



Analysis of Nanomagnetism on Cobalt Through SX-STM

“High School Goes Nano”

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Abstract

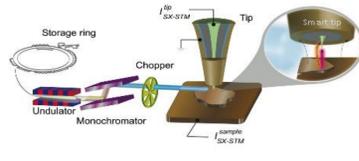
In the current age of information, we have a growing reliance on the ability to access and store data. Hard drives are becoming progressively smaller and more powerful, and cloud storage enables collaboration on a worldwide level. However, these technologies are approaching their physical limits. As we look toward the future, we must consider the power of nanotechnology, and more specifically, nanomagnets, to revolutionize the field of data storage.

Developments in nanotechnology suggests that individual molecules could be used as a binary piece of information. However, instead of 1's and 0's, these molecules would be characterized by their quantum spin: up or down. Quantum spin also indicates whether or not an atom is ferromagnetic, so by analyzing an atom's magnetisation directions, information could be read and stored. Using Synchrotron X-Ray Scanning Tunneling Microscopy (SX-STM), we can examine the chemical, topographical, and magnetic properties of metals at the atomic level in high resolution. SX-STM allows us to examine a metal's feasibility for use in nanomagnetic data storage.

About SX-STM

The scanning tunneling microscope (STM) was developed in 1981, earning its inventors, Gerd Binnig and Heinrich Rohrer, the Nobel Prize in Physics. It is an instrument for imaging surfaces at the atomic level. This is revolutionary as there is no device that can picture the atomic level of metals such as gold and cobalt at the atomic level. Thus, the STM is the first and only technology that can study these elements at the atomic level and concurrently image them. Later, a joint effort between the Center for Nanoscale Materials and Argonne's Advanced Photon Source created the synchrotron X-ray scanning tunneling microscope (SX-STM). In addition to achieving a high lateral and vertical resolution, it employs polarized X-rays to determine the magnetic, elemental, chemical, and topographic properties of a surface. In order to make SX-STM more widely available, a synchrotron branch will be constructed and be operational in 2018.

Fig. 1: Schematic of Synchrotron X-Ray Scanning Tunneling Microscope, not to scale.



Methods

Our experiment was performed using Synchrotron X-Ray Scanning Tunneling Microscopy (SX-STM) at the Center for Nanoscale Materials at Argonne National Laboratory. Our sample was defined as a base of gold with cobalt islands laying across the top. First, the base of gold had to be clean. In a vacuum approximately 10^{-10} psi, the gold base was bombarded with argon gas to rid the surface of excess carbon, oxygen and other impurities. Due to the extremely low pressure of the preparation chamber, there are very few molecules from the atmosphere, like carbon oxygen to cover the base of gold and cause impurities after it is bombarded. The extent of impurities is found by using Auger Electron Spectroscopy. Once the gold base is clean, cobalt is vaporized into gas particles and fired at the gold base. As they land on the gold they solidify again due to differing temperatures causing islands to form.



Fig. 2: Preparation Chamber

The sample was transported to the SX-STM in a portable vacuum “suitcase”, and data was recorded for two scanning modes. First, the sample was scanned by the tip to measure topography and elemental composition (Fig 4). In a second experiment, the tip was fixed over one cobalt island and right circularly polarized light was directed at the sample. The photon energy was varied in this experiment to graph an emission spectrum (Fig 5). Circularly polarized light was used due to the fact that its cross section to excite electrons is dependent on the electron spin.



Fig. 3: SX-STM V3

Purpose and Objectives

The objective of our research is to attain baseline measurement of electron excitations with right circularly polarized light on cobalt islands.

Performing these objectives improves the understanding of the element cobalt at the nanoscale. It provides a foundation for other research to build upon, specifically investigations that determine how magnetic properties and stability change at the nanoscale.

Results: SX-STM

The figure on the right shows the topographical composition of our sample taken by SX-STM. The differing colors are the respective height of the sample. The red and yellow areas indicate islands of cobalt atoms, and the blue indicates the gold surface. The image demonstrates that cobalt islands are ordered in evenly spaced rows. The uniformity of the cobalt atoms can be explained by the herringbone reconstruction. The height of the atoms is determined due to the tip of the STM. The tip has a current it maintains, 1mA, by changing its height over different elements. The scan range of the image is 100 nm x 100 nm.

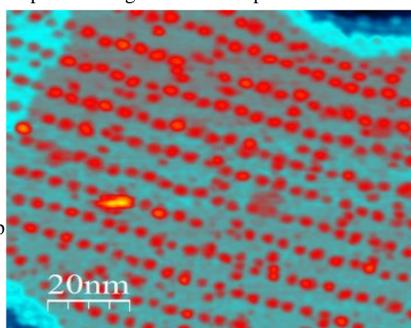


Fig. 4: SX-STM image of Co islands on Au(111) surface, Scan Range: 100 nm x 100 nm, Bias Voltage: -1 V, Current: 1 nA

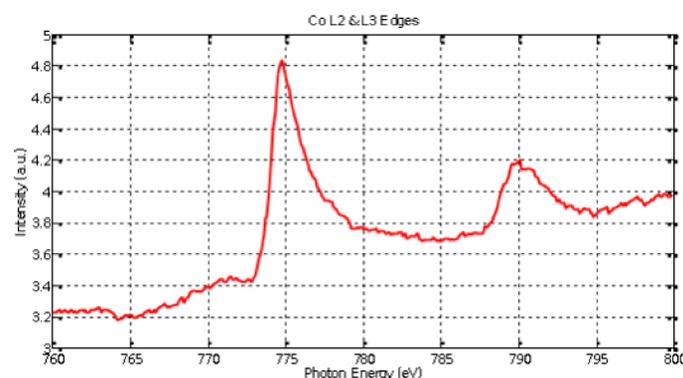


Fig. 5: SX-STM spectrum of Co nano-islands on Au(111). The peak at ~775 eV is the Co L3 peak. The peak at ~790 eV is Co L2.

Through Synchrotron X-Ray Scanning Tunneling Microscopy, we mapped the intensity of excited electrons on cobalt as a function of photon energy from right circularly polarized light. The graph has a general linear trend, due to the fact that a higher photon energy has a higher probability to excite electrons. The two peaks, L2 (at 790 eV) and L3 (775 eV), are the energy levels where electrons are most likely to be excited. The peaks are considerably wide, as the cobalt on our sample exists in bands, however, if we were able to isolate a singular atom completely, the peaks would be much thinner. Regardless, the SX-STM spectrum reveals that depositions are pure Cobalt islands, not cobalt oxide or another impure substance.

Acknowledgements

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Materials: Cobalt Islands on Gold

In this procedure we utilized the transition metals Gold (111) and Cobalt to topographically and chemically visualize Cobalt islands evaporated onto a Gold substrate.

Gold(111) is an ideal surface for deposition due to its unique “herringbone” surface reconstruction. In the prep chamber, we prepared the Au (111) surface through repeated Ar etching and subsequent annealing to temperatures up to 700 °C. After confirming purity through Auger electron spectroscopy, we know that the resulting surface will clearly show the signature of the “herringbone” reconstruction. This is a result of Gold's(111) tendency to assume the lowest energy structure which also means that the Cobalt atoms will deposit at these evenly spaced intersections to minimize energy. Since these Cobalt atoms have a high probability to freely move into these evenly spaced intersections (once

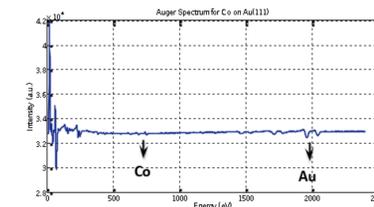


Fig. 6: Auger electron spectrum (AES) obtained in the preparation chamber after the deposition of Co islands on Au(111).

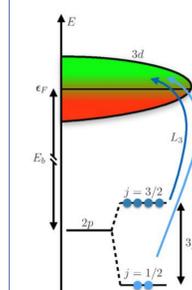


Fig. 7: Schematic picture of the L2 and L3 edge. An electron is excited from the 2p core states to the 3d valence states.

evaporated into single atoms), we can then use our SX-STM to visualize these evenly spaced individual islands where these atoms fell. In Fig. 6 we took one more spectroscopy to confirm the successful binding of the Cobalt islands.

Additionally, to understand our results we need to look at the ionization tendencies of Cobalt ($[Ar] 3d^7 4s^2$). Due to spin-orbit splitting, electrons in the 2p orbital of Cobalt in two different energy levels and the excitation and subsequent release of energy that is measured when these 2p electrons are excited to 3d characterizing peaks are created and are often referred to as the L2 and L3 edges (Fig. 7). When firing a photon beam at the island's there is a probability associated with each edge that details relative chance of excitation which is plotted against the varying energy. Since the cobalt atoms are actually bonded together

they form energy bands where electrons flow: creating the wide peaks in cross-sections that we observed. The polarization of the photons have an effect on the type (spin) of electrons that are excited. These intensities give a cross-section of probabilities of electrons of each spin. Currently we only used right circularly polarized light, but if we used left circularly polarized light as well and found the net difference in intensities for each polarization we could get the magnetic moment of the element. For now, we know the energy levels where the probability cross sections of these edges primarily center around are unique to each metal and can be used to identify the metal itself. Thus, after targeting a specific island and varying the photon energy, if we see the correct edges at their respective energies, we can confirm the identity of the island to be Cobalt.

Discussion and Future Work

By obtaining baseline measurements of electron excitations on Cobalt using right circularly polarized light, our experiment intends to show that specific magnetic properties could be read at the nanoscale. However, in understanding cobalt's nanomagnetic properties, our results are one piece of the puzzle. While using right circularly polarized light is revealing about one direction of electron spin in cobalt, we cannot make claims about ferromagnetic properties without comparing data from both spin directions. To get a full picture, a follow-up experiment could be performed on the same material using left circularly polarized light. By comparing the L2 and L3 peaks between right and left circularly polarized light, we can compare electron spins in the 2p orbital, giving us a better understanding of cobalt's ferromagnetic properties.

Currently, nanoparticles are already being utilized for medical and commercial purposes. For example, they can act as an antibacterial/fungal coating for materials or as effective conducting/magnetic material surrounding the outside of an object. In the future, magnetism from the atomic sizes of nanomaterials may also pave way for novel electronics, which may be improved drastically by quantum phenomena and effective data storage. Data storage is dependent on the magnetism of electrons from their respective spins; 1 being an arbitrary spin and 0 being the opposite spin. These 1's and 0's attribute to data collection and storage, however, due to the size of laptops and electronics, heat creates inefficiencies and forces electronics to be larger because of the addition of fans. Using atomic nanomaterials, these issues would be solved. Specifically, since SX-STM can be used to record the magnetism of a single atom so that binary data can be stored in a much more compact area.

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