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Characterization of the Interface Between Fe_3O_4 Nanoparticles and a GaAs Substrate As a Platform For Next Generation Spintronic Devices

Sahar Hihath [1,2], Paul M. Riechers [3], Andrew M. Thron [1], Jun Chen [4], Christopher B. Murray [4], Richard A. Kiehl[3], Klaus van Benthem[1]

[1] Department of Chemical Engineering and Materials Science, University of California, Davis, CA.
[2] Department of Physics, University of California, Davis, CA.
[3] Department of Electrical and Computer Engineering, University of California, Davis, CA.
[4] Department of Materials Science and Engineering, University of Pennsylvania, Philadepia, PA.

Semiconductor spintronics have recently gained tremendous attention because successful implementation could offer the development of magnetic memory with high storage volume. One possible method for creating spintronic devices is to combine half-metallic ferromagnetic materials with semiconductor substrates. In such hybrid-devices, spin injection from the ferromagnetic metal to the non-magnetic semiconductor could combine the magnetic storage of information with electronic integrated circuits in a single semiconductor device [1].

Previously, Riechers et. al. has reported a method for bonding self-assembled monolayer arrays of Fe_3O_4 nanoparticles to a GaAs substrate via an optimized thermal annealing cycle [2]. Oleic-acid coated Fe_3O_4 nanoparticles suspended in hexane solution were adsorbed on to a (100) GaAs substrate and heated to 300°C for one hour in the presence of Nitrogen and Argon gas [3]. Cross-sectional TEM samples were prepared by wedge polishing using Allied Multiprep equipment and subsequent ion milling for 1.5 hours at 3.5 kV. TEM imaging was performed with a 200 keV JEOL-JEM 2500SE while aberration-corrected STEM imaging and Electron Energy Loss Spectroscopy (EELS) measurements were carried out with a 200 keV JEOL-JEM 2100F/Cs. For accurate interface characterization the sample was tilted to an edge-on orientation, i.e. the electron beam was parallel to the <110> zone axis in the GaAs substrate.

A top view SEM image of 17 nm Fe_3O_4 naoparticles on GaAs and a cross sectional TEM image of the interface configuration are shown in Figure 1A and 1B, respectively. These images indicate a robust bonding of the nanoparticles to the substrate, and reveal that the substrate and the deposited nanoparticles are separated by an amorphous layer with 7nm thickness. A detailed characterization of the interface structure and chemistry is critical to attain a fundamental understanding of the device functionality based on the potential for spin injection. Studies of Fe_3O_4 thin films on GaAs prepared by oxidation of as-deposited Fe films have shown that the presence of interfacial phases is inevitable even in highly controlled environments [4]. Therefore, EELS spectrum imaging was used to investigate the elemental distribution across the interface. Elemental distribution plots are shown in Figure 2. This observation suggests that the interface is mainly composed of gallium oxide and may indicate some Fe incorporation into the oxide layer underneath the nanoparticle/oxide interface. Currently, further cross-sectional EELS profiling using aberration-corrected electron optics are underway to quantitatively evaluate local changes of the Fe oxidation state.

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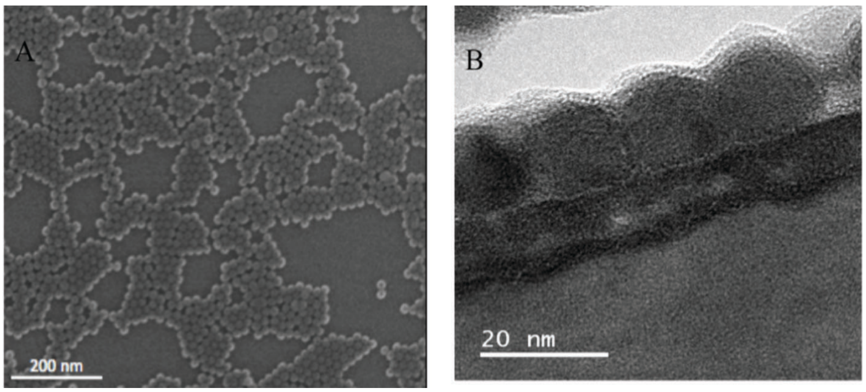

Figure 1. A) SEM image of 17 nm Fe_3O_4 nanoparticles on GaAs after the bonding protocol. B) Cross-sectional TEM image.

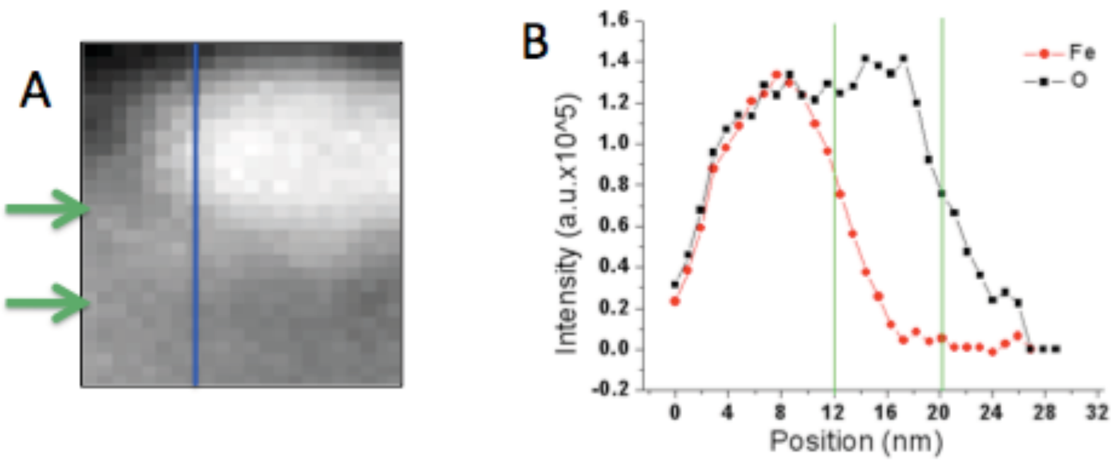

Figure 2. A) Spectrum image of the nanoparticle with amorphous interface layer. The green arrows indicate the amorphous layer. B) EELS elemental distribution plots indicating the distribution of Fe, and O across the interface along the blue line on the spectrum image. The green lines designate the location of the amorphous region.

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