Impact Ionization Coefficients of $Al_xGa_{1-x}AsSb$ (x=0 – 1) Lattice Matched to InP Substrates

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Abstract

Impact ionization is a crucial process in the physics of semiconductors that influences the operation and performance of various semiconductor devices. It is utilized in avalanche photodiodes (APDs) to increase signal-to-noise ratio, but it can also lead to avalanche breakdown in electronic devices. To ensure reliable device operation, it is vital to determine the impact ionization coefficients of electrons and holes (α and β), respectively. In this study, we present the α and β for a range of $Al_xGa_{1-x}AsSb$ compositions, covering x from 0 to 1, as determined through measurements of avalanche multiplication. Additionally, we explore the relationship between the impact ionization coefficients and the bandgap (E_g) change (Γ and X points) along with the indirect-to-direct transition. This is because the impact ionization process is influenced by the material's band structure and the E_g.

Four PIN $Al_xGa_{1-x}AsSb$ APDs with x of 0, 0.5, 0.65 and 0.85 were grown on InP using the RIBER Compact 21DZ molecular beam epitaxy, and standard photolithography with a citric-based wet-etch technique was used to fabricate devices for electrical characterizations. The measured photocurrent spectra of the four APDs are presented in Fig. 1 (a), which illustrates that the cut-off tail moves toward lower energy as the x gradually decreases. To investigate the behavior of the E_g with various Al compositions, the $E_{g,\Gamma}$ and $E_{g,X}$ were extracted, as shown in Fig. 1 (b), and compared with the theoretical change in E_g proposed by Adachi [1]. The discrepancy of E_g between the theory and experiment may come from the alloy disorder that can induce lower E_g than expected in the theoretical calculation. The result suggests that the cross-over should happen around x=0.5 which is similar value predicted by Adachi [1].

The α and β for $Al_xGa_{1-x}AsSb$ with x=0, 0.85 [2], and 1 [3] were plotted as a function of inverse electric field as shown in Fig. 2 (a). Fig. 2 (b) illustrates the α and β for $Al_xGa_{1-x}AsSb$ with x=0, 0.85, and 1 as a function of x at 290 kV/cm. The α remains fairly constant until x=0.85, where it jumps up at x=0, while the β gradually increases as the x decreases from 1 to 0. This suggests that the α can change abruptly at a critical x point, and a similar point may exist for the rate of change in the β, as seen in other material systems such as AlGaInP and AlGaAs on GaAs [4]. To gain more insight, we will explore the behavior of E_g and α and β for additional x=0, 0.2, 0.4, 0.45, 0.50, 0.55, 0.65, 0.75, 0.85, and 1 in $Al_xGa_{1-x}AsSb$. Knowing these coefficients and E_g parameters will allow engineers and scientists to design and optimize the performance of optoelectronic and electronic devices.

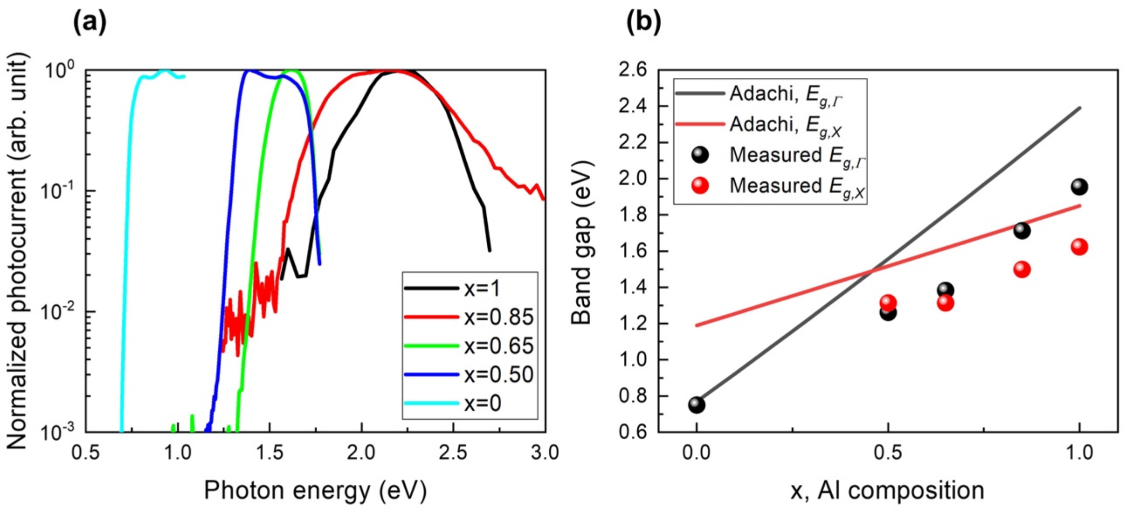

Figure 1 (a) The photocurrent spectra of $Al_xGa_{1-x}AsSb$ (x=0, 0.5, 0.65, 0.85, and 1) and (b) their band gap change as a function of Al composition. The measured bandgaps were compared with the ones theoretically calculated by Adachi.

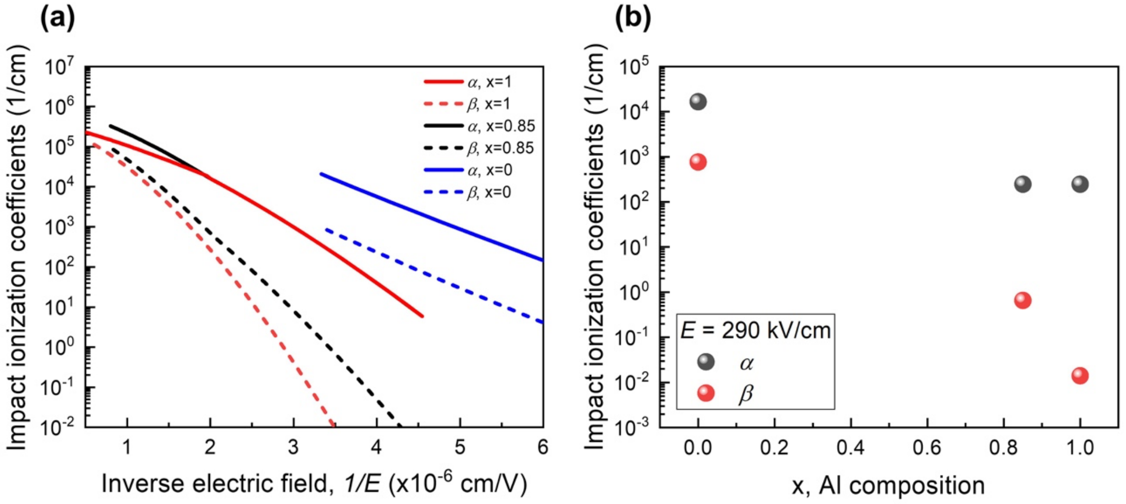

Figure 2 (a) Impact ionization coefficients (α and β) of $Al_xGa_{1-x}AsSb$ (x=0, 0.85, and 1) as a function of inverse electric field. (b) The α and β values extracted at 290 kV/cm as a function of Al composition.

References

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