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Nanoscale Characterization of Materials for Magnetic Recording Applications

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In order to accelerate learning and shorten research and development cycle lifetimes in devices based on nanoscale magnetic materials [1], it is important to correlate processing conditions and physical properties with microstructural characterization. The atom probe combines quantitative 3-D atomic-scale imaging with high analytical sensitivity [2-4]. This technique, known as atom probe tomography [3], operates by taking needle-shaped specimens apart one atom at a time. Individual specimen atoms are ionized from the surface of a sharp specimen by a rapidly-pulsed electric field, and are then accelerated to a position-sensitive detector. The location where each ionized atom impacts this detector directly maps to its original specimen position by projection microscopy, while time-of-flight measurement determines elemental identity.

Magnetoresistive spin valves and tunnel junctions are two structures commonly used to form the “reader” portion of magnetic recording heads. Fig. 1 shows atom maps of a simple tunnel junction containing an alumina barrier. A composition profile across the barrier is shown in Fig. 2 [5,6] where the composition of the barrier region is determined to be $\sim(Al_2O_3)_{80}Co_{20}$. In addition, significant diffusion of oxygen into the lower Co layer is detected in this structure.

Spin valve structures use thin alternating layers of Co and Cu to produce an electron spin-dependent resistance change as the reader moves across individual bits in magnetic recording media. Interface width values from composition profiles such as that shown in Fig. 3 (alternating Co/Cu layers ~1nm thick) show that there is more undesired chemical intermixing of atoms when Co is deposited onto Cu than when Cu is deposited onto Co [7]. Another type of spin valve uses a “current confined path” containing a nano-oxide-layer with small metallic paths in order to increase the magnetoresistance while maintaining low overall device resistance. Fig. 4 shows the analysis of such a structure using the local electrode atom probe (LEAP) [4]. Fig. 4b shows quantification of the spatial distributions of alumina and Cu regions contained in the device using isoconcentration surfaces [6,8].

Perpendicular recording media using oxygen to magnetically isolate individual grains in Co alloys [9] is currently being used to increase the recording density in hard drives. An oriented non-magnetic layer (Ru) is used to seed the magnetic layer (Co alloy), Fig. 5, in order to engineer both grain size and crystallography. Fig 5a shows a cross section LEAP atom map (Co and O atom positions shown as light and dark dots, respectively) while Fig. 5b shows the plan view section (from the dashed box region in Fig 5a) where both Si and O segregation to the grain boundaries is observed [8].

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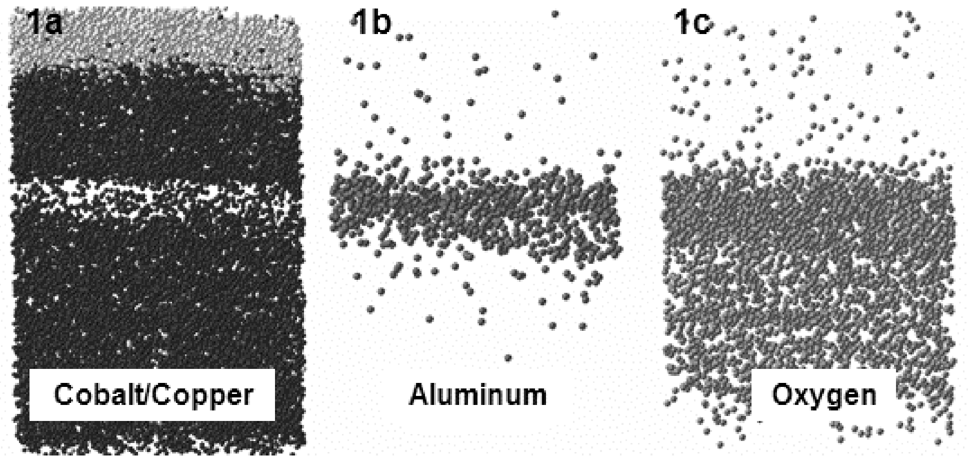

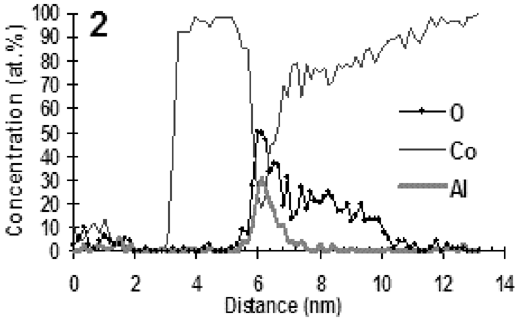

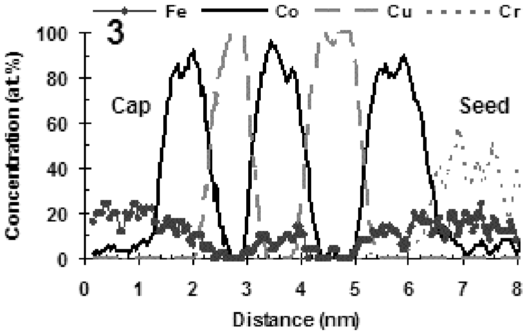

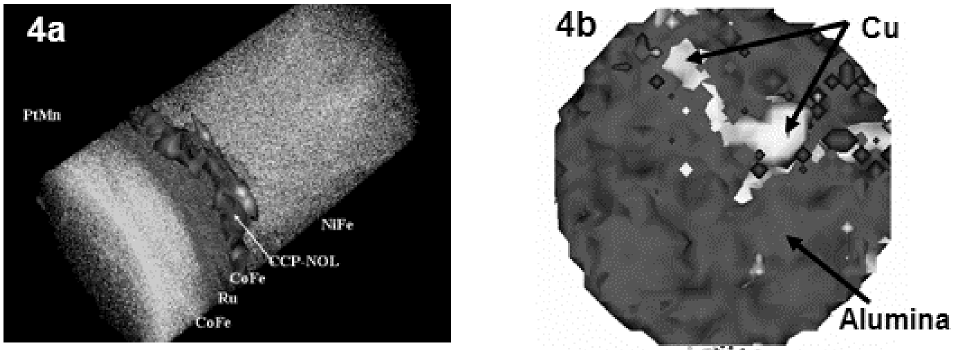

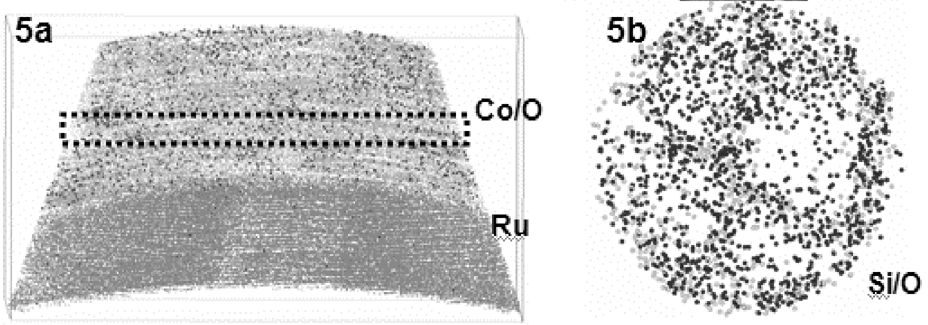

Fig. 1. Atom maps (~8nm by 12nm) of a) Co, b) Al and c) O in a simple tunnel barrier structure.
Fig. 2. Concentration profile normal to the barrier plane from the data shown in Fig. 1.
Fig. 3. Concentration profile across Co and Cu layers typically used in a "spin valve" structure.
Fig 4. a) Atom map (~25nm by 40nm) of a current confined path spin valve and b) isoconcentration surfaces (~30 nm diameter) for the alumina (dark) and copper (light) regions contained in the spin valve.
Fig 5. a) Cross section atom map (~20nm by 35nm) and b) plan view section of Si (dark) and O (light) atoms showing grain boundary segregation.