Simulation of Dynamic Characteristics of GaN p-i-n Avalanche Diode Type Particle Detector

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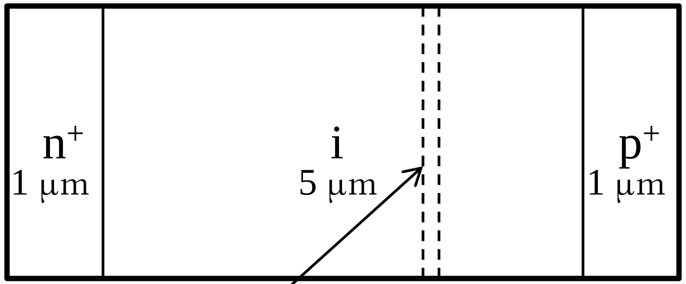
Introduction

Gallium nitride is one of the most promising materials for the production of particle detectors working at high level irradiations within a harsh environment. The carrier pair generation by high energy protons results in an efficiency of 40-80 pairs per μm length of the device active region per proton. For efficient particle detection relatively long (300-500 μm) devices are needed. However, the GaN crystalline material of a proper quality is usually obtained by the MOCVD technique, and grown epi-layers are rather thin (2-12 μm). The inevitable noise level in the measurement circuit amounts to about $3 \cdot 10^4$ electrons. For exceeding this level in the 2-12 μm device internal amplification through carrier impact ionization processes is needed.

GaN Diode model



Optical excitation domain (0.1 μm, 2 ps, $\lambda = 0.473$ μm, $I = 10^4$ W/cm^2)

Drift-diffusion model according to Synopsys TCAD Sentaurus. Shockley–Read–Hall (SRH) recombination, Auger recombination, radiative recombination and charge generation due to impact ionization (the van Overstraeten and de Man model based on the Chynoweth law).

Carrier mobility in undoped region μ_n = 1500 cm^2/Vs, μ_p = 100 cm^2/Vs. Saturation velocity $v_{ns} = 1.8 \cdot 10^7$ cm/s, $v_{ps} = 10^7$ cm/s. The diode area $S = 7.85 \cdot 10^{-5}$ cm^2.

1. Constant voltage source connected to the diode.

2. Constant voltage source in series with the diode and load resistance R_L = 50 Ohm.

Results (1)

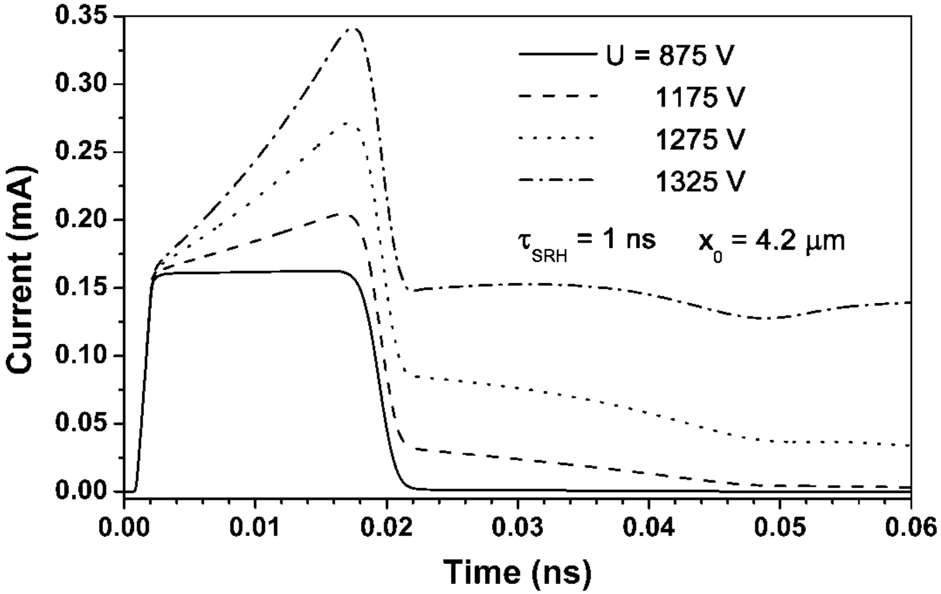
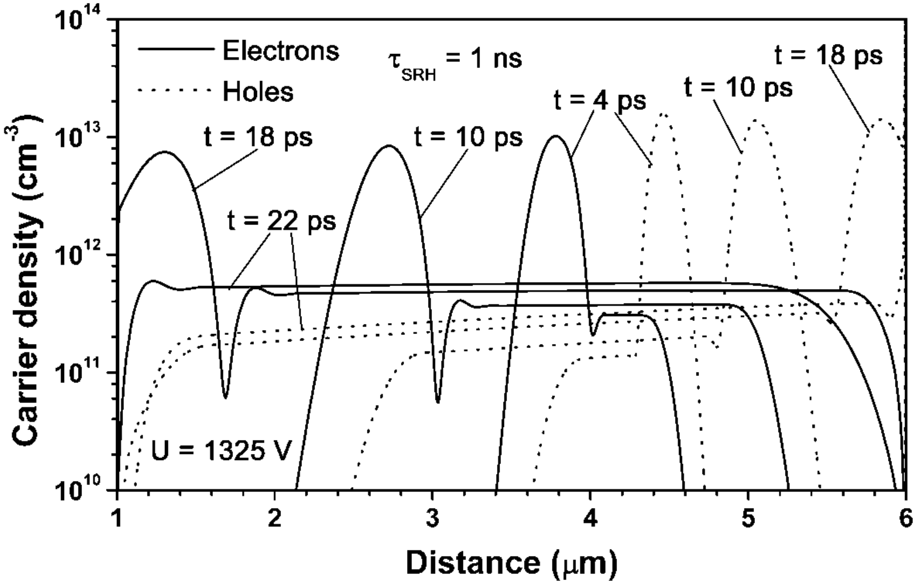


Fig. 1. Time dependence of the diode current at different levels of diode voltage

Fig. 2. Carrier distribution in the intrinsic layer during the primary carrier drift from $x_0 = 4.2$ μm to the n^+ (electrons) and p^+ (holes) regions



Results (2)

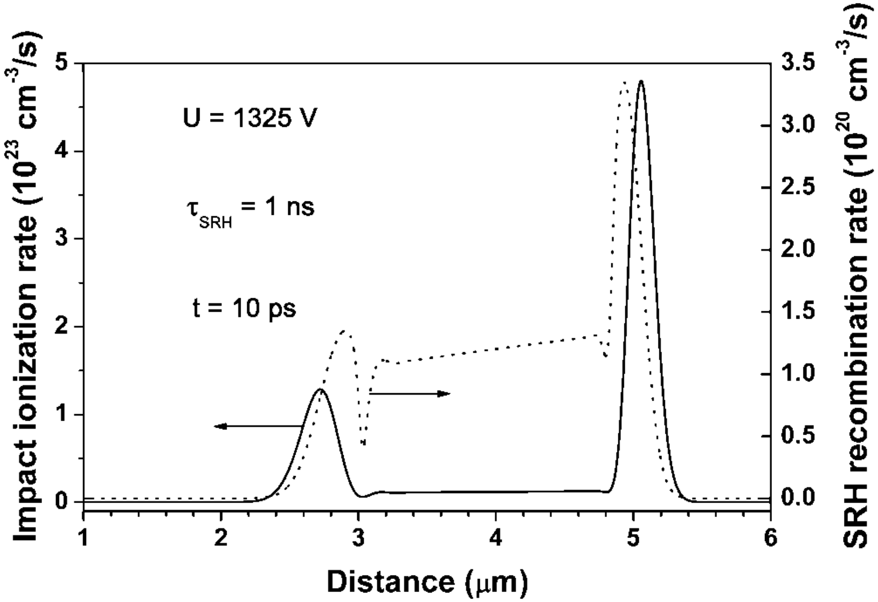
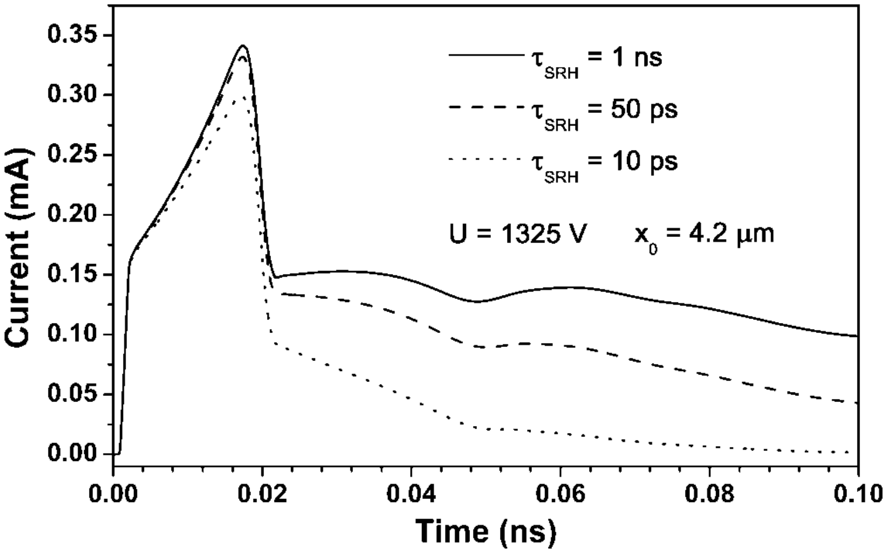


Fig. 3. Generation and recombination rate distribution in the intrinsic layer at t = 10 ps

Fig. 4. Time dependence of the diode current at different levels of the carrier lifetime



Results (3)

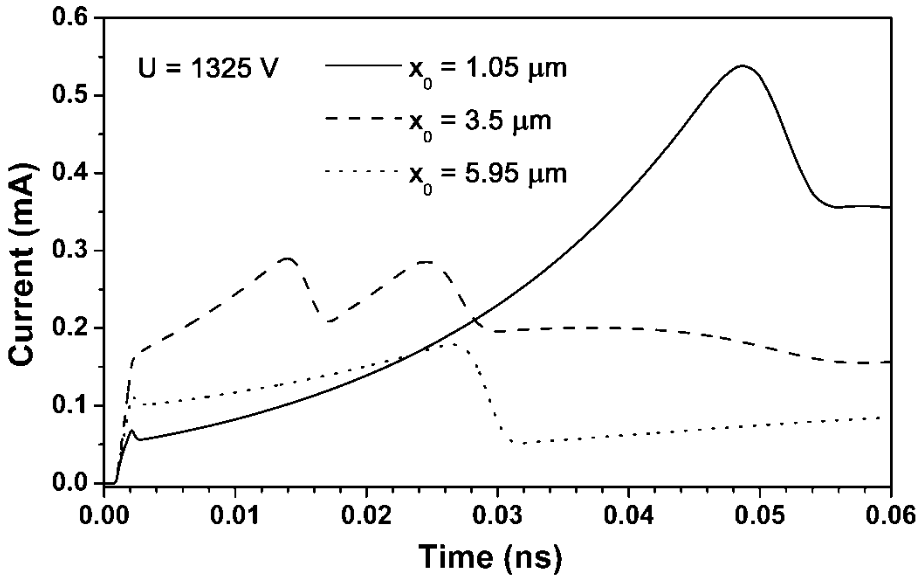


Fig. 5. Time dependence of the diode current with different optical pulse location x_0 in the intrinsic layer

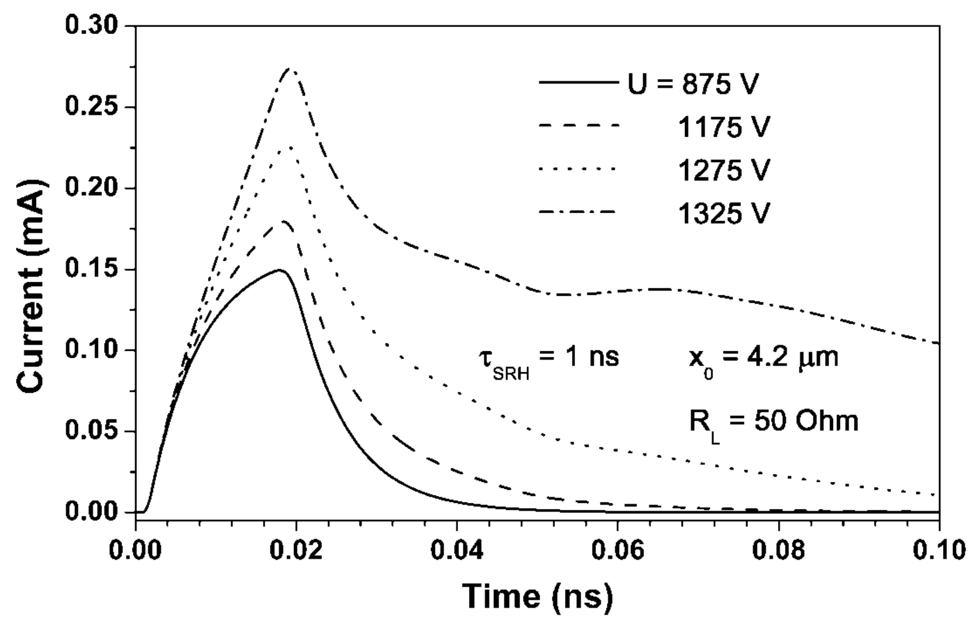


Fig. 6. Time dependence of the diode current at different levels of diode voltage in the circuit with load resistor R_L = 50 Ohm

Conslusions

1. Only SRH recombination is sufficient. Auger and radiated recombination may be neglected.

2. The diode current pulse shape depends strongly on the location of photo-excited excess carrier domain.

3. The explanation of the fast and slow parts of the current pulse fall was based on the carrier distribution in space at different moments of time. The process of carrier packets entering the high doping regions coincides very well with the fast diode current fall.

4. Residual secondary, ternary and other carriers ensure a sufficiently lower charge generation rate and the diode current relaxes slowly to a very low dark current level.

5. The charge collection is sufficient even in the case of a very low carrier lifetime of 10 ps.

6. In the case of load resistor R_L = 50 Ohm the $R_L C_d$ = 7.4 ps plays a significant role in the formation of the diode current pulse shape. The diode current fast rise time of 2 ps disappears. The diode current pulse amplitude decreases by 21 percent and we have almost no fast current pulse fall at $t > 20$ ps.

Thank you!