Magnetic Characteristics of Transition-metal/Semiconductor Structures

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Introduction

With the advent of spin-based electronics ("spintronics"), the integration of thin magnetic layers with semiconductors is a priority [1]. The physics behind spintronics relies on the ability to inject spin-polarized currents into magnetic hetero-structures. One such system that has shown very promising results is based on III-V materials [2]. It has been observed that spin injection into semiconductor quantum wells can retain spin coherence over length scales of 100 µm. This is several orders of magnitude more than transition-metal-based devices are capable of. However, the current magnetic semiconductors suffer from low spin polarization and ordering temperatures. Transition metals are more favorable but are potentially incompatible with semiconductors [3]. Alloying with the semiconductor results in the formation of a magnetically dead layer and strongly modified magnetic anisotropy (see Fig. 1).

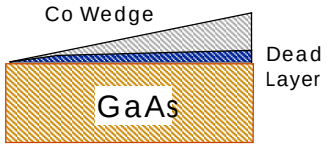

FIG. 1. An illustration of the magnetic dead layer that forms at the interface, inhibiting such spin injecting devices.

To date, the detailed nature of the dead layer and anisotropy are not well understood. A study that uses a combination of polarized soft x-ray techniques (x-ray magnetic circular dichroism [XMCD] and x-ray resonant magnetic scattering [XRMS]) has been initiated to gain an intimate understanding of the fundamental contributions to magnetic characteristics from growing the transition metals Fe, Co, and Ni on Ge and GaAs. The samples were grown by molecular beam epitaxy at the University of Arizona. The high quality of the sample growth was monitored during growth with reflection high-energy electron diffraction (RHEED). The transition metals have been grown in a wedge format ranging in thickness from 0 to 50 Å and capped with a 35-Å Au protective layer. This sample provides continuous access to the whole thickness range, which is necessary for a precise mapping of the onset of magnetic order.

Methods and Materials

XMCD is specifically powerful within this arena because of the accessibility to the 3d states of the transition metals [4]. Figure 2 indicates the separate absorption spectra taken with opposite magnetic field directions. The resultant difference is the XMCD signal. XMCD is both element- and site-specific and has the ability to separate the constituent parts of the total magnetic moments into the spin and orbital contributions [4]. This offers the possibility for assessing theoretical efforts to develop magnetic anisotropic energy models that currently describe ultrathin transition magnetic materials on semiconductor substrates [5].

Results and Discussion

Results on the Co wedge on GaAs at 300K are shown in Fig. 3 as a function of Co thickness. The onset of order is seen by a nonzero XMCD signal at 8-Å Co (4 monolayers [ML]). The intensity grows with increasing Co material but is not linear. Figure 4 indicates the rate of

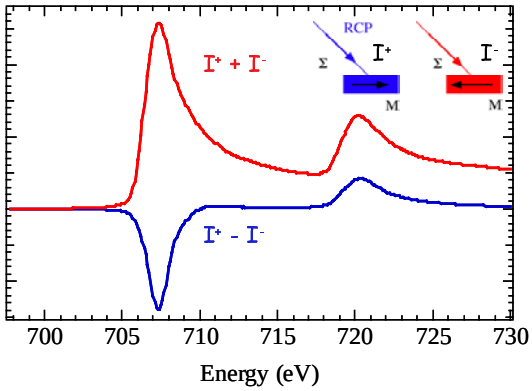

FIG. 2. Polarization-dependent absorption spectrum measured at the Fe L edge. This contrast is a powerful tool for element-by-element magnetic analysis. The inset shows the orientation of photon helicity and magnetization for each measurement.

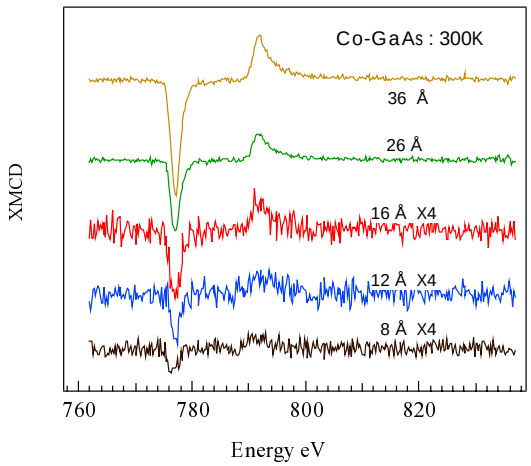

FIG. 3. Series of XMCD with a total electron yield at 300K and with different Co coverages. The XMCD signal shows the onset of magnetic order at 4-ML coverage.

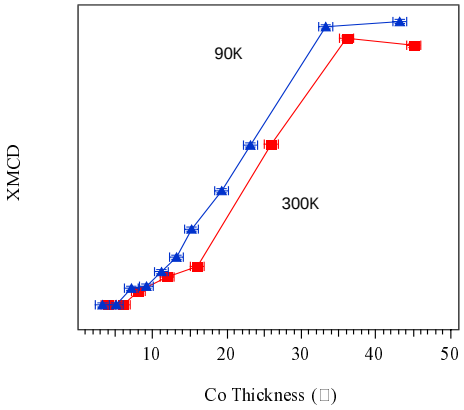

FIG. 4. Thickness dependence of Co grown on GaAs. Note how the onset drops to 2.4 ML at 90K. More detailed analysis of the spin and orbital moments will provide insight into the thickness dependence.

signal change with respect to Co thickness at both 300 and 90K. There is a significantly different rate of dichroism change at lower Co coverage. This indicates an interface environment with a lower T_c. Primarily, dichroism at such low coverages has not been seen, nor has the magnetic character been investigated to such a degree. Here we see the effects of the "dead layer" at very low coverages. Interestingly, the onset of dichroism shifts to lower Co coverage at lower temperatures, from ~4 ML at room temperature to ~2.6 ML at 90K.

Figure 5 shows a typical rocking curve spectrum taken with 20 Å of Co. The spectrum is composed of two primary parts — the specular signals and diffuse signals — the ratio of which contributes to an understanding of the physical and related magnetic roughness at the interface. Analysis of the sum and XMCD signals provides a measure of the chemical and magnetic perpendicular roughness (σ) near 2 Å. The narrow width indicates a long range order in the plane of the film.

The application of the aforementioned techniques on such high-precision samples offers unprecedented information about the intrinsic characteristics of transition metals on semiconductors. Understanding the fundamental issues pertaining to such interfaces may refuel interest in such spin injection devices.

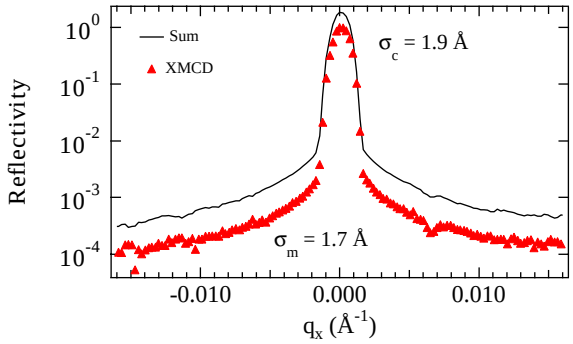

FIG. 5. X-ray resonant magnetic diffuse scattering at the Co L_3 edge. Analysis of the sum and XMCD signals provides a measure of the chemical and magnetic perpendicular roughness (σ). The narrow width indicates a long-range order in the plane of the film.

Acknowledgments

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