Linear-chain assemblies of iron oxide nanoparticles

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1. Introduction

To date, most magnetic nanoparticle applications have focused on spherical primary nanoparticles or nanoparticle assemblies with aspect ratios close to 1, while utilization of magnetic nanowires and linear-chain assemblies of magnetic nanoparticles has been very much limited. However, 1D magnetic structures have the potential to open up new applications in biomedicine, as their high aspect ratio results in a much larger dipole moment, allowing their manipulation with lower magnetic field strengths. Flexible long chains of magnetic particles could also be of importance across a wide range of applied materials technologies. Additionally, it is important to achieve structural precision for optimization of properties and functions. Electronic and plasmonic coupling between metallic nanoparticles has been known to yield novel electronic and optical properties. Such coupling is critically dependent on structural parameters such as inter-particle spacing and the spatial organization of individual nanoparticles. In comparison with higher-order nanostructures, 1D nanoparticle chains are more expedient building blocks for circuits in nanoelectronics, optoelectronics, and biosensors. Minimizing structural irregularity is essential: a large gap can break the coupling along a chain, and branching can cause a short circuit. Therefore, the investigation of magnetic particle assembly in linear chain-like structures is of great interest among concerned researchers.

Several methods, often utilizing polymer templates to direct the assembly, have been employed to form nanoparticle chains [1, 2]. For example, there have been many studies on nanoparticle self-assembly at interfaces within and on the surfaces of block co-polymers. Our current focus is template-free self-assembly of magnetic nanoparticles, which approach offers the potential for control and tunability of the self-assembly process without the use of templates.

2. Results

In this study, we successfully synthesized high-uniformity 200 nm monodisperse iron oxide nanoparticles and discovered interesting linear-chain self-assemblies that can be enforced from the vortex state of each iron oxide nanosphere.

3. Discussion

One of our recent investigation showed that the exchange binding interaction is the dominant factor in the assembly of nanoparticles with a 3D magnetic vortex, and that the dipolar binding interaction inhibits increasing numbers of particles in the linear configuration [20]. Also, it was interesting to observe that the value increases with increasing numbers of magnetic nanoparticles participating in the linear-chain formation. This observation could be explained by the fact that there exist four easy axes energetically equivalent to each other in the Fe3O4 nanosphere, which implies that there are three other easy axes also in the linear-chain direction. Magneto-crystalline anisotropy binding interaction hinders the formation of the linear chain in a specific easy axis,

due to the existence of freedom at the other three binding sites.

4. Conclusion

We demonstrated the linear assembly of 200 nm iron oxide nanoparticles and the relation to the 3D magnetic vortex structure and binding energy. From the micromagnetic simulation analysis, it is clear that the intra-exchange interaction has an important role in modifying the internal spin configuration of the core of an iron oxide nanosphere. In this regard, it is helpful to reduce the magnetic binding energy necessary for magnetic nanoparticle assembly. We believe that this study provides valuable insights into the interplay between particles' assembly patterns and their spin-vortex magnetic properties.

5. References

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