CHAPTER 7

ANGULAR DEPENDENCE OF THE MAGNETIZATION REVERSAL OF Ni NANODOTS

As mentioned in Chapter 6, it is important to understand the angular dependence of the in-plane magnetization reversal mechanism which influences several important properties of the ferromagnetic nanodots. This plays a vital role with respect to utilization of nanodots as bit patterned media.

It is known that, in nanostructures with unaxial anisotropy, the reversal process is caused either by coherent rotation or domain wall unpinning [47].

Figure 7.1: Magnetization reversal takes place by one of two fundamental mechanisms: coherent rotation (left) or by the nucleation and growth of reverse domains (right).

To understand the dynamics it is important to realize that each atom in a ferromagnetic material like nickel behaves as a tiny magnet and can be represented by a magnetic moment. If these atomic moments are pointing in random directions, they tend to cancel each other out. Hence, to bring about a remnant magnetic state, one needs to apply a strong external magnetic field in the direction of interest to force the individual moments into alignment. On removal of the external field, the moments tend to remain aligned, and
it takes another equally strong field in the opposite direction to reverse the alignment [48]. This process is called magnetization reversal. There are two basic energies involved in the manipulation and control of the magnetic properties of such materials. Exchange energy controls magnetic order, and anisotropic energy controls the magnetic orientation. A soft ferromagnet such as nickel has a large exchange value but a small anisotropy, making ferromagnetic order stable at higher temperatures but with an unpredictable orientation of the magnetization, especially in structures of nanoscale dimensions.

Studies conducted by Krishnan et al. [48] show that there is an asymmetry in the manner by which the magnetic moments align in a ferromagnetic material, with one mechanism known as coherent rotation (because the moments rotate together) dominating certain directions or orientations and another known as nucleation and growth (because oppositely oriented islands tend to grow in size) dominating in the other orientations. The study of this magnetization dynamics would go a long way in establishing the usability of the fabricated nickel nanodots as a magnetic media. The angular dependence of the reversal mechanism of the fabricated Ni nanodots was studied by measuring the magnetization of the sample at different angles in the plane of the sample to establish the existence of any directional anisotropy of the nanodots, in the plane of the sample, if any. This allows us to get an additional insight into the magnetic domain configuration and domain wall movements of the uniaxial nickel nanodots [43 – 44].

The in-plane magnetization analysis was done by studying the angular dependence of magnetization reversal using the magnetization data obtained from the VSM performed at different angles of field orientation between the magnetizing field and the shorter axis of the elliptical nanodots as obtained from the AFM results. The hysteresis loops are shown below in Figure 7.2. The analysis was done after subtracting the sample offset, as described in Diaz-Castanon, et al [36]. A graphical representation of the orientation of the nanodots with respect to the VSM loops measurement directions is shown in fig 7.3.
Figure 7.2: Hysteresis loops of nickel nanodots sample taken at different angles $\theta$, in-plane of the sample. (a) $\theta = 0^\circ$, b) $\theta = 30^\circ$, c) $\theta = 45^\circ$, d) $\theta = 60^\circ$, e) $\theta = 90^\circ$. 
It can be seen that at $\theta = 0^\circ$, the hysteresis loop is slightly rectangular in shape with a saturation magnetization of around 60 $\mu$emu. As the field is rotated, it can be seen that the hysteresis loop becomes more rectangular in nature until at $\theta = 45^\circ$, the curve has an almost perfect rectangular shape indicating a high remanence and squareness (remnant magnetization/saturation magnetization) almost equal to one. As the angle is further rotated, the magnetization forms a loop more with lesser remanence and a weak hysteresis. This indicates the presence of a distinct hard and easy axis (along the longer axis) of the nanodots in the plane of the substrate. The existence of easy axis of magnetization is understood as arising from the strong influence of shape anisotropy because of the predominant elliptical nature of the nanodots.

The existence of easy axis of magnetization is understood as arising from the strong influence of shape anisotropy because of the predominant elliptical nature of the nanodots. This indicates that while the reversal mechanism of the nanodots will be dominated by coherent rotation of the nanodots when the field is applied close to the hard
axis while on the other hand when the external field is applied close to the easy axis the magnetization dynamics will be dominated by domain wall unpinning mechanism due to the quick growth of unpinning domains [49,50]. This compares well with the MFM results with indicate sharp switching of the nanodots when the external field is applied along the easy axis of magnetization.

It is important to note that such sharp switching of the nanodots is highly advantageous for the realization of bit patterned media, as it greatly increases the reliability of the switching process and greatly reduces the transitional noise and stray field effects due to incomplete or partial switching. This would allow us to identify the ideal read write mechanism for storing and retrieving data from the Ni nanodots using the magnetization reversal phenomenon.