On the Carrier Profiling of GaAsSb/GaAs Heterostructures

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Carrier profiles of MBE grown Ga(As,Sb)/GaAs heterostructures were studied. In low Sb content samples of Ga(As,Sb)/GaAs grown by MBE the experimentally measured carrier profiles exhibit double dips in concentration, whereas a single large dip is obtained for higher Sb content with larger lattice-mismatched samples. The capacitance voltage (C-V) carrier profile of a Schottky barrier n-N heterojunction of Au/n-GaAsSb/N-GaAs has been modeled and double dips occur when nonuniform doping is present which may explain the experimentally observed double dips in a GaAs$_{0.95}$Sb$_{0.05}$/GaAs specimen. For large lattice mismatch and therefore large heterointerface charge density in the model, the accumulation peak due to $\Delta E_c$ is shown to be overwhelmed by a pronounced single dip as observed in higher Sb content samples such as GaAs$_{0.91}$Sb$_{0.09}$/GaAs and GaAs/GaAs$_{0.9}$Sb$_{0.1}$. 

Key words: Heterostructures, GaAsSb, GaAs, Schottky barrier, molecular beam epitaxy.

INTRODUCTION

Band discontinuities and interface charge densities are important parameters for heterostructure device applications. A bipolar heterojunction transistor (BJT) with a 0.24eV conduction-band step can in principle increase the ratio of the electron current injected into the base to the hole current injected into the emitter by a factor of 8000. C-V carrier profiling in n-N structures with a Schottky barrier junction is widely used to investigate band discontinuities and interface charges in isotype heterojunctions. With uniform doping densities on both sides of a heterojunction, the carrier profile normally consists of an accumulation peak and a depletion dip around the heterointerface. The band discontinuity and interface charge can in principle be determined from the peak and dip. Double peaks, however, have been reported with the extra one assigned to emptying out of electrons trapped at the heterointerface region and depending on the trap energy, density and the temperature of measurement. The band discontinuity determined from such data, however, is not reliable when the doping concentration is not uniform near either side of the interface region. In a recent study of (Ga,In)P/GaAs band discontinuities by C-V profiling, difficulties in fitting simulated C-V carrier profiles with experimental results were attributed to possible nonuniform doping or graded concentration profiles. The doping profile during MBE heterostructure growth, especially for a lattice mismatched system, may not be uniform even though the dopant flux is kept constant possibly because of the large native defect concentration in the first few hundred angstrom layer near the interface or due to effects such as strains, surface segregation of dopants or different incorporation coefficients for different materials. C-V carrier profiles for lattice mismatched heterostructures can not be used to accurately determine the band discontinuities because of the lack of information about the non-two-dimensional interface trap distributions. Such carrier profiles, however, do contain interesting information about interface charge and doping uniformity across heterointerface as will be revealed by the present study.

EXPERIMENT

Samples of GaAs/(GaAs,Sb)/GaAs and Ga(As,Sb)/GaAs have been grown on Si-doped n-type (100) GaAs substrates ($2 \times 10^{18}$ cm$^{-3}$) by molecular beam epitaxy (MBE) with substrate temperatures at 495 or 520 °C for Ga(As,Sb) growth. The Si dopant flux was kept constant throughout the growth. Carrier concentration profiles were measured by C-V measurements of an electrolytic Schottky barrier using a Polaron semiconductor profile plotter model NGA4100. Au Schottky barrier C-V measurements were also made and showed qualitatively similar concentration profiles.

The experimental carrier concentration profiles for N-GaAs/n-GaAs$_{0.9}$Sb$_{0.1}$ and for n-GaAs$_{0.91}$Sb$_{0.09}$/N-GaAs are shown in Fig. 1(a,b). Both samples exhibit a single dip rather than a peak and a dip. Notice that an apparent nonuniform profile extends either side of the interface in Fig. 1(b) although the Si dopant flux was maintained constant. As a result of the high Sb content a large lattice mismatch and therefore a large interface charge density is expected and is indeed observed when one compares the magnitudes of the dips in the carrier profiles in Fig. 1(a,b) and in Fig. 2 for a low Sb content sample, n-GaAs$_{0.95}$Sb$_{0.05}$/N-GaAs. For this low Sb content sample, one peak and two dips are observed which relate to the nonuniform doping profile in MBE heterostructure growth. The nonuniform region in this carrier profile is about 400Å wide.

No reliable study has been reported for the con-
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Fig. 1 — Experimental C-V profiles of N-GaAs/n-GaAs$_{0.9}$Sb$_{0.1}$ (Fig. 1(a)) and of n-GaAs$_{0.9}$Sb$_{0.1}$/N-GaAs (Fig. 1(b)). The large single dips in Fig. 1(a-b) indicate that the interface charge is negative and overwhelms the band gap discontinuity accumulation and depletion effect.

Fig. 2 — Experimental C-V profile of n-GaAs$_{0.9}$Sb$_{0.1}$/N-GaAs. Double dips are consistent with a doping density dip near the interface as suggested by the simulation results.

GaAs$_{1-x}$Sb, suggests that the barrier height is not a linear function of Sb content. Following Tersoff's model and the Schottky barrier height data, $\Delta E_c$ is considered likely to be about 0.14eV for Ga(As,Sb) on GaAs with 8 to 10% Sb content. Such $\Delta E_c$ values are needed in modeling the heterostructures. To understand qualitatively the underlying reasons for the change in carrier profile from double dips to a single dip as the Sb content is increased, numerical modeling of C-V carrier profiles have been made and are presented in the following section.

MODELING OF C-V CARRIER PROFILES OF Au/n-Ga(As,Sb)/N-GaAs

In modeling the carrier profile, Poisson's equation is discretized and solved numerically for the conduction band energy $E_c(x)$ with respect to Fermi level with suitable boundary conditions at the metal-semiconductor and the heterojunction interfaces. Assuming a sheet interface charge density $\sigma_i$ cm$^{-2}$ at the heterointerface and neglecting the reverse leakage current, the minority carrier effects in the Au Schottky diode, and any quantum effects in the possible electron accumulation region, Poisson's equation is

$$\frac{d^2}{dx^2} \left( E_c - E_{F} \right) = \frac{q^2 (n - N_D^*)}{kT}$$

(1)

and the boundary conditions are

$$E_c - E_F(x=0) = q V_{app} + \Phi_B$$

(2)

$$\epsilon_1 \frac{dE_c}{dx} \bigg|_{x^-} - q \sigma_i = \epsilon_2 \frac{dE_c}{dx} \bigg|_{x^+}$$

(3)