Transient Simulation of UTC-PD Using Drift-diffusion Model

Tao Liu, Yongqing Huang, Qingtao Chen, Jiarui Fei, Kai Liu, Xiaofeng Duan, Xiaomin Ren
Institute of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications, Beijing 100876, China

***Abstract*-In this paper, the reliability of transient simulation results of uni-traveling-carrier photodiodes (UTC-PDs) is demonstrated by compared with experimental and reported simulation results, when the parameters of drift-diffusion model are set correctly.**

I. INTRODUCTION

The advantages of the physics-based simulation method are that, the performance of the optoelectronic devices can be predicted and studied in detail without costly experiments by using the physics-based modeling. Transient simulation can help to clarify the major factors affecting the photo-response by analysis electric field, carrier velocities and densities variation with position at different time [1], and then auxiliary photodiode structure designs and improve the device performance. It is convenient when transient simulation is applied to the research of phase retardation [2] and amplitude to phase conversion (AM-to-PM) [3] in photodiodes. However, appropriate physical models and corresponding parameters must be incorporated to ensure the accuracy of the simulation, especially carrier transport models, because carrier velocity plays a significant role in determining the performance of photodiode.

Two numerical modeling can be applied to transient simulations utilizing commercial Silvaco software (ATLAS): drift-diffusion [4] and energy balance [5] models. The latter is more accurate, because it introduces new independent variables for electron and hole temperatures, adds continuity equations for the carrier temperatures, and treats mobility and impact ionization coefficient as functions of the carrier temperature rather than functions of the local electric field [6]. The parameters of TAUMOB.EL and TAUMOB.HO are very important for energy dependent mobility model, however, can't find the available experiment test values corresponds to them for InP and $In_{0.53}Ga_{0.47}As$ materials. In addition, impact ionization

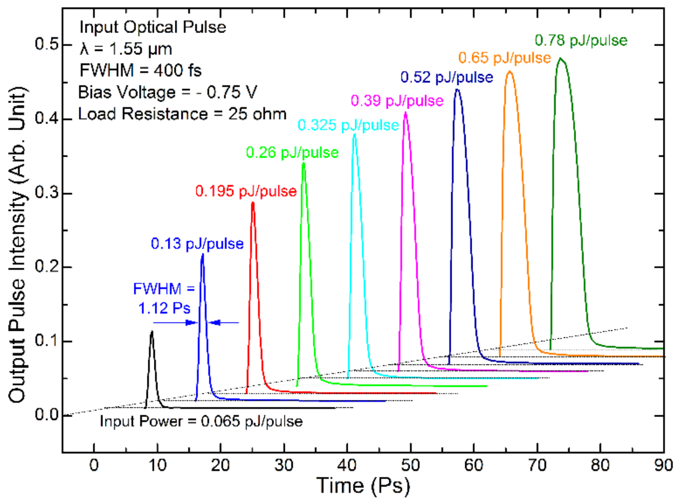

Fig. 1. Variation of output waveform with input power of UTC-PD1.

doesn't play a significant role in the UTC-PD [7]. The former is widely used to describe the carrier transport and the experiment test parameters of InP and $In_{0.53}Ga_{0.47}As$ materials in the models of concentration dependent mobility (CONMOB) and parallel electric field mobility (FLDMOB), which are available in the ref. [8]. In this paper, drift-diffusion model is applied to the transient simulation of UTC-PD1 [9], UTC-PD2 [10] and UTC-PD3 [11] and the simulation results agree with the experimental results, which indicates that simulation results are reliable when the parameters of drift-diffusion model are set correctly.

II. SIMULATION AND ANALYSIS

Fig. 1 shows the simulation result of transient photo-response of UTC-PD1, the output pulse intensity increases with increasing input power and saturated under high power conditions. The FWHM increases monotonically with increasing input power which is consistent with the experimental results of ref. [9]. This phenomenon is basically due to the negative influence of the space charge effect on the average electron velocity is more prominent than the positive influence of the self-biasing effect in the absorption layer at high current density, which reduces the electric field in the depletion region and, thus, the output performance of the device deteriorates. Fig. 1 also indicates that the output peak voltage is about 0.2 V when input power is 0.13 pJ/pulse, which is consistent with the results of ref. [9]. However, the simulated FWHM is less than the experimental results because the response-pulse widening due to the finite width of the pump- and probe-pulses in the experiment.

Fig. 2 reveals that the output pulse intensity increases at first and then decreases with increasing reverse bias, while the FWHM behaves on the contrary, which agrees with the report of ref. [10]. This is because that the nonlinear carrier velocity-field relation [8]. The principal physical reason for this behavior is that the ratio of heavy (X- and L-valley) electrons to light (Γ-valley) electrons increases as the electric field increases.

Fig. 3 shows the output intensity increases almost linearly with the input power increases up to 0.3 pJ/pulse and the correspond peak voltage is 0.82 V. When higher power light was injected, the output starts to saturate and the pulse widens obviously. The fall time of output pulse changes little even when output saturation occurs. This indicates that the saturation takes place at currents exceeding a certain level and that the operation can return to the linear response mode. Both our simulation results and the report of ref. [5] have suggested the output intensity is larger than the experimental results of ref. [11] for same input power. Beyond that, our simulation result reveal that to achieve similar output intensity the input energy is only a quarter of the value of ref. [11]. It is possible that the actual coupling input energy is less than the ideal value in the experimental measurements.

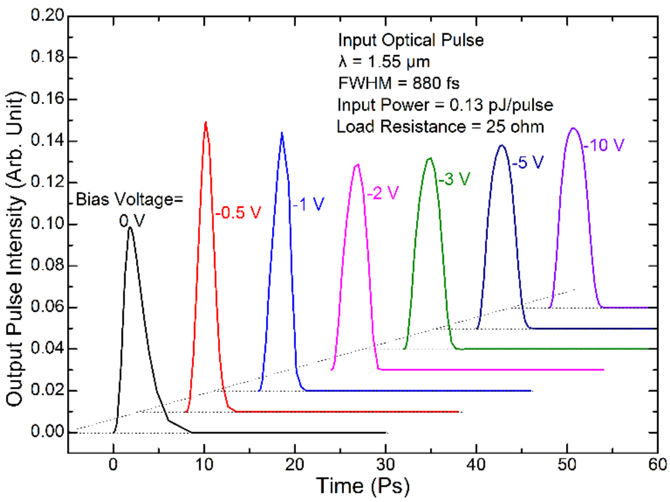

Fig. 2. Variation of output waveform with input power of UTC-PD2.

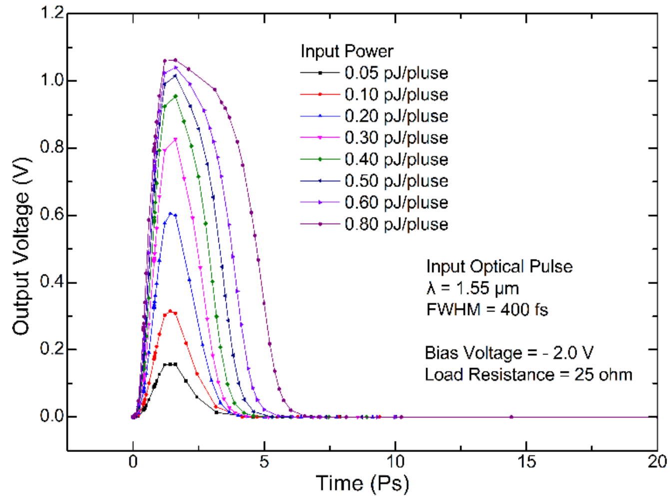

Fig. 3. Variation of output waveform with input power of UTC-PD3.

ACKNOWLEDGMENT

This work is supported in part by the National Basic Research Program of China (2010CB327600), the National- Natural Science Foundation of China (61020106007, 61274044), the Natural Science Foundation of Beijing (4132069), and Program of Key International Science and Technology Cooperation Projects (2011RR000100).

REFERENCES

[1] N. A. Zakhleniuk. “Theory and Modelling of High-Field Carrier Transport in High-Speed Photodetectors”, International Conference on NUSOD, 2007.
[2] Marc Currie, and Igor Vurgaftman. “Microwave Phase Retardation in Saturated InGaAs Photodetectors”, IEEE Photonics Technology Letters, Vol.18, No.13, pp.1433-1435, 2006.
[3] J. Taylor, S. Datta, A. Hati, C. Nelson, F. Quinlan, A. Joshi, and S. Diddams. “Characterization of power-to-phase conversion in high-speed p-i-n photodiodes”, IEEE Photonics Journal, Vol. 3, No. 1, pp. 140-151, 2011.
[4] Li-sa Liu, Sheng Xie, Lu-hong Mao, Shi-lin Zhang, and Hai-tao Qi. “Transient simulation and optimization of InP/InGaAs uni-traveling carrier photodetector”, Optoelectronics Letters, Vol. 6, No. 3, pp. 191-194, 2010.
[5] S. M. Mahmudur Rahman, Hans Hjelmgren, Josip Vukusic, Jan Stake, Peter A. Andrekson, and Herbert Zirath. “Hydrodynamic Simulations of Unitraveling-Carrier Photodiodes”, IEEE Journal of Quantum Electronics, Vol. 43, No. 11, pp. 1088-1094, 2007.
[6] ATLAS User's Manual, Silvaco International, Santa Clara, 2010.
[7] M. N. Feiginov. “Analysis of limitations of terahertz p-i-n uni-traveling-carrier photodiodes”, Journal of Applied Physics, Vol. 102, No. 8, 2007.
[8] Yong-Liang Huang and Chi-Kuang Sun. “Nonlinear saturation behaviors of high-speed p-i-n photodetectors”, Journal of Lightwave Technology, Vol. 18, No. 2, pp. 203-212, 2000.
[9] H. Ito, T. Furuta, T. Furuta, N. Watanabe, T. Ishibashi and S. Kodama, “InP/InGaAs uni-travelling-carrier photodiode with 220 GHz bandwidth”, Electronics Letters, Vol. 35, No. 18, pp. 1556-1557, 1999.
[10] Tadao Ishibashi, and Naofumi Shimizu, “Uni-Traveling-Carrier Photodiodes as an optoelectronic driver”, OSA TOPS Ultrafast Electronics and Optoelectronics, Vol. 28, PP. 203-207, 1999.
[11] T. Ishibashi, T. Furuta, H. Fushimi, S. Kodama, H. Ito, T. Nagatsuma, et al, “InP/InGaAs Uni-traveling-carrier photodiodes,” IEICE Trans. Electron, Vol. E83-C, pp. 938–949, Jun. 2000.