A simulation analysis of electrical characteristics of type-II InAs/GaSb superlattice mid-infrared p-i-n photodetector

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For photosensitive devices such as infrared (IR) photodetectors, dark current is an important mechanism limiting the performance because it causes a decrease in the signal-to-noise (SNR) ratio and the responsibility. In term of materials for the high-performance IR photodetectors, the type II InAs/GaSb superlattice (T2SL) captures the attention of many research groups due to the unique features to improve the overall performance of the devices. In this work, the electrical performance of InAs/GaSb T2SL IR detectors has been analyzed theoretically using a two dimensional device simulator based on the drift-diffusion model [1] (see Fig. 1). We especially focus on the dark current characteristics. In some previous works, the material parameters of T2SL used in the device simulation were set by calculating the average of InAs and GaSb bulk values [2]. In our model, intrinsic physical parameters such as the effective density of states and effective mass were extracted from the **k·p** band calculation [3]. Only carrier lifetime parameter is considered as a fitting parameter because it strongly depends on the defects of material and is an unknown factor in our model.

Figure. 2 shows the schematic structure of the p-i-n diode assumed in this study. The ratio of the binary components has been changed, i.e., $R \equiv d_{\mathrm{InAs}}/d_{\mathrm{GaSb}}$ for the T2SL used in the active region. Figure. 3 shows the simulated current density compared with the experimental data [4], in which three samples with different R were compared, but they were tuned to have the same band gap energy (0.25 eV). Note that the leakage current of the IR photodetector depends on R; the InAs-rich (larger R) SL detectors exhibit the smaller dark current. We discuss that not only the longer carrier lifetime [4], but also the smaller intrinsic carrier density would be important contribution.

References: [1] ATLAS Device Simulation Software User's Manual, Silvaco Inc., Santa Clara, CA, 2017. [2] M. Delmas *et al.*, J. Appl. Phys. **116**, 113101 (2014). [3] H. M. Dong *et al.*, Thin Solid Films **589**, 388 (2015). [4] R. Taalat *et al.*, J. Phys. D: Appl. Phys. **47**, 015101 (2014).

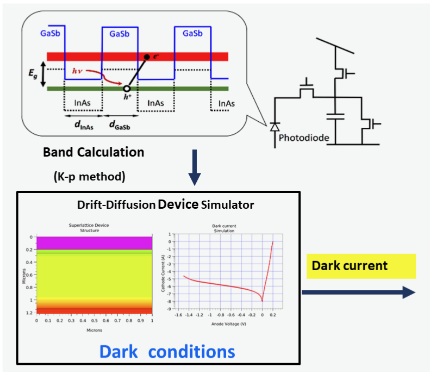

Figure 1: Drift-diffusion model combined with **k·p** calculation band structure.

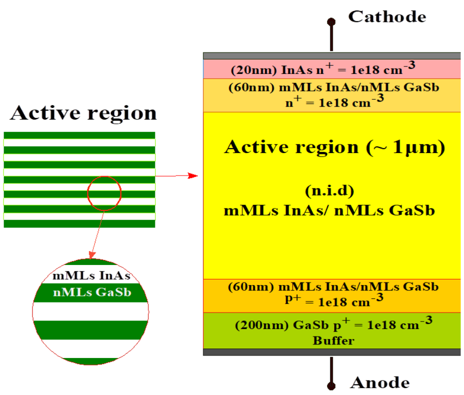

Figure 2: Cross-sectional view of the p-i-n photodiode structure simulated in this study.

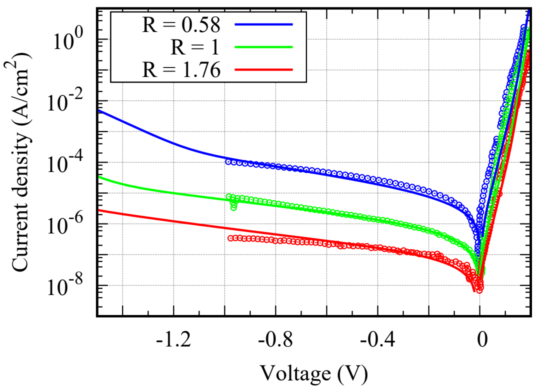

Figure 3: Experimental [4] (dots) and simulated (lines) $J - V$ curves at $T = 77$ K for different R.