



# Interlayer coupling magnetic vortex pair in FM/NM/FM trilayer nanodisks



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## Introduction

### Background

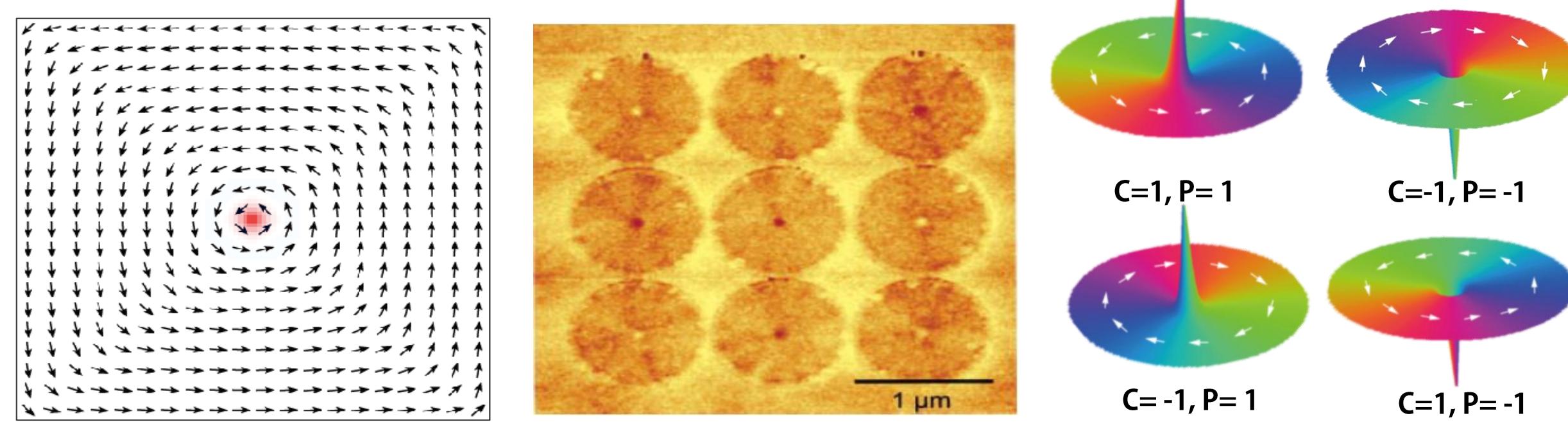


Fig1.Magnetic vortex state in nanoscale ferromagnetic disks<sup>[1]</sup>.

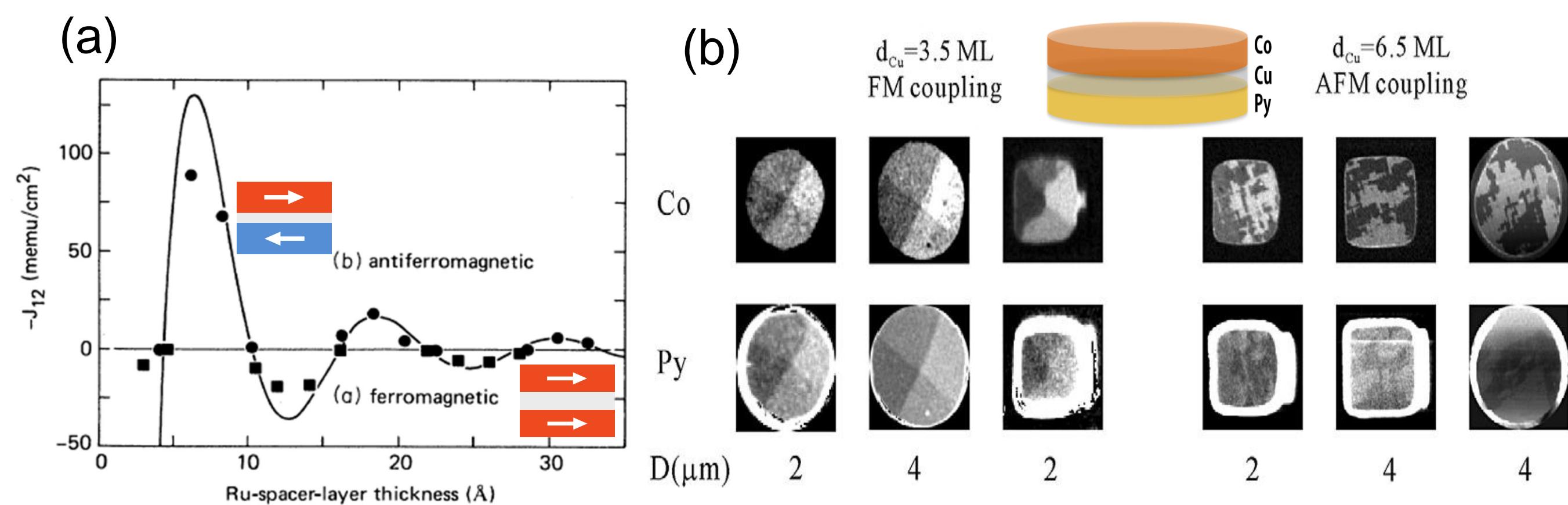


Fig2. (a):Oscillatory interlayer exchange coupling in NiCo/Ru/NiCo trilayers<sup>[2]</sup>. (b): Magnetic states observation in Co/Cu/Co single crystal trilayer nanodisks by XMCD. The ferromagnetic(FM) coupling vortex was observed, while antiferromagnetic(AF) coupling vortex was not observed<sup>[3]</sup>.

### Motivation

Here we try to get a phase diagram of magnetic states evolution with increasing AF and FM coupling strength by micromagnetic simulation.

### Reference

1. T. Shinjo, Science 289, 930 (2000).
2. S.S.P. Parkin, PRB, 44, 7131 (1991)
3. J. Wu, Condens. Matter J. Phys 22 342001(2010)

## Methods

We use OOMMF(Object Oriented Micromagnetic Framework) code to do micromagnetic simulation, which based on the Landau-Lifshitz-Gilbert equation(LLG equation).

$$\frac{d\vec{m}_i}{dt} = -|\gamma|\vec{m}_i \times \vec{H}_{eff} - \frac{\alpha}{M_s}\vec{m}_i \times \frac{d\vec{m}_i}{dt}$$

$$U = \frac{1}{4\pi\mu_0 r^3} \left\{ \vec{M}_1 \cdot \vec{M}_2 - \frac{3}{r^2} (\vec{M}_1 \cdot \vec{r})(\vec{M}_2 \cdot \vec{r}) \right\}$$

$$E_{ij} = -J_{ij} \vec{m}_i * \vec{m}_j$$

$$E_i = -\vec{m}_i \cdot \vec{H}$$

$$E_{ij} = \frac{\sigma[1 - \vec{m}_i * \vec{m}_j]}{\Delta_{ij}}$$

Unit cell:  $\vec{m}_i = (m_x, m_y, m_z)$

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## Results

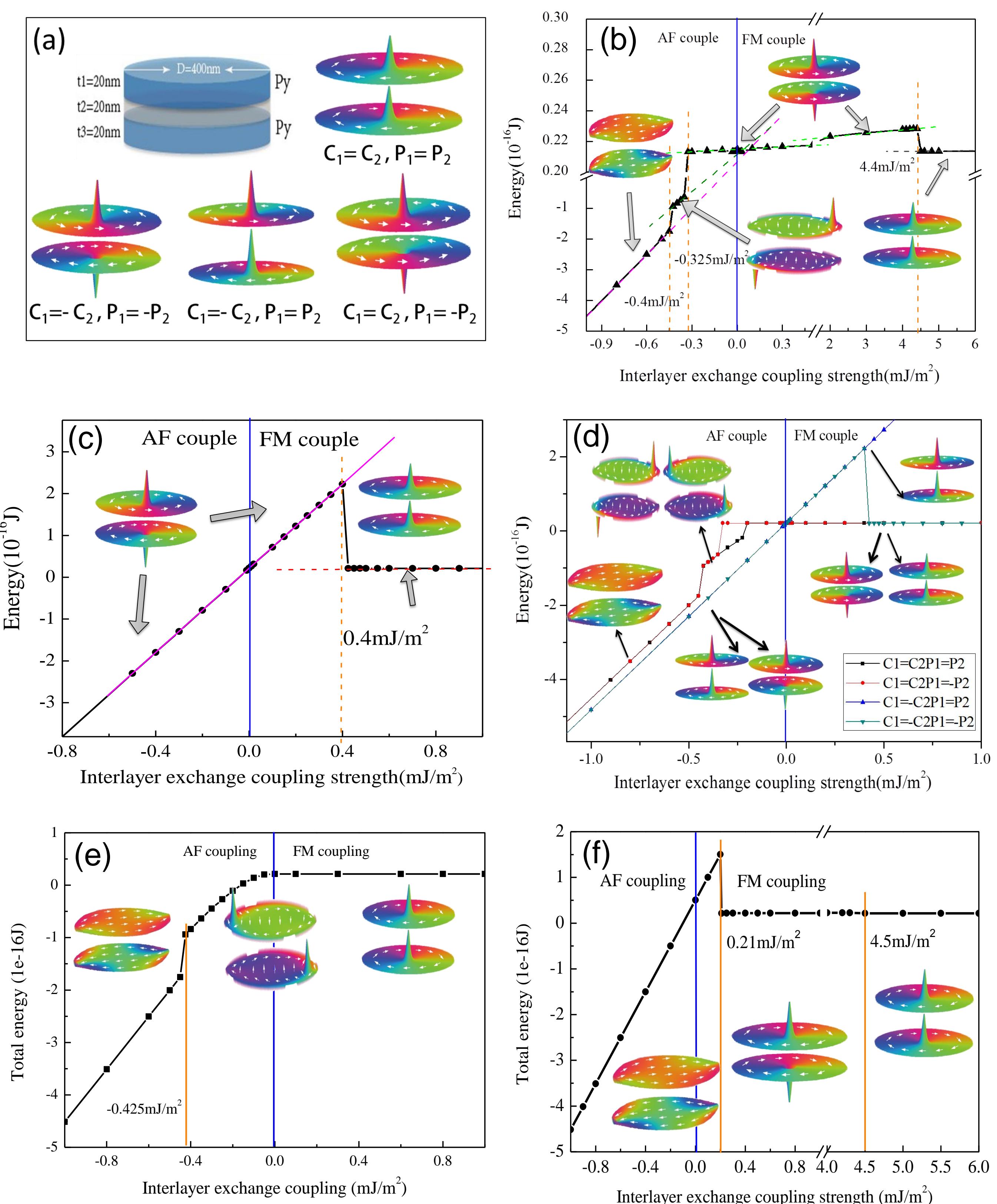


Fig3.simulation results of magnetic states for a Py/NM/Py multilayer nanodisk: (a) The possible magnetic states for a Py/NM/Py trilayer nanodisk in the absense of interlayer coupling. (b-c) Magnetic states evolution with increasing AF and FM coupling strength for parallel(b) and antiparallel vortex pair(c). (d) Comparison of the magnetic state evolution with increasing coupling strength for four kinds of magnetic vortex pair. (e-f) magnetic states evolution with increasing coupling strength for the metastable states appeared in AF coupling situation.

## Conclusions

- The phase diagram give us a complete picture of the influence of interlayer coupling on vortex states in FM/NM/FM trilayer nanodisk.
- From the diagram we find there exists metastable states in AF coupling situation, giving a reasonable explanation why AF coupling vortex pair is hard to observe in experiment.