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DEVICE AND TECHNOLOGY SIMULATION OF IGBT ON SOI STRUCTURE

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Abstract. Results of computer simulation of manufacturing a bipolar transistor with insulated gate (IGBT) on the base of technology “Silicon on insulator” (SOI) are presented. Current-voltage characteristics of the investigated IGBT device were calculated. The results obtained were used as a base for optimization of the most significant technological parameter, a gate oxide thickness. It is shown that the gate oxide thickness has a significant impact on the electrical characteristics of the IGBT. The calculated values of the switch-on and switch-off times less than one order, and the value of the collector current is more than two orders of magnitude for the vertical structure of the IGBT based on bulk silicon in comparison with IGBT on SOI structure.

1. Introduction

Nowadays two base types of the contemporary power electronics devices are dominant: field transistors (Metal Oxide Silicon Field Effect Transistor, MOSFET) and bipolar transistors with an isolated gate (Isolated Gate Bipolar Transistor, IGBT), as well as various integrated structures on their basis. IGBT due to its exceptional functional features, combining the positive properties of the power field and bipolar transistors, is a widely applied power device and finds a wide application in the devices of the electric thrust and AC motors, induction heating systems, radiological systems, power back-up sources, switching elements. Perfecting the IGBT structures is oriented towards enhancing the efficiency, limit commutating currents and break voltages. IGBTs, manufactured by SOI technology have several advantages: high input impedance, low output impedance, low forward voltage drop, high breakdown voltage and compatibility with CMOS technology. Compared with the devices manufactured on bulk silicon technology, SOI powerful integrated circuits require full isolation with a dielectric. This reduces the leakage current, increases device speed, increases noise immunity and there is the possibility of the operation at high temperatures.

Earlier there had been conducted researches of dependence of the static and dynamic IGBT parameters on various formation parameters for the structure represented in Fig. 1. Thickness of the epitaxial layer of such structure was selected to be equal to 141 μm, and thickness of the p^+-collector layer – 17 μm, as in work [1]. From the entire variety of possible IGBT structures on SOI, described in literature [2-6], in our study the IGBT structure, represented in Fig. 2, was selected.

2. Simulated IGBT on SOI structure

The transistor base is essentially a silicon film, located on an isolation material. IGBT may possess any polarity: a pnp bipolar transistor with n-MOS transistor or a bipolar transistor of the npn-type with a p-MOS transistor. A greater current density in the IGBT structures is attained by means of the formed n-well of a source, increasing the base current of the bipolar transistor in IGBT. The gates can control one or two channels of the MOS transistors. The vertical sizes of the n-type of the drift area are augmented to enhance the current density without growth of the voltage drop value in the n-drift region. Simulation of the IGBT structure on SOI process formation was performed by means of SILVACO package [7] in compliance with the last trends in the IGBT on SOI manufacturing [8–10]. The peculiarity of the modeled structure is the presence of two gates that control the transistor channels. Increasing the number of gates is used for increasing the value of the switched current. The depth of the buried oxide is 1 μm, the doping concentration in the n+-emitter region $C_E=10^{19}$ cm^{-3}, the doping concentration in the p-collector region $C_C=8\times10^{18}$ cm^{-3}, the doping concentration in the n-base region $C_B=10^{18}$ cm^{-3}.

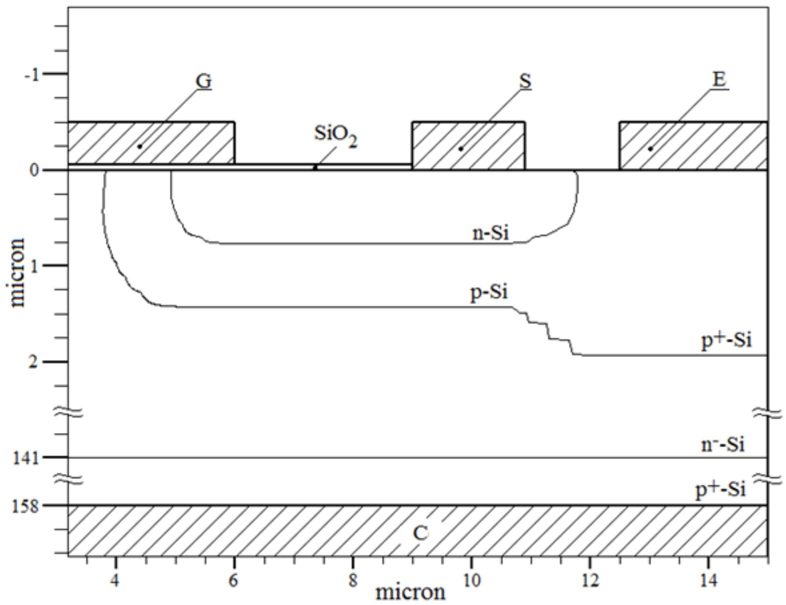


Fig. 1. Structure of the IGBT on a bulk silicon.

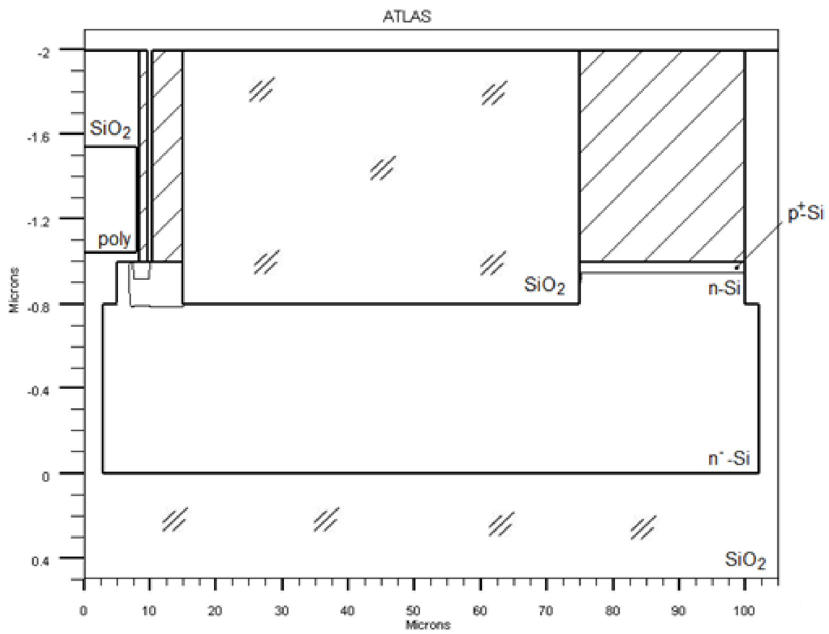
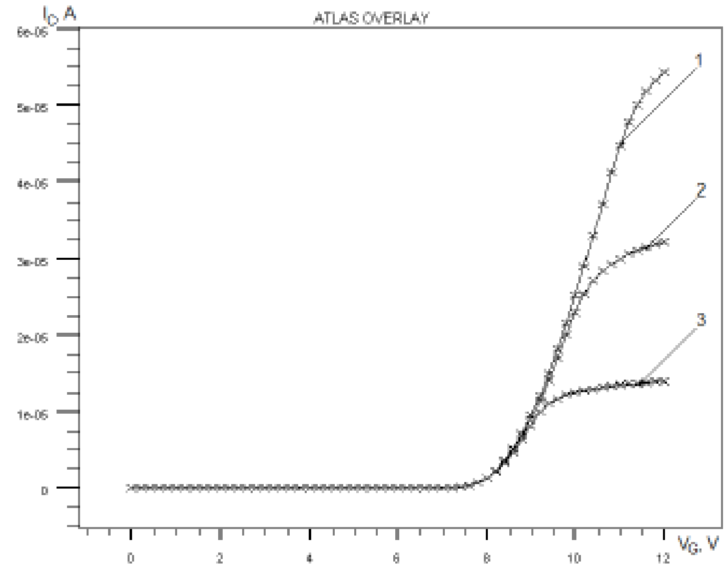


Fig. 2. Structure of the IGBT on a SOI.

3. Results

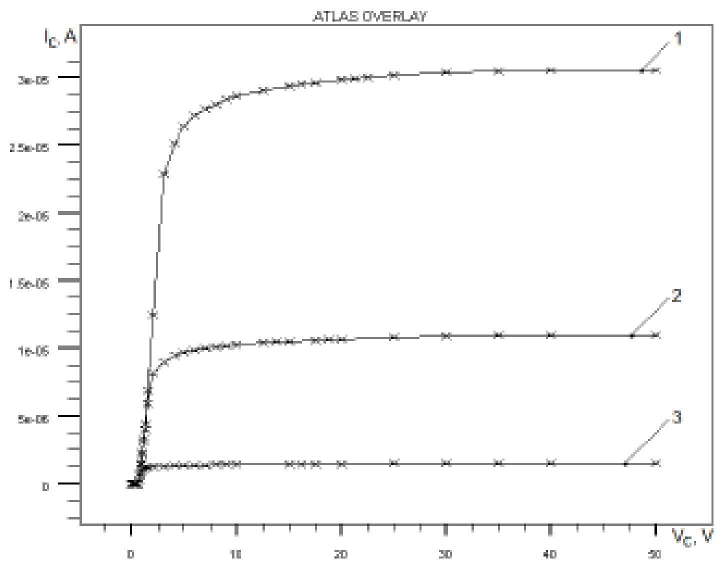
Simulation of the IGBT on a SOI structure features was carried out with use the module Atlas of the software package SILVACO. As a result of the device simulations, both static and dynamic characteristics were calculated. They used as the basis for parametric investigations. The family of curves of the collector current I_C dependencies from the gate voltage V_G is shown in Fig. 3. These curves were obtained for different values of collector voltage V_C (2, 3, 4 V).



1 – V_C = 4V; 2 – V_C = 3V; 3 – V_C = 2V;

Fig. 3. Collector current dependencies I_C on the gate voltage V_G at different values of a collector voltage V_C.

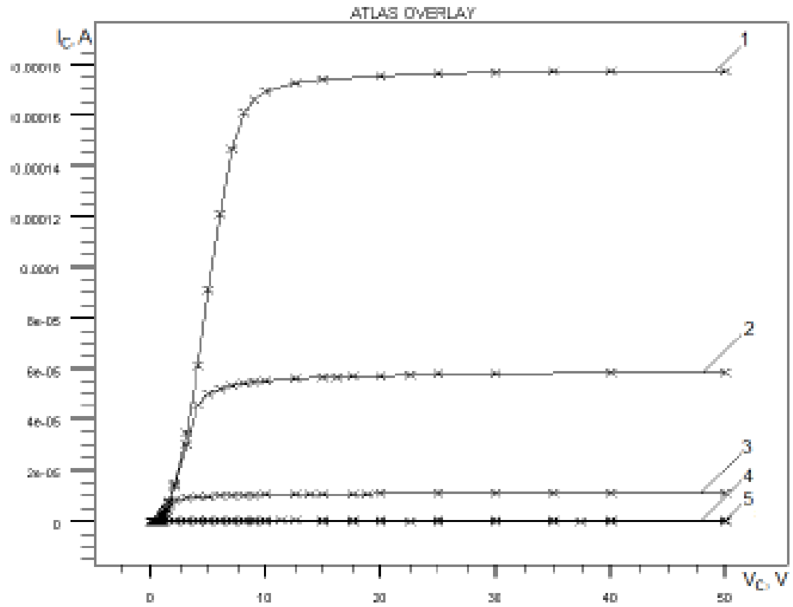
The family of curves of the collector current I_C from the collector voltage V_C at different values of the gate voltage V_G (8, 9, 10 V) is shown in Fig. 4.



1 – V_G = 10V; 2 – V_G = 9V; 3 – V_G = 8V;

Fig. 4. Collector current dependencies I_C on the collector voltage V_C at different values of a gate voltage V_G

The I-V features were calculated with the various thickness values of the gate h_{ox} (Fig. 5). The thickness was varied within the limits from 30 to 70 nm.



1 - h_{ox} = 30 nm; 2 - h_{ox} = 40 nm; 3 - h_{ox} = 50 nm; 4 - h_{ox} = 60 nm; 5 - h_{ox} = 70 nm

Fig. 5. Dependencies of collector current I_C on the collector voltage V_C for the structures with various h_{ox}

The gate oxide thickness has a significant impact on the electrical characteristics of the IGBT. With decreasing oxide thickness from 50 nm to 40 nm, transistor base current is increased and thus the saturation current collector value is also increased (change from =10 μA to =55 μA). The greater change of the current saturation occurs at the further reduction of oxide thickness to 30 nm (the change is from 55 μA at h_{ox}=40 nm to 175 μA at h_{ox}=30 nm). It should be noted that a considerable dependence of the threshold voltage V_{TH} of the transistor on a gate oxide thickness takes place. Namely, decreasing the oxide thickness h_{ox} to 10 nm reduces the threshold voltage V_{TH} to 1.5 V. (The concrete values are: V_{TH} = 10.5 at h_{ox} = 70 nm, V_{TH}=9.0 V at h_{ox}= 60 nm, V_{TH}=7.5 when h_{ox}=50nm, V_{TH}=6 V at h_{ox} =40 nm, and V_{TH}=4.5 V at h_{ox} = 30 nm).

4. Optimization of the IGBT dynamic characteristics

It is known that IGBT turn-on depends on a gate voltage. The speed of turn-on is increased when the gate current is intensified [1]. The IGBT turn-on process is faster than that of bipolar transistor (BT); however the IGBT turn-off is slower than that of MOSFET due to the necessity of forcing both the MOSFET and BT inside the IGBT into conduction state. Thus, the turn-on time ton of IGBT is determined by the charging time of this capacitance (transconductance value).

The current flow in the MOSFET part of IGBT stops (the base current of BT becomes equal to zero). BT reverts to its blocking state and the IGBT is turned off. The turn-off time t_{off} of IGBT is defined as the time taken by the collector current to decrease from 90 % of its steady-state value to 10% of this value. The tailing off of collector current increases the turn-off losses. Both separate regions can be clearly recognized in the turn-off transient of IGBT (fall time values t_{off1} and t_{off2}).

Fall time t_{off2} is governed by the carrier lifetime in the n-base. Finite lifetime of minority carriers in the n-base is a main obstacle to increase IGBT speed. To achieve the desired t_{off2}

value, the lifetime can be reduced by the electron irradiation or proton implantation (localized lifetime decreasing) as well as an n-buffer layer using. These methods allow the gain of the PNP transistor to be decreased and thereby increase the forward voltage drop of the IGBT. Significant minority-carrier lifetime produces a quasi-saturation condition at turn-on, making the turn-on losses larger than the turn-off losses.

Figure 6 shows the shape of the control impulse applied to the gate of the IGBT when modeling transient characteristics. Calculated dynamic characteristics for different values of collector voltage V_C (2, 3, 4V) are shown in Fig. 7. Dynamic characteristics at different gate dielectric thicknesses are shown in Fig. 8 (the collector voltage V_C = 2V).

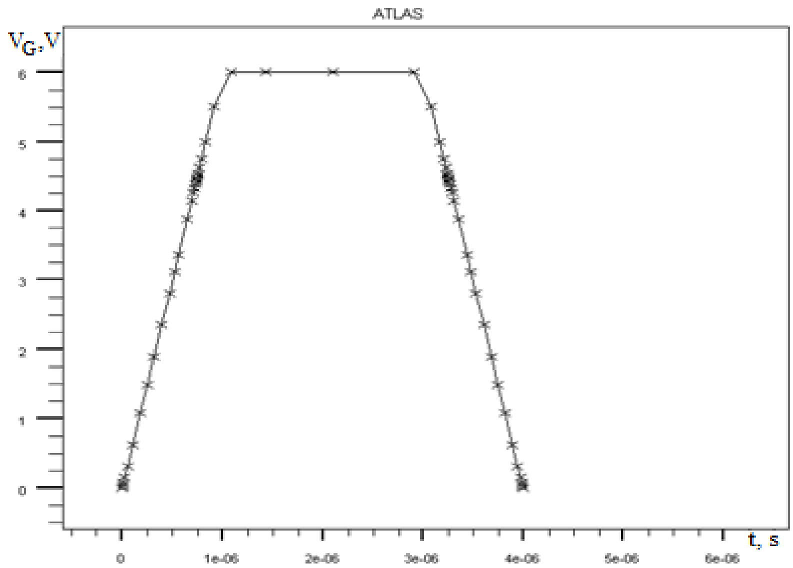
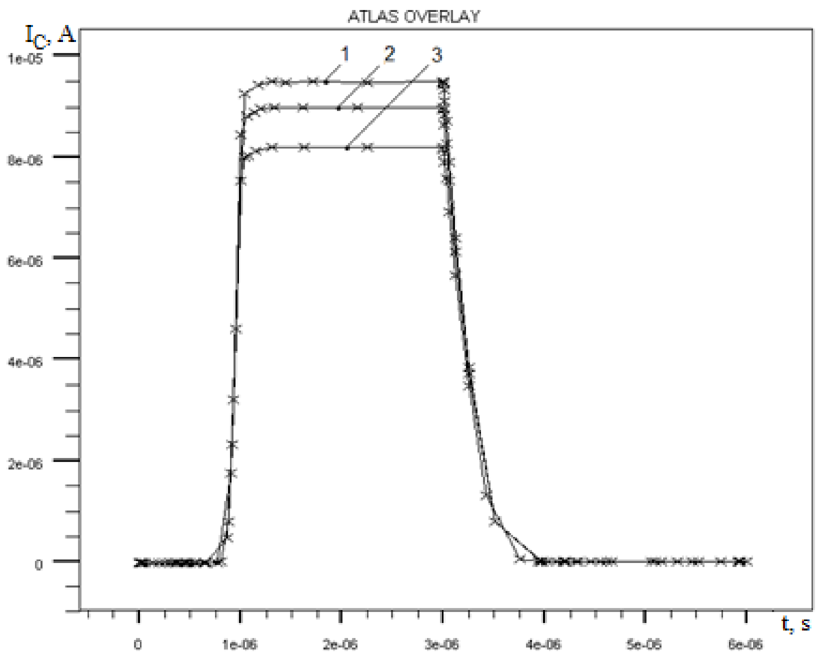
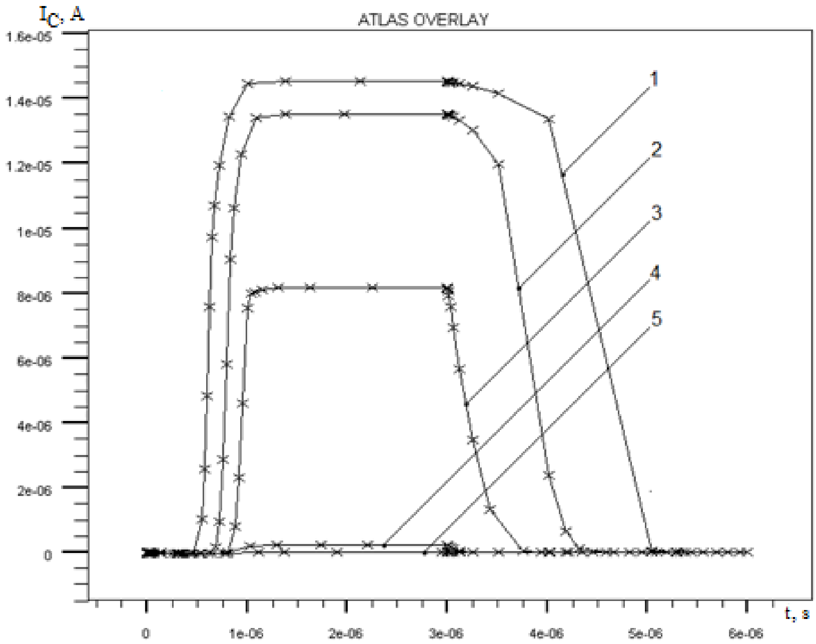


Fig. 6. Control impulse applied to the gate of IGBT.



1 – V_C = 4V; 2 – V_C = 3V; 3 – V_C = 2V

Fig. 7. Dynamic characteristics of IGBT.



1 – h_{ox} = 30 nm; 2 – h_{ox} = 40 nm; 3 – h_{ox} = 50 nm; 4 – h_{ox} = 60 nm; 5 – h_{ox} = 70 nm

Fig. 8. Dynamic characteristics of IGBT at different values of a gate oxide thickness.

The switch-on time for the IGBT on the SOI structures, with varying of the gate oxide thickness is equal to 25 ns and the turn-off time is increased from 55 ns at h_{ox}=40 nm to 75 ns at h_{ox}=30 nm.

Table 1 shows IGBT data for devices manufactured by technology of SOI and by bulk silicon technology [11–12]. One can see that IGBT manufactured by SOI technology have improved electrical characteristics as compared with the IGBT manufactured using standard, bulk silicon technology.

Table 1. Electrical characteristics of IGBT manufactured by SOI technology and by the standard bulk silicon technology.

Parameter	Bulk silicon technology	SOI technology
Collector current, μA	5	175
Threshold voltage, V	2,5	4,5
Switch-on time, ns	350	25
Switch-off time, ns	870	75

5. Conclusions

Computer simulations of technological processes applied for fabrication of a bipolar transistor with an isolated gate (IGBT).were done. Silicon on Insulator (SOI) technology was modeled and the I-V parameters were obtained. On the basis of the results obtained, optimization of design-process parameters was carried out, in particular, of such parameter as the gate oxide thickness. It was shown that this parameter has a substantial influence on the IGBT electric parameters. With reduction of the oxide thickness from 40 nm to 30 nm, the base current of the bipolar transistor increases leading to enlarging the collector saturation current from ≈ 55 μA to ≈ 175 μA. Meanwhile, the switch-on time for the both IGBT structures remains equal to 25 ns, although the switch-off time increases from 55 ns at h_{ox}=40 nm to 75 ns at h_{ox}=30 nm. The calculated values of the switch-on and switch-off times are by an order smaller (25 ns and 75 ns for IGBT on SOI and 350 ns and 870 ns for the structures on the bulk silicon), and the current value of the collector (170 μA) is greater by an order than that of for the vertical IGBT structure on the basis of the bulk silicon (4 μA). IGBT devices, manufactured by SOI technology, have a number of advantages: high input impedance, low output impedance, low forward voltage drop, high breakdown voltage and compatibility with CMOS technology, which enables the integration of on-chip power and the logic part of the integrated circuit. IGBT's on the SOI assume complete dielectric isolation. This provides reducing the leakage current, speed and noise immunity increasing, and allows operate at a high temperature.

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