Spatial Impact Range of Single-Molecule Magnet (SMM) on Magnetic Tunnel Junction-Based Molecular Spintronic Devices (MTJMSDs)

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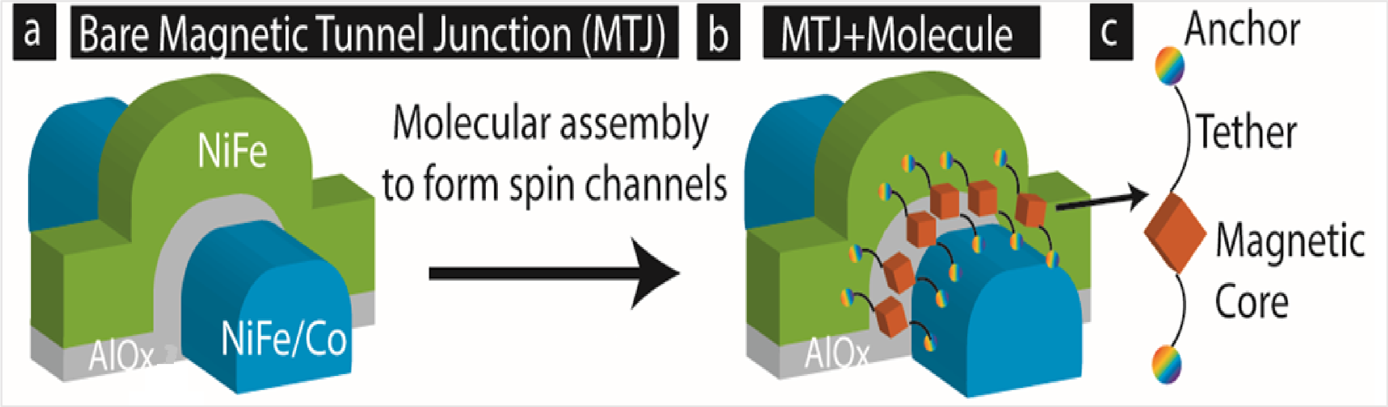
Introduction:

What is MTJMSD?

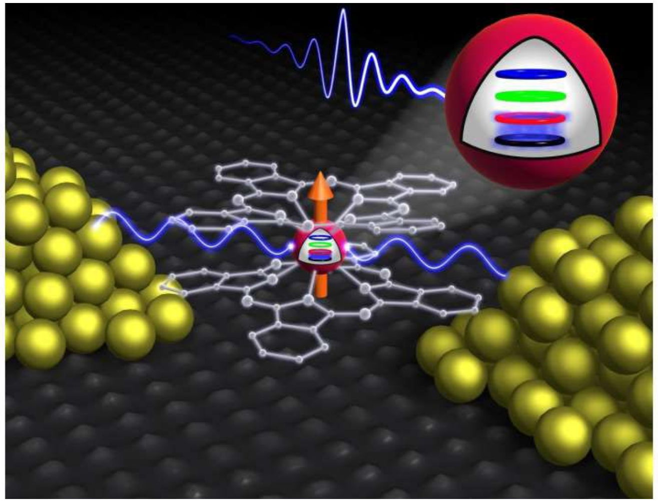
A multilayer-shaped structure composed of :

- **Potentially creating high-density devices architecture with low power consumption and high speed**
- **MSD is considered as a potential route to cross the fast-approaching miniaturization limit**
- **Molecules can be unmatched device elements**
- **MSD has the potential to be more economic**

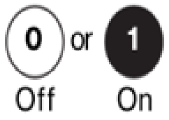
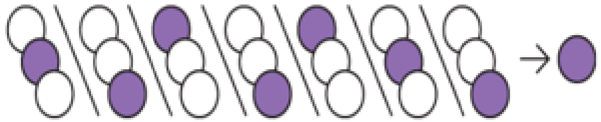


MTJMSD 3D-architecture (a) before and (b) after magnetic molecules treatment

Motivation:

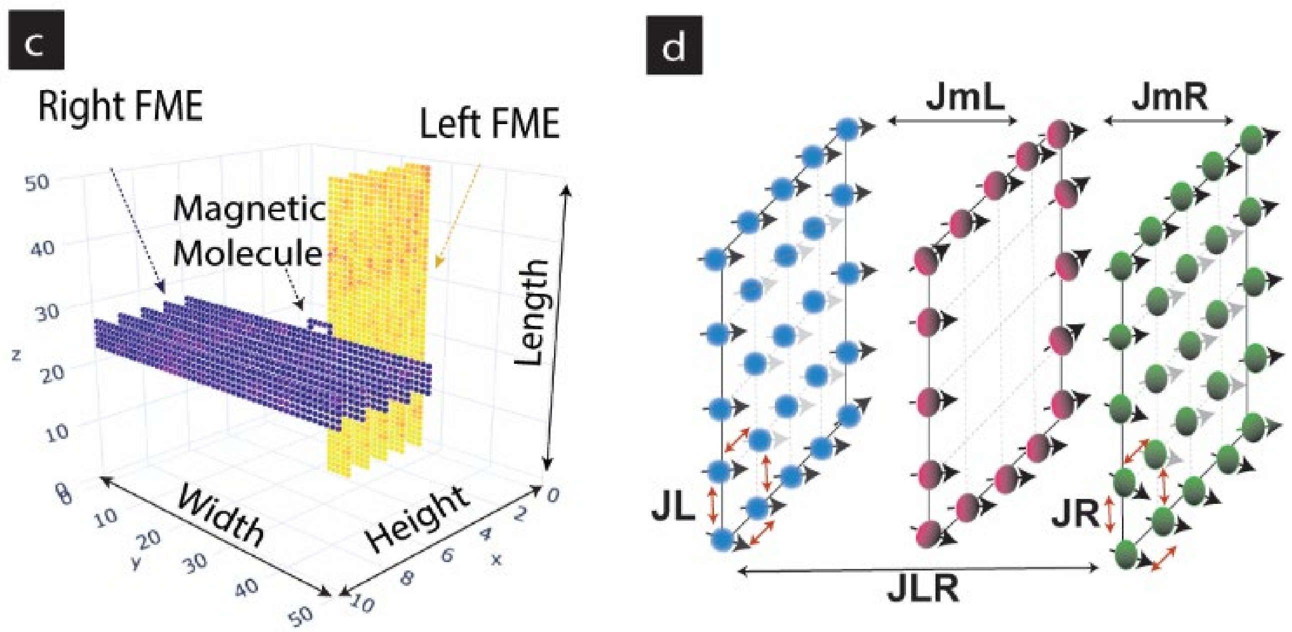


- Potential candidate for advanced next-generation memory devices & computational technologies (e.g., quantum computation)
- Higher information/data processing speed
- Consume significantly less power

Conventional computers	Doing calculations using bits, either off (0) or on (1) state 	Tries possible answers one by one, until it finds the right one → Too slow for complex problems 
Quantum Computers	Qubit can exist as 0 or 1 or superposition of 0 and 1 	Enables computers to work faster by considering many possibilities at once, Sorting through sets of probable outcomes → converge on the correct answer 

Parameters used in the MSD

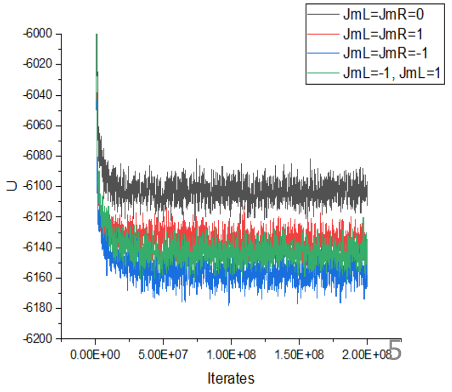
- kT
- JL
- JR
- SL,SR,SM
- JML
- JMR
- AL : ALx, ALy, ALz
- AR : ARx, ARy, ARz
- Size of the device



3D Ising model describing inter-and intra-atomic Heisenberg exchange coupling energies between FM electrodes and magnetic molecules

MTJMSD energy:

$$E = -J_L\left(\sum_{i\in L} \vec{S}_i \vec{S}_{i+1}\right) - J_R\left(\sum_{i\in R} \vec{S}_i \vec{S}_{i+1}\right) - J_{mL}\left(\sum_{i\in L,i+1\in mol} \vec{S}_i \vec{S}_{i+1}\right) - J_{mR}\left(\sum_{i-1\in mol,i\in R} \vec{S}_{i-1} \vec{S}_i\right)$$



Methodology:

(Strength of couplings)

A wide range of weak to strong FM and anti-FM coupling possibilities ($-1<JmL$ & $JmR<1$)

(Nature of couplings)

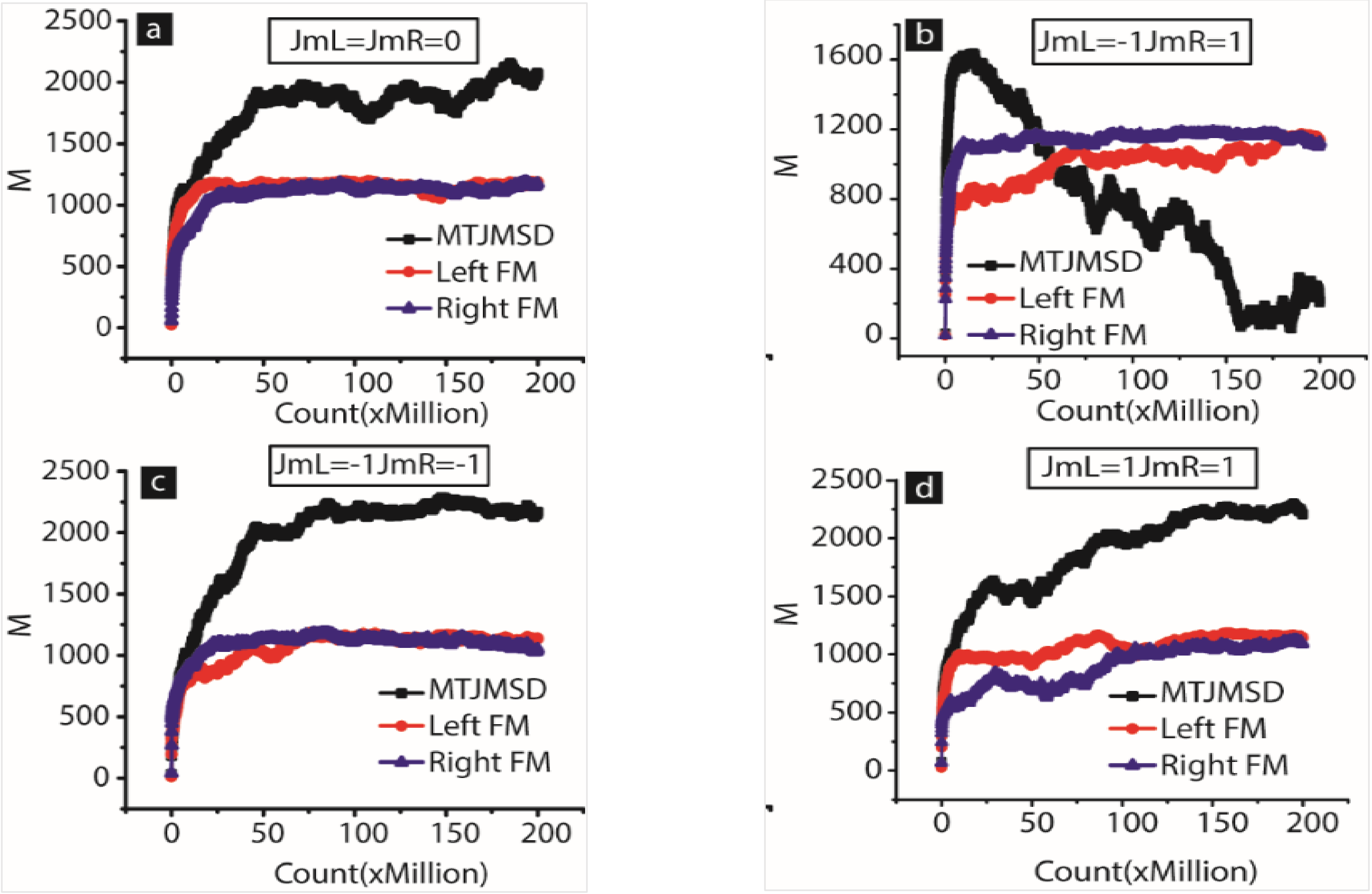
(i) FM couplings with two electrodes
(ii) Anti-FM couplings with two electrodes
(iii) FM coupling with one electrode and anti-FM coupling with another electrode

(FM Electrodes Dimension at a constant coupling)

(i) FM electrodes length variation
(ii) FM electrodes thickness variation

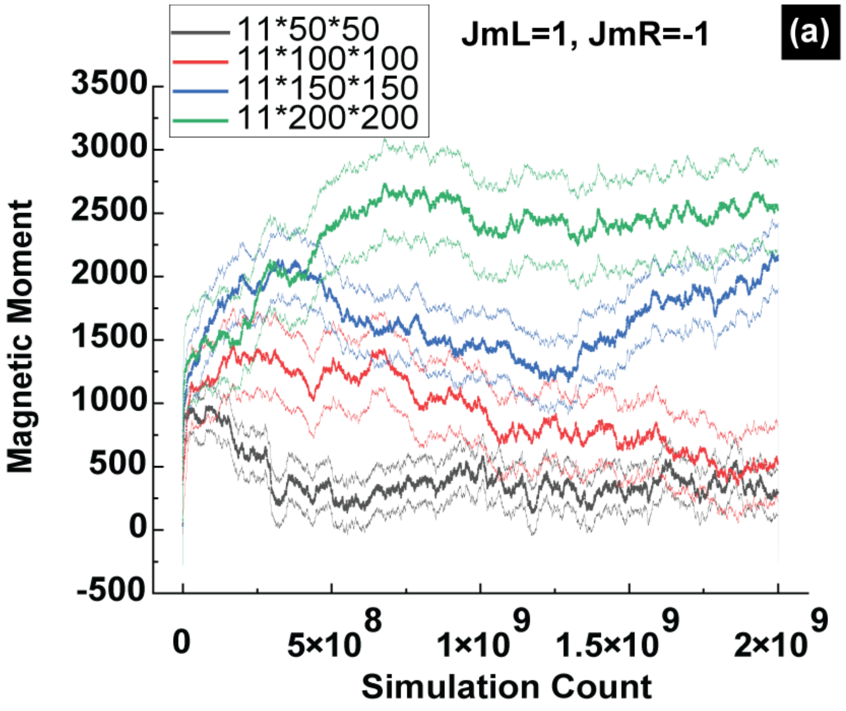
RESULTS AND DISCUSSION

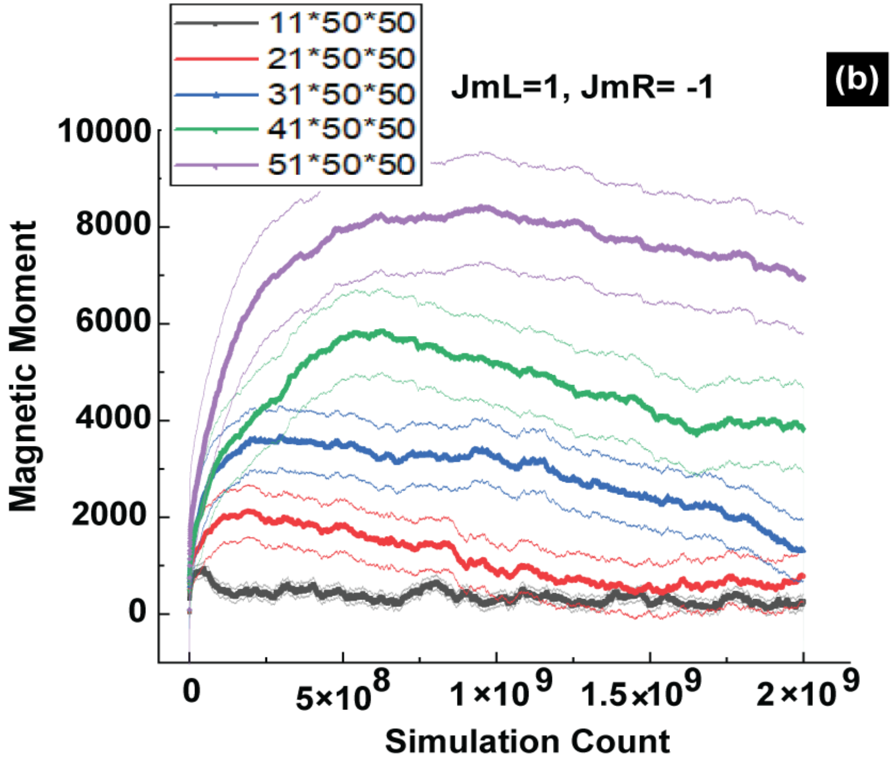
Temporal evolution of magnetic moment Of four extreme coupling cases (11*50*50)



RESULTS AND DISCUSSION

Comparison of Time evolution in different devices sizes



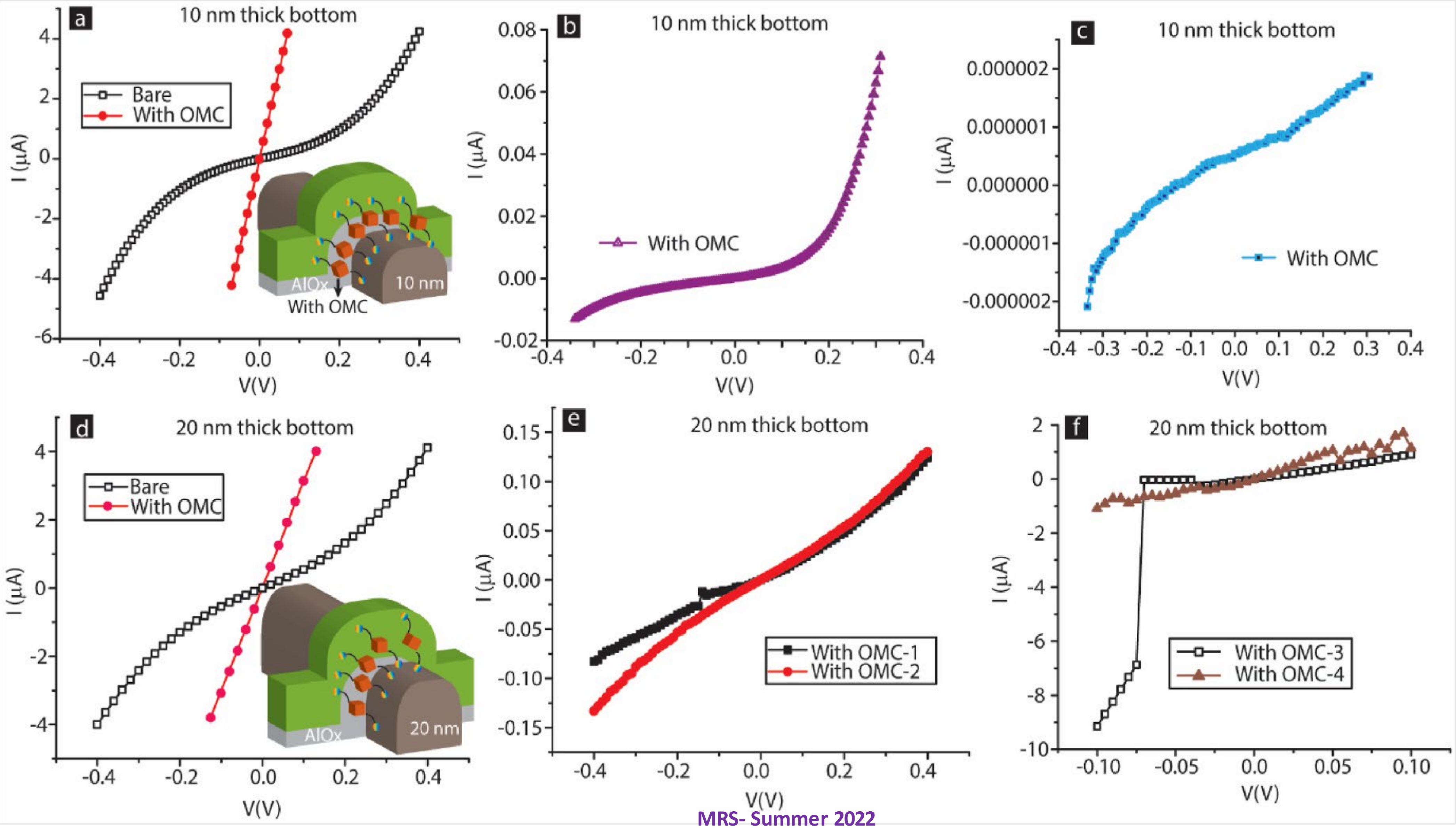


Average ±standard error of Temporal evolution of MTJMSD magnetic moment when magnetic molecules made ferromagnetic coupling with left electrode (JmL=1) and antiferromagnetic coupling with right electrode (JmR= -1) for MTJMSD (a) increased length (b) increased thickness

RESULTS AND DISCUSSION

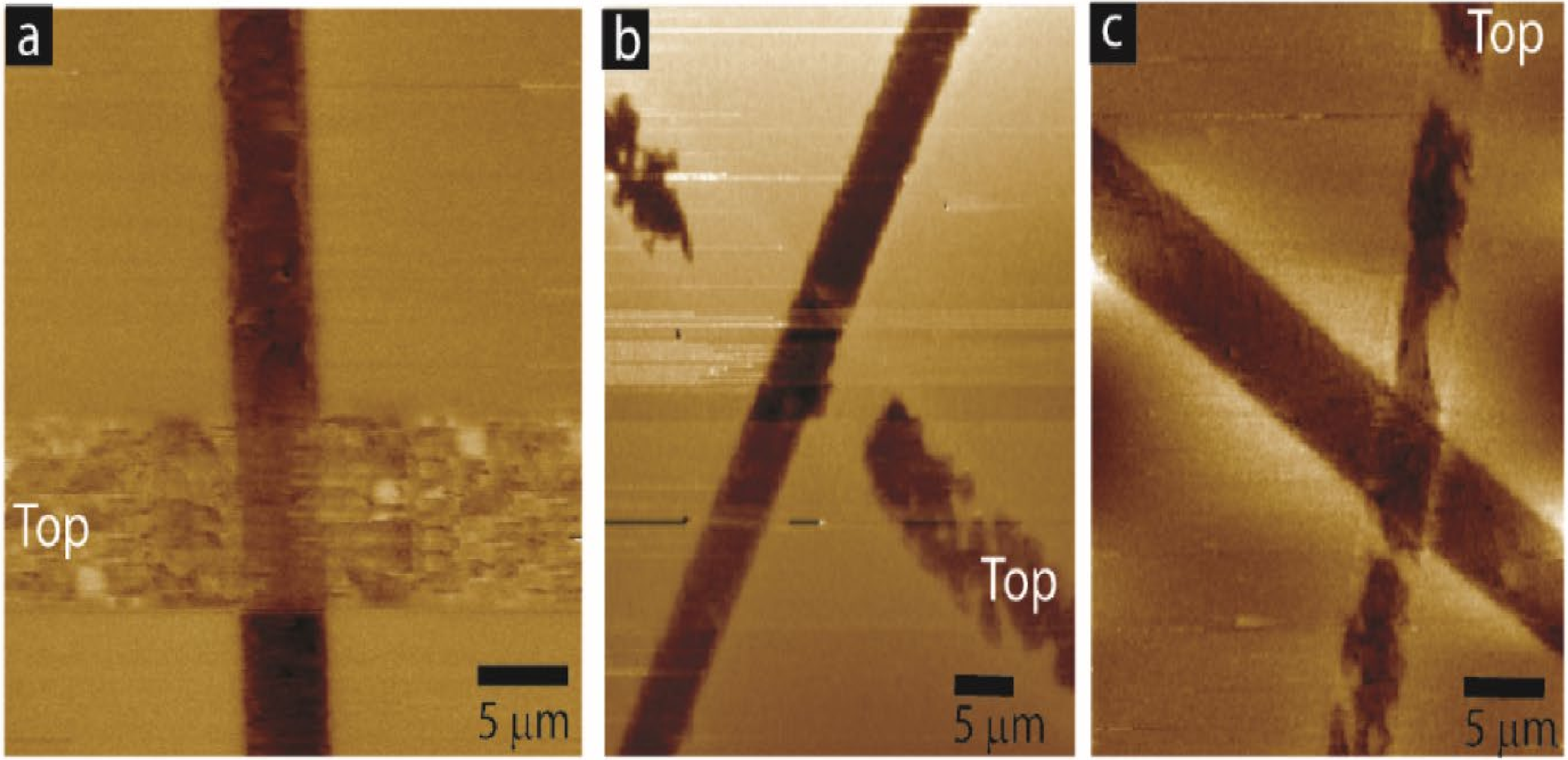
Comparison of 4 device sizes Lattice plots

over >24 months



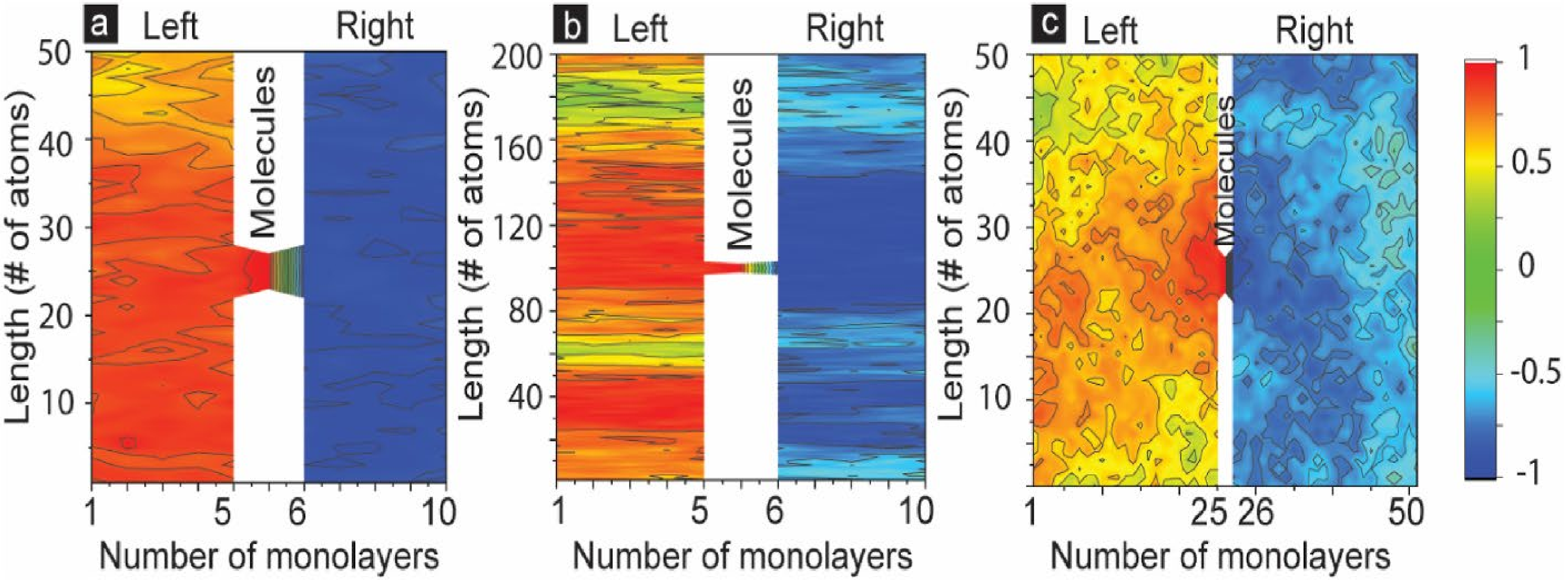
RESULTS AND DISCUSSION

MFM images of MTJMSD



RESULTS AND DISCUSSION

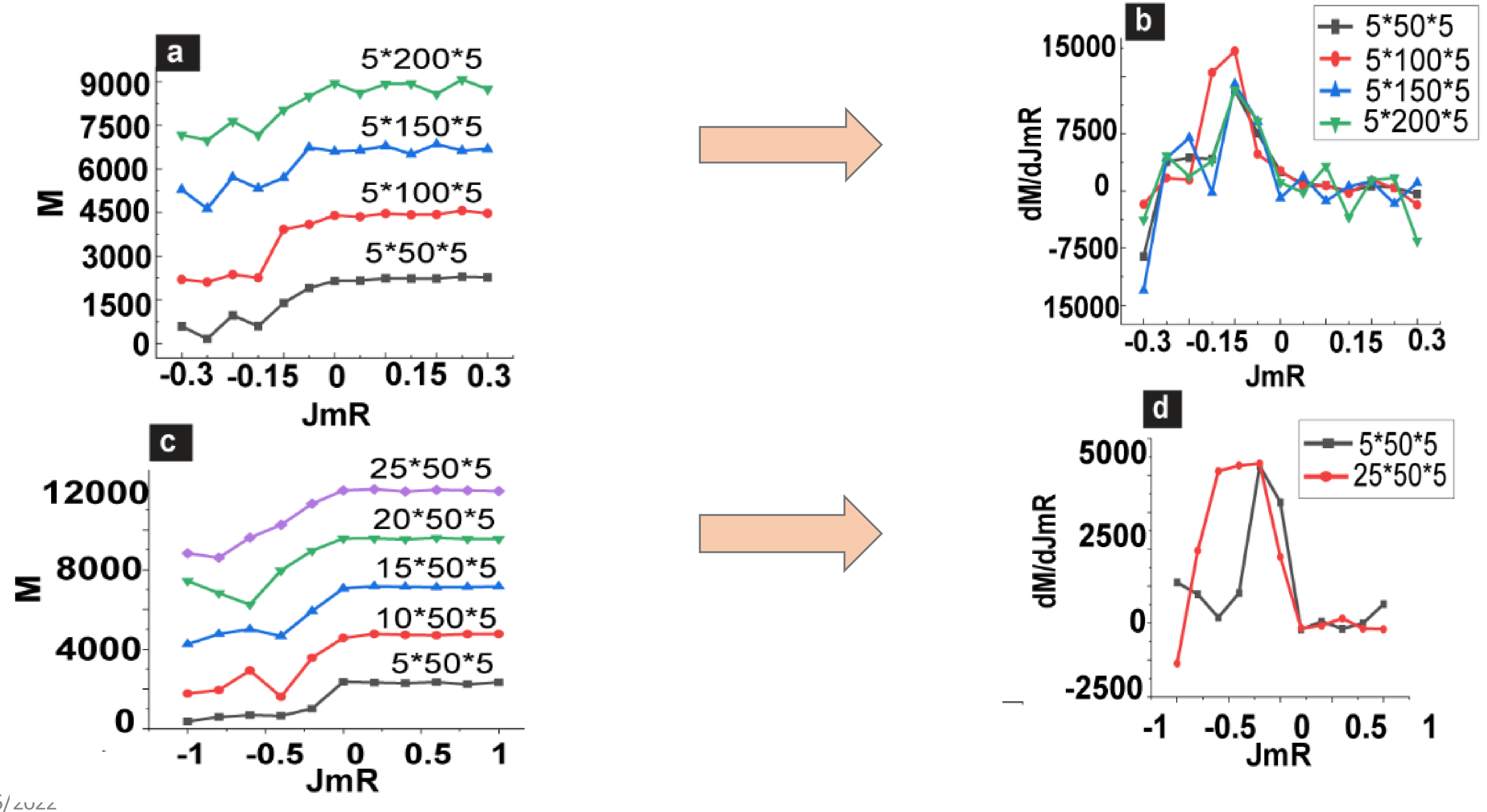
Autocorrelation contour plots of MTJMSD



$$C = (S_m\vec{x} + S_m\vec{y} + S_m\vec{z}).(S_{FM}\vec{x} + S_{FM}\vec{y} + S_{FM}\vec{z})$$

RESULTS AND DISCUSSION

High To Low Transition Coupling Energy



Conclusion

- **Experimental transport study:** increasing FME thickness → did not allow the strong molecular coupling effect to produce the same orders of current suppression.

- **Experimental transport study:** extended FME → a significant difference in and around magnetic phases with time.

- **MCS study:** increasing thickness weakens the molecular coupling impact range.
- With increasing thickness, a gradient of magnetic properties appeared. The section of FM electrode away from the junction possessed disordered states.

- **MCS study:** increasing FM electrode length for low thickness FM electrode did not alter critical molecular coupling strength.

- **MCS study:** increasing thickness made it difficult to switch a device between high to low magnetic moment states. This result is of critical importance and suggests that experimental studies should focus on thin films. According to our experimental study, the critical thin film thickness is around 10 nm

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