English
Research Express@NCKU Volume 1 Issue 10 - October 26, 2007
[http://research.ncku.edu.tw/re/articles/e/20071026/3.html]

A Novel Dilute Antimony Channel In0.2Ga0.8AsSb/GaAs HEMT

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published in IEEE Electron Device Letters, 28, 96 (February 2007)

Dilute nitride quaternary compounds InxGa1-xAs1-yNy have been intensively studied in the past few years. The InGaAsN heterostructures possess the advantages of improving the electron confinement at high temperatures due to their high conduction-band discontinuity barriers. InxGa1-xAs1-yNy, which may be strained or lattice-matched to the GaAs substrate, has been applied to the 1.3-μm laser diodes. Besides, InGaAsN-based heterojunction bipolar transistors (HBTs) have also demonstrated significant reductions in the turn-on voltages as compared to the AlGaAs-based HBTs. The incorporation of N atoms can reduce the energy bandgap, yet usually resulting in poor crystal qualities. Consequently, the N incorporation would seriously degrade the carrier transport for the electronic device applications. In order to improve the optical property, annealing processes were attempted to remove the defects or the non-radiative impurities. Recently, some efforts have been devoted to using Sb atoms as surfactants in the GaAs/InGaAsNSb QW laser to improve the crystal quality and to suppress the three-dimensional (3D) growth. The advantages of incorporating Sb atoms into the optoelectronic devices can not only improve the threshold current densities but also effectively reduce the energy bandgap and red-shift the light emission. In this paper, for the first time, a high electron mobility transistor using the dilute antimony In0.2Ga0.8AsSb channel grown by molecular beam epitaxy system to improve the interfacial quality, carrier transport properties, and the channel confinement capability at the same time. Significantly enhanced device characteristics have been successfully achieved for the proposed InGaAsSb/GaAs HEMT, including the improved carrier mobility, drain saturation current density, extrinsic transconductance, gate-voltage swing, and high-frequency characteristics. This proposed new device is very important for application in high frequency, low noise, and wide operation voltage region.

In this study, the epitaxial structure consists of a 0.4-μm GaAs buffer layer on a (100)-oriented semi-insulating GaAs substrate, sequentially followed by a 9.5-nm In0.2Ga0.8AsSb channel, a 4-nm undoped GaAs spacer layer, a 20-nm Si-doped (5×10^{18} cm^{-3}) GaAs carrier supply layer, a 15-nm undoped GaAs Schottky layer, and finally a 20-nm Si-doped (7×10^{18} cm^{-3}) GaAs cap layer. An identical InGaAs/GaAs HEMT structure, except without incorporating the Sb atoms into the InGaAs channel, was also grown to provide direct comparison.

Hall measurements were carried out on the proposed InGaAsSb/GaAs HEMT and the conventional InGaAs/GaAs HEMT samples to characterize the two-dimensional electron gas (2DEG) concentration (n2DEG) and the electron mobility (μn) under a magnetic field of 5000 G. The values of •n and the corresponding n2DEG were 2951 (2340) cm^2/V-s and 3.1 (3) x 10^{12} cm^{-2} for the InGaAsSb (InGaAs)/GaAs HEMT at 300 K, respectively. Almost 26 % improvement on the electron mobility with similar 2DEG concentrations has been observed and verified the enhanced transport property by the Sb incorporation.

In the inset of figure 1 shows the secondary ion mass spectrometry (SIMS) intensity as a function of the junction depth of the InGaAsSb/GaAs HEMT. The InGaAsSb channel is inserted about 59 nm below the wafer surface. The Ga and As ions were both maintained with stable amounts during the sample growth, but both the In and Sb ion intensities were increased to their maximums at about 60 nm deep. The SIMS profiles demonstrated the successful incorporation of the Sb atoms within the channel growth. The Sb atoms reacted like surfactants to be slightly incorporated into the InGaAs film to improve the crystalline quality.

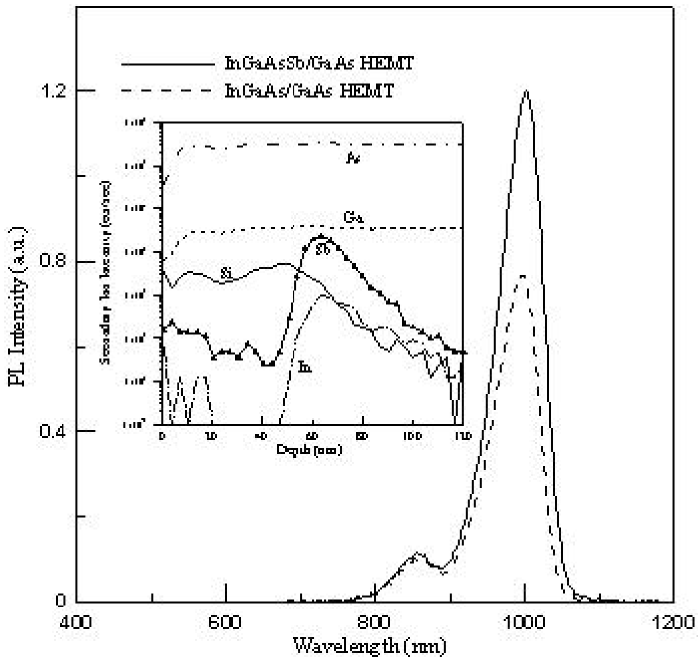

Fig. 1 Room-temperature PL spectra for the InGaAsSb/GaAs and InGaAs/GaAs HEMTs, respectively. The inset shows SIMS measurement profiles for the InGaAsSb/GaAs HEMT.

Figure 1 shows the room-temperature PL spectra for the InGaAsSb/GaAs and InGaAs/GaAs HEMTs, respectively. The PL peak intensity of the InGaAsSb/GaAs HEMT increases about 1.56 times as compared to InGaAs/GaAs HEMT. The emission wavelength is shifted from 0.993 •m to 1.002 •m due to the decreased energy bandgap by the incorporation of Sb atoms. Both the PL intensity and the full width half maximum (FWHM) clearly indicate the improved interfacial quality by adding the surfactant-like Sb atoms in the InGaAs channel. The PL characterization has shown consistent verification with the Hall measurement results, as discussed before.

Figures 2(a) and 2(b) show the TEM pictures for the InGaAs/GaAs and InGaAsSb/GaAs HEMTs, respectively. The InGaAsSb/GaAs interfaces within both the spacer/channel and channel/buffer heterostructures are observed to be more flat and uniform than in the InGaAs/GaAs sample. The TEM photos also clearly demonstrate the improved crystal quality after the incorporation of Sb atoms.

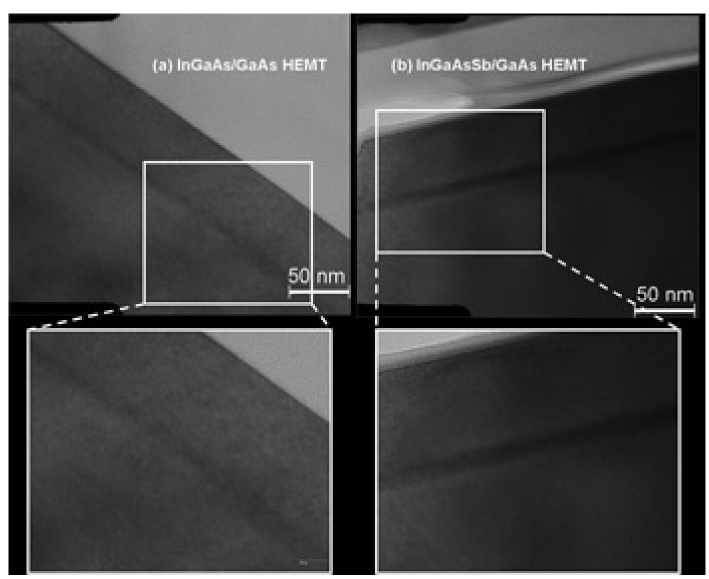

Fig 2. TEM pictures of (a) the InGaAs/GaAs and (b) InGaAsSb/GaAs HEMTs, respectively.

Figure 3(a) shows the typical current-voltage characteristics of the InGaAsSb/GaAs HEMT and the conventional InGaAs/GaAs HEMT at 300 K, respectively. The drain-source saturation current densities (IDSS), defined at VGS = 0 V, are 208 and 171 mA/mm for the InGaAsSb/GaAs HEMT and the conventional InGaAs/GaAs HEMT, respectively. With comparable 2DEG concentrations as observed from the Hall measurement, the enhanced current drive capability of the present device is mainly attributed to the improved transport properties and the interfacial quality by adding the Sb atoms within the InGaAs QW channel.

Figure 3(b) indicates the gm, max and IDSS characteristics versus the applied gate-source bias for the studied InGaAsSb/GaAs and the conventional InGaAs/GaAs HEMTs at 300 K, respectively, with VDS = 3 V. The values of the gm, max and the drain-source current density (IDS) measured at VGS = 2 V, are 227 (181) mS/mm and 473 (421) mA/mm at 300 K for the studied HEMT with (without) adding the Sb atoms into the InGaAs channel, respectively. Significant improvement of about 25 % in gm value has been successfully achieved by employing the dilute antimony channel.

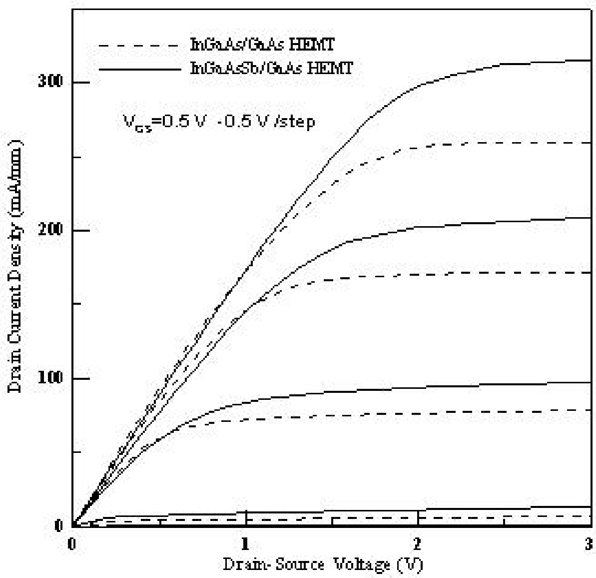

Fig 3(a) Room-temperature current-voltage characteristics for the InGaAsSb/GaAs HEMT and the InGaAs/GaAs HEMT, respectively.

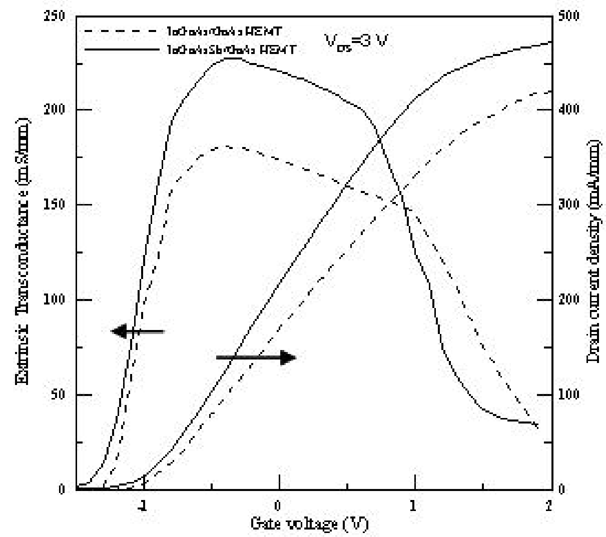

Fig 3(b) IDSS and gm, max characteristics versus VGS at 300 K, for the InGaAsSb/GaAs HEMT and the InGaAs/GaAs HEMT, respectively.

In summary, a novel dilute antimony channel In0.2Ga0.8AsSb/GaAs HEMT grown on a GaAs substrate has been successfully investigated for the first time. Introducing the Sb atoms into the InGaAs channel to serve as surfactants can effectively improve the crystalline quality of the InGaAsSb/GaAs heterointerface. In addition, the decreased energy bandgap of the dilute antimony channel can significantly improve the carrier transport properties and the channel confinement capability. Various characterization techniques, including the SIMS spectrometry, the PL spectra, the Hall measurement, and the TEM photography have been performed to verify the improvement. Consequently, superior device performances of high linearity, high extrinsic transconductance, and high current drive capability of the proposed InGaAsSb/GaAs HEMT have been successfully achieved in this work.