

Synthetic Antiferromagnetic Particles for Biosensing

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Abstract:

Magnetic nanoparticles can be highly useful in many biological applications. The magnetic moments of these particles need to be large to provide large magnetic signal or to facilitate magnetic manipulation of biomolecules. In traditionally synthesized superparamagnetic nanoparticles, increasing the size of the particle increases the magnetic moment. Larger particles, however, do not always revert to a non-magnetic state when not in the presence of a magnetic field, making them non-ideal for work in biological systems. Synthetic antiferromagnetic particles, however, do not have this restriction due to their structure. In this study, particles were synthesized using a nanoimprint method followed by layered deposition of metals. The nanoimprint process was improved by using a spin-coated polymer layer as the release layer rather than a metal (which requires deposition), thus saving fabrication time. The magnetism of the particles was measured using alternating gradient magnetometry. Once the process for synthesizing the synthetic antiferromagnetic particles had been optimized, they could be functionalized for many different biological processes such as protein sorting or cancer signaling.

Introduction:

In order to achieve high magnetic moments without remanence caused by superparamagnetic particles at sizes above the superparamagnetic limit, synthetic antiferromagnetic particles were designed [1]. Their structure was that of a titanium cap followed by a layer of ferromagnetic iron. At such small sizes, the layer had an aligned total moment. The following titanium layer acted as a spacer and was followed by another ferromagnetic iron layer. Due to the small sizes of the layers, as the iron was deposited the layers' total magnetic moment aligned opposite to the previous iron layer. This created the synthetic antiferromagnetic condition of the particles and was what gave it zero remanence outside of a magnetic field.

Experimental Procedure:

A nanoimprint technique was used on a tri-resist coated standard silicon wafer followed by layered metallic deposition to produce the synthetic antiferromagnetic particles.

First durimide, as a final release layer, was spin-coated onto the wafer at 3000 rpm for 60 seconds. The wafer was then baked at 300°C for 10 minutes and allowed to cool. A second layer of polymethylglutarimide was spin-coated at 6000 rpm for 30s and then baked at 200°C for five minutes. After cooling, a final layer of polymethylmethacrylate (PMMA) was spin-coated onto the wafer at 6000 rpm for 30 seconds and then baked at 140°C for five minutes.

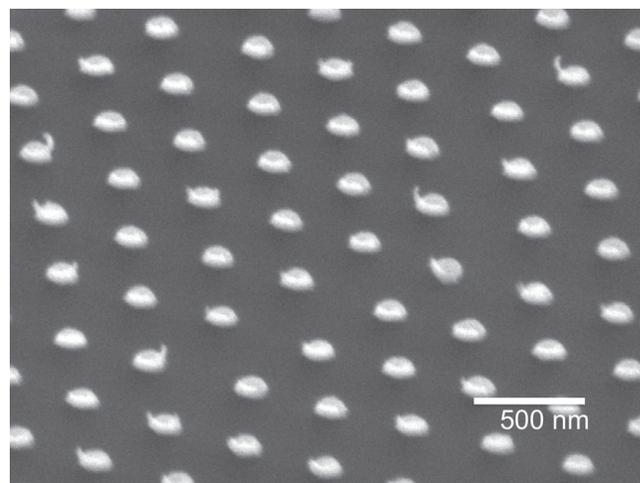


Figure 1: Scanning electron microscope image of synthetic antiferromagnetic particles before final release.

Once cooled, the wafer underwent nanoimprint with a nanopillar stamp at 180°C under 40 bar for 60 seconds. After removing the stamp, the wafer underwent oxygen plasma etching to remove 20 nm of PMMA. Deposition wells were etched into the PMMA layer with chemical development for 20 seconds. The reaction was then quenched with distilled water, and the wafer rinsed a second time.

Evaporation of the metallic layers was done in the order of 5 nm of titanium followed by 10 nm of iron, followed by 3 nm of titanium, followed by 10 nm of iron, and capped with 5 nm of titanium.

Particles were then released into solution by selectively lifting off the individual resist layers. Once in solution they were centrifuged repeatedly to change the solvent to distilled water.

Results and Conclusions:

Images of the particles were obtained before release from the durimide polymer layer via scanning electron microscope (SEM). As seen in Figure 1, the particles were evenly distributed on the silicon wafer. This indicated the reliability of the stamp used during nanoimprint. The fact that the particles were found on the wafer indicated that each layer could be independently removed, so the lift off process was successful. Figure 2 shows an alternating gradient magnetometry graph of the total moment of a small portion of the particles before final release. The graph shows a small amount of remanence at zero external applied field. This indicated that the particles were of a non-ideal shape and suggested an issue with the metallic deposition.

In conclusion, the process works but needs to be further optimized to increase output of ideal particles.

Future Work:

Future studies of the particles will center on functionalization. After they are released into solution they can be functionalized with a silica shell. This shell can then be further functionalized with different proteins for various applications. It is important that each particle is covered in its own shell and not aggregated into a large particle with multiple cores. As seen in Figure 3, it is difficult to be certain that each magnetic particle has a distinct silica shell. Tuning of the functionalization parameters is necessary to reduce aggregation of the particles into bulk material.

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References:

- [1] Hu, W; "High-Moment Antiferromagnetic Nanoparticles with Tunable Magnetic Properties"; *Advanced Materials*, 20, 1479-1483, 2008.

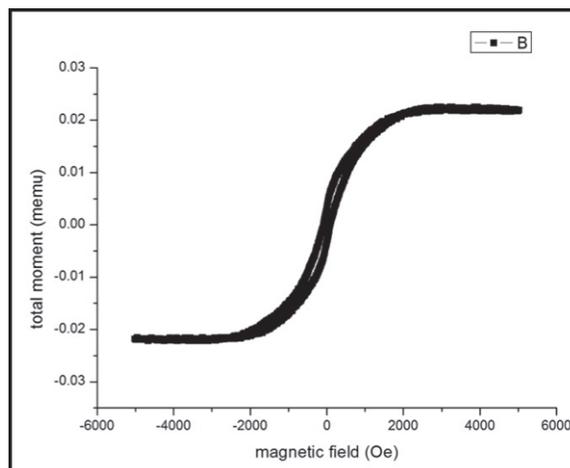


Figure 2: Alternating gradient magnetometry graph of the total moment of particles vs. applied magnetic field.

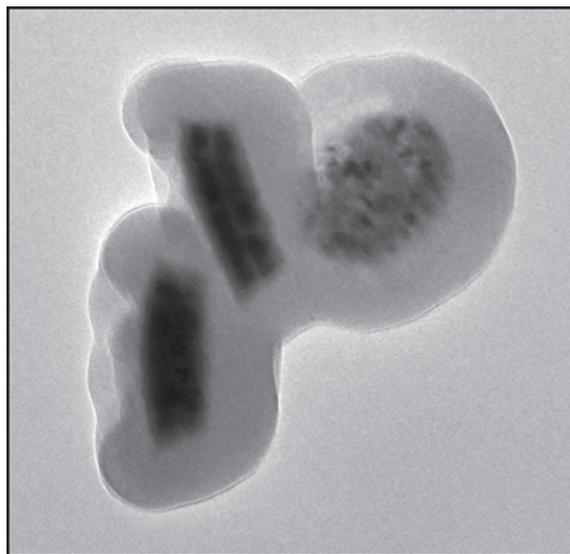


Figure 3: TEM image of synthetic antiferromagnetic particles after functionalization with silica shell.