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Determination of free carrier concentration of polar semiconductors using LOPC modes: an example of InP

Free carrier concentration is one of the important properties of semiconductor devices/materials that may directly affect the performance of several applications in microelectronic and optoelectronic fields such as photodetector, lasers and light-emitting diodes [1]. This property therefore needs to be precisely controlled and measured. Conventional techniques (Hall Effect measurements and C-V characterization) can provide accurate results but usually require a time-consuming and/or destructive sample preparation. In polar semiconductors such as GaN, GaAs, InP, SiC, etc., the coupling between the longitudinal-optical phonon mode (LO) and the collective oscillations of the free carrier systems (plasmons) results in the so-called LO phonon-plasmon coupled modes (LOPC) [2-4]. This spectral feature, which strongly depends on the free carrier concentration, makes Raman spectroscopy an alternative nondestructive and contactless technique for rapid determination of doping concentration and can be used upon process validation and/ormass production. It is to note that, depending on the nature of the material as well as the doping type (n- or p-type), the evolution of LOPC modes vary differently as varying free carrier concentration. The LOPC consist of two branches: L^- and L^+ at low and high frequency, respectively. In general, the free carrier concentration can be deduced from L^+ peak position by fitting Raman spectral data to theoretical mathematic equations [2-4]. However, the doping concentration measured by different theoretical models existing in literature (and associated adjustable parameters) may present a significant variation (up to > 30%) [2]. Thus, establishing a calibration curve dedicated for an interesting concentration range is still needed to ensure the highest accuracy of quantitative measurement. The simplest way is correlating directly the spectral parameters measured at a given experimental configuration to the carrier concentrations obtained from a conventional method. Among the aforementioned semiconductors, the LOPC modes of InP is sensitive the most to the measurement conditions, especially the excitation wavelength and power due to the photogenerated carrier phenomenon [4]. Knowing the impact of different measurement parameters is primordial for accurate quantitative measurements. In this presentation, we present Raman analyses of n-doped bulk InP samples of various carrier concentrations performed with different configurations to illustrate their impact. The free carrier concentration deduced by Raman analyses is then compared to results of Hall Effect measurements. Finally, we present the calibration data linking directly the L^+ peak position to the carrier concentration obtained from Hall Effect measurements.

References

[1] Ghyselen, Bruno, et al., physica status solidi (a) 219.4 (2022): 2100543.
[2] Ochoa et al., Journal of applied physics 128.7 (2020): 075703.
[3] Haboeck, U., et al., Physica status solidi (c) 6 (2003): 1710-1731.
[4] Artús, L., et al., Physical Review B 60.8 (1999): 5456.

Figures

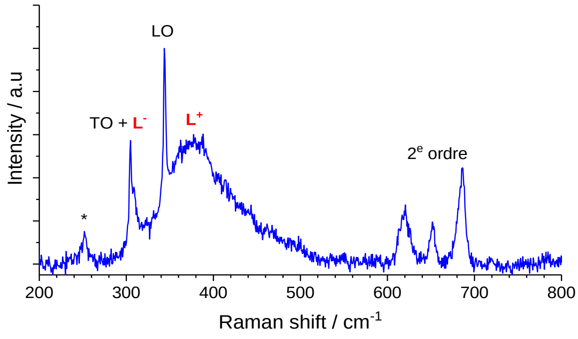

Figure 1: Raman spectrum of n-doped InP showing phonon and LOPC modes (L^- and L^+).