Reading and Writing Magnetic States with Spin-Polarized Current

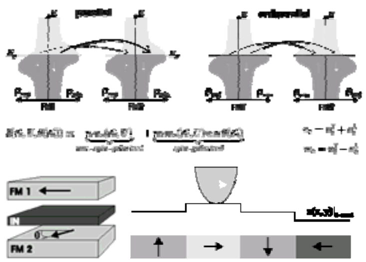
Taehwan Kim

Center for Nanophase Materials Sciences

SP-STM is one of the most powerful methods for mapping the magnetic domains and domain walls on the nanometer and atomic scale. Ultrathin magnetic film tips considerably reduce the magnetic stray field from the magnetic tip. Using spectroscopic techniques allow a clear separation between topographic and magnetic information. The *dI/dV* signals can be obtained by a lock-in technique at a fixed tunneling gap (in SP-STS) or current (in spatially-resolved SP-STS).

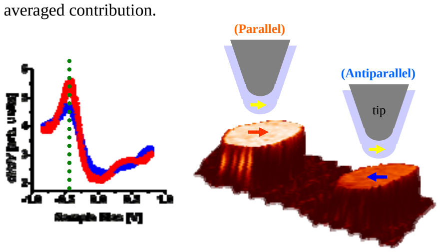
In a one-dimensional chain, magnetic dipoles tend to point along the line joining them when the easy axis of nanoparticles is parallel to the chain. In the case of two-dimensional square lattices of dipoles, the magnetostatic energy will be minimized with anti-parallel coupling between the nearest-neighbor chains. However, if the easy axis of nanoparticles are deviated from the nearest-neighbor direction between nanoparticles, the predicted anti-parallel coupling between neighboring magnetic chains is no longer valid. This "magnetic dipole frustration" can be observed with spin-polarized scanning tunneling microscopy by changing the angle between the easy axis of nanoparticles and the nearest-neighbor direction between nanoparticles.

Spin-Polarized Tunneling



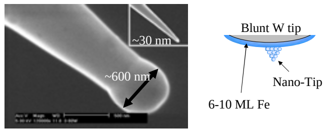
Spin-Polarized Scanning Tunneling Microscopy

In a *dI/dV* measurement, the voltage can be adjusted as to maximize the spin-polarized contribution over the spin-averaged contribution.



Differential conductance depends on the relative direction of magnetizations between the magnetic tip and sample.

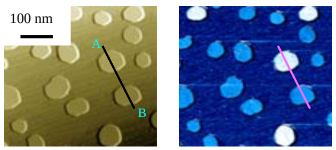
Ultrathin Magnetic Film Tips



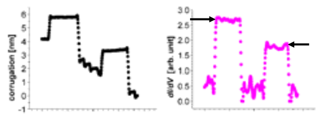
Heating
- Electron Bombardment
- $T > 2100$ K
- Blunt W Tip with (110)-Surface

Coating
- 6-10 ML Fe Deposition
- In-Plane Magnetization
- Nanotips

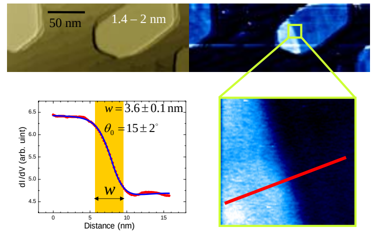
Magnetic Contrast in Fe dots on W(110)



STM Image (Constant-Current Image)   Spatially Resolved SP-STS Image (Differential Conductance at -0.5 eV)

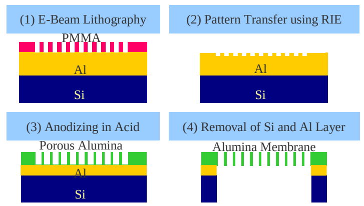


Domain Wall

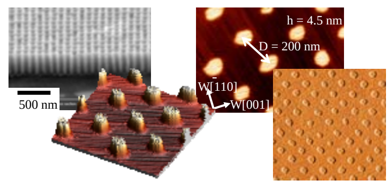


$$y = y_0 + y_1 \cos[\arccos\{\tanh(\frac{x - x_0}{w/2})\} + \theta_0]$$

Fabrication of Alumina Shadow Mask



Fabrication of Fe Dot Array on W(110)



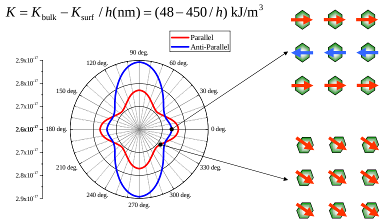
Micromagnetic Simulation

- Objective Oriented MicroMagnetic Framework
- Angle between easy axis and the nearest-neighbor direction between dots

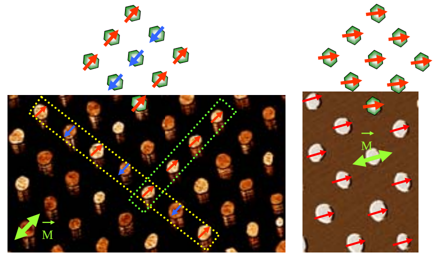
$M_s = 1700$ kA/m

$A = 2.1 \times 10^{-11}$ J/m

$K = K_{bulk} - K_{surf} / h(\text{nm}) = (48 - 450/h)$ kJ/m^3

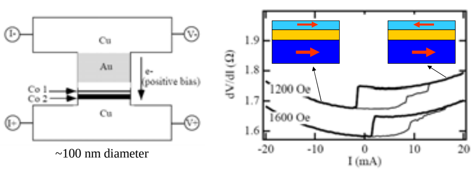


SP-STM on Patterned Fe Dots on W(110)

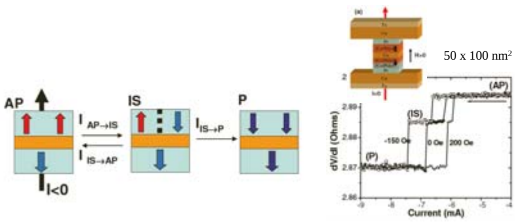


(Left) Easy axis is parallel to the nearest-neighbor direction between Fe dots.
(Right) The angle between easy axis and the nearest-neighbor direction is about 35°.

A key issue for the study of magnetic nanostructures is to control their domain structure. Recently, a spin-polarized direct current injected into magnetic nanostructures can generate coherent precession of the magnetization of small magnetic elements. The magnetization of the magnetic nanostructures can be reversed by spin transfer from a spin-polarized current. We would like to manipulate magnetization of individual magnetic dots by using magnetic or nonmagnetic scanning probes. Scanning probe microscopy with magnetic sensitivity (spin-polarized STM or MFM) would allow us to manipulate magnetization by injecting spin-polarized currents from local probe into magnetic dots (writing) and image magnetic states (reading).

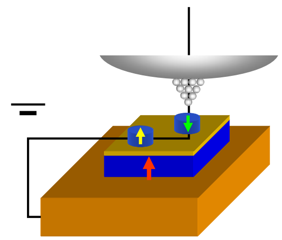


J. A. Katine *et al.*, PRL **84**, 3149 (2000)



D. Ravelosona *et al.*, PRL **96**, 186604 (2000)

Nonmagnetic Tip



Magnetic Tip