Performance evaluation of picosecond high voltage power switches based on propagation of superfast impact ionization fronts in SiC structures

Igor V. Grekhov, Pavel A. Ivanov*, Pavel B. Rodin
Ioffe Institute of RAS, St. Petersburg, Russia, http://www.ioffe.ru

Closing high voltage switches based on propagation of impact ionization fronts in Si structures are capable to switch on hundreds Ampere current with subnanosecond risetime commutating megawatt power per pulse. The front of impact ionization propagates about 10 times faster than the saturated drift velocity $\upsilon_s \approx 10^7$ cm/s leaving a dense electron-hole plasma behind and modulates conductivity of a semiconductor structure faster than any other non-optical process. In comparison to Si, wide bandgap silicon carbide (SiC) has much higher thresholds of electric and thermal breakdown combined with somewhat higher saturated carrier velocities and is expected to widely replace silicon in power electronics devices including pulse power electronics. The aim of our presentation is to evaluate the performance of the prospective high voltage subnanosecond closing switches based on propagation of superfast impact ionization fronts in 4H-SiC p^+-n-n^+ structures.

We develop an elementary analytical theory which allows to relate the order of magnitude values of the front velocity υ_f and the concentration of generated electron-hole plasma N to the main material and structural parameters

$$\upsilon_f \sim \upsilon_s \frac{N}{N_d}\left(\frac{E_{\max}}{E_b}-1\right)\frac{1}{\ln(N/n_0)}, \quad N \sim \frac{\alpha_0 \varepsilon\varepsilon_0 E_b}{q}.$$

Here $E_b \sim 2\cdot 10^6$ V/cm is the effective threshold of impact ionization, $\alpha_0 \sim 10^5$ cm^{-1} is the characteristic value of the impact ionization coefficient, N_d is the doping of the n base. Details of the derivation can be found in [P.B. Rodin, P.A. Ivanov, I.V. Grekhov, J. Appl. Phys. **99**, 2006, in print].

For SiC we evaluate concentration of the generated plasma as $N_{SiC} \sim 10^{18}$ cm^{-3} vs. $N_{Si} \sim 10^{16}$ cm^{-3} for Si. Because of the high current density $J \sim 10^4...10^5$ A/cm^2 after switching the residual voltage is determined by electron-hole scattering and can be evaluated as 10...50 V for a diode with kilovolt static breakdown voltage. The velocity υ_f is determined by the ratio $E_{\max}/E_b$ that characterizes the "overstress" of the p-n junction and by the doping concentration N_d. For example, for the moderate "overstress" $E_{\max}/E_b$ = 1.1 and $N_d = 10^{15}$ cm^{-3} we find $\upsilon_f^{SiC} \sim 10^8$ cm/s that is 3 times faster than υ_f^{Si}. Triggering of the superfast front requires that the steepness of the applied voltage pulse exceeds 10 kV/ns.