Dilute Nitride GaAsSbN Grown by Gas-Source Molecular Beam Epitaxy

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In this paper, we report the gas-source molecular-beam epitaxial (GSMBE) growth of dilute nitride GaAsSbN bulk layers lattice-matched to GaAs substrates, the energy gap of the dilute nitride, the effect of thermal treatment on the optical properties of the alloy and the application to long wavelength detectors.

The incorporation behaviors of As, Sb, and N atoms in GaAsSbN have been studied. The source of As was As$_2$ beam by cracking AsH$_3$ precursor in a gas cracking cell. Sb source was a mixed monomer and dimer beam from a cracking cell and N radical source was from a RF plasma cell. We found that N atom is more reactive and more competitive than Sb atom at the growth temperature ranging from 420 to 450°C. The increment in Sb beam flux hardly changes the N composition. However, the increment in N flux retards the incorporation of Sb. In addition, the increment in As$_2$ flux makes the Sb and N compositions decrease at the same rate. Based on these behaviors, we have successfully grown GaAsSbN epilayers lattice-matched to GaAs substrates with lattice mismatch less than 2×10^{-3}. The energy gap of the as-grown GaAsSbN at room temperature is as low as 0.803 eV. Negative deviation from Vegard’s law [1] in lattice constant is observed in these layers.

The composition dependency of the energy gap of GaAsSbN dilute nitride alloys lattice-matched to GaAs has been studied. The compositions of the alloys are determined by electron probe microanalysis. The nitrogen mole fraction in these samples is from 0 to 3%. We found that the energy gap reduction induced by the incorporation of nitrogen is independent of the Sb composition. The behavior can be successfully explained by using a “double” band anti-crossing model [2-4]. In this model, the localized state of N atomic level is at 0.23 eV above the bottom of GaAs conduction band, while that of Sb atomic level is below the maximum of GaAs valence band by 1.0 eV. The model accounts for two interactions, a interaction between N atomic level and GaAs conduction band with a hybridization parameter of $C_N = 2.7$ eV [4] and a interaction between Sb atomic level and GaAs valence band with a hybridization parameter of $C_{Sb} = 1.05$ eV [3]. For the valence band anti-crossing model, we calculated the $k=0$ case of a k-p formalism developed for GaAsSb [3]. The calculated results fit quite well with our experimental results, which indicates that the conduction band and valence band of dilute nitride GaAsSbN can be independently manipulated by incorporating nitrogen and antimony in respectively.

Though the incorporation of N can reduce the conduction band energy and contract the lattice constant, it deteriorates the electrical and optical properties of the alloy. Thermal treatment is a commonly used method to improve the quality of the dilute nitrides. In dilute nitride InGaAsN, strong blue shift resulting from thermal annealing is almost inevitable [5-6], which has been attributed to the chemical change in the atomic structure. Thermal annealing tends to replace the as-grown Ga-N bonds with In-N bonds, leading to the strong blue shift in the energy gap. Since GaAsSbN has only one group III element, the rearrangement of the first-nearest-neighboring atoms to N atoms is impossible. However, the observations and explanations on the annealing-induced blue shift in dilute nitrides with single group III element, including GaAsN and GaAsSbN, are widely divided in literatures. Some works demonstrated negligible blue shift in their GaAsN [7] and GaAsSbN samples [8]. Others observed blue shifts and ascribed them to the reduction of tail state density [9], the improvement in the homogeneity [9], or the out-diffusion of nitrogen atoms [10]. In this work, we systematically studied the effect of annealing temperature on the blue-shift in GaAsSbN epilayers. Below 750°C, only negligible blue-shift was observed. Strong blue shift starts when the annealing temperature is ≥750°C. We compared the absorption, including the portion that below the energy gap, of GaAsSbN, GaAsSb and GaAsN epilayers. GaAsSb shows virtually no blue shift in absorption gap, while the other two alloys start to blue shift at similar temperature. It suggests that the blue shift is relevant to nitrogen. We also found that thermal treatment can improve the homogeneity in composition by investigating the below energy gap absorption. However, the improvement on the homogeneity in composition cannot explain the blue shift quantitatively. We studied the GaN local vibration mode absorption behaviors of GaAsSbN samples undergone different thermal treatments. The intensity of the vibration mode increases concomitantly with the blue shift in absorption gap, indicating that the blue shift could
result from not only the improvement on the composition homogeneity but also the chemical change of the second-nearest-neighboring atoms to the N atoms.

Effect of thermal annealing on the electrical properties of the GaAsSbN has been investigated. Increment in net acceptor concentration was observed in annealed GaAsSbN. This effect leads the conduction type of the undoped GaAsSbN and Si-doped GaAsSbN to convert to p type, which results in the moving of p-n junction in the device containing undoped GaAsSbN and Si-doped GaAsSbN. A heterojunction n-GaAs/i-GaAsSbN/p-GaAsSbN structure which has better immunity from the annealing induced type conversion was proposed. The structure has been fabricated and compared with homojunction p-i-n GaAsSbN device. Both devices showed a cut-off wavelength of 1.5 μm. However the heterojunction has a better quantum efficiency of 0.13 at 1.1 μm.

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