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Regular Article

Manipulate the magnetic anisotropy of nanoparticle assemblies in arrays

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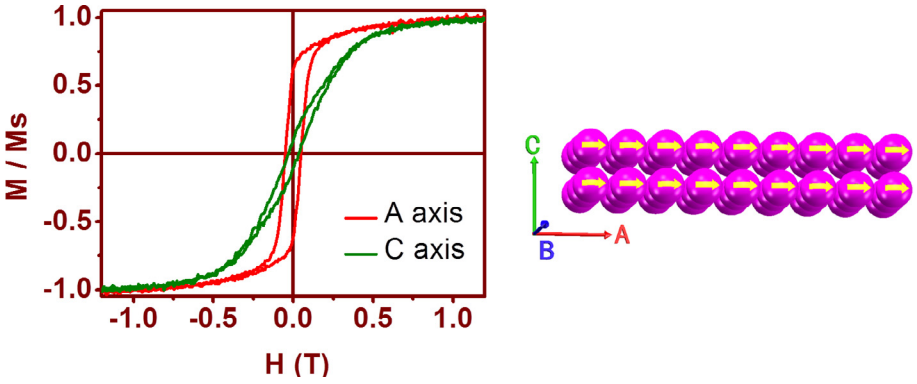
GRAPHICAL ABSTRACT



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ABSTRACT

Tuning the magnetic anisotropy of nanoparticle assemblies is critical for their applications such as on-chip magnetic electronic components and electromagnetic wave absorption. In this work, we developed a facile hierarchical self-assembly method to separately control the magnetic shape and magnetocrystalline anistropy of individual nanoparticle assemblies in arrays. Since magnetic nanoparticle assemblies in the array have the same size, shape and alignment, we are able to study the magnetic properties of individual nanoparticle assembly by measuring the whole arrays. The interplay between the two magnetic anisotropies was systematically studied for disk- and bar-shaped nanoparticle assemblies. Maximum magnetic anisotropy was obtained when the easy axis of magnetic nanoparticles was aligned along the long axes of the bar-shaped nanoparticles assemblies.

1. Introducton

While colloidal magnetic nanoparticles (MNPs) have shown great potentials for biomedical applications in imaging, diagnostics and therapy [1–6], their possible applications such as in electronic devices [7–10] and electromagnetic wave absorption [11–14] are also very obsessed. For the latter, it is often required MNPs being well spatially positioned and organized, which is essential for device fabrication [9,15] and/or performance enhancement [16,17]. Further, MNPs for these applications often behave as ensembles, in which the magnetic properties are not only determined by the intrinsic properties of individual MNP but also by their interactions [16,18–20]. More recently, it is found that the shape of the MNP ensembles can also play a crucial role in

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determining their magnetic response to external stimuli [21]. Here we demonstrate that the magnetic anisotropy of MNP ensembles can be manipulated by sophisticated self-assembly techniques. The interplay between shape and magnetocrystalline anisotropy of MNP ensembles give us more dimensions to tune their magnetic properties and design their applications.

Embedding colloidal MNPs in polymer matrices is a facile and broadly used technique for MNP organization and device fabrications [3,22–24]. The distribution of MNPs is determined by the interaction between MNPs and the polymer matrices [22,24]. These hybrid magnetic nanocomposites have been utilized for applications such as granular magnetoresistance [23,25], microwave absorption [13,26], and high-Q inductors at high frequency [27]. However, the random distribution of MNPs in magnetic nanocomposites limits our capability for tuning their magnetic properties and improving their performance in various applications [22]. In addition, large gaps between MNPs due to polymer insertion in nanocomposites often reduce the real part of the permeability [28], deteriorating their performance in many applications such as the magnetic core of an inductor.

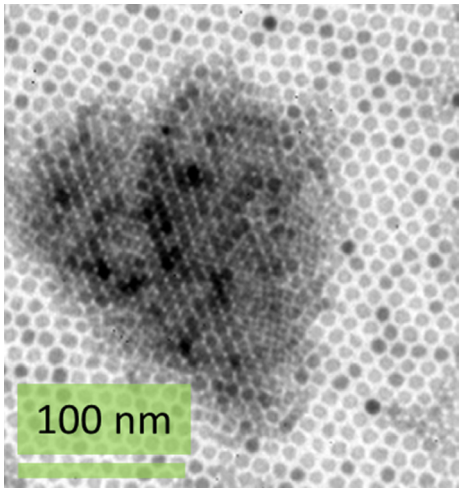

Fig. 1. TEM image of Cobalt ferrite MNPs.

Sophisticated self-assembly methods have been developed to make single piece monolayer of nanoparticles in centimeter scales with clean interfaces [29]. These monolayers have been used in a variety of applications such as flash memory [30], nanoparticle lithography [31], magnetic recording [32], catalysis [33], exchange bias [34]. And recently they were used as functional layers in terahertz wave modulators by our group [35,36]. However, monolayers of MNPs have only very subtle signals in response to external magnetic field, limiting their use in many circumstances. Nanoparticle multilayers deposited layer-by-layer method [37,38] could give stronger magnetic signals. However, it is required for subsequent patterning for on-chip applications [39]. Technically, this approach is very difficult and uneconomical. It is very tedious for multiple depositions, and it is of no easy to conserve the MNP orderings during the multiple deposition and subsequent patterning process. As a result, it is demanding to develop facile methods to make MNP assemblies in designated positions, which gives sufficient signals to external magnetic field.

MNP crystals can be simply obtained by destabilizing MNPs from solution with addition of poor coordinating solvent [20,40,41]. However, these MNP crystals have random shapes, sizes and alignments, making it difficult to characterize individual MNP crystals and limiting their use in device fabrications. Recently, a hierarchical self-assembly method was developed by our group to fabricated MNP assembly arrays on silicon substrate. These MNP assemblies on silicon have the same shape, size and aligned orientations, allowing us to detecting the magnetic properties of individual assembly by measuring the whole arrays [21]. The assembly method is also compatible with the processing of silicon technology, making it easy for on-chip magnetic device fabrication.

In this work, by applying an external magnetic field to physically rotate the easy-axes of MNPs during assembly on silicon mold, we are able to align the easy axis of MNPs in the assemblies.

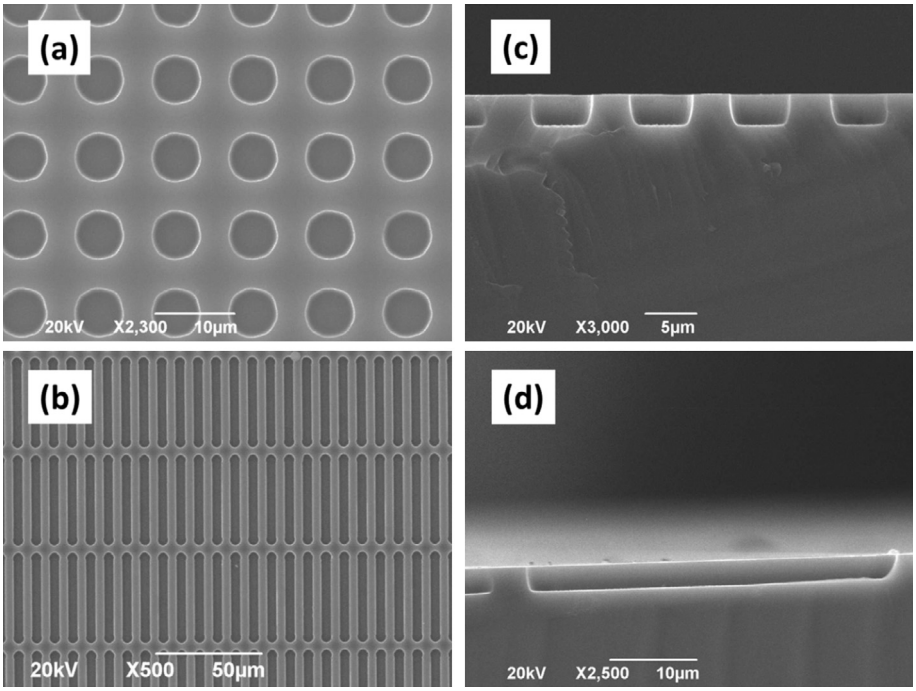

Fig. 2. The top view of (a) disk and (b) bar trenches, and the corresponding side views of the mold are shown in (c) and (d) respectively.