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Two dimensional simulation and modeling of the electrical characteristics of the a-SiC/c-Si(p) based, thyristor-like, switches

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ABSTRACT

The electrical characteristics of the Al/a-SiC/c-Si(p)/c-Si(n$^+$)/Al switches were successfully simulated here for the first time. Forward breakover voltage V_{BF}, forward voltage drop V_F and anode current simulated values of the device showed very good agreement with the experimental results. Electric field and impact generation rate across the switches are also simulated for different anode current conditions extending to second breakdown region of the device, showing a shifting of the phenomena caused by electric field and impact generation rate, from c-Si(p) region to a-SiC film as anode voltage values increase from V_{BF} up to second breakdown region of the device. A both simulation and experimental based model describing the device behavior, is also presented here. Two critical facts leading to switching transition are proved to be at first a-SiC/c-Si(p) heterojunction breakdown dominated by impact generation rate and second subsequent trap filling in the amorphous film. Al/a-SiC/c-Si(p$^+$)/c-Si(p)/c-Si(n$^+$)/Al switches with reduced V_{BF} and V_F values, were also fabricated and successfully simulated here, enhancing the validity of our simulation procedure and making the switches candidates for ESD protection devices, also due to their advantages of high anode current value density of 5 A/mm^2 before reaching second breakdown conditions in conjunction with cheap and easy fabrication procedure mainly due to r.f. sputtering technique used for a-SiC film fabrication.

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1. Introduction

Amorphous SiC and Si films applications include a variety of known devices such as TFT's, heterojunction transistors, solar cells, photodetectors [1–4] and switches [5–8] due to their important properties. Especially amorphous SiC exhibits wide optical band gap, photoluminescence, electroluminescence, mechanical strength and high saturation electron velocity.

The use of the hydrogenated amorphous silicon carbide is preferred in comparison with monocrystalline material because of the relatively low formation temperature, which guarantees a larger compatibility among the fabrication processes of the silicon carbide layer with current silicon technology. At the same time amorphous SiC films can be deposited at large areas using low temperature techniques like r.f. sputtering and CVD and in conjunction with ultrafast recombination and trapping phenomena occurring generally inside amorphous films [9], can be used for manufacturing high speed switches, as we presented elsewhere [7].

Amorphous SiC films properties and applications remain attractive fields for researchers involved with areas a few of them mentioned below, such as the properties of a-SiC coatings [10], a-SiC based luminescent microcavity [11], nano scale thermal properties of a-SiC [12], trap limited hydrogen diffusion in amorphous SiC films [13], characterization of a-SiC:H thin films grown by RF PECVD [14] and interface reaction between Ni and amorphous SiC [15].

In spite of all the above research no work has been done concerning simulation of a-SiC/c-Si heterojunction devices and manage to gain insight into the switching mechanism problem on an actual device.

We present here, for the first time, a two dimensional simulation for the a-SiC/c-Si(p) based heterojunction switches, exhibiting thyristor-like behavior. In this paper the transfer characteristics of a thyristor are studied through systematic analytical simulation and model calibration and correlation with test results. From the experimentally measured transfer characteristics of the device we can extract the important parameters a-SiC/c-Si heterojunction breakdown and subsequent trap filling of the a-SiC layer which characterize the behavior of the thyristor affecting its V_{BF} and V_F

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values. Through simulation, all the known physical models that govern our device's characteristics were identified and confirmed the operation with impact generation rate playing definitive role in a-SiC/c-Si heterojunction breakdown. Our experimental and respective simulation current–voltage results are in very good agreement.

Simulation results concerning electric field and impact generation rate through the device at different anode current values conditions from initial to V_{BF} and finally second breakdown region, showed that from initial until V_{BF} breakdown region most of the phenomena like impact generation rate take place within a-SiC/c-Si(p) heterojunction region and mainly within c-Si(p) region. Approaching second breakdown region, by increasing anode voltage across the device, nearly the whole impact phenomenon takes place within a-SiC/c-Si(p) region and mainly within the a-SiC film. Although experimental thyristors function before second breakdown region in order to avoid device destruction, our device simulation extended to after second breakdown region extracting important conclusions about device function. It must be mentioned that second breakdown region must reach high anode current values for ESD protection candidate devices [16], which holds true for our switches.

Al/a-SiC/c-Si(p^+)/c-Si(p)/c-Si(n^+)/Al structure named type-2 switches using ion implanted and thermally annealed c-Si(p^+) layer, were also fabricated and successfully simulated here also validating our proposed model and simulation procedure. This leads to possible ESD protection applications because of simultaneous reduction achieved for V_{BF} from 132 to 56 V and V_F from 95.7 to 36 V, showing that further reduce is efficient, in conjunction with cheap and easy fabrication procedures especially due to the presence of R.F. sputtered a-SiC thin film.

Finally our proposed model based on experimental results and describing device behavior proved to be in agreement with simulation results for both structure switches mentioned above.

2. Device fabrication

P/N$^+$ wafers of c-Si, with an epitaxially grown p-type layer on an n^+-type substrate were used in experimental procedures of this work. The wafers had p and n^+-type regions with doping concentrations 1.3×10^{15} and 7×10^{18} cm^{-3}, respectively, and 18 μm for p-type region thickness. All samples were chemically cleaned, and they were dipped into HF solution to remove the SiO_2 layer from the surface. The RF sputtering technique was used for the deposition of an a-SiC thin film onto c-Si type layers using a target of SiC with a constant composition (66% Si and 34% C), 99.8% purity and 81 cm^2 in area. The RF power was 250 W and the chamber pressure was about 10^{-7} mbar before the introduction of argon. The argon flow rate was 20 sccm, while the substrate temperature during deposition was $T_S = 30$ °C, resulting in 42% Si atom concentration in deposited a-SiC films. The deposition produced 1 μm thick a-SiC film. Aluminum dots 5000 Angstrom thick and 1 mm = 1000 μm in diameter were deposited on the amorphous film providing an active device area of 0.785 mm^2, while the back side of the c-Si n^+-type layer was covered with an aluminum layer about 5000 Angstrom thick for all samples. A cross sectional view of the experimental device is shown in Fig. 1a which can be viewed as a pnpn thyristor, without gate electrode, with the first pn junction replaced by the Al/a-SiC Schottky barrier junction. It can be seen that the device includes three junctions. Al/a-SiC is junction 1 (J_1), a-SiC/c-Si(p) is junction 2 (J_2) and c-Si(p)/c-Si(n^+) is junction 3 (J_3). The back ohmic contact is c-Si(n^+)/Al. An 8 KΩ resistance was connected in series with the switch in order to avoid destruction upon switching. Fig. 1b shows a cross sectional view of the device structure used in simulation procedures obtaining very good agreement with the experimental results.

Type-2 switches of Al/a-SiC/c-Si(p^+)/c-Si(p)/c-Si(n^+)/Al structure using P/N$^+$ wafers mentioned above but including a p^+ type layer on c-Si(p) substrate were also fabricated here. The p^+ type layer resulted from B^+ 30 KeV and 9×10^{13} dose ion implantation on p-type substrate layer and subsequent thermal annealing at 860 °C for 30 min, producing 0.2 μm thick film with peak concentration of about 10^{19} cm^{-3}. Type-2 switches helped us for both checking the validity of our simulation procedure and also trying to develop the device I–V characteristics.

3. Simulation, physical modeling and qualitative description of the switching phenomenon

Numerical simulation studies were conducted by using a two dimensional (2D) device analysis program (Atlas by Silvaco Inc.) implemented on a Unix system [17]. This software solves the

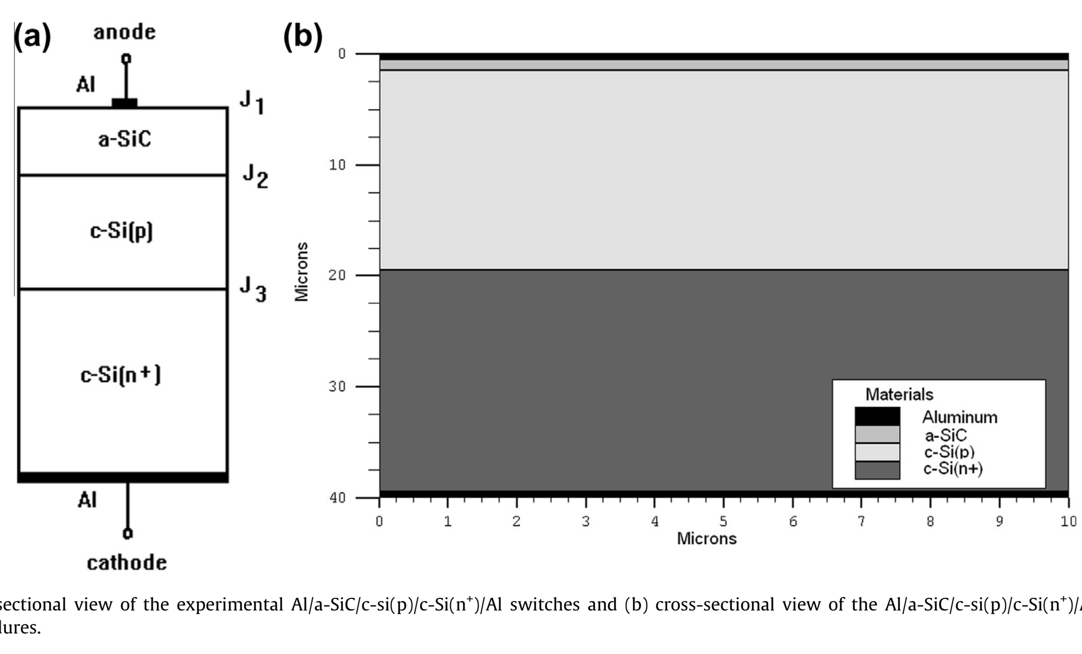

Fig. 1. (a) Cross-sectional view of the experimental Al/a-SiC/c-si(p)/c-Si(n^+)/Al switches and (b) cross-sectional view of the Al/a-SiC/c-si(p)/c-Si(n^+)/Al switches used in simulation procedures.

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