CRYSTAL
GROWTH
& DESIGN
2008
VOL. 8, NO. 2
704–706

Raman Studies of Carbon-Doped GaAs Layers Grown by a Metallic-Arsenic-Based Metalorganic Chemical Vapor Deposition System

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Received October 24, 2006; Revised Manuscript Received October 26, 2007

ABSTRACT: High-quality *p* type GaAs epilayers were grown by metalorganic chemical vapor deposition using trimethylgallium and metallic arsenic as gallium and arsenic sources, respectively. The range of hole concentration analyzed goes from 10^{17} to 10^{19} cm^{-3}, as measured by the Hall−van der Pauw method. For controlling the hole concentration, a mixture of hydrogen and nitrogen was used as the carrier gas. Raman scattering spectra show transversal optical mode at 270 cm^{-1} for low-doped samples and a longitudinal optical (LO) mode at 292 cm^{-1} produced by phonon-hole-plasmon coupling for high-doped samples. The relative intensity of the LO mode for the doped samples correlates very well with the hole concentration. As the carrier concentration increases, the LO phonon-plasmon-coupled mode increases. The corresponding decrease of the intensity of the LO mode is interpreted as the decrease in the depletion layer as the carrier concentration increases.

1. Introduction

Heavily doped semiconductor layers are necessary to improve the performance of electronic devices. Metalorganic chemical vapor deposition (MOCVD) is a useful technique for producing heavily carbon-doped GaAs epilayers. GaAs carbon doping is preferred because of its small diffusivity[1] and the high attainable concentration levels.[2] These features are desirable in semiconductor devices such as high-gain, high-frequency heterojunction bipolar transistors (HBTs). The required diffusivity of the dopant in the transistor base makes carbon the best choice in HBTs, because the base width needs to be narrow.[3]

Raman spectroscopy can be used to study both local structure and long-range crystalline order in epilayers. In this work, Raman scattering was used as a diagnostic tool for determining the relation between free carrier concentration and optical parameters of GaAs epilayers. In polar semiconductors such as the III-V group, the longitudinal optical (LO) phonons strongly interact with the carrier plasma.[4] The interaction produces the LO-phonon-plasmon-coupled mode (LOPC). Thus, it is possible to use the relative intensities between the signals of undoped and doped samples arising from the depletion layer and also the frequencies and widths of the mixed LOPC arising from the surface charge region to confirm the free carrier concentration of the GaAs epilayers.

In *n* type GaAs epilayers, the phonon-plasmon-coupled modes have been investigated and the behavior of the LOPC modes denoted as L_+ and L_- is well-known.[5] The frequencies and intensities of the LOPC modes change as a function of the electron concentration, and thus, they serve as a way to measure the carrier concentration. As the electron concentration increases, the L_+ mode weakens and shifts from the LO mode to the higher frequency side, while the L_- mode strengthens and approaches the TO mode from the lower frequency side.

In *p* type GaAs, the high-energy plasmon-like LOPC mode is weak, resulting in a single phonon-like mode near the transversal optical (TO) phonons[6] for $p > 10^{18}$ cm^{-3}. This behavior has been explained by using higher hole effective masses, lower hole mobility, and higher plasmon damping constants.[7] Another effect of the greatest relevance for extremely high carrier concentration is the breakdown of selection rules for the wavevector $k = 0$, due to the strong scattering of holes by ionized impurities in the Raman process.[8]

Holes near the valence band edge control the amplitude of the plasma oscillations. However, the structure of the valence band edge of GaAs is rich, exhibiting heavy and light hole states, with their respective effective masses, and the nearby split-off hole band. Even though only a fraction of the carriers are light holes,[9] their influence on the optical and electrical properties of the plasma cannot be ignored due to their comparatively large plasmon energy and higher mobility. It is necessary to use at least two hole masses in describing the plasma.[7] Light scattering studies of the LOPC modes in *p* type GaAs have been carried out for zinc[7,8] and beryllium doping (for gallium substitution)[9,10] or germanium,[11] silicon,[12] and carbon (for arsenic substitution).[13]

2. Experimental Section

The details of the MOCVD growth system were published elsewhere.[14] Briefly, arsenic vapor from a solid arsenic source was transported until the growth zone, and trimethylgallium (TMG) was used as the gallium precursor. To prevent precracking of the Ga precursor, the dosing line of the metalorganic compound was maintained cold. The TMG flow was fixed at 0.8 μmol/min. The arsenic flow was fixed at 15.0 μmol/min. Undoped GaAs epilayers were grown using palladium-purified hydrogen as the carrier gas. The growth temperature was fixed at 680 °C. At this temperature, undoped GaAs samples were produced with *n* type conductivity. The film thickness was fixed at 2 μm. The carbon doping was performed by replacing the carrier gas with a hydrogen−nitrogen mixture.[14] For controlling the carbon doping, the N_2/H_2 mixture ratio was varied from 0 to 1.0. Previous to the growth of the GaAs epitaxial layers in all of the cases, a high-quality GaAs buffer layer was grown at 650 °C.

Raman scattering experiments were performed at room temperature using the 5145 Å line of an Ar-ion laser at normal incidence for excitation. The light was introduced into a microscope having a 50× (numerical aperture 0.9) microscope objective. The measurements were made with a laser power of 20 mW. Care was taken not to heat the

10.1021/cg0607452 CCC: $40.75