Quasi-stable vortex magnetization structures in nanowires with perpendicular anisotropy

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There have been several experimental reports of successful growth of cobalt nanowires with perpendicular crystallographic anisotropy. In such wires with radii in the tens of nanometers, periodic magnetic structures have been observed. Some authors point out that these structures are formed only in "virgin" nanowires and "cannot be re-observed after a magnetic field of significant amplitude is applied" [1]. Explanations of the periodic nature of the magnetization have been advanced, including an analytic theory [2] (Fig. 1 (a)). We investigate this subject using micromagnetic modeling, and find that in nanowires with radii in this range two different states are formed — see Fig. 1 (b) and (c). Both of these states have a vortex-like structure; (c) is periodic, (b) is not.

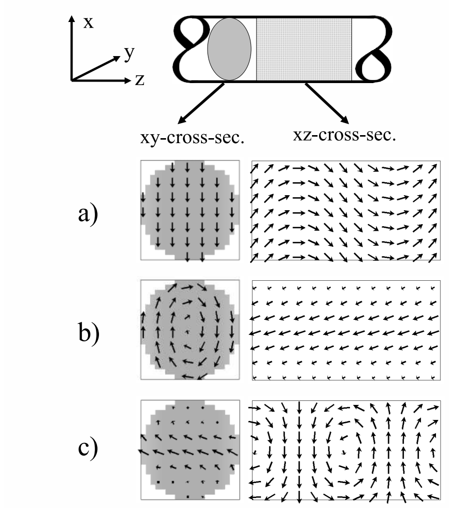

Fig. 1. Schematic figure of three different magnetization states in a nanowire extending in z-dimension. xy cross sections are show to the left, xz cross sections are shown to the right. Bergmann *et al.* investigate a sinusoidal state (a) using an analytic theory. We use micromagnetic modeling to show that a non-periodic z-vortex state (b) and a periodic y-vortices state (c) have lower energy.

We denote the structure in Fig. 1 (b), which has its vortex core axis parallel to the wire axis, as *z-vortex* (we assume the z-axis to be the wire axis). Similarly, the structure shown in Fig. 1 (c) is called *y-vortices.* In all of our modeling results, using cobalt material parameters taken from literature and for a range of radii 30 nm – 200 nm, the found equilibrium states are always one of these two vortex states. In general, either may be obtained, depending on the initial magnetization configuration and various random factors in our micromagnetic model. These results, along with the similar energy density for these states, suggest a possible metastability. Actually, for a wide range of radii the z-vortex seems to be preferred as its energy is slightly lower — see Fig. 2.

Our results explain two experimental facts reported in nanowires with perpendicular anisotropy. First, periodic magnetization patterns can be formed in these wires. Second, they are meta-stable, as there exists another state with a lower energy and no periodic character — the z-vortex state.

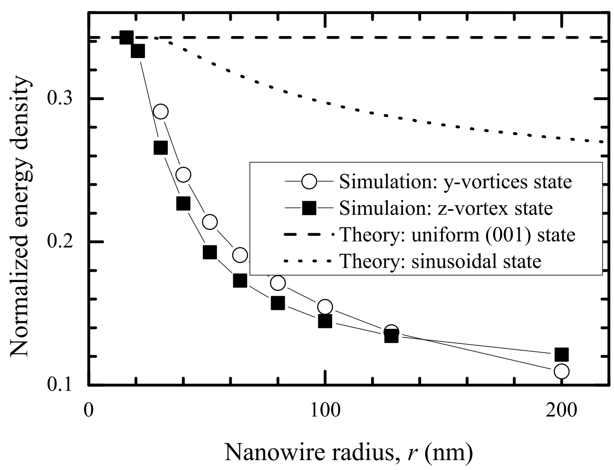

Fig. 2. Energy density of the z-vortex and y-vortices structures for different nanowire radii. Results of simulations (points) are compared with theoretical values for a uniformly magnetized (001) and a sinusoidal state (as in Fig. 1 (a)). Material constants are same as in the first row of Table 1 in Ref. [2].

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