Digest of Tech. Papers The 8th Conf. (1976 International) on Solid State Devices, Tokyo

A-0-4
(INVITED)

Growth and Doping Kinetics in Molecular Beam Epitaxy

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Surface kinetic data relating to the growth and doping of thin films of III-V compounds can be obtained using modulated molecular beam techniques. In this method[1] perturbation of an incident flux gives rise to a time varying concentration of adsorbed molecules on the substrate surface, and hence to a time dependent desorption rate, which is measured using an appropriate detector, usually a quadrupole mass spectrometer. By modulating the desorption flux, atomic and molecular species which are leaving the surface directly can be identified and distinguished from background vapour species. In addition, UHV and surface analytical techniques now available permit a detailed assessment of substrate surfaces to be made at any stage of a process.

The application of this approach to the study of growth and doping kinetics in molecular beam epitaxy (MBE) will be the subject of this paper. Attention will be restricted to the growth of GaAs, and doping by Sn, Mg, Mn and Zn, but the general principles have much wider relevance.

There are two growth procedures which may be used for the preparation of autoepitaxial GaAs films by MBE: either beams of Ga and As_4 (derived from an arsenic source) or of Ga and As_2 (from a GaAs source) are directed onto a heated GaAs substrate, where interaction occurs. The chemistry of each of these surface reactions has been investigated in detail, and although there are substantial differences between them, kinetic models can be formulated which are fully consistent with the experimental data from both systems. The primary requirement is that Ga is supplied to the surface, and then with an incident As_4 beam there is a pairwise dissociation - recombination reaction on adjacent Ga lattice sites, so the sticking coefficient of As_4 is always $\lesssim 0.5$ [2]. With As_2 incident, however, all processes are first order, and the sticking coefficient can reach unity. Above $\sim$ 600K, loss of As_2 from the substrate leads to a temperature dependent Ga adatom population, while below $\sim$ 450K there is no dissociative chemisorption of either As_2 or As_4.

The development of a model for doping kinetics commences with an investigation of the fundamental adsorption - desorption behaviour of the dopant elements on GaAs substrates, both with and without co-incident fluxes of Ga and As_4 (or As_2). From measurements of the sticking coefficient as a function of substrate temperature and incident fluxes, it is possible to determine what fraction of the dopant atoms which arrive at the surface will be incorporated in a layer, and results will be presented for Sn, Mg, Zn and Mn. Analogous measurements

enable the manner in which the dopant flux affects the growth kinetics to be determined, but information on the extent of electrical activity cannot be obtained in this way. Conventional and differential resistivity and Hall effect measurements, together with capacitance-voltage carrier profile determinations have therefore been made on grown films, with emphasis on those doped with Sn. It appears that at high growth temperatures (> 820K) there is some segregation of free carriers towards the surface, but this does not occur at lower growth temperatures. A mechanism for the incorporation of tin has been proposed that is closely similar to that previously derived for VPE growth,[3], in which the concept of surface band bending is used to explain the amphoteric behaviour of Sn.

References

1. C.T. Foxon, M.R. Boudry and B.A. Joyce, Surface Science 44 (1974) 69.

2. C.T. Foxon and B.A. Joyce, Surface Science 50 (1975) 434.

3. C.M. Wolfe and G.E. Stillman, Solid State Comm. 12 (1973) 283.