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Metalorganic Vapor Phase Epitaxy of III-Mn-V Thin Films for Spintronics

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1. Introduction

There is continuing interest in the development of ferromagnetic semiconductors for spintronic applications. Of particular note are the group III-Mn-V compounds, especially InMnAs and GaMnAs. The synthesis of films has centered on molecular beam epitaxy (MBE) due to its ability to form a random solid solution at low temperature. Much less is known about the deposition of these compounds by metalorganic vapor phase epitaxy (MOVPE). This is due, in part, to the belief that the higher deposition temperature used in MOVPE would lead to formation of Mn containing precipitates, especially at the concentrations of 2 to 10 per cent required for formation of the ferromagnetic phase.

2. Discussion

Two decades ago we reported on MOVPE of InAsP layers doped with Mn and showed that single phase, p-type epitaxial films could be formed [1]. Subsequently we used this deposition technique to prepare InMnAs alloys with Mn contents ranging from 2 to 15 per cent [2]. We were able to deposit single phase layers as indicated by x-ray diffraction and transmission electron microscopy despite using deposition temperatures 200 degrees higher than that used in molecular beam epitaxy. The magnetic properties of the films were excellent with magnetizations as high as 60 emu/cm³ and a Curie temperature T_c of 330 K. This is in contrast to MBE films where T_c is less typically less than 40 K. While the origin of high T_c films is still under study, detailed TEM analysis did not indicate the presence of hexagonal MnAs precipitates, which is ferromagnetic with a comparable T_c. Subsequent extended x-ray absorption fine structure (EXAFS) analysis did indicate the presence of dimer complexes in the form of Mn-As-Mn where the Mn substitutes for In on a tetrahedral site. [3] Theory also predicts that Mn trimers and tetramers should be stable and

electrically active. They can hybridize with host lattice atoms resulting in p-d exchange and ferromagnetism. Recent magneto-optical Kerr effect measurements on these alloys also indicate the presence of Mn defect complexes. Ferromagnetic InMnAs has now been used in heterojunction devices that show a giant magnetoresistance of up to 1300 per cent at room temperature [4].

Our latest materials studies have centered on other alloy systems deposited by MOVPE including InMnAsP and InMnSb. For InMnSb single phase alloys have been stabilized with Mn concentrations of up to five per cent. Temperature dependent magnetization measurements indicated that T_c is in excess of 400 K. Using a Brillouin function to fit the temperature dependent magnetization data, the extrapolated value of T_c is 590 K. This is in contrast to a T_c of 10 K previously measured for films prepared by MBE. EXAFS studies are underway to determine the structure of the Mn complexes formed in the InMnSb alloys.

3. Conclusions

Metalorganic vapor phase epitaxy is a viable method for obtaining phase pure, epitaxial ferromagnetic semiconductors. Furthermore the technique is suitable for fabrication of heteroepitaxial magnetic semiconductor junctions operating at room temperature.

Acknowledgements

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References

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