ULTRA HIGH FREQUENCY OPERATION OF A SELF SWITCHING DIODE

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Recently, a nanoscale unipolar rectifying diode, so called self-switching diode (SSD), based on electrostatic effects, was presented in [1]. This device provides a rectifying behavior without the use of any doping junction or barrier structure (like in *p-n* or Schottky barrier diodes) and can be fabricated with a simple single-step lithographic process. The downscaling of the SSDs is therefore so simple that, together with the intrinsically high electron velocity of InGaAs channels, the fabrication of devices working in the THz range can be envisaged. Indeed, the high frequency performance of SSDs can be dramatically improved thanks to a much shorter transit time, due not only to a smaller channel length but also to an enhanced electron velocity associated to ballistic transport. In this work we will make use of a semiclassical 2D Monte Carlo (MC) simulator (employed previously to succesfully model nanoscaled ballistic devices: TBJs, YBJs and ballistic rectifiers [2-4]) to optimize the high frequency performance of SSDs.

A SEM picture of a fabricated SSD is shown in Fig. 1(a). The geometry of the corresponding simulation domain is sketched in Fig. 1(b). The operating principle of the SSD is based on the propagation to the vicinity of the channel of the voltage applied to the anode (right contact). At equilibrium, the channel of the SSD is closed due to the depletion induced by the surface charges located at its lateral walls. When $V>0$, the positive potential reaches the lateral regions of the SSD channel, so that the potential barrier is lowered (or even removed for high enough V), thus allowing the electron flow (the channel is open). On the contrary, when $V<0$ the potential profile in the right part of the device and in the channel is almost unchanged with respect to the equilibrium situation. Thus, *I-V* curves typical of a rectifying diode are found, Fig. 1(c). 2D top-view MC simulations of the structure schematically shown in Fig. 1(b) were performed by considering a contact density $N_c=10^{17}$ cm^{-3}, a background doping $N_{Db}=10^{17}$ cm^{-3}, and a surface charge density $\sigma=0.3\times10^{12}$ cm^{-2} [3]. Even if the real geometry of the measured devices is not precisely known, the main features of the experimental curves are well reproduced by MC simulations; namely, the current rectification and the increase of the threshold voltage when the channel is narrowed. The non-simulated dimension Z used for the comparison with the experimental current was estimated by using the measured Hall sheet density $n_s=10^{12}$ cm^{-2}, giving a value for $Z=n_s/N_{Db}=10^{-5}$ cm.

In order to optimize the high frequency operation of SSDs we have downscaled their geometry. In this process, short channel effects (comparable to those found in traditional FET transistors) appear when the aspect ratio of the channel (L/W) decreases. The main problem is that the barrier preventing the current flow under inverse bias can disappear if the potential of the lateral regions is not able to deplete the channel, thus allowing an inverse leakage current. This may happen because of a too wide channel or too thick lateral trenches. To reduce this undesirable effects, we have simulated SSDs with (very thin) 5 nm wide trenches, W=50 nm and small channel lengths. The results indicate that the forward current is much improved by reducing the channel length, while the inverse leakage is prevented by the thin trenches even for very short channels (it only appears for L=100 nm). The dynamic behavior of these optimized devices has been analyzed by means of the MC simulation of their response to sinusoidal input voltage signals of increasing frequency. Fig. 2 shows the time-dependent current in the SSDs with L=100 nm and

L=300 nm for periodic voltage excitations with amplitude of 0.5 V and different frequencies (100 GHz, 0.5 THz and 1 THz). For 100 GHz, the rectification is nearly perfect, with a higher forward current in the shorter structure. When increasing the frequency of the applied signal up to 1.0 THz, the shape of the current is degraded, but still shows a positive mean value (for L=100 nm this happens up to frequencies over 2.0 THz), thus making possible the operation of these devices as, for example, power detectors of THz waves (or T-rays [5]). However, we have to note that these intrinsic high-frequency capabilities can be deteriorated by the extrinsic contact resistances and capacitances. Therefore, strong efforts (both at technologic and design levels) must be made to minimize their effect.

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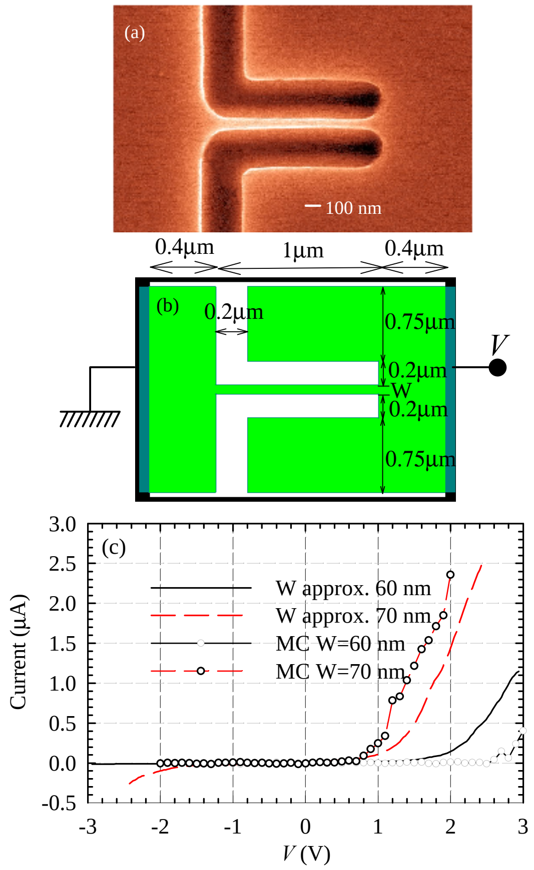

Figure 1: (a) SEM picture of a typical SSD, (b) geometry of the simulated device, and (c) comparison of the measured and simulated I-V characteristics of SSDs with different channel widths W.

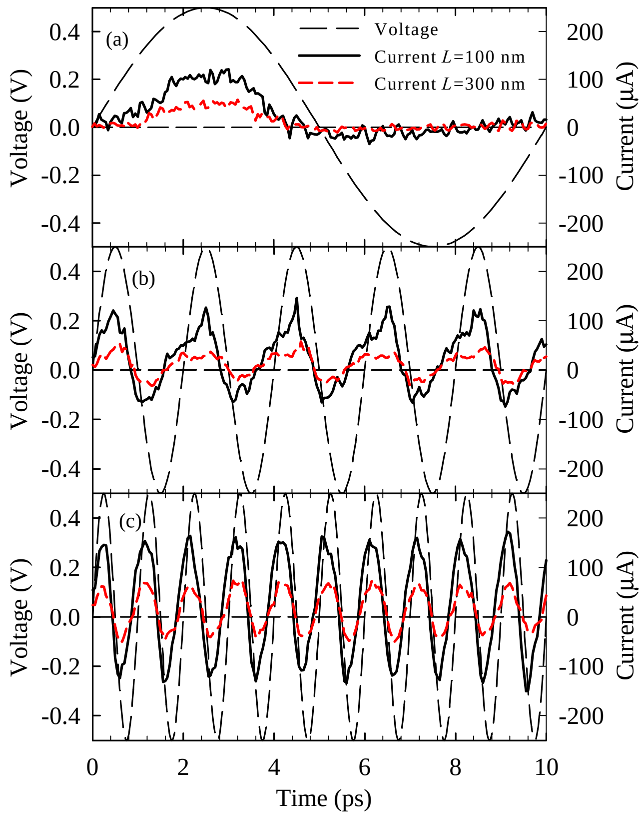

Figure 2: Current response to input voltages with amplitude of 0.5 V and frequencies of (a) 100 GHz, (b) 0.5 THz and (c) 1.0 THz applied to SSDs with W=50 nm, 5 nm wide trenches and channel lengths of L=100 nm and L=300 nm.