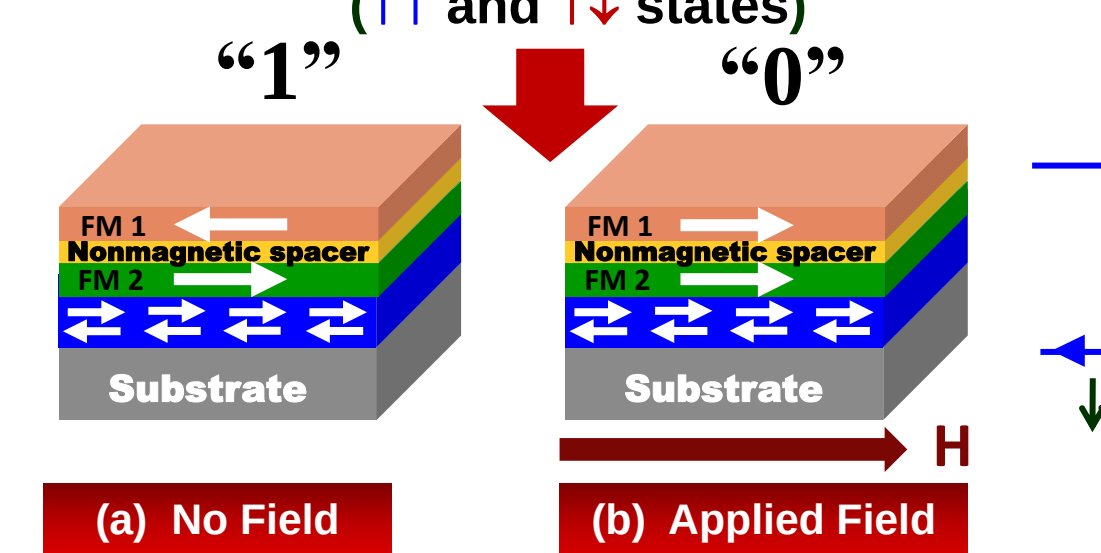
1. Shifted Hysteresis loop
2. Enhanced FM coercivity
3. Asymmetric magnetization reversal
4. Training Effect

Where does EB originate from ?



Why is EB important ?

Magnetic Tunnel Junction or Spin Valve



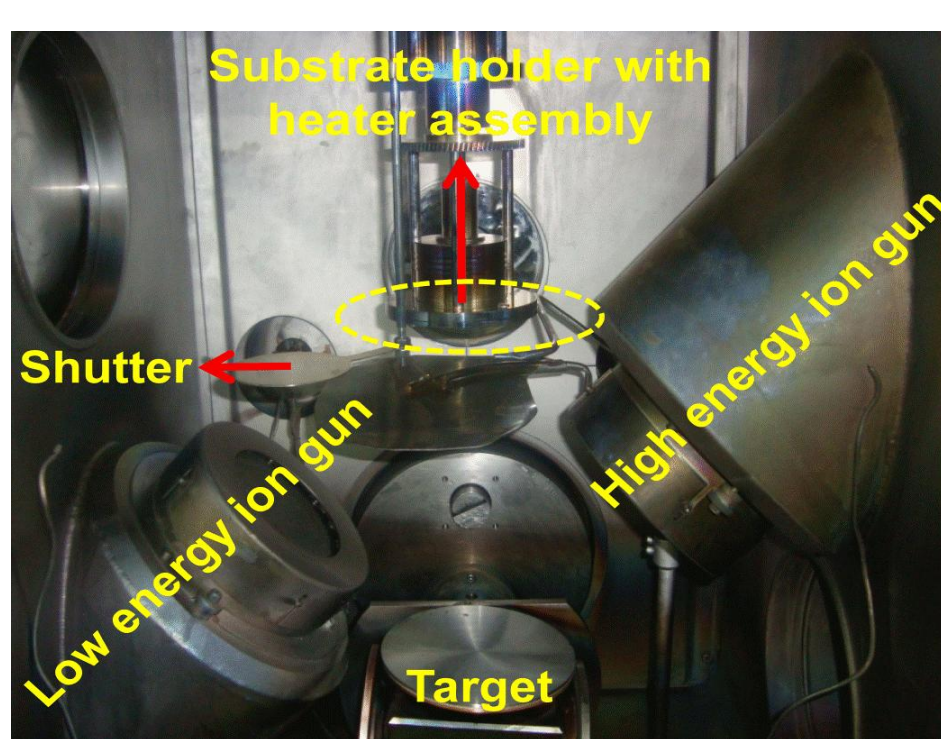
- Potential application in Spintronics devices
- Exhibits very high thermal and magnetic stability
- Intriguing manifestation associated with EB !!

MOTIVATION

- Poorly understood phenomena associated with EB: (a) Training effect, (b) reversal asymmetry
- Can MR effect be exploited as an alternative probe to demonstrate all the generic features associated with EB?

EXPERIMENTAL DETAILS

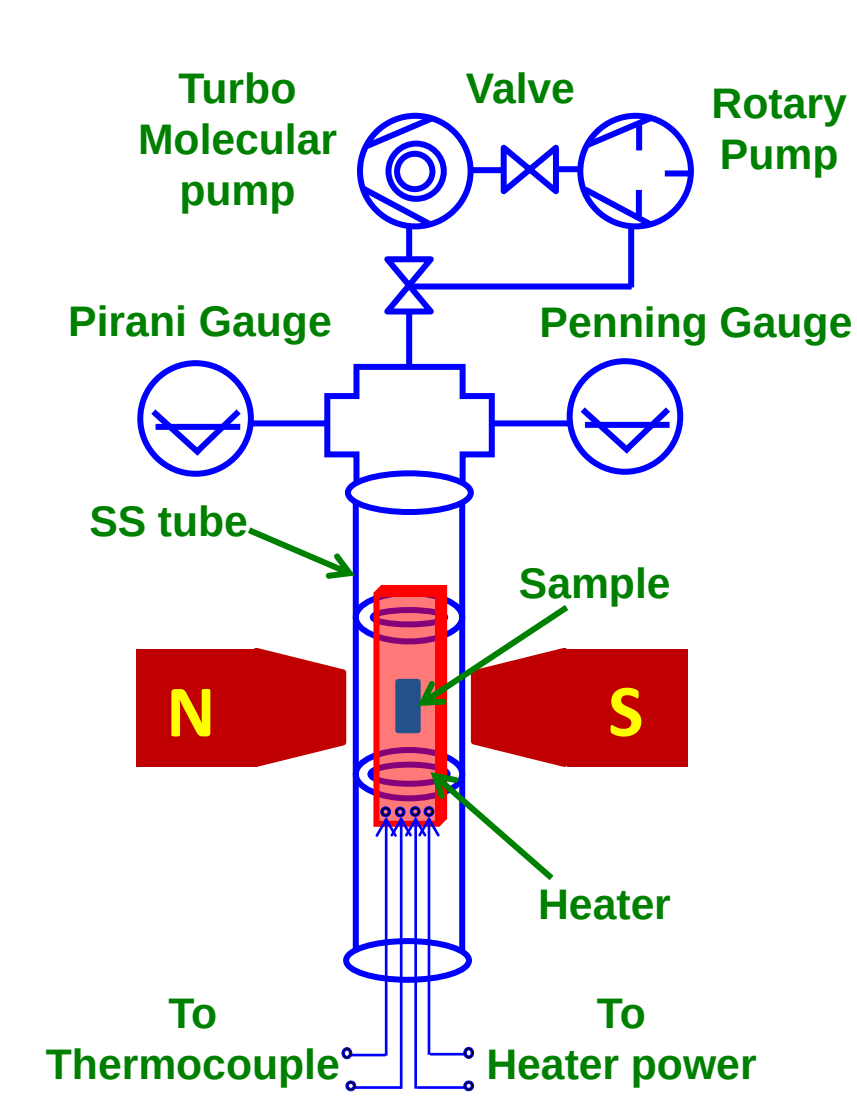
Ion-beam sputtering system



Sample preparation details:

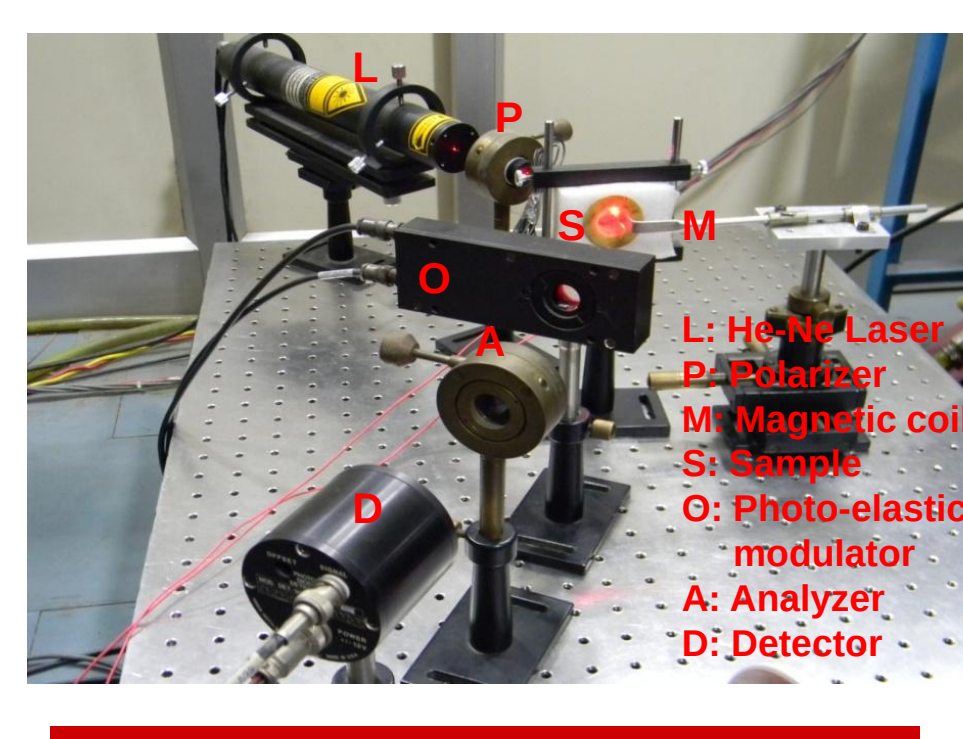
Growth temperature: 300 K
Base vacuum: 2×10^{-6} Torr
Working pressure: 1.5×10^{-4} Torr
Applied in-plane magnetic field: 200 Oe
RF power (6" area): 95 to 125 W
Grid Voltages: = 500 V, -270 V

Magnetic annealing (MA) set-up



- Pressure : 10^{-6} Torr
- Temperature : 200°C - 450°C
- In-plane field : 3 kOe

Longitudinal MOKE set-up

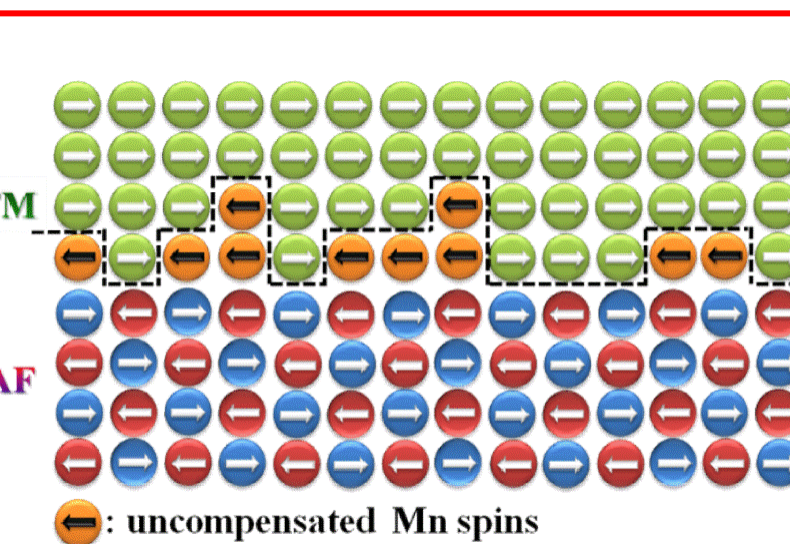
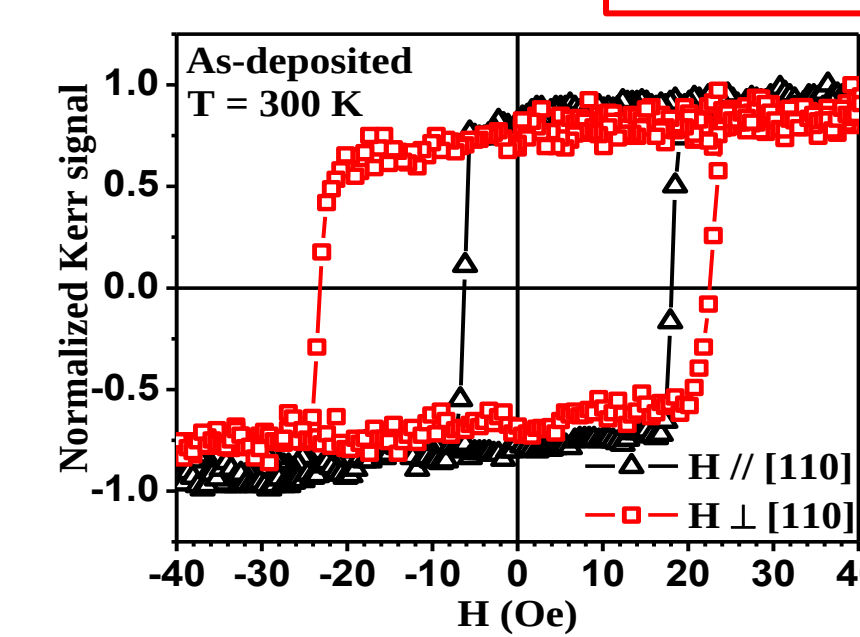


MR measurements

With standard four probe method (current-in plane)
 $R(\theta) = R_0 + \Delta R_0 \cos^2(\theta)$, $\Delta R_0 = R_{||} - R_{\perp}$
Spin-orbit coupling and magnetization direction dependent anisotropy in scattering probabilities

Positive exchange bias (PEB) in as-deposited IrMn/CoFeB bilayers

Si/IrMn(15 nm)/CoFeB(10 nm); MA = 350°C/1.2 kOe



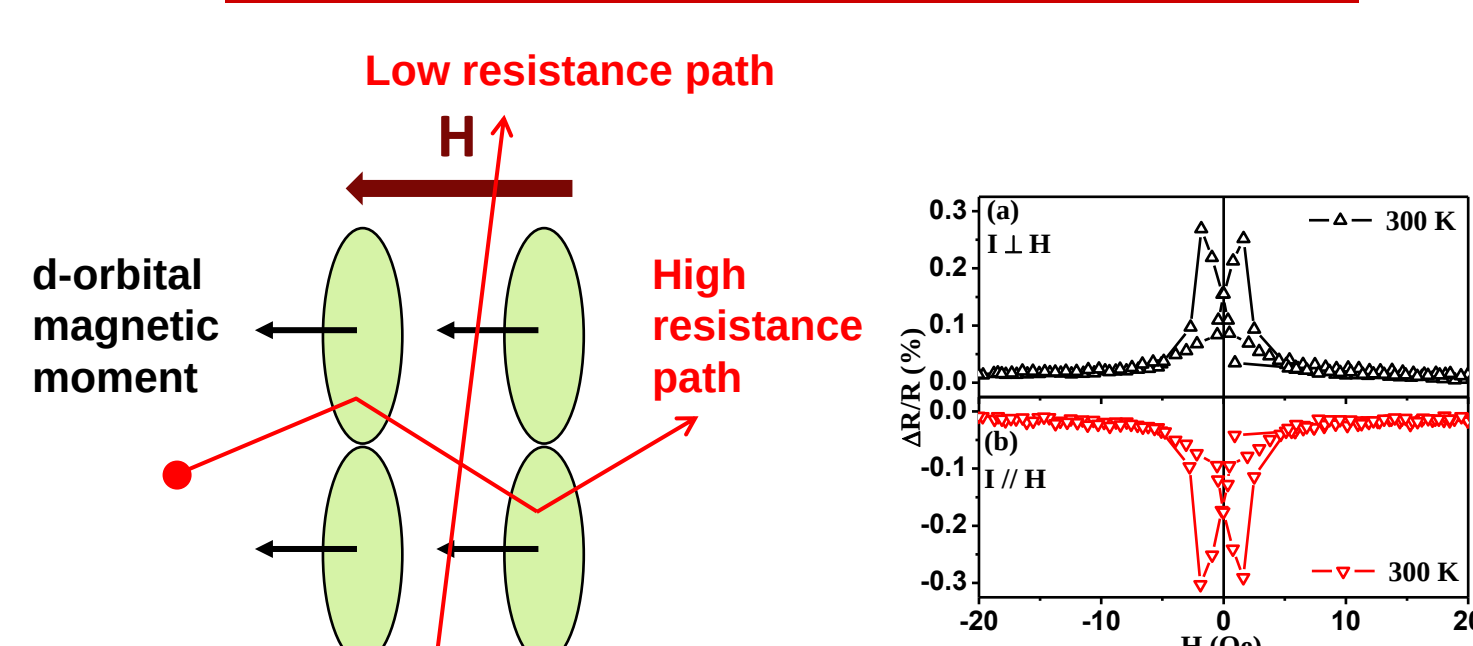
- PEB in as deposited IrMn/CoFeB system without any field cooling protocol
- Uncompensated Mn spins coupled antiferromagnetically to CoFeB spins at the interface
- Absence of Training Effect: Stability of the magnetic microstructure of the AF layer
- Magnetic Annealing caused disappearance of PEB and enhancement of H_C (from 12 to 92 Oe)

Fulara et al., J. Appl. Phys., 110, 093916 (2011)

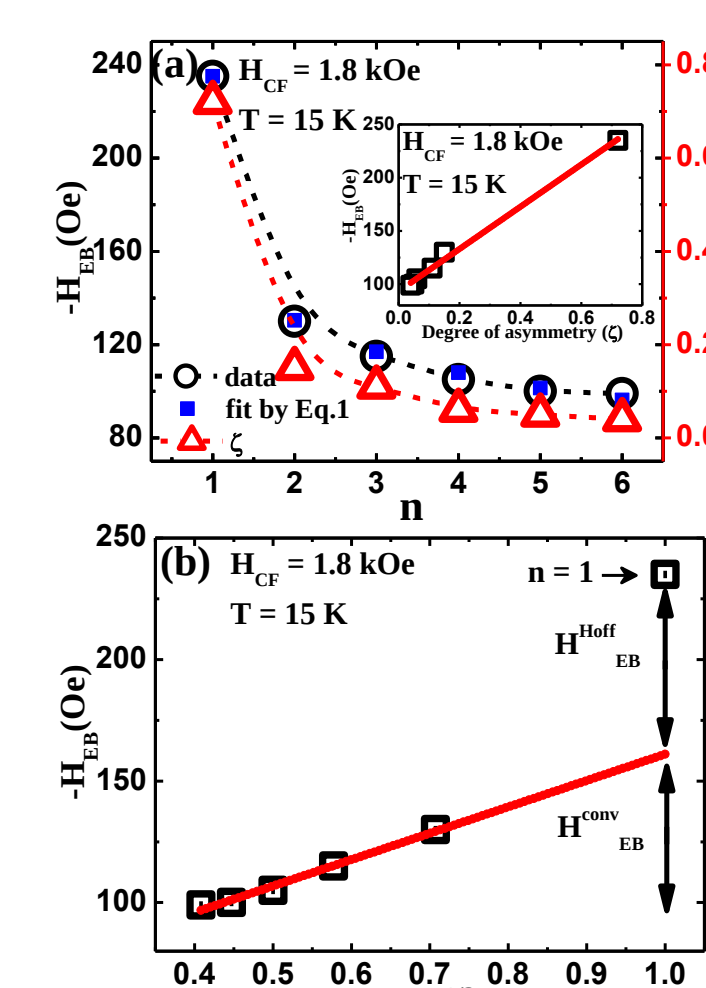
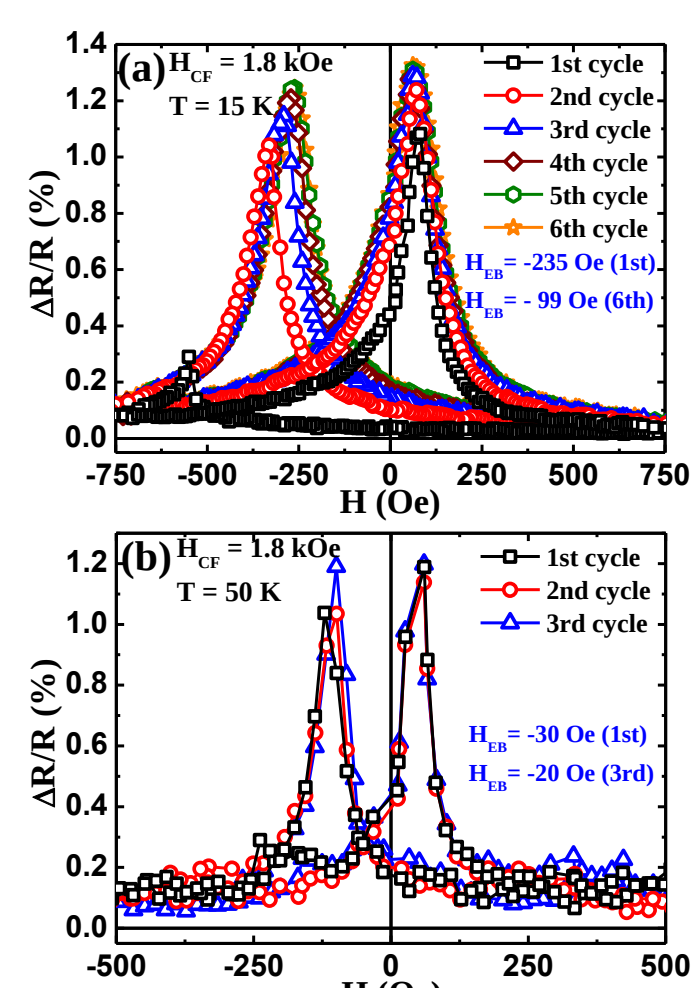
Magnetoresistance investigations in IrMn/NiFe bilayers

Si/Ta(5 nm)/IrMn(20 nm)/NiFe(10 nm)/Ta(5 nm); MA = 300°C/3 kOe

What is Magnetoresistance effect ?



The electrons traveling along the field experience more scattering than those traveling perpendicular to the field !

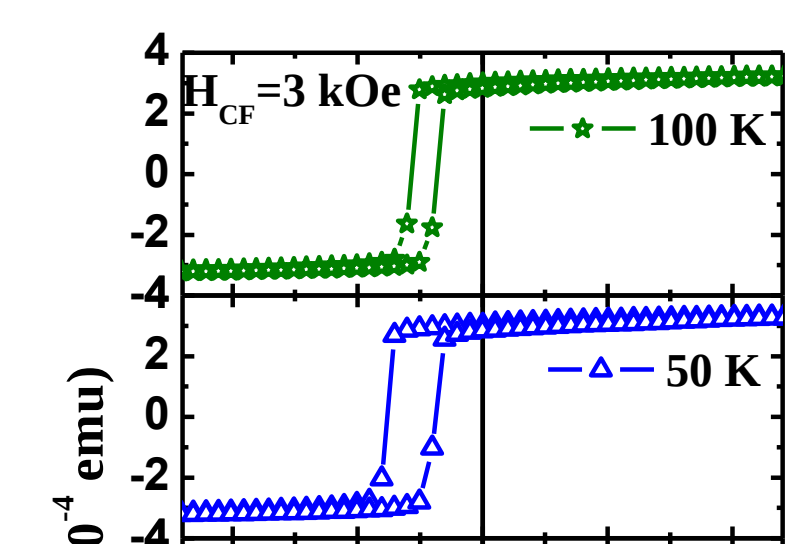
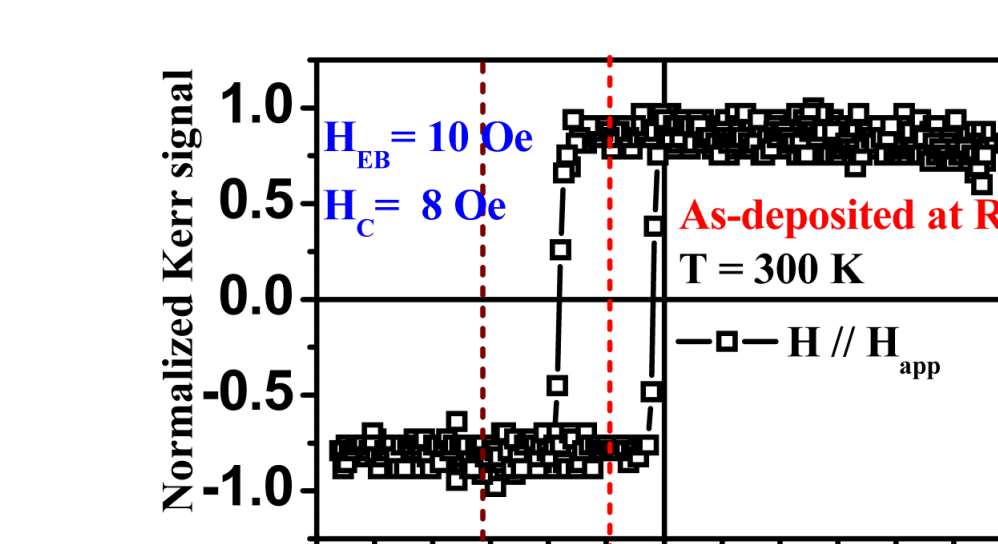
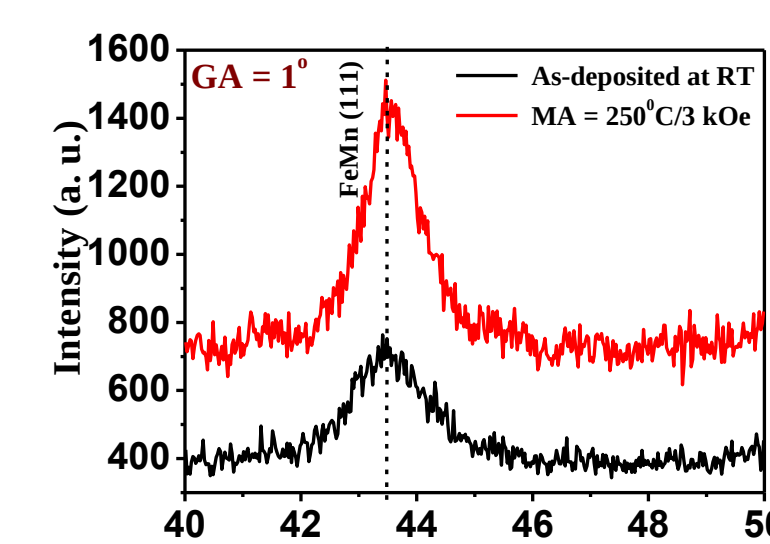


- H_{EB} and H_C increase remarkably at 15 K : increase in the ordering of disordered spins at the interface
- Reversal asymmetry and Training effect are directly linked to each other !!
- Two distinct training mechanisms ("athermal" and "thermal") are operative !

Fulara et al., Appl. Phys. Lett., 101, 142408 (2012)

Negative exchange bias (NEB) effect in FeMn/NiFe system

Si/Cu(10 nm)/FeMn(30 nm)/NiFe(10 nm)/Cu(5 nm); MA = 250°C/3 kOe



- High degree of γ -FeMn(111) orientation promoted by Cu seed layer.
- Negative EB at 300 K in as-deposited case without magnetic annealing treatment
- Magnetic annealing caused marked increase of 300% in EB, though H_C remains unaffected.

MAJOR OUTCOMES

- Unlike other EB systems, **POSITIVE** exchange bias was observed in **as-deposited IrMn/CoFeB** without any field cooling protocol.
- **Magnetoresistance** effect has been exploited as an **alternative probe** to investigate **REVERSAL ASYMMETRY** and **TRAINING EFFECT** in **IrMn/NiFe** system.
- The interdependence between **REVERSAL ASYMMETRY** and **TRAINING EFFECT** in AF/FM system has been demonstrated.
- **Tuning of H_{EB} without affecting the H_C value** in **FeMn/NiFe** bilayer (**Technologically promising for Spintronics devices !!**).

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