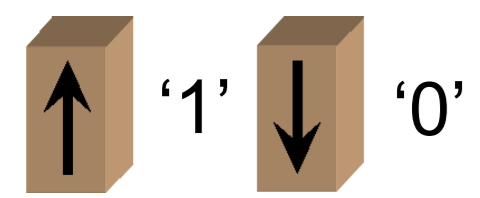




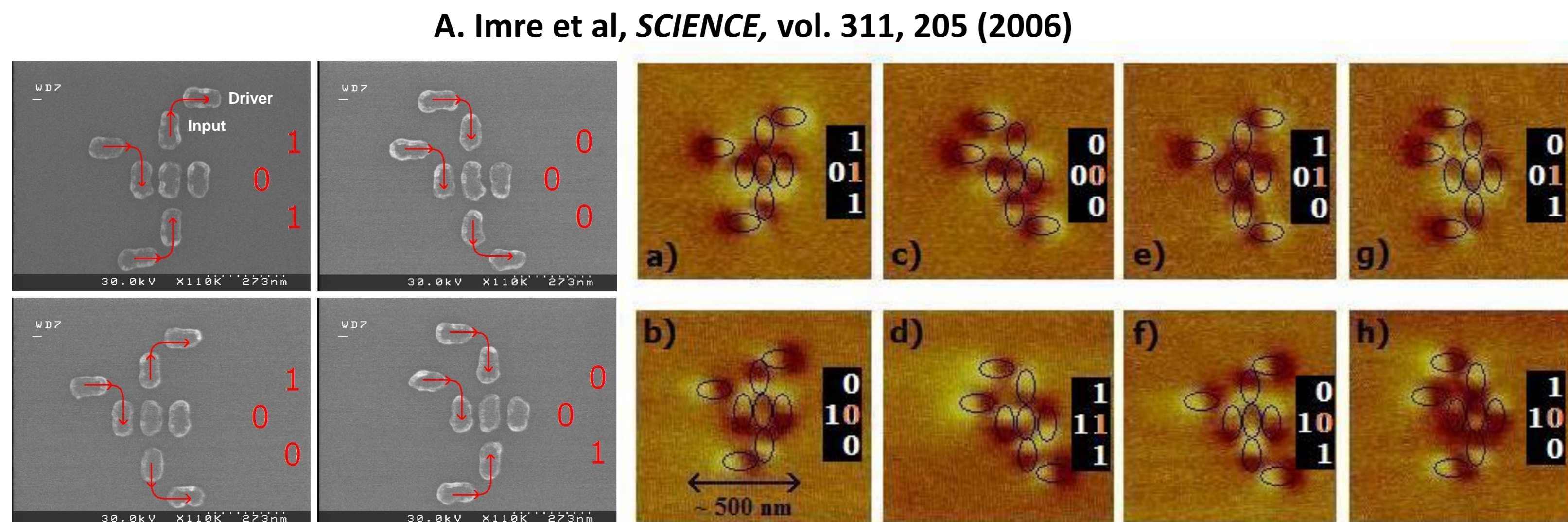
Background and Motivation

Nanomagnet logic (NML)

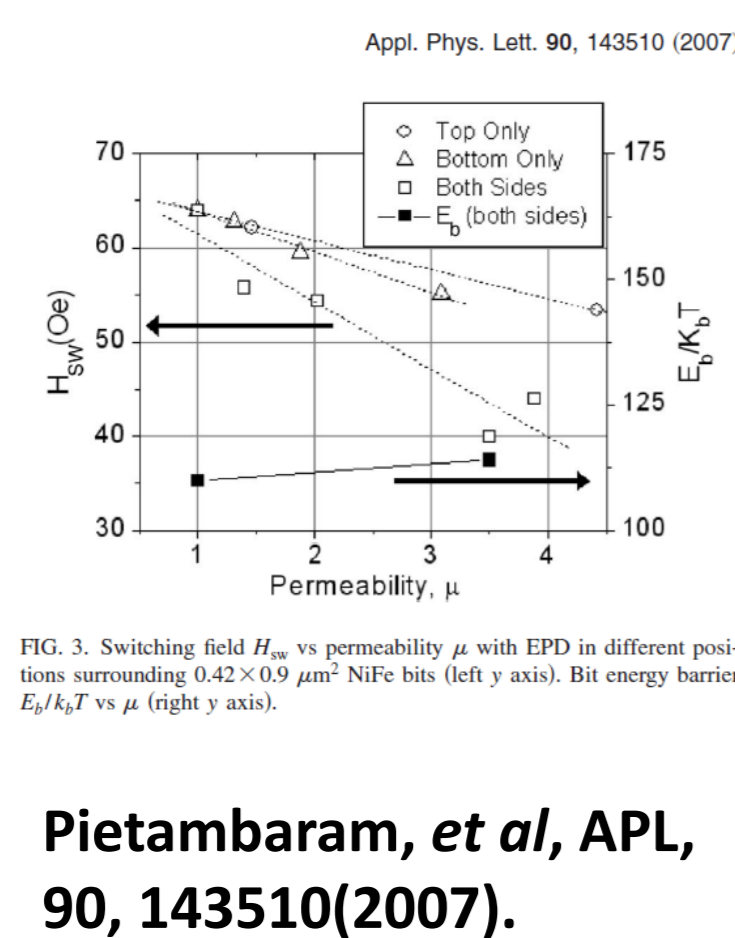
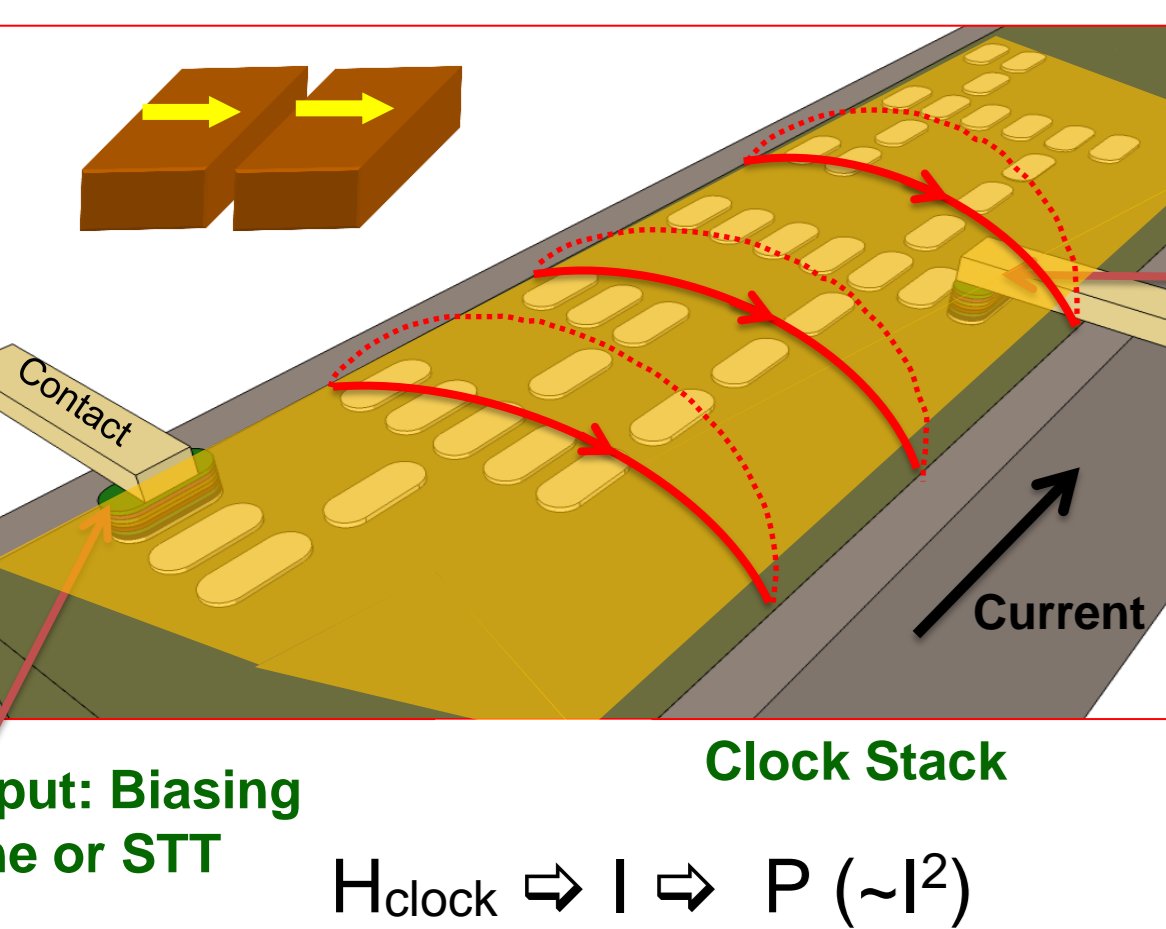
- Single domain magnets to represent information
- Magnetic coupling to propagate information



- Low power dissipation
- Non-volatile



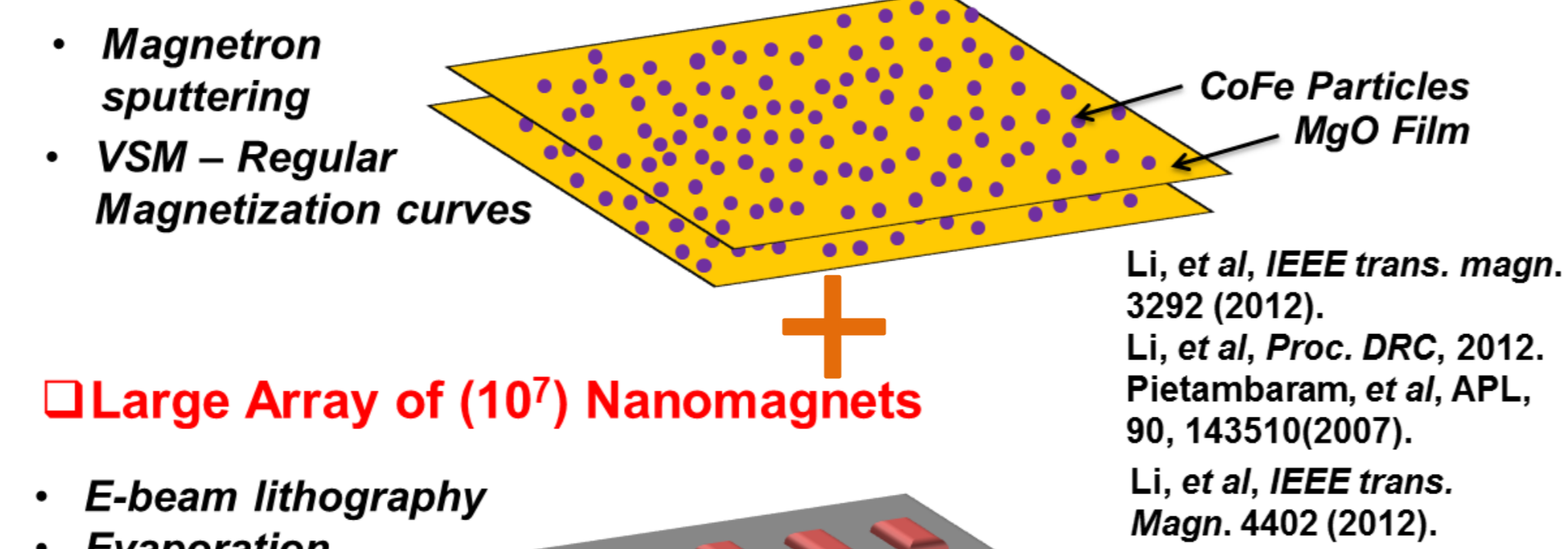
High-Current Driven Clocking



- Magnetic field is generated in the clocking structure to bias magnets in the hard axis for re-evaluation
- Enhanced permeability dielectrics is expected to constrain flux lines and improve the efficiency of field generation

High/Enhanced Permeability Dielectrics (EPD)

Enhanced Permeability Dielectrics (EPD)

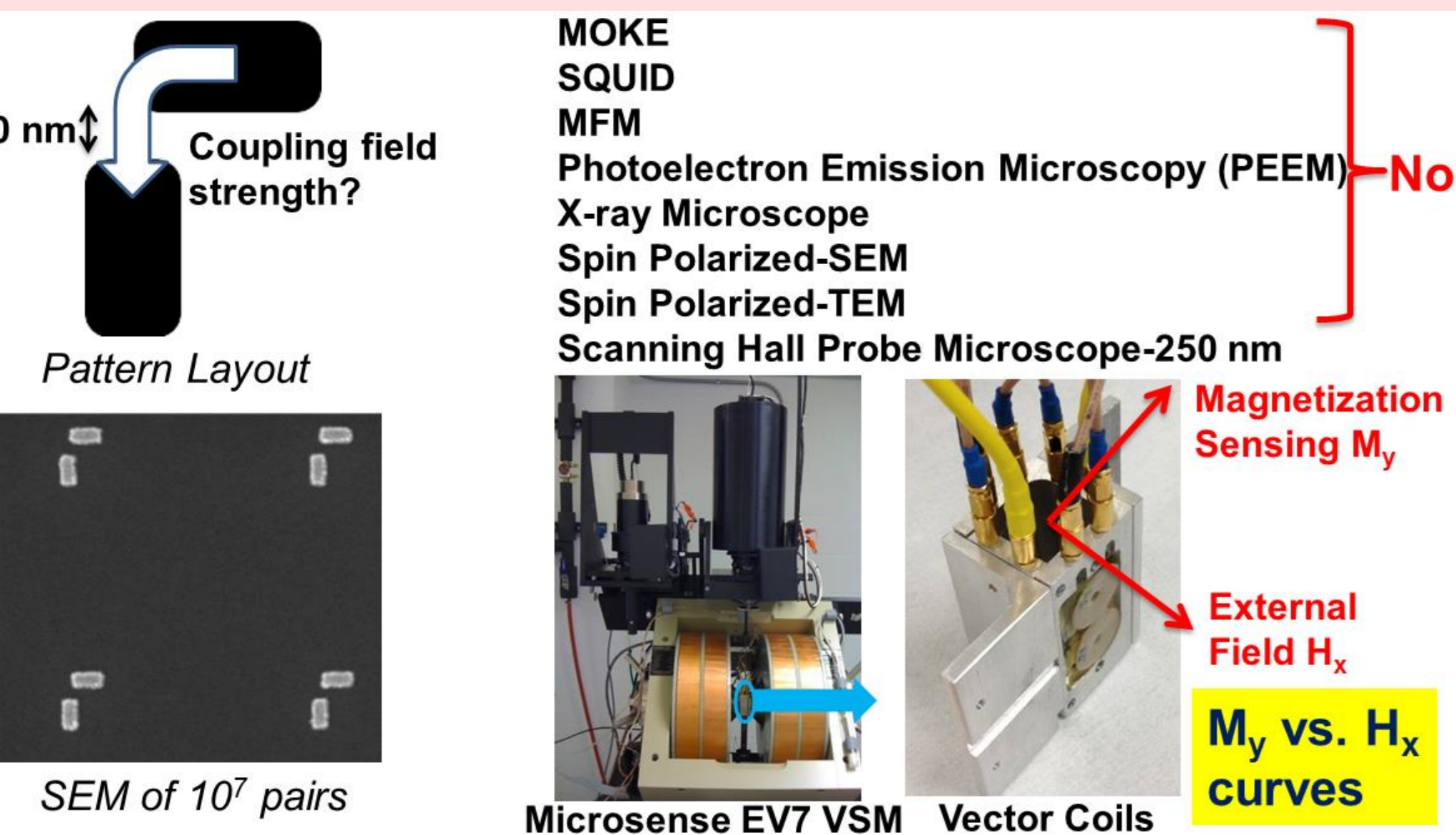


Large Array of (10^7) Nanomagnets

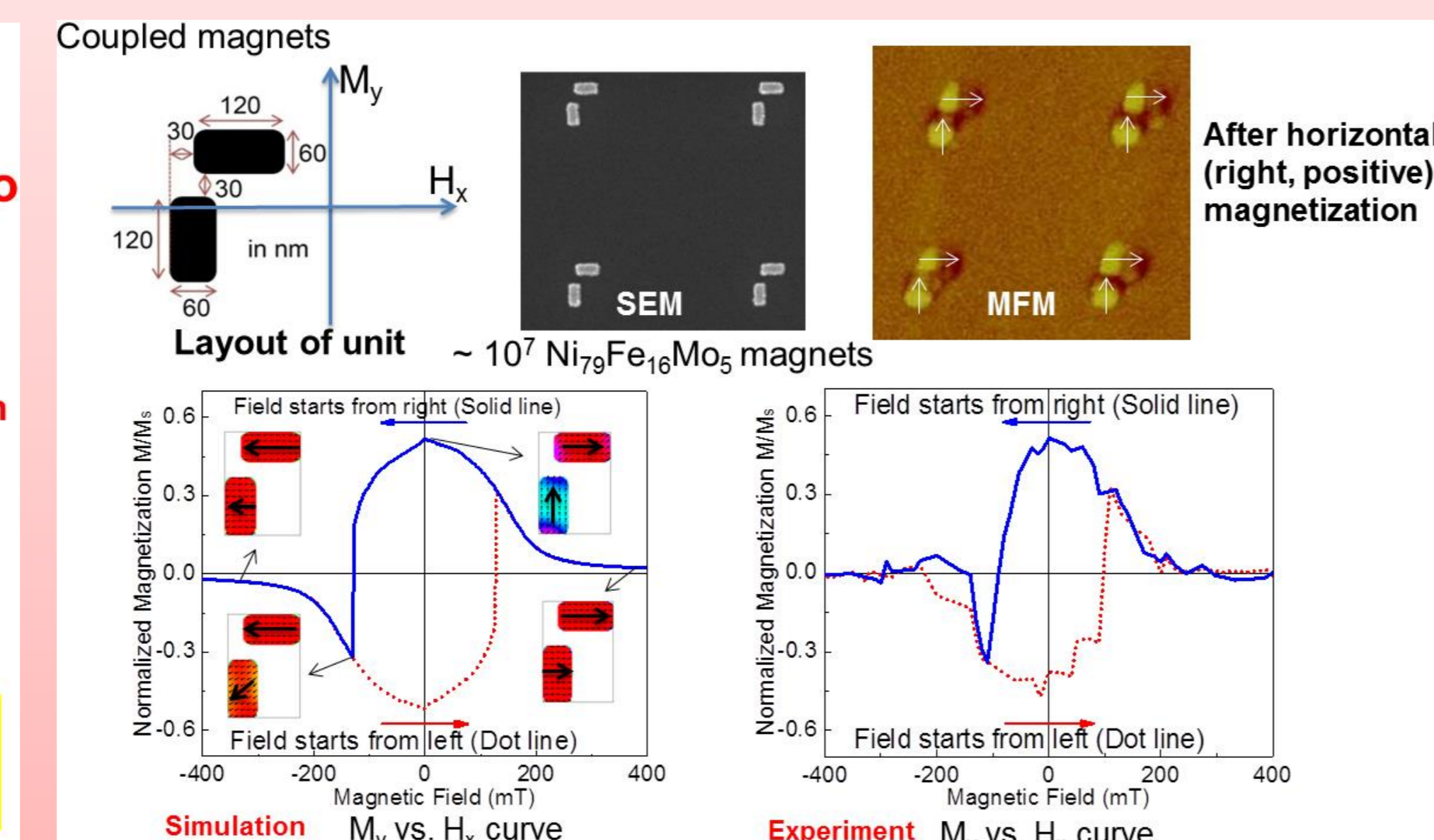
- E-beam lithography
- Evaporation
- Liftoff
- VSM Transverse magnetization measurement

Transverse Magnetization Metrology (TMM)

Transverse magnetization metrology (TMM)



Direct measurement of magnetic coupling

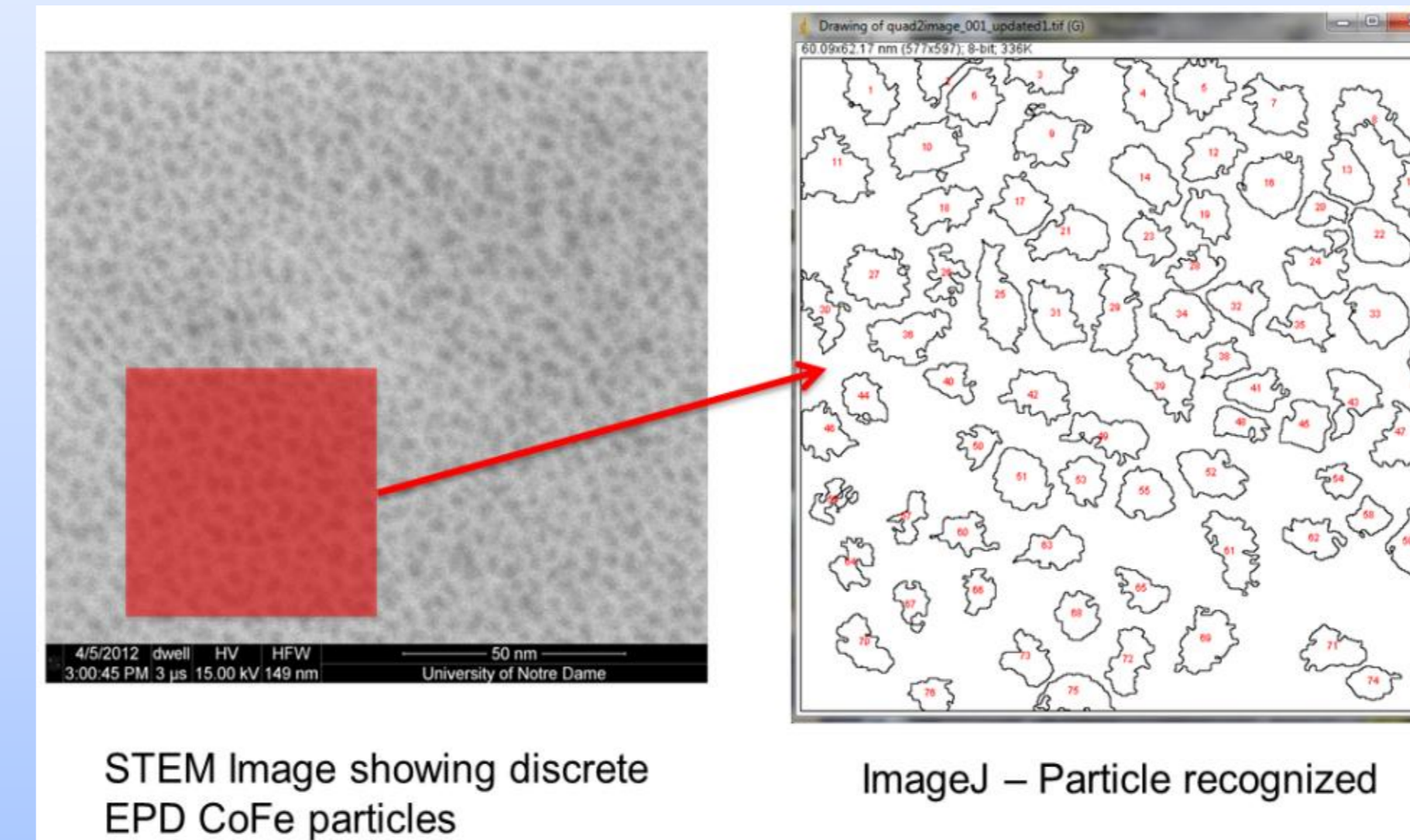


- Sample consists of millions of coupled horizontal-vertical magnet pairs
- Magnetic field is swept along the horizontal axis while magnetic moments were measured along the vertical axis (M_y) by vector coils to create M_y vs. H_x curves

- M_y vs. H_x curve demonstrates magnetic coupling and reveals switching behaviors of coupled magnets
- Measurement results are well correlated to the simulation data, which validates the simulation model and improves its accuracy

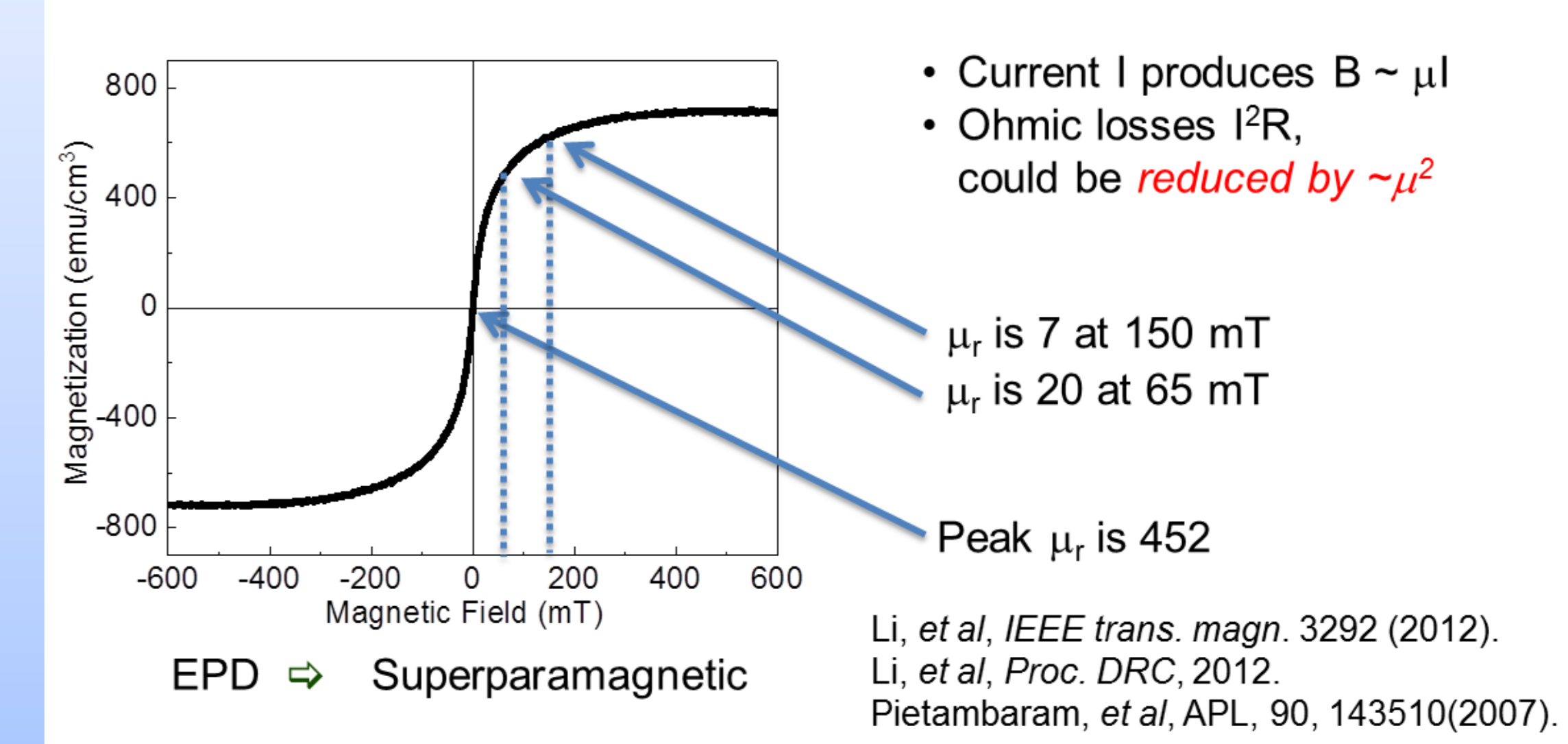
Measurement of EPD

EPD Morphology



• Single layer EPD consists of CoFe particles with a size of $4.6 \text{ nm} \pm 1.1 \text{ nm}$

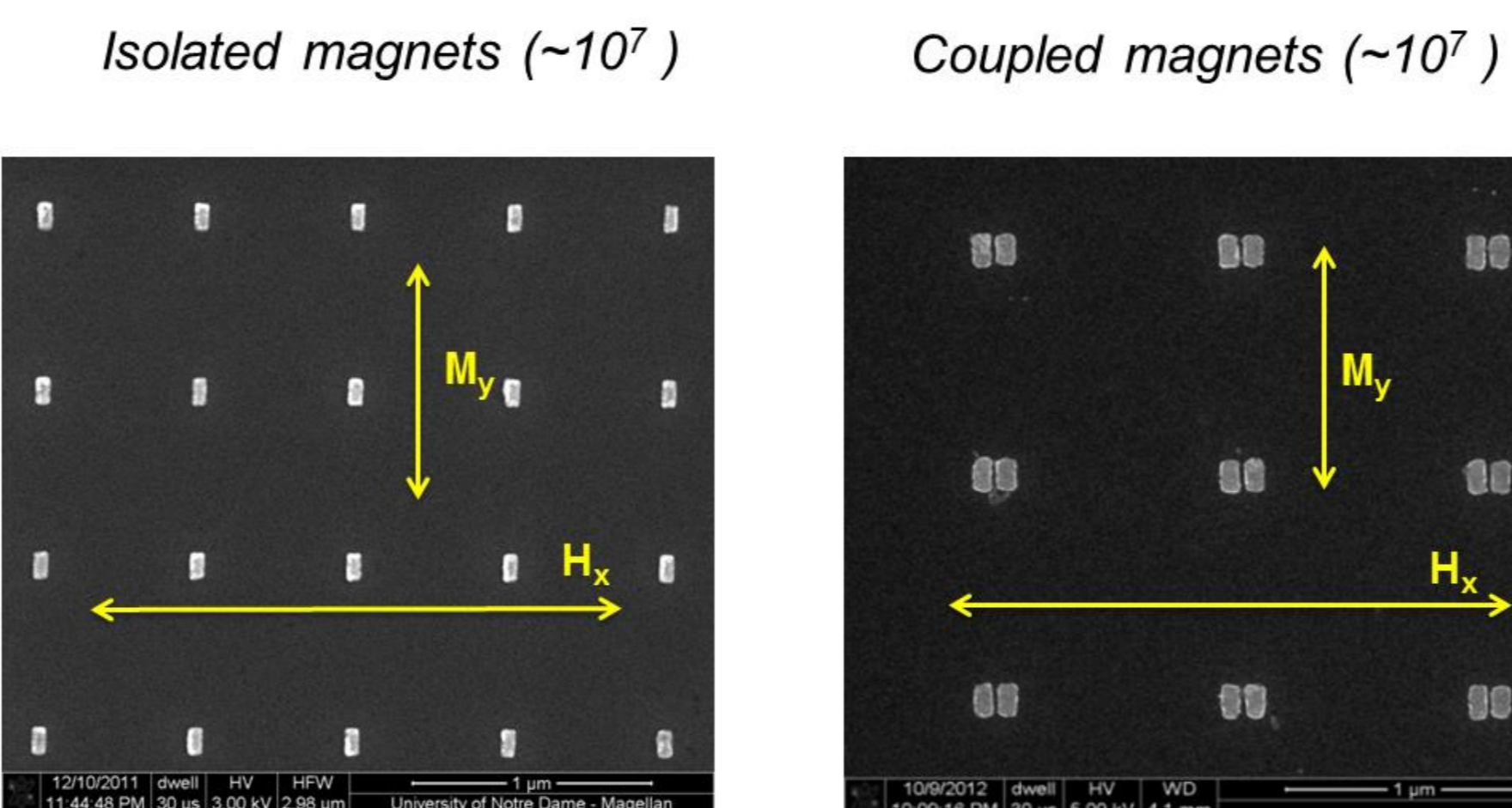
Magnetization Properties



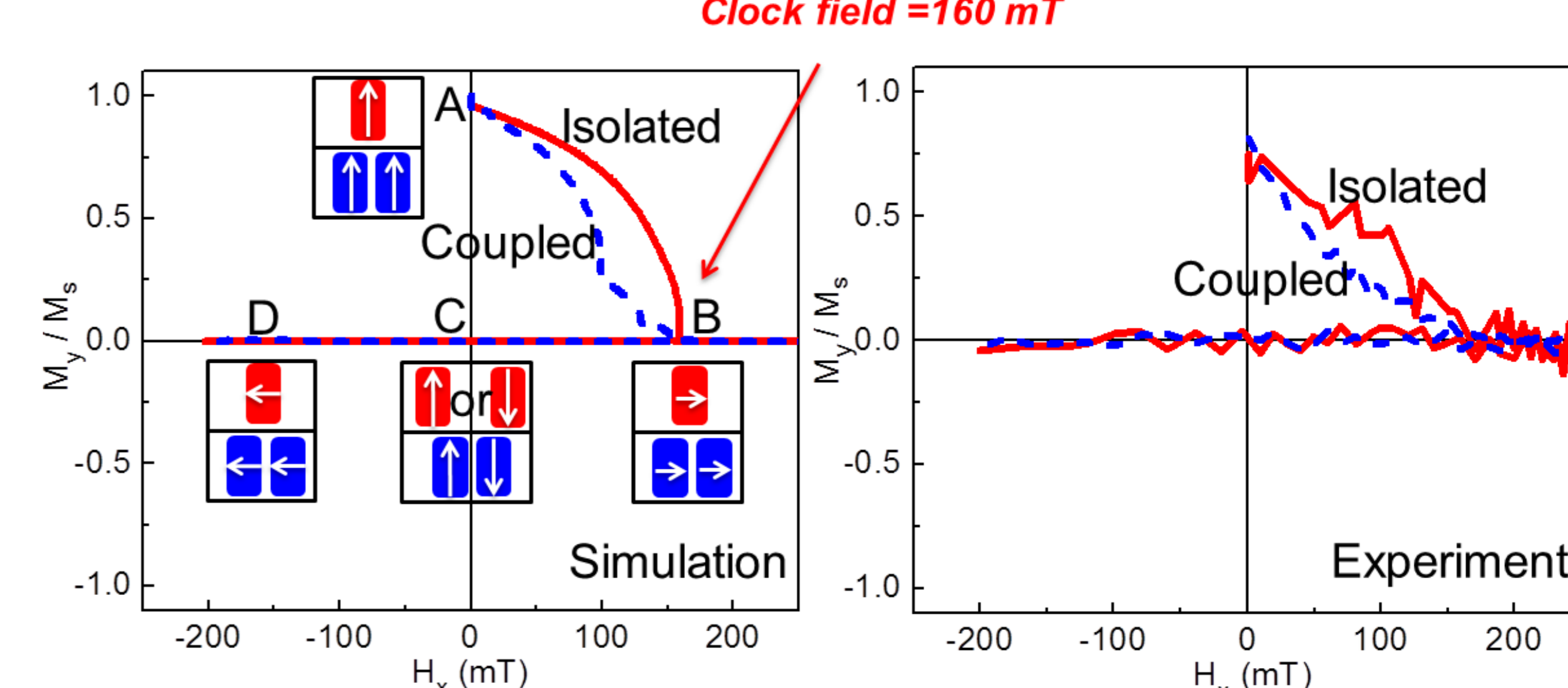
• Magnetization curve of EPD shows that it is superparamagnetic at room temperature

Measurement of EPD on Nanomagnets

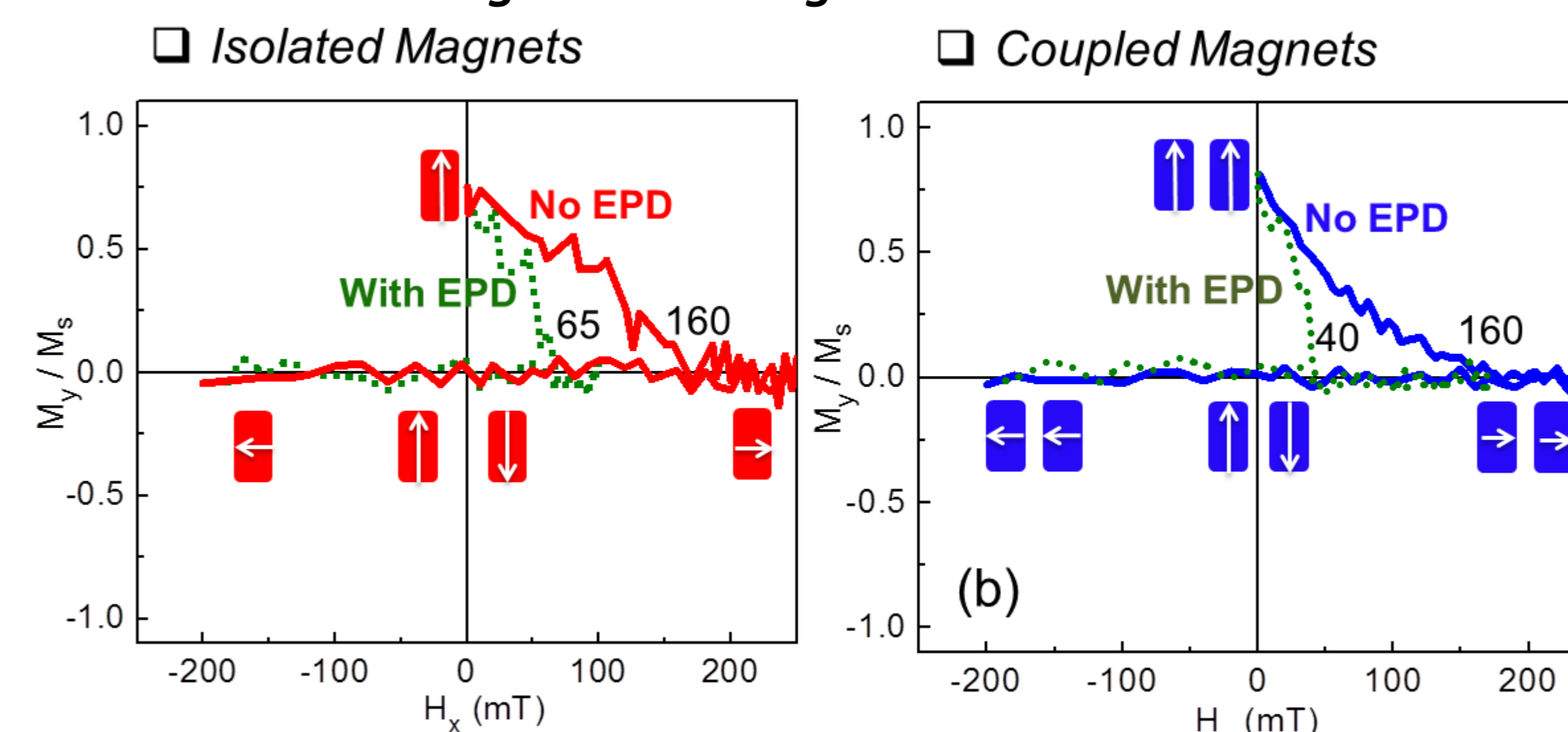
Nanomagnet samples



TMM - Nanomagnet Switching without EPDs

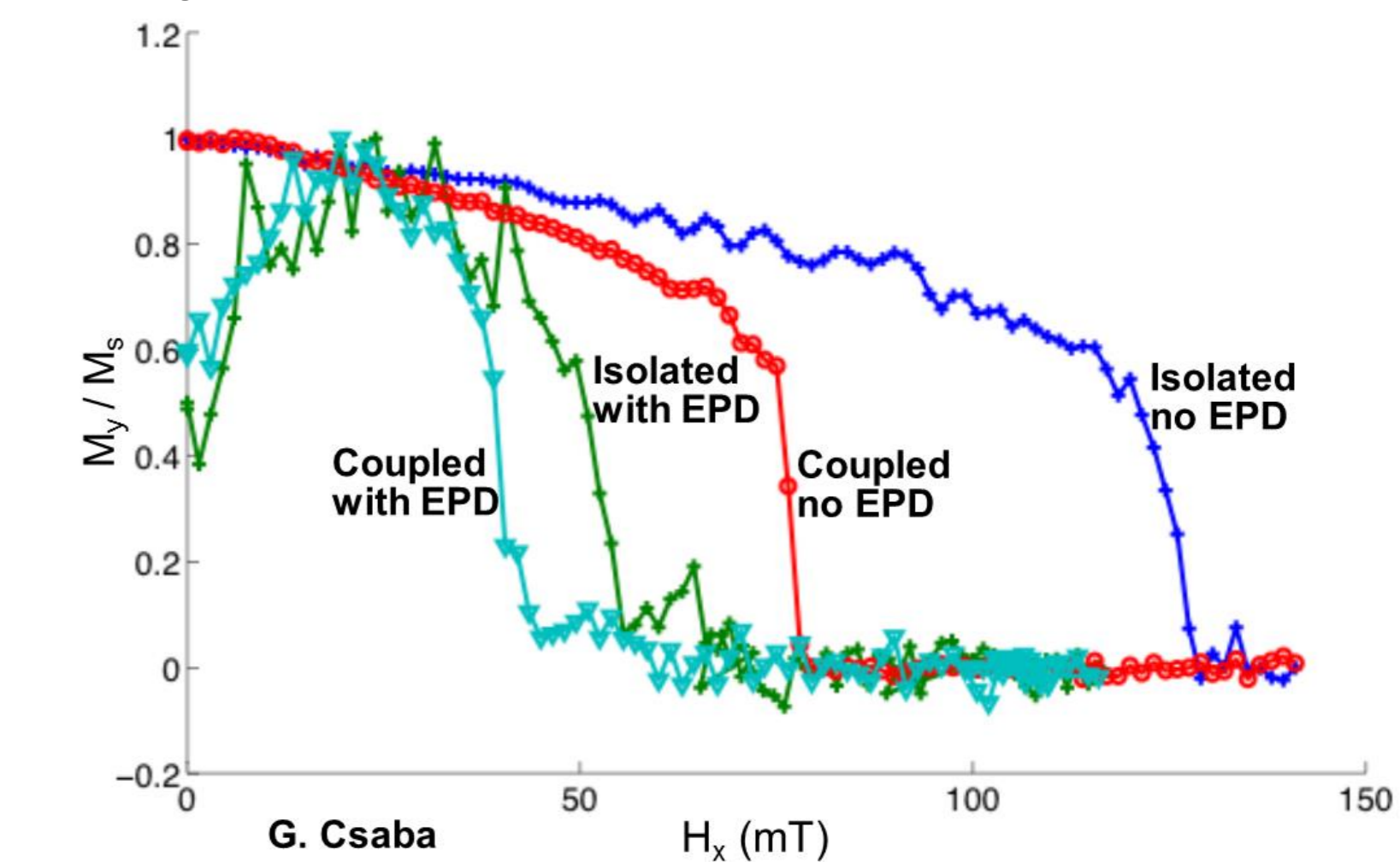


TMM - Nanomagnet Switching with EPDs



- Isolated magnets: 2.5 times reduction in clock field; coupled magnets: 4 times reduction, translating to 16 times reduction in power
- Remanent magnetization keeps unchanged - EPD does not add bias to NML

Comparison with Simulations



- Reduction in clock field is well predicted, which is consistent with experiments
- Reduction in remanent magnetization - improvement of model may be needed

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- Best Presentation in Session Award, *TECHCON*, 2012
- Best Poster Award, *NRI- MIND Meeting*, 2012
- Best Student Paper Award Finalist, *IEEE International Magnetics Conference*, 2012

