Relationship between defect density and photoreflectance spectroscopy for $InAs_xP_{1-x}$ metamorphic buffer layer

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In recent decades, the $InAs_xP_{1-x}$ metamorphic buffer layer has been applied in advancing infrared photodetectors, chemical gas sensors, and optical communication devices.[1] To improve the devices performance utilizing metamorphic buffer layer, it is crucial to reduce defect density by growing with graded composition ratios. Therefore, we prepared three samples with different $InAs_xP_{1-x}$ (x=0.7, 0.55, 0.5) compositions to examine the differences in defect density based on composition. Afterward, we investigated how these density differences impacted the PR results, exploring the potential of using photoreflectance (PR) measurements to infer defect densities. First, to determine the dislocation density of each sample, X-ray diffraction (XRD) measurements were conducted, resulting in values of 1.32 $\times10^7$, 5.37 $\times10^6$, and 1.12 $\times10^7$ for the x=0.7, 0.55, and 0.5 samples, respectively, confirming that the x=0.55 sample had the lowest defect density [2]. Following that, the internal electric field (F) was calculated from the Franz-Keldysh oscillation (FKO) signals obtained through the PR signal. The calculated F at the main peaks were 162, 84, and 160 *kV/cm* for the x=0.7, 0.55, and 0.5 samples, respectively. For the x=0.55 sample, the F was approximately 80 *kV/cm* lower. While this result could be attributed to differences in the built-in potential caused by composition variations, the dramatic difference is not observed in the x=0.7 and x=0.5 samples. Therefore, the 80 *kV/cm* difference cannot be fully explained by composition-related built-in potential alone. In General, lower defect density in a semiconductor reduces the number of photo-generated carriers trapped by defect states, enhancing the field screening effect and resulting in a lower calculated F, as indicated by the FKO signal. Additionally, we performed PR measurement as a function of modulation frequency to determine the time constant to verify the process of photogenerated carriers being trapped at defect states. The results showed that the x=0.7, 0.55, and 0.5 samples exhibited time constants of 54.4, 43.9, and 51.5 us, respectively, with the x=0.55 sample having the lowest time constant. These results are due to the lower defect density in the x=0.55 sample, which reducing the probability of photo-generated carriers being trapped at defect states during transport.

[1] S.Park, Adv.Funct.Mater, 240635(2024)
[2] T.T.Nguyen, JKPS, 78(2021)

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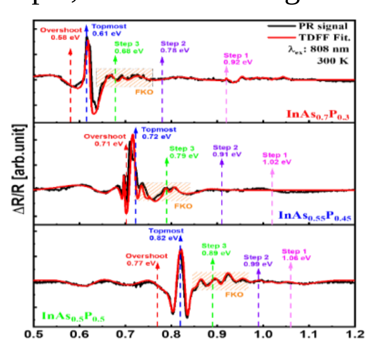

Figure 1. PR spectrum of $InAs_{0.7}P_{.3}$ (x=0.7), $InAs_{0.55}P_{0.45}$ (x=0.55), and $InAs_{0.5}P_{0.5}$ (x=0.5) samples and third-derivative form function (TDFF) results at 300 K

Suplementary information:

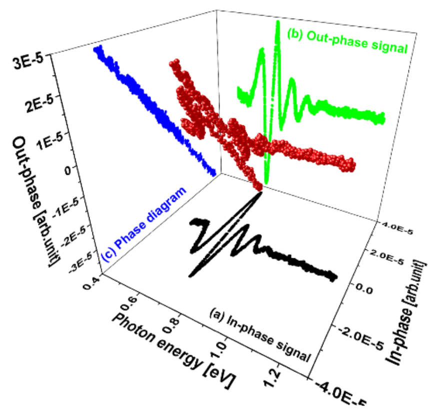

Figure 2. The 3D spectrum of the original photoreflectance signal includes various components such as the (a) In-phase part, (b) Out-phase part, and (c) the phase diagram, providing a comprehensive representation of the signal's characteristics.

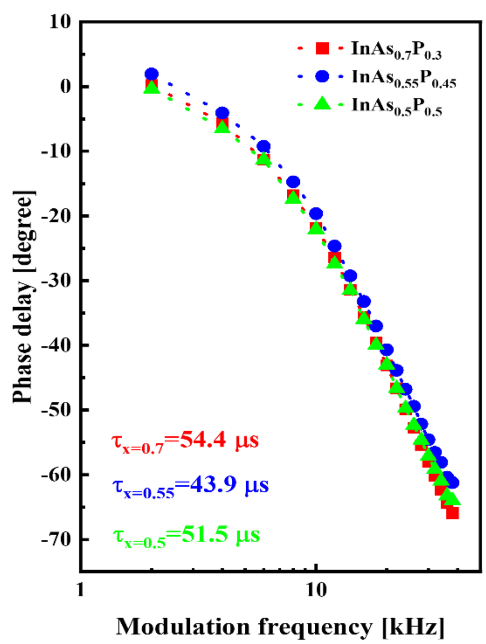

Figure 3. Phase delay results and time constant values of $InAs_{0.7}P_{0.3}$ (x=0.7), $InAs_{0.55}P_{0.45}$ (x=0.55), and $InAs_{0.5}P_{0.5}$ (x=0.5) as function of modulation frequency dependence PR measurement