Time-domain Monte Carlo simulation of GaN planar Gunn nanodiodes in resonant circuits

B. G. Vasallo, J. F. Millithaler, I. Íñiguez-de-la-Torre, T. González and J. Mateos
Dpto. Física Aplicada, Universidad de Salamanca, Spain
e-mail: bgvasallo@usal.es

INTRODUCTION

Planar Self-Switching Diodes (SSDs) [1] are being considered for THz signal emission at room temperature, since their topology is especially appropriate for the development of Gunn oscillations [2]. Power emission can be enhanced by means of parallelization, while improved broadband performance and flexibility of design can be achieved thanks to the possibility of fabricating together several devices with different characteristic frequencies. Moreover, the properties of GaN allow to envisage the generation of Gunn oscillations approaching the THz range [3]. However, no experimental demonstration of this effect has been achieved so far (neither in vertical nor in planar diodes). In order to accomplish such experimental demonstration it seems necessary that Gunn diodes are embedded into a resonant circuit, which can be just a parallel RLC circuit connected in series with the devices. Here we provide a Monte Carlo (MC) theoretical study of GaN SSDs connected in series with such a resonant circuit with the aim of identifying the optimum operation conditions for the achievement of oscillations. Two kinds of designs of GaN SSDs (the simple square and the optimized V-shaped), are analyzed and compared in terms of oscillation frequencies and DC to AC conversion efficiency.

PHYSICAL MODEL AND MAIN RESULTS

For the calculations, we make use of a semiclassical ensemble MC simulator self-consistently coupled with a 2D Poisson solver whose validity for the analysis of the physical behavior of SSDs has already been demonstrated [3], [4]. The schematic top-view topologies of (a) the square and (b) the V-shaped GaN planar SSDs under analysis have been plotted in Fig. 1. In order to account for thermal effects, a self-consistent method making use of the thermal resistance of the structure has been implemented, the global lattice temperature being iteratively adapted self-consistently with the power dissipated within the device [5]. The intrinsic MC simulation of the diode has been coupled to the resolution of a parallel RLC resonant circuit connected in series [6], with the total current flowing through the diode calculated following the Ramo-Shockley theorem. The coupling of the circuit equations with the MC simulator is carried out in a discrete time mesh using the same time step as the simulator. In order to analyze the diodes capability as emitters, the dissipated DC power (P_{DC}) and the time-average AC power (P_{AC}) are evaluated, and the conversion efficiency is calculated as $\eta = -P_{AC}/P_{DC}$ (positive values of η indicating AC generation from DC).

According to our simulations (without including thermal effects), a maximum efficiency of at least 0.18% for a DC bias of V_{DC}=30 V is achieved for a resonant circuit with R=0.5 MΩ, C=0.01 fF and L=12 nH in the square SSD at room temperature. This low value, even if it could be already experimentally useful, can be further enhanced by optimizing the values of R, L and C, by using different circuit configurations, and also by improving the intrinsic characteristics of the SSD. With the same RLC resonant circuit, a comparison has been established between the square and the V-shaped SSDs for different DC biasing conditions at room temperature. Fig. 2 presents the values of η as a function of V_{DC}. The V-shaped SSD exhibits a threshold voltage for the onset of oscillations of V_{DC} =20 V, lower than in the square SSD, which needs V_{DC} >25 V. For both kind of diodes, the efficiency presents a maximum value at V_{DC} =30 V, significantly enhanced for the V-shaped SSD, reaching about 0.35%. The oscillation frequencies are about 265-275 GHz in the V-shaped SSD (only slightly dependent on V_{DC}), being these values slightly lower than in the square SSD, which provides 275-290 GHz.

In order to better reproduce the real behavior of SSDs as Gunn oscillators, the optimization of the values of R, L and C for the V-shaped SSD has been performed when considering the heating of the devices. The results obtained using a thermal resistance of R_{th} =10×10^{-4} K/(W/m) and V_{DC} =25 V, Fig. 3, show that it is possible to improve the efficiency of such oscillators up to almost 0.75%. More results relative to the Gunn-oscillator operation of the planar GaN-based SSDs will presented at the workshop.

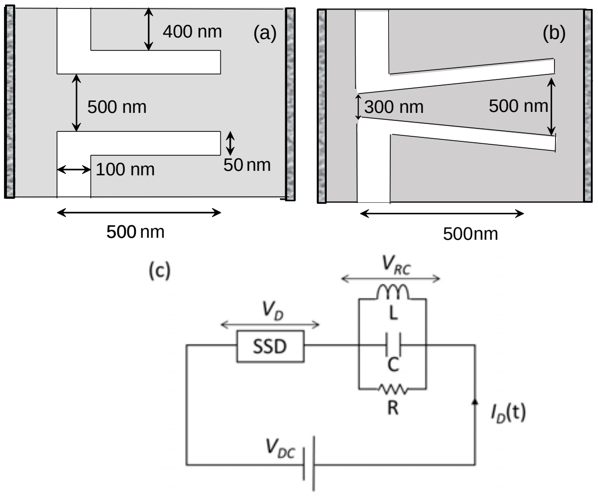

Fig. 1. Geometry of (a) the square and (b) the V-shaped GaN SSDs under analysis. (c) Circuit configuration of the series connection of the parallel RLC resonant circuit with the SSD within the MC simulations.

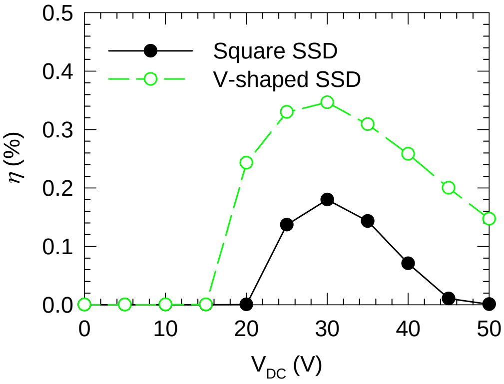

Fig. 2. DC to AC conversion efficiency η as a function of the applied DC voltage for the square and V-shaped SSDs sketched in Fig. 1, connected in series with a resonant circuit with R=0.5 MΩ, C=0.01 fF and L=12 nH at room temperature.

ACKNOWLEDGMENTS

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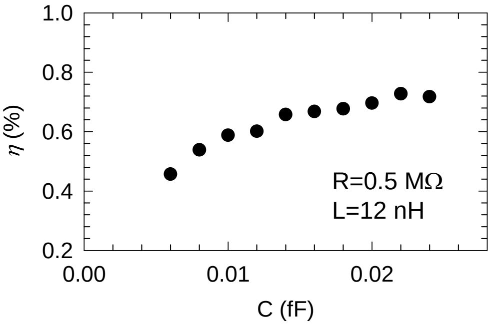

Fig. 3. DC to AC conversion efficiency η as a function of C in the V-shaped SSDs sketched in Fig. 1(b) connected in series with a resonant circuit with R=0.5 MΩ and L=12 nH, considering R_{th} =10×10^{-4} K/(W/m). The DC bias is V_{DC}=25 V.