A Comparative Study of Iron Films on II-VI and III-V-Semiconductors

K. Bierleutgeb, H. Sitter, H. Krenn, and H. Seyringer

Institut für Halbleiter- und Festkörperphysik, J. Kepler Universität Linz, 4040 Linz

The incorporation of magnetic layers in semiconductor heterostructures is an increasingly active area of study. Especially the growth of ferromagnetic iron is an attractive field of investigation. A UHV chamber has been attached to an MBE system to study the growth of iron films on GaAs as well as on II-VI-semiconductors. Since interfacial effects are expected to play an important role in thin-film heterostructures resulting in a broad range of magnetic properties depending on film thickness and deposition conditions, we performed a comparative study of iron on III-V and on II-VI semiconductors. The obtained films are characterized by superconducting quantum interference device to determine the magnetic properties.

1. Introduction

The study of transition metal overlayers on semiconductor substrates is an attractive field of investigation. There is great interest in the catalytic, electronic, and magnetic properties of these materials in thin film form. Properties of thin films often differ significantly from those of the bulk due to surface and interface effects, which may dominate the overall behavior of these films.

The motivation for installing a UHV-chamber for iron thin film growth includes the investigation of the effect of magnetic fields onto dilute magnetic semiconductors such as unusual magneto-optic and magneto-transport properties. Besides we plan to grow hybrid ferromagnetic / semiconductor structures offering devices like magnetic memory elements, spin polarized current injection devices etc. [1].

We report about the first steps we have taken: A UHV-chamber, which has been designed to grow ferromagnetic bcc α-iron on the prototype materials GaAs or II-VI semiconductors like ZnSe, was attached to the existing MBE chamber. While GaAs and ZnSe possess a fcc zincblende structure, α-iron is bcc and the lattice parameters differ by a factor very close to two. We expect that at the Fe/GaAs interface interdiffusion will take place leading to the formation of FeAs compounds. The Fe/ZnSe interface is less reactive than the Fe/GaAs interface [2].

2. Experimental

A UHV-chamber for the growth of epitaxial iron films was attached to our existing MBE-system via a UHV tunnel, which also has access to an Auger electron spectrometer. In the MBE-system, which has been described elsewhere [3], we can grow II-VI-compound semiconductors (Zn,Cd)(Se,Te). A reflection high energy electron diffraction (RHEED) and a reflectance difference spectroscopy (RDS) system are installed in the

MBE chamber allowing to make *in situ* investigations in UHV without the effects of oxidation.

3d-transition metals (Fe, Co, Ni, …) have a relatively low vapor pressure and therefore require source temperatures in excess of 1100 °C to achieve deposition rates commonly employed in surface studies [4]. Therefore we chose a rod-fed electron beam source, which allows clean and controlled deposition of high-temperature materials at relatively low rates. With this method the heat load onto the source material is minimized.

Via the UHV tunnel it is possible to transfer the samples from the iron evaporation chamber to the MBE system to perform investigations of the surface structure by RHEED. We plan to attach a spectroscopic ellipsometer directly to the iron-chamber, which will allow us to make in-situ characterization during growth.

Iron films were either deposited directly onto (100) GaAs substrates or on ZnSe epilayers grown previously on GaAs in the MBE system.

Prior to growth the (100) GaAs substrates were heated up to 720 °C and kept at that temperature for a few seconds to remove the oxide till a streaky RHEED-pattern could be observed. When growing a ZnSe epilayer we used a Zn and a Se effusion cell with beam equivalent pressures of $0.2*10^{-8}$ mbar and $0.9*10^{-7}$ mbar respectively. ZnSe was grown in atomic layer epitaxy (ALE) mode yielding a growth rate of 10 Å/min at a substrate temperature of 300 °C. The thickness of the ZnSe epilayer was chosen to be 500 Å, which is below the critical thickness at which dislocations start to form. At that thickness the ZnSe is still pseudomorphic to the GaAs substrate [2].

Then the sample was cooled down to 100 – 150 °C before being transferred to the iron-chamber through the UHV tunnel. There the sample was heated up to 165 °C again. During iron growth the flux monitor current observed was around 2900 nA. This yielded in an growth rate of approximately 9 Å/min.

After growth of iron the sample was transferred back to the MBE-system to perform RHEED measurements. Then the samples were exposed to air and could oxidize.

Figure 1 shows the RHEED patterns taken at different steps of growth: After growing iron directly onto the GaAs substrates (Fig. 1 (a) – (b)) the RHEED-pattern indicates a flat surface although the iron-surface does not approach the flatness of the GaAs substrate. When inserting a ZnSe epilayer (Fig. 1 (a) – (c) – (d)) we see that the ZnSe epilayer heals surface roughness of the GaAs substrate resulting in a more streaky pattern. The RHEED pattern in Fig. 1 (d) was taken along the [110] direction after growth of iron. The iron surface with a ZnSe epilayer even seems to be smoother than the surface of iron directly on GaAs as the RHEED streaks are more pronounced.

From RHEED we see that iron grows in registry with the (001) GaAs / (001) ZnSe surface such that [100] Fe || [100] GaAs / [100] ZnSe. The streaks in the RHEED-pattern of iron have twice the distance than the streaks of GaAs / ZnSe. This factor of 2 in the reciprocal lattice gives a factor of 0.5 for the lattice constant as expected.

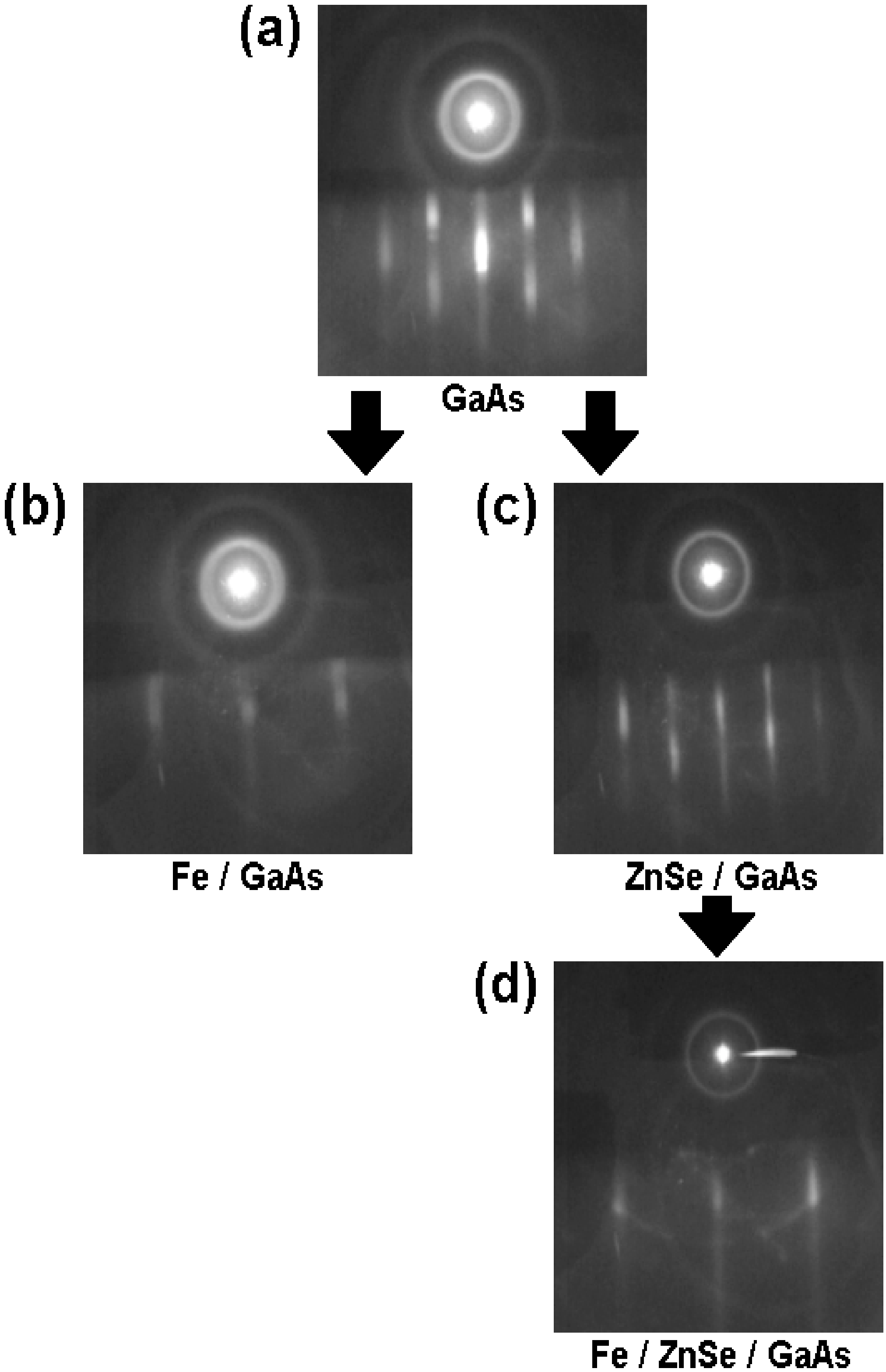

Fig 1: RHEED-patterns taken along the (110)-direction. (a) GaAs after deoxidation, (b) Fe after growth direct on GaAs, (c) ZnSe layers after growth, (d) Fe after growth on ZnSe epilayers.

We took AFM images (topography in contact mode) of the iron surface to study the mode of film growth. From literature we expected a three-dimensional growth mode for iron on GaAs while a predominantly layer-by-layer growth can be expected for iron on ZnSe [5]. While the surface of iron on GaAs is completely island-like, the growth of iron on a ZnSe epilayer is not completely layer-by-layer, but we can see larger smooth regions between remaining islands. As the ZnSe epilayer also was not completely flat, we can interpret the islands in the Fe surface as a reproduction of the ZnSe surface roughness.

Superconducting Quantum Interference Device measurements are currently undertaken. The curves of magnetization versus applied magnetic field show a pronounced rectangular hysteresis indicating a single domain behavior, which proofs the excellent internal structure of the iron films. This was observed for iron films both on GaAs as well as on ZnSe epilayers.

3. Conclusion

A new UHV chamber has been installed to grow iron films on II-VI- and on III-V-semiconductors. The use of electron beam evaporation allows clean deposition at relatively low growth rates and minimizes the heat load onto the source material.

We were successful in growing high-quality epitaxial iron films with an excellent internal structure directly on GaAs and on ZnSe epilayers. Although growth on ZnSe is not completely layer-by-layer-like, we see significant differences in comparison to growth on GaAs both in RHEED-patterns and in AFM-images.

Acknowledgements

This work was supported by the Fonds zur Förderung der Wissenschaftlichen Forschung.

References

[1] G. A. Prinz, “Science and Technology of Nanostructured Magnetic Materials”, *Plenum Press New York*, 1991, p. 41

[2] B. T. Jonker and G. A. Prinz, *J. Appl. Phys.* 69 (1991) 2938

[3] W. Faschinger and H. Sitter, *J. Cryst. Growth* 99 (1990) 566

[4] B. T. Jonker, *J. Vac. Sci. Technol.* A 8 (1990) 3883

[5] B. T. Jonker, G. A. Prinz, and Y. U. Idzerda, *J. Vac. Sci. Technol.* B 9 (1991) 2437