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Order From Chaos: α -Fe(001) Growth on GaAs(001)

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Abstract

The growth of Fe upon GaAs(001) has been studied with Spin-Resolved Photoelectron Spectroscopy (SRPES), Photoelectron Spectroscopy (PES) and X-ray Magnetic Linear Dichroism (XMLD) in PES. Despite evidence of atomic level disorder such as intermixing, an over-layer with the spectroscopic signature of α -Fe(001), with a bcc real space ordering, is obtained. The results will be discussed in light of the possibility of using such films as a spin polarized source in device applications.

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Ferromagnetic – semiconductor interfaces are important for the future applications of spintronic devices. One possibility for a room temperature spin injector is Fe/GaAs. Fe/GaAs displays a wide range of magnetic behavior depending upon factors such as substrate preparation, termination, thickness and temperature. Fe/GaAs also grows in a complex island domain structure. [1,2] Here, we report the observation of spectral features consistent with α -Fe(001), a body centered cubic (bcc) structure, from the Fe overlayers deposited upon GaAs(001). The spectral features include the observation of strong spin dependencies in the Spin Resolved Photoelectron Spectroscopy (SRPES, Figure 1) and k-dependent dependencies in Angle Resolved Photoelectron Spectroscopy (ARPES, Figure 2). These results are observed despite the strong evidence of mixing from the core level photoelectron spectroscopy of the Ga 3d and As 3d levels. (Figure 3)

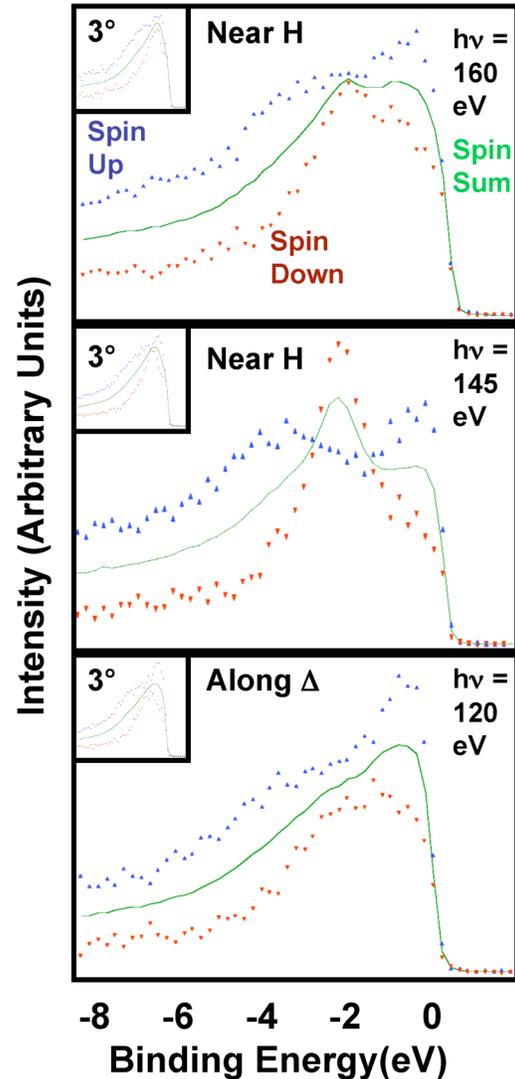


Figure 1
SRPES results for the photon energies of 160, 145 and 120 eV, for the valence bands of Fe/GaAs(001). The energy resolution was approximately 0.4eV, based upon the 10%- 90% width of the Fermi Edge at 0eV Binding Energy. The angular acceptance was +/- 7 degrees. The insets contain the corresponding results for Fe grown upon a vicinal surface of GaAs, with a 3 degree offset from the [001] direction of GaAs.

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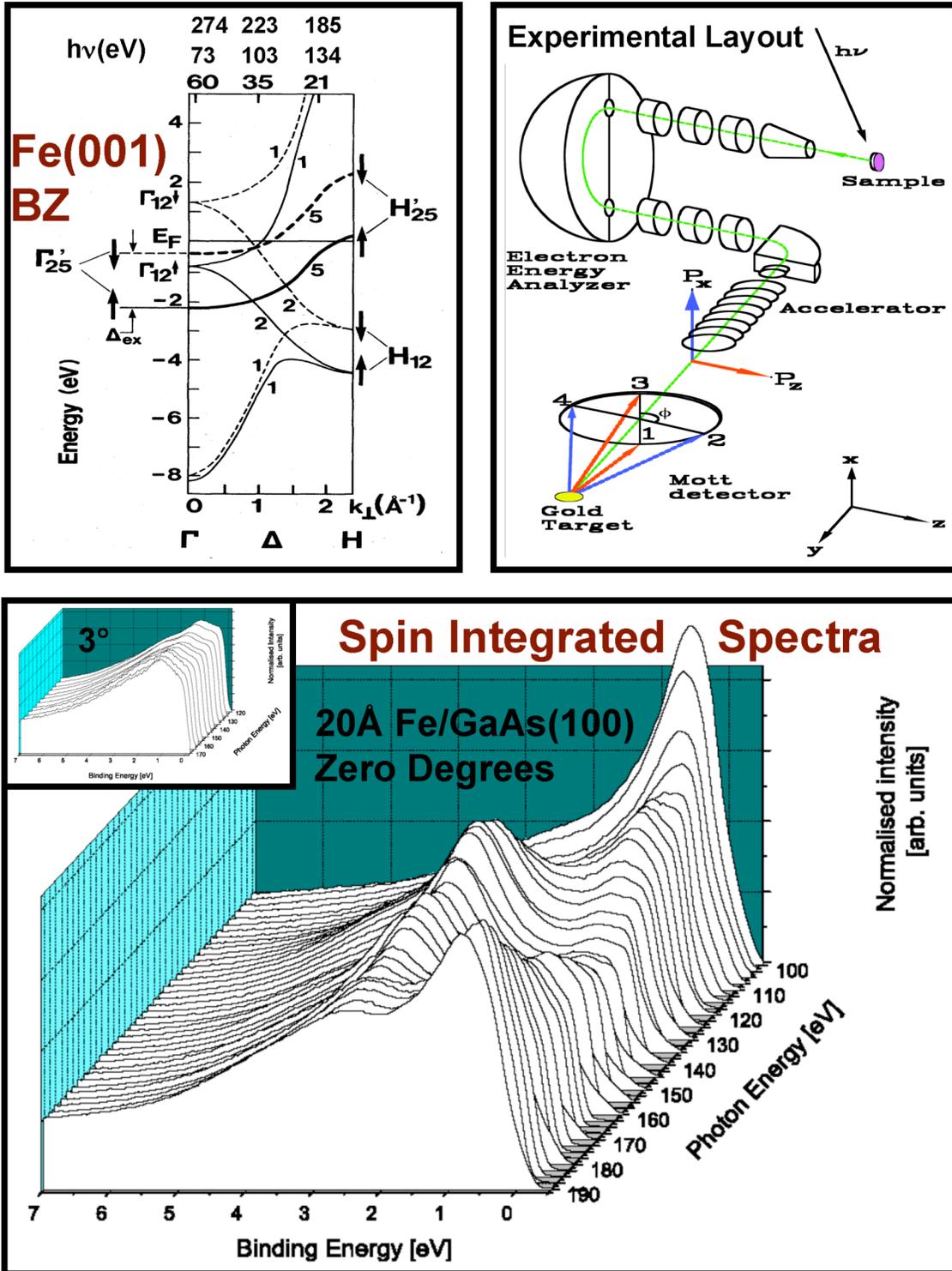


Figure 2
 Top left: the spin specific bands and Brillouin Zone of α -Fe(001) from Kisker et al. [3]. Top right: the experimental layout. Bottom: the spin integrated spectra from 20 \AA of Fe/GaAs. The inset contains the corresponding results for Fe grown upon a vicinal surface of GaAs, with a 3 degree offset from the [001] direction of GaAs.

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The experiments were performed at Beamline 7.0 at the Advanced Light Source of Lawrence Berkeley National Laboratory in Berkeley, CA, USA, [4] using a spin resolving spectrometer described elsewhere. [5] The x-rays were linearly polarized, with the Poynting vector of the x-ray, the linear polarization vector of the x-ray and the emission direction of the collected electrons all in a y-z plane as defined in Figure 2. The angle between the incoming x-rays and the outgoing collected electrons was 55 degrees. For the clean GaAs(001) and Fe/GaAs(001), the emission direction was normal to the surface and along the [001] direction of the bulk GaAs(001). For the vicinal surface results, shown in the insets in Figures 1 and 2, a three or six degree offset was used, which corresponds to (001) steps with 60 or 30 angstrom widths, respectively. The magnetization direction was perpendicular to the y-z plane, along +/- x, as defined in Figure 2. Spin integrated spectra were collected using a multi-channel detector at the exit plane of the hemisphere shown in Figure 2. Spin-resolved spectra

were collected using the Mott detector, also shown in Figure 2.

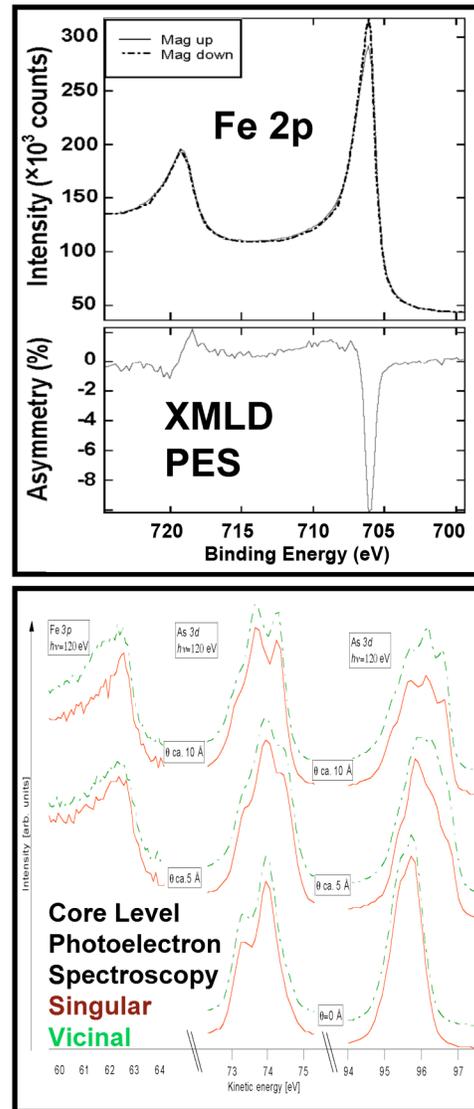


Figure 3
Top: X-ray Magnetic Linear Dichroism in Photoelectron Spectroscopy (XMLD-PES) of the Fe 2p doublet. $h\nu = 810$ eV. [2] Bottom: Core level PES of the Fe 3p, As 3d and Ga 3d for clean GaAs and a pair of Fe depositions. The photon energy was 120 eV. Singular refers to the flat GaAs(001) surface and vicinal refers to the surface with the small angular offset and (001) steps.

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The success of the magnetization process was confirmed, independently of the Mott detector, by the performance of XMLD-PES, [2,6,7] as shown in Figure 3. Here a dichroism of the Fe2p is produced via the reversal of the magnetization. Similar data was collected using the Fe3p as well. [2] The data collection is spin integrated, using the multi-channel detector. The Fe deposition process and its effects upon the underlying GaAs substrate can be followed via the core level spectra of the Fe 3p, Ga 3d and As 3d levels, as shown in Figure 3. The strong perturbation of the Ga and As peaks suggests strong intermixing. A far more extensive experiment, using the core levels to follow the intermixing, is the subject of another work and is presented elsewhere. [1] The net result is that Fe deposition upon GaAs(001) disrupts the substrate order and induces very chaotic interface due to the substantial intermixing. The question then becomes, can sense be made of the electronic structure

of this chaotic interface? The answer is yes, it can.

The spin integrated spectra in Figure 2 exhibit a strong oscillatory behavior in the spectral features as function of photon energy. Interestingly, the phases seems to be reversed, with a maximum (minimum) in the higher binding peak (near -2 to -3 eV) corresponding to a minimum (maximum) in the peak near the Fermi Energy (0 eV). If one looks at the Brillouin Zone for α -Fe(001), the reason for these oscillations become clear: the maximum at about 2.5 eV occurs when the emission is from near the Zone Boundary, H, with $h\nu$ around 145 to 160 eV. Similarly, the maximum in the Fermi Edge peak occurs when the electron momentum is along Δ , away from H, with $h\nu$ near 120 eV or 190 eV. To make this easier to see, we have added additional photon energies from the outer Brillouin Zones, at the top of the plot. The original work by Kisker et al [3] was performed at lower photon energies and several examples ($h\nu = 60, 35$ and 20 eV)

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were included to illustrate the relationship between photon energy and electron momentum at normal emission. We have chosen to show the corresponding spots at higher energies, moving first from near Γ to near H ($h\nu = 73, 103, 134$) and then back from near H to Γ ($h\nu = 185, 223, 274$). Of course, these positions are somewhat approximate: the curves will be steep but not vertical and will represent the downward shifted final state. Nevertheless, one gets the correct feel for the location in momentum space. One way to confirm the nature of origin of these oscillations is to make them disappear. This can be done by disrupting the order: an example of this is shown in the inset in Figure 2, for the 3 degree vicinal surface. Here, the oscillations as a function of photon have completely disappeared, confirming our analysis above.

A stringent test of this hypothesis would be to determine the spin dependence of these spectra features and compare them to the BZ in Figure 2 and the previous spin-resolved results for α -

Fe(001). [3,8,9] This has been done and the results confirm the hypothesis, as will be discussed next. The spin resolved spectra for $h\nu = 120, 145$ and 160 eV are shown in Figure 1. As can be seen, there is a strong spin dependence in the spectra that varies with position within the BZ and $h\nu$. Near H ($h\nu = 145$ and 160 eV), one can clearly see the spin down bands near -2 eV binding energy and the spin up bands near -3 and 0 eV binding energies, corresponding to the $H_{12}\downarrow$, $H_{12}\uparrow$, $H'_{25}\uparrow$ bands, respectively. The agreement is essentially perfect. Similarly, at $h\nu = 120$ eV, along Δ , the spin up spectrum has peaks near -4 eV and 0 eV that correlate with $\Delta_{12}\uparrow$ and $\Delta'_{25}\uparrow$. The spin down spectrum has a single broad peak near -1.5 eV, from $\Delta_{12}\downarrow$ and $\Delta'_{25}\downarrow$ bands. The assignment at $h\nu = 120$ eV is further bolstered by the strong resemblance to the experimental data from the Kisker Group at $h\nu = 117$ eV, in a paper by Jungblut et al. [8] However, this comparison raises an interesting point about experimental geometries. The Kisker experiment is performed at

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normal incidence and normal emission, which provides tremendous selectivity. [3,8] Our configuration, with p-polarized light, is far less selective. Thus the agreement at $h\nu \approx 120$ eV is due in part to the position within the BZ. Comparisons with Kisker spectra near H are less agreeable, but there is strong agreement between our spectra near H and those collected by Heimann and Neddermeyer, who also used a p-polarization configuration. Finally, the vicinal surface spectra, shown in the insets in Figure 3, are all essentially the same and significantly different than the Fe/GaAs(001) spectra, again confirming the disruption of the Fe ordering in the vicinal surface depositions.

Using Spin-Resolved and Angle-Resolved Photoelectron Spectroscopy (SRPES and ARPES), it has been demonstrated that despite significant intermixing and disruption of the underlying substrate, a ordered α -Fe(001)

structure develops in Fe/GaAs(001). Thus, the spin-specific emission characteristics of this interface will be limited primarily to that associated with α -Fe(001).

Acknowledgements

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