Ultraviolet Photodetectors Fabricated on 4H-SiC

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Abstract—**The aim of the present work is an application of the fabrication technologies of p-n junctions working as photodetectors into the ultraviolet region. Usually, the ultraviolet (UV) photodetectors are fabricated as a standard p-n diode structure with the anode on the top and the cathode on the bottom on silicon carbide (4H-SiC) substrates. The critical part for detectors is the formation of the p-n junction. It can be done by different technological processes, such as ion implantation, epitaxy, etc. This paper presents three different technological approaches to fabricate UV photodetectors as p-n photodiode.**

Keywords- ultraviolet photodetector; semiconductor; thin film; ultraviolet light.

I. INTRODUCTION

Ultraviolet (UV) photodetectors have drawn extensive attention owing to their applications in industrial, environmental and even biological fields. All these applications require very sensitive devices with high signal-to-noise ratio and sometimes high response speed. Compared to UV-enhanced Si photodetectors, a new generation of wide bandgap semiconductors, such as III–V nitrides, gallium nitride (GaN) and SiC, allow to position the p-n junction deeper in the semiconductor structure, which results in lack of sensitivity to unwanted planar defects. Moreover, the SiC material is present in different morphology monolithic and amorphous, which enables realization of advanced stacked photodetecting structures [1]. The monolithic SiC photodiodes are commonly characterized by high responsivity, high thermal stability, robust radiation hardness and high response speed. But, their parameters depend on the material polytype. The 4H-SiC polytype device, due to its large bandgap (Eg=3.26 eV), offers lower leakage current and excess noise factors compared to other SiC polytypes such as the 6H-SiC and 3C-SiC. The aim of this work is the presentation of the fabrication techniques of p-n SiC junctions, aimed to work as photodetectors in UV region, and comparison of obtained results in the form of collected electrical characteristics.

The paper consists of 4 sections. The first section is the introduction, where the new generation of wide bandgap materials for the ultraviolet photodetectors are presented. The second section describes 3 fabrication approaches of SiC p-n junctions. The results of the electrical characterization of the photodiodes are presented in section three. The conclusion is gathered in section four.

II. TECHNOLOGIES AND ELECTRICAL CHARACTERIZATION OF SIC P-N JUNCTIONS

A p-n junction photodiode is just a p-n junction diode that has been specifically fabricated and encapsulated to permit light penetration into the vicinity of the metallurgical junction. The formation of the p-n junction is critical for detectors. It can be done by different technological processes, such as ion implantation, epitaxy etc.

Three different technological approaches to fabricate UV photodetectors as p-n photodiode where the p-n junction is made by [2]–[4]:

- p-type epitaxial layer grown in the chemical vapor deposition process (CVD) (#1),
- 4H-SiC wafers purchased (Cree Inc.) with formed p-n epitaxial layer (#2),
- multiple optimized plasma Al ion implantation (#3),

are under examination. All photodiodes are based on the SiC(n^{++}) substrate with a back metal electrode on the bottom, which use 3-inch diameter 4H-SiC wafers purchased from Cree Inc. The junction is formed from the top by the above mentioned technologies. The whole structure has a metal electrode formed on the top. For experiments, the wafer was diced into segments (10 mm × 10 mm) with a diamond cutting saw.

A. Approach #1: p-type epitaxial layer grown in the CVD process

The p-n junctions were fabricated on the substrate having an n-type resistivity of 0.015-0.028 Ωcm (~10^{18} cm^{-3}). A p-type epitaxial layer was grown on the (0001) Si face via CVD to a thickness of 0.5 μm and a carrier concentration of 10^{15} cm^{-3}, as presented in Figure 1.

 ISBN: 978-1-61208-581-4

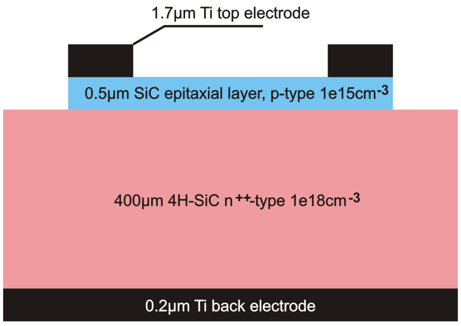

Figure 1. Cross-section of UV photodetector structure with p-type epitaxial layer grown in the CVD process.

The devices are fabricated using mesa geometry to delineate the p-n junction by standard photolithography. The junction was passivated by a thin layer of thermal oxide, which was followed by plasma-enhanced-chemical-vapor deposited silicon oxide (SiO_2). Silicon oxide provides an edge termination of the diode metal contact. The electrodes on n-type and p-type regions were formed by titanium (Ti) and Ti/Al (aluminium) evaporation (lift-off technique), respectively. The contacts were annealed for 5 minutes at 1050°C in argon (Ar) ambient using a rapid thermal annealing (RTP).

B. Approach #2: 4H-SiC wafers purchased (Cree Inc.) with formed p-n epitaxial layer

In the approach #2, contrary to approach #1, the p-type layer was formed by implantation using plasma source of aluminum ions through windows made in a 1um thick deposited oxide. Aluminum is the preferred dopant to produce p-type regions in SiC because of its stability during post-implantation annealing. In fact, the severe ion-induced lattice damage caused by the implantation process requires an appropriate post-implantation annealing for the electrical activation of the dopant and for recovering the crystalline structure, even when an ion implantation at high temperature is performed.

The dopant activation was made by subsequent annealing at 1600°C for 20 min. The electrodes on n-type and p-type regions were formed by Ti/Al/Ti and Ti evaporation (lift-off technique). Both contacts were annealed simultaneously at 1050°C for 5 min. in Ar ambient. The scheme of the obtained structure is presented in Figure 2.

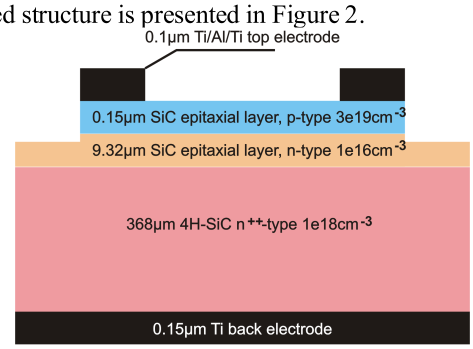

Figure 2. Cross-section of UV photodetector structure with formed p-n epitaxial layer in producer (Cree Inc.).

C. Approach #3 multiple optimized plasma Al ion implantation

The diodes were fabricated on wafers consisting of n-type 4H-SiC substrate with resistivity of 0.021 Ωcm, 0.5 µm thick n-type buffer epitaxial layer with a doping concentration of 1×10^{18} cm^{-3} and 4.5 µm n-type top epitaxial layer with a doping concentration of 1.52×10^{16} cm^{-3}. The cross-section of the fabricated diodes is presented in Figure 3.

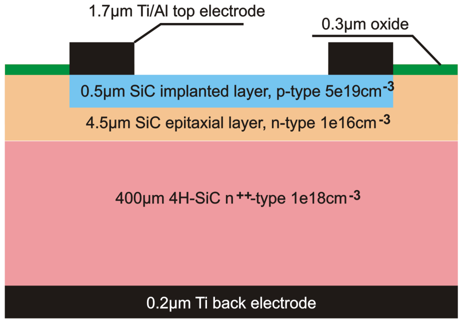

Figure 3. Cross-section of UV photodetector structure with multiple optimized plasma Al ion implantation.

The p-type dopant was again Al and the technology was the implantation. But, the main boundary conditions of implantation as maximally flat (quasi flat, box-shape) profile were taken into implementation. According to the experimental results, it was assumed that minimum implantation energy should be around 55 keV and should not exceed 250 keV. Such process of the flat distribution of p-type Al dopant and a box-shaped profile was realized with multiple energy ion implantations. The total fluence was 7×10^{14} cm^{-2}.

III. RESULTS

The electrical characterization of the p-n photodiodes is mainly covered by measurements of reverse characteristics at room temperature in the dark conditions. These characteristics are most suitable to the leakage current representation, which determines the photodetector quality and sensitivity. The results of the electrical characterization of the prepared photodiodes structures with the use of KEITHLEY SMU 237 [5] are presented in Figure 4.

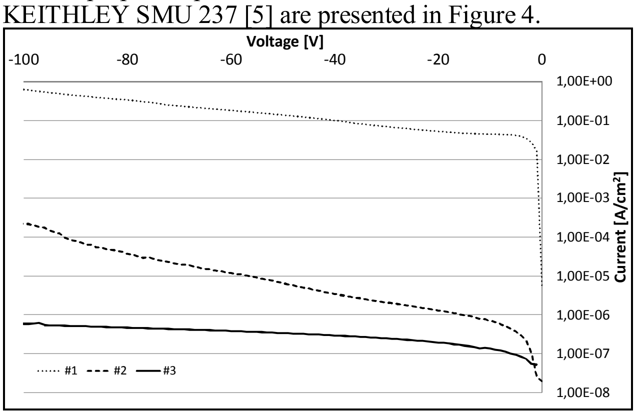

Figure 4. Comparison of reverse I-V characteristics of the circular SiC p-n photodiodes for all three technological approaches.

A comparison of the obtained results shows that the optimization of the quality of p-n junctions leads to expected improvement of photodiode quality by reducing the leakage current by about one order of magnitude. The best characteristics of the device fabricated by approach #3 can also be explained by the fact that the p-type region was formed not by a simple singe implantation, but by an optimized multiple ion implantations.

IV. CONCLUSION

In this paper, the general ideas of various technological approaches of the p-n junctions' formation and characterization were presented. For the UV photodetector purpose, the most suitable technological approach is optimized multiple Al plasma ion implantations. Purchased 4H-SiC substrates with the epitaxial p-n layer are also good for photodiodes preparation. The epitaxial layer grown in the CVD process looks as the least promising technology for use in SiC photodiodes. In future work, we are planning to test structures developed with the use of different UV radiation sources.

ACKNOWLEDGMENT

This work was partially supported by the NCN grant 2012/06/A/ST700398 "Oxide nanostructures for electronic, optoelectronic and photovoltaic applications".

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