Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Linear Chain of Nanomagnets: Engineering the Effective Magnetic Anisotropy

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1. Static Magnetic Properties for 30 nm and 70 nm Thick Linear Chains

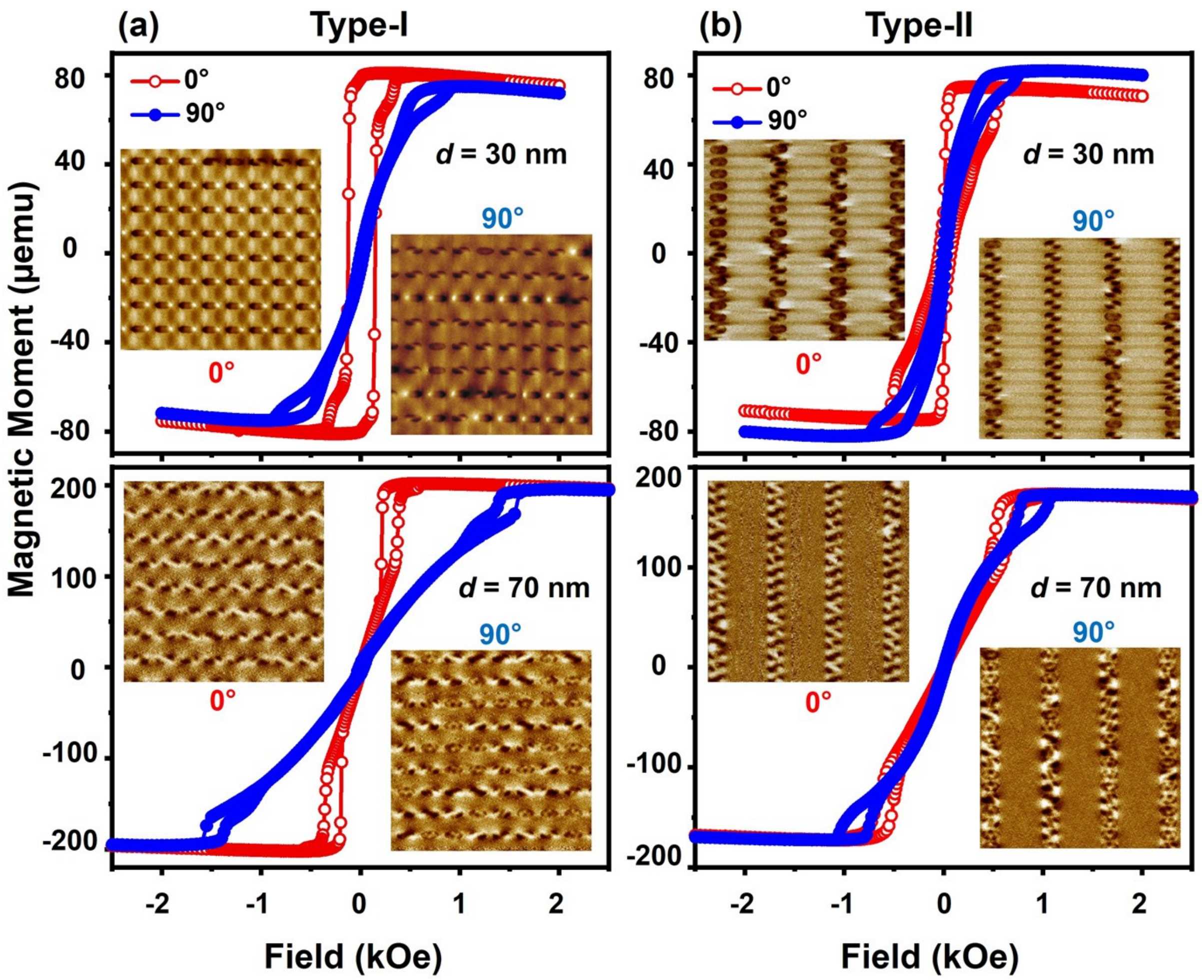

Fig. S1. Hysteresis loops and corresponding MFM images at remanence for (a) type-I and (b) type-II arrays of LC with the thicknesses of 30 nm (top) and 70 nm (bottom).

The hysteresis loops and the magnetic force microscopy (MFM) images at remanence for 30 and 70 nm thick arrays of linear chains (LC) for different applied field angles (φ) are shown in **Fig. S1**. At a thickness (*d*) of 30 nm, an almost rectangular hysteresis loop is observed for φ = 0°, the remanent state of magnetization of which depicts mostly single domain magnetic islands (**Fig. S1**a), as observed for 20 nm thick type-I arrays (**Fig. 2**a of the main manuscript). However, only a few islands (from the left-top corner) shows the formation of vortex. The density of vortex states increases for φ = 90° and the remanence (M_R) decreases subsequently. Single elongated vortex states of different chirality populated the 70 nm thick type-I arrays for φ = 0°, according to **Fig. S1**a. The combination of elongated single vortex states and multiple vortices states with the cores at different positions can be observed when the magnetic field (H_{app}) is field along 90°. Due to the nucleation of vortex states, the total magnetic energy of the system reduces and results in negligible M_R and coercivity (H_c). It is very clear from **Fig. S1**a that the saturation field (H_s) is much higher along φ = 90° which signifies the presence of easy axis along φ = 0°, as observed for all the other thicknesses, discussed in the main manuscript.

In comparison with type-I arrays, the M_R and H_c reduce significantly for type-II arrays, shown in **Fig. S1**b. The MFM images ensure the formation of vortex for most of the nanoislands along both the direction of H_{app} but the vortex density is more for φ = 90°. For *d* = 70 nm, both the loops are slanted where the magnetization reversal is dominated by the nucleation and annihilation of vortices, observed from the inset MFM images of **Fig. S1**b. The easy axis of magnetization is along φ = 0° which agrees with the previously reported results.[1] However, the difference between the values of H_s along the easy and hard axes decreases with increasing thickness. This gives the indication of reduction of the effective anisotropy with increasing thickness for type-II arrays, exactly opposite of type-I arrays which has been elaborated in the main manuscript.

2. MFM Images at Remanence along φ = 45°

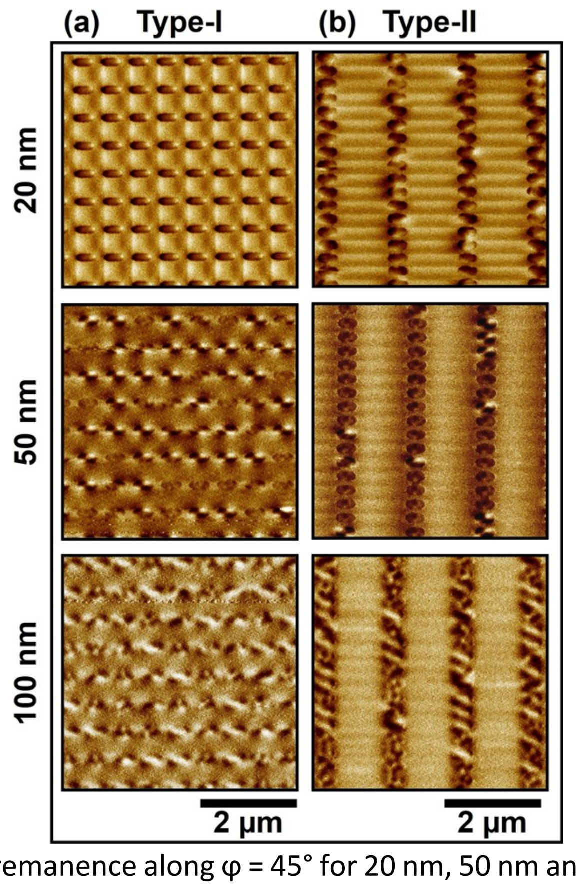

Fig. S2. MFM images at remanence along φ = 45° for 20 nm, 50 nm and 100 nm thick (a) type-I and (b) type-II arrays.

The MFM images of the type-I and type-II nanostructures for *d* = 20, 50 and 100 nm along φ = 45° are shown in Fig. S2. For type-I structure, all the nanomagnets (NMs) are in a single domain state for *d* = 20 nm. The density of vortex states increases at φ = 45° compared to φ = 0° (**Fig. 2**a of the main manuscript) for 50 nm thick nanostructure. However, some of the NMs still show the distorted single domain states. The combination of NMs with single elongated vortex and multiple vortices at different core positions is observed for *d* = 100 nm. By comparing with these MFM images with the images along φ = 0° and 90°, shown in the **Fig. 2** of the main manuscript, it can be easily understood that φ = 45° shows a transition state of magnetization between the 0° and 90°, as expected. For type-II arrays in **Fig. S2**b, distorted single domain islands are present for 20 nm thick NMs whereas nucleation of few vortex states is seen at 50 nm and the 100 nm thick arrays are mostly populated with elongated vortex states along with few NMs with multiple vortices.

3. Simulated Static Magnetic Properties

Table S1: Thickness-dependent variations of H_c , M_R/M_s, and H_s at different angles of applied in-plane magnetic field, obtained from micromagnetic simulation.

d (nm)	φ (°)	H_c (Oe)		M_R/M_s (%)		H_s (Oe)	
		Type-I	Type-II	Type-I	Type-II	Type-I	Type-II
20	0	264.9	224.3	90	87	400	540
	90	31.6	195	53	64.9	800	620
30	0	265.4	108.4	89.8	82.6	500	660
	90	0	195.1	0.1	61.2	1050	780
50	0	0	0	0	0	450	740
	90	0	0	0	0	1450	980
70	0	1.2	0	0.16	0	560	1300
	90	0.37	0	0.02	0.7	1650	1000
100	0	0.94	0	0.1	0	620	1200
	90	0.24	0	0.01	0	2000	1100

Reference

[1] S. Jain, A. O. Adeyeye, N. Singh, *Nanotechnology* **2010,** *21* (28), 285702.