ESRF	Experiment title: **Magnetic exchange interactions in GaMnAs dislute magnetic semiconductors across the metal-insulator transition**	**Experiment number**: **HE-1632**
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Shifts: 18	**Local contact(s)**: Dr. Julio Criginski CEZAR	

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Report:

Introduction

The doping of III-V semiconductors such as GaAs with magnetic Mn atoms leads to ferromagnetic order at relatively high temperatures (T_C ~ 100K) [1] which makes these materials interesting candidates for spintronics applications [2]. Substitutional Mn atoms replacing Ga provide local magnetic moments of 3*d* electrons and also form electron acceptors doping holes into the semiconductor valence shell. This leads to an insulator-to-metal transition with increasing Mn concentration. Itinerant holes are also responsible for ferromagnetic order between localized Mn since the observed T_C values scale with the number of holes [3]. The hole concentration and, thus, T_C is limited for as-grown samples by the presence of highly mobile interstitial Mn. These are doble donors that can nominally compensate two substitutional Mn atoms. The removal of interstitial Mn by low-temperature annealing of as-grown samples has lead to a spectacular increase in T_C which is reflected in the hole concentration and the sample conductivity [4].
So far antiferromagnetic coupling between Mn nearest neighbor atom and its possible influence on T_C has been completely neglected for $(Ga_xMn_{1-x})As$ [4]. In this report we show that such a picture has to be modified. We find a strong reduction of the number of ferromagnetic Mn atoms through nearest-neighbor antiferromagnetic Mn-Mn exchange especially at high Mn concentrations. We also provide spectroscopic evidence that magnetically dead Mn interacts strongly with itinerant holes effectivly limiting the number of carriers available for mediating long-range ferromagnetism.

Experiment

The experiments were performed at the beamline ID8 using the high-field superconducting magnet. X-Ray absorption (XAS) was detected by a fluorescence diode. We probed the hybridization of Mn 3*d* and Ga/As orbitals for $(Ga_xMn_{1-x})As$ films at two concentrations x = 0.01 and 0.06. The films with respective thicknesses of 350nm and 180nm were grown epitaxially onto GaAs substrates. For the lower concentrations the samples remain insulating while the high-concentration sample is metallic [5]. The conductivity for x = 0.06 was further improved by low-temperature annealing at 180^{o}C for 12 hours [6]. This process leads to accumulation of interstitial Mn atoms at the surface [7] which were subsequently removed by in-situ Ar ion sputtering.

Results

Typical XAS and XMCD L_3-edge spectra are shown in Fig. 1 for two Mn concentrations resulting in insulating (lines) and metallic (lines and symbols) conductivity. In both cases the samples were magnetically saturated in strong external fields. While the XAS lineshape broadens significantly upon increasing the Mn concentration the XMCD lineshape remains essentially the same for the insulating samples and for the annealed x=0.06 specimen.
The unaltered XMCD lineshape indicates basically identical local Mn magnetic moments at all concentrations. The observed reduction of the XMCD intensity with Mn concentration by 60% roughly corresponds to the expected number of Mn-Mn nearest neighbors at x=0.06. It is, therefore, reasonable to assume that the reduced XMCD signal is caused by either non-collinear or antiferromagnetic order at small Mn nearest neighbor distances.
In contrast the XAS lineshape broadens significantly upon crossing the insulator-to-metal transition with increasing Mn concentration for the as-grown samples. Further broadening is observed between as-grown (not shown) and annealed x=0.06 XAS spectra. This could indicate an influence of sample conductivity, i.e. the number of GaAs valence holes, of the XAS lineshape.

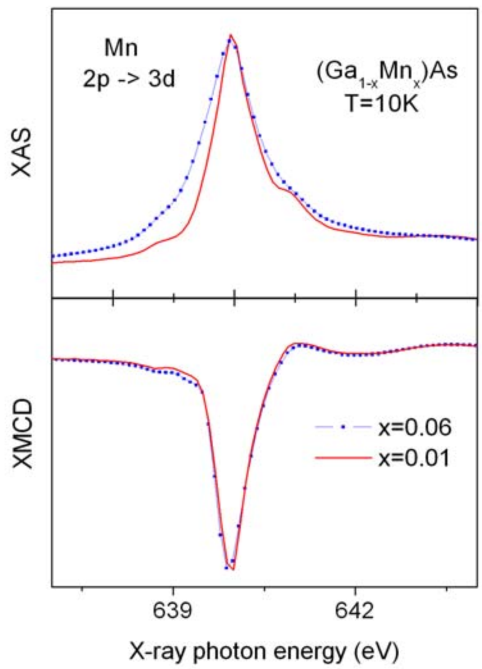

Fig. 1: X-ray absorption (XAS) and x-ray magnetic circular dichroism (XMCD) of two $(Ga_xMn_{1-x})As$ samples with x = 0.01, and 0.06. The x=0.06 XMCD spectrum is rescaled by a factor of 1.5.

references

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