Breakdown of GaN-based Planar Gunn Diodes investigated through a Combined Deep Learning-Monte Carlo Model

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ABSTRACT

In this contribution we present a study of GaN Planar Gunn Diodes (PGDs) through a combined deep learning-Monte Carlo (MC) approach. MC simulations will be used to analyze the effect of the leakage current through the buffer, which originates the avalanche breakdown of the diodes due to the onset of impact-ionization (II) phenomena at high-enough voltages. A neural network is then employed to predict the breakdown voltage, thus contributing to optimize the design and reliability of practical GaN PGDs.

INTRODUCTION

The wide bandgap and moderately high mobility of GaN is attracting increasing interest for its use in high-power applications at microwave frequencies [1]. Moreover, given its negative differential mobility, it is being also explored as an interesting material for fabricating high power Gunn diodes. Although only indirect evidence of Gunn oscillations in GaN-based diodes has been experimentally achieved [2,3], MC simulations confirm the possibility of attaining high-power generation in the THz range using PGDs based on highly doped GaN epilayers [4]. However, GaN PGDs fabricated with shaped nanochannels do not display Gunn oscillations, since their breakdown takes place when the applied bias exceeds 20-25V, below the expected threshold for the onset of the oscillations.

MONTE CARLO MODEL AND MAIN RESULTS

A semi-classical ensemble MC tool self-consistently coupled with a two-dimensional (2D) Poisson solver is employed for the simulation of electronic transport in the analyzed structures. II processes are implemented by means of the Keldysh approach. The breakdown voltage V_B at which II mechanisms become relevant is obtained through a model based on a neural network which uses backpropagation, trained with the data obtained from a set of selected MC simulations. This model radically reduces the computational time as compared to MC calculations covering all the possible cases.

Fig. 1(a) sketches the structure of the simulated device, featuring a doped GaN layer with N_D in the range $0.5\text{-}10\times10^{18}$ cm^{-3}. Gunn oscillations are predicted according to our top-view MC simulations, Fig. 1(c). However, when fabricated devices have been characterized, they suffer a catastrophic breakdown before displaying any oscillating behavior. To investigate the origin of the breakdown, in addition to top-view simulations (where electric field hot-spots are observed at the anode corners of the isolating trenches, Fig. 2), we have simulated the lateral cross-section shown in Fig. 1(b). As observed in Fig. 3(a), the electric field reaches values higher than 5 MV/cm at 25 V, also at the same point, but at the bottom corner of the etched trench. Highly energetic electrons, unintentionally leaked across the undoped substrate, are present at that point, Figs. 3(b) and (c), thus leading to II mechanisms, Fig. 3(d). From the data obtained from this type of simulations, our neural network is able to predict the breakdown voltage V_B, determined as the bias at which the average electron energy in the hot spot area surpasses the threshold for the onset of II mechanisms (3.5 eV). Higher values of V_B are predicted by the model for lower N_D and higher permittivity κ_r of the dielectric filling the trenches, as well as at higher T (Fig. 4).

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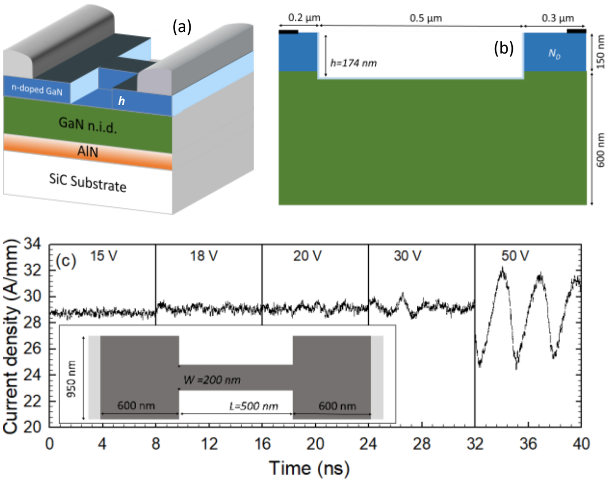

Fig. 1. (a) 3D structure of the simulated device. (b) Longitudinal cut at the etched sides of the channel with an isolation depth of h=174 nm. (c) Time-sequence of the current density for N_D=5×10^{18} cm^{-3}, κ_r=1 and T=300 K for the single channel device shown in the inset.

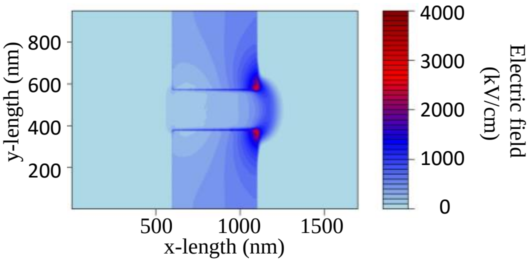

Fig. 2. Map of the electric field modulus obtained with a top-view MC simulation using N_D=5×10^{18} cm^{-3}, κ_r=1 and T=300 K, for a bias of 25 V.

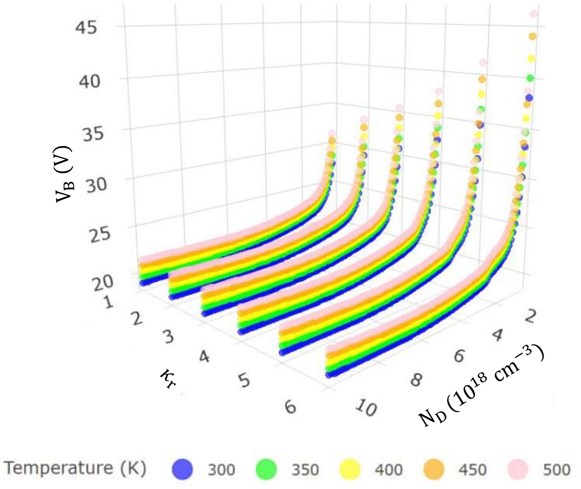

Fig. 4. Dependence of V_B on N_D, κ_r and T obtained with the neural network model.

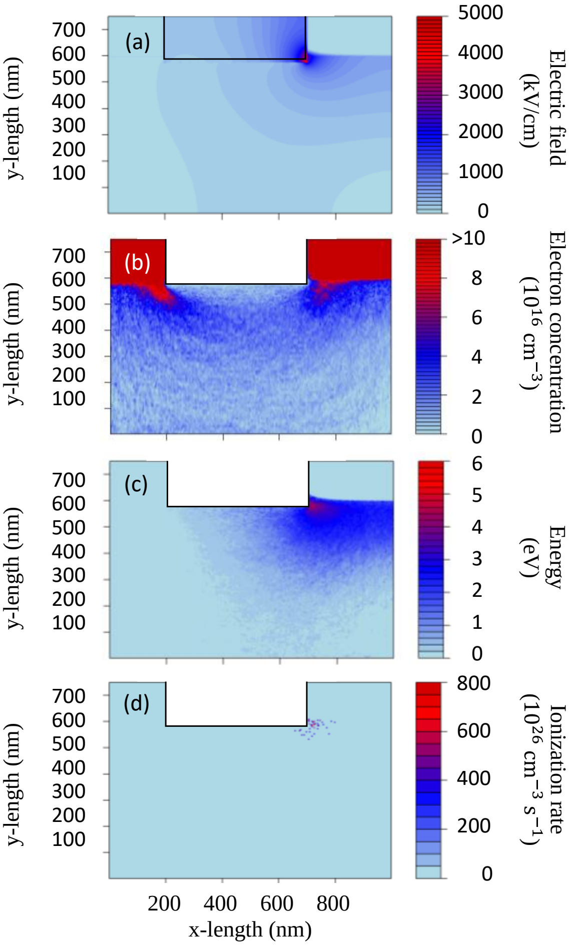

Fig. 3. Maps of (a) electric field modulus, (b) electron concentration, (c) total energy, and (d) II rate obtained with a front-view MC simulation using N_D=5×10^{18} cm^{-3}, κ_r=1 and T=300 K, for a bias of 25 V.