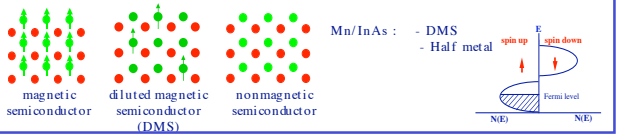
Atomic Structure and Magnetic Properties of Mn on InAs(100) and InSb(100)

K. Hricovini[1,2], C. Richter[1], O. Heckmann[1], M. Zerrouki[1], P. De Padova[3], C. Quaresima[3], P. Perfetti[3], P. Le Fevre[2], C. Teodorescu[4], F. Bondino[5], M. Zangrando[5], M. Zacchigna[5]

[1]LMPS, Université de Cergy-Pontoise, Neuville/Oise, 95031 Cergy-Pontoise, France, [2]LURE, Bat. 209 d., 91 898 Orsay, France, [3]CNR-ISM; via Fosso del Cavaliere, 00133 Roma, Italy, [4]NIMP, Bucharest, Romania, [5]ELETTRA, Trieste, Italy,

Introduction

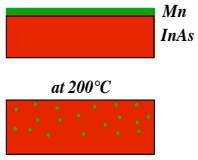
A new category of semiconductors, called diluted magnetic semiconductors (DMS), are alloys between a nonmagnetic semiconductor and a magnetic element (manganese in most cases).
An important property of these materials is that the carrier density can be controlled over a wide range between n- and p- types. This opens up the possibility to control magnetic properties simply by changing the carrier density. This behaviour is generally called "carrier-induced ferromagnetism" because hole carriers introduced into the system mediate the ferromagnetic coupling between Mn ions.
So, in such systems, both, the charge and the spin of the electron can potentially be used to create new types of semiconductor devices.



Experimental

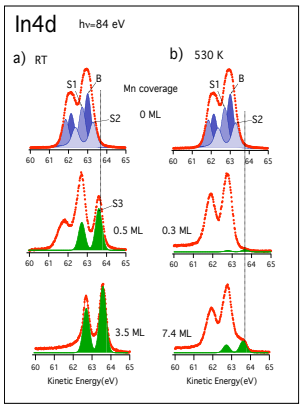
We have studied $In_{1-x}Mn_xAs$ samples prepared by a technique, which consists in manganese deposition on the semiconductor substrate at higher temperature.
The temperature of the substrate was chosen to be high enough to allow the diffusion of Mn atoms, without being so high that segregation of MnAs clusters could occur.

Sample preparation



Core-level spectroscopy (VUV beamline , Elettra)

Fig. 1
In4d core-level photemission spectra of clean InAs(100)(4x2)c(8x2) and Mn/ InAs(100)(4x2)c(8x2) for different Mn coverages. depositions at RT a) and at 530 K b).



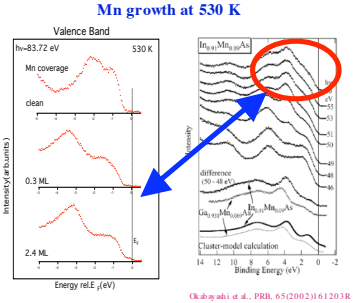
Dramatic changes appear in the core-level spectra after deposition even of the very first thin Mn layers.
A new component lying at higher kinetic energy then the bulk one (+0.75 eV) appears in In4d spectra (S3).
S3 is attributed to free In atoms (i.e. atoms forming In-In bonds, rather than In-As ones) that are the result of the reaction between Mn and As.

Valence band spectroscopy (VUV beamline , Elettra)

VB spectra measured after the deposition at 530 K are comparable to spectra measured on MBE grown $In_{1-x}Mn_xAs$ samples. It is interesting to note that the VB spectrum does not exhibit important changes with increasing Mn amount at 530 K (bottom panel). For 2.4 ML, however, an emission from the Fermi level is observed, which is in agreement with increasing intensity of the S3 component in In4d spectrum (fig.1.b bottom panel).

Mn growth at 530 K

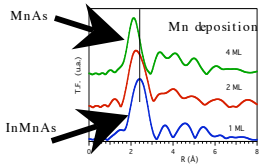
Fig. 2



Okabayashi et al., PRB, 65(2002)161203R

Surface EXAFS (DCI, LURE)

The FTs of the EXAFS spectra show that the distance of the first nearest neighbour decreases with increasing an amount of Mn atoms.
For low Mn deposition (1 ML) manganese atoms replace In atoms in the InAs crystal, (InMnAs DMS is formed), whereas for larger amounts the MnAs compound is preferentially formed.



The Fourier Transform (FT) of the EXAFS oscillations

X-ray Magnetic Circular Dichroism (BACH, ELETTRA)

The amplitude of our dichroic signal is of 17% (Fig.3). The form of the spectra is very similar to the one found for $(Ga_{0.98}Mn_{0.02})As$ by Ohldag and collaborators [1] indicating that Mn is in an atomic like state with a high individual atomic moment.

In fig. 4 we represent the field dependence of the maximum of the dichroic signal of Mn for a sample of 2,7 ML of Mn/InSb. The evolution of the dichroism I with the magnetic field is approximately linear. There is no saturation up to 5 T, indicating that we align only a part of the Mn atoms.

We suggest that one of the origins of this discrepancy between individual and effective moments is an irregular spatial distribution of Mn atoms due to diffusion processes.

[1] H. Ohldag, et al. Appl. Phys. Lett 76, 2928 (2000)

Magnetic moment of Mn/InSb(100)

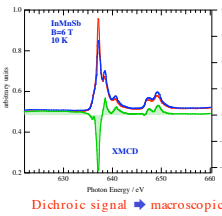


Fig.3. X-ray absorption and XMCD spectra for 0,7 ML of Mn deposited on InSb at the temperature of 530 K.
The spectra were measured at the temperature of 10 K in an applied magnetic field of 6 T.

Dichroic signal ➡ macroscopic magnetic moment per atom ≈ 0.7 μ_B

Ratio L_3/L_2 ➡ atomic magnetic moment > 3 μ_B

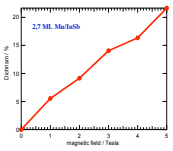
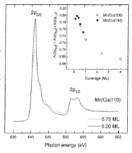


Fig. 4. Field dependence of the maximum of the dichroic signal of Mn for a sample of 2,7 ML of M deposited on InSb at the temperature of 530 K.



Dürr et al., Phys. Rev. B **56**, 8156 (1997).

Conclusions

Small amounts (typically 1 ML) of Mn atoms diluted into InAs(100) (InSb(100)) by simple deposition at high temperature (T=530 K) form $In_{1-x}Mn_xAs$ and $In_{1-x}Mn_xSb$ compounds in which In atoms are substituted by Mn atoms and thus the zinc-blende structure of InAs (InSb) is conserved.

For higher deposition amounts of Mn atoms, MnAs compounds with hexagonal packed structure are formed.

$In_{1-x}Mn_xAs$ and $In_{1-x}Mn_xSb$ present ferromagnetic ordering with a high magnetic moment per Mn atom.

The Mn effective moment determined from the sum rules is found to be about 1 μ_B per atom and the atomic Mn moment is determined to be about 3 μ_B.

We suggest that the technique of Mn deposition at high temperature of the InAs and InSb substrates is suitable for the preparation of the $In_{1-x}Mn_xAs$ $In_{1-x}Mn_xSb$ diluted magnetic semiconductors.