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INFLUENCE OF P⁺ LAYER PARAMETERS ON 4H-SiC UV PIN PHOTODETECTOR CHARACTERISTICS

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ABSTRACT

This paper presents a study of 4H-SiC UV photodetectors based on p⁺n thin junctions. Two kinds of p⁺ layers have been implemented, aiming at studying the influence of the junction elaborated by the ion implantation process (and the subsequent annealing) on the device characteristics. Aluminum and Boron dopants have been introduced by beam line and by plasma ion implantation, respectively. Dark currents are lower with Al-implanted diodes (2 pA/cm² @ - 5 V), giving rise to higher values of the UV/dark current ratio.

1. INTRODUCTION

During the past years there has been considerable interest in systems able to record very low light levels in the ultraviolet range in severe conditions of use. The advantage of Silicon Carbide (SiC) with respect to nitride alloys – the major wide band-gap semiconductor used today in industry – relies on three major points : a low residual doping for epitaxial layers (in the 10¹⁴ cm⁻³ range and concentrations of residual defects/impurities at least one order of magnitude lower), a high thermal conductivity allowing high temperature operations, and a very good radiation hardness. It is then possible to use SiC for fabrication of devices capable to operate under extreme conditions. Photodetectors based on SiC allow to obtain good wavelength selectivity in the UV range, without any optical filters.

2. EXPERIMENTAL

The role of the p⁺ emitter layer properties has been particularly studied in this paper. Among these properties, the doping and the thickness are thoroughly key parameters for controlling the device reliability. Photodetector simulations based on finite element method were performed, optimizing the design of the thin junctions for improvement of the light absorption and the carrier harvest. We also investigated the technological process giving rise to the dopant introduction into the SiC matrix. The comparison between standard ion implantation and pulsed-Plasma Immersion Ion

Implantation (PIII) processes is expected to be fruitful, since PIII technology produced impressive results for Si solar cells in the UV range [1]. To our knowledge, PIII doping has never been carried out in SiC material. 4H-SiC n-type epilayers were either implanted with Aluminum by standard ion implantation at 27 keV, or with Boron by PULSIONTM system (pulsed-plasma ion immersion) – B₂H₆ at 8 keV, in order to produce p⁺-type layer thicknesses of 30 and 10 nm, respectively. The doses were adjusted for obtaining peak concentrations of few 10¹⁹ cm⁻³ for Al and few 10²⁰ cm⁻³ for B. Each sample was then annealed at 1650°C or 1700°C, aiming at analysing the influence of the annealing temperature on the device characteristics.

A prototype of furnace was used during this work (purchased from VEGATECTM), consisting in a vertical resistive reactor allied with a lift system. This allows to perfectly control the heating-up and the cooling-down rates, up to ~ 20°C/s. After Al implantations, we observed that a high heating-rate improved the sheet resistance whatever the annealing temperature, and preserved the surface roughness for annealing temperatures lower than 1700°C, which is crucial for thin implanted layers. The heating rate has indeed proven to be an important parameter for controlling the reverse current of the related diodes [2].

3. PLASMA IMPLANTATION IN SiC

We propose to study the combination of PIII with a proper annealing, which should results in thin p⁺ implanted layers (lower than 30 nm) particularly suitable for UV photon detection. PIII were performed on PULSIONTM (Plasma ion implantation tool from the french company I.B.S.) using N₂ gas. Specificity of PULSIONTM is that it uses a pulsed DC polarization and a remote ICP plasma source allowing to work at low pressure (< 1x10⁻³ mbar) with the use of low gas flow rate (< 10 sccm). This helps to minimize parasitic etching or deposition usually encountered on Plasma doping tools.

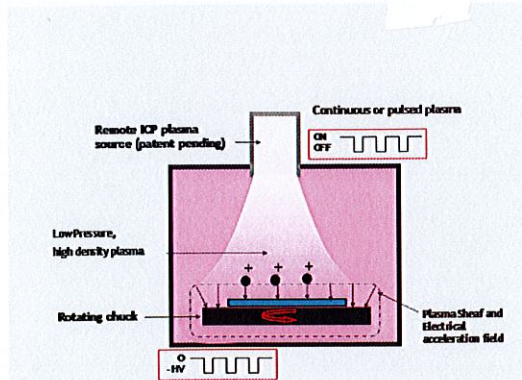


Fig.1 PULSION™ set-up

A former study proved that, at a given energy, the plasma-process lead to a better surface morphology, a lower bulk defect concentration and a thinner junction than a standard beam implantation process. This is accompanied with some dopant outdiffusion during the annealing, and a higher sheet resistance of the implanted layer [3].

4. SIMULATION

The optical simulation of photodetectors under the UV light have been realised by FDTD method (Finite Difference Time Domain), using the commercial software Sentaurus edited by Synopsys society [4]. Electromagnetic solver based on the FDTD method is used to calculate the electromagnetic field propagation inside UV-photodetector device.

Fig.2 displays the variation of the current density with the reverse bias (with an incident light wavelength at 200 nm), for two distinct p⁺-layer thicknesses. In a general way, the current density increases with a thinner junction. When the space charge region is closer to the surface, much more carriers undergoing the electric field are then harvested, leading to a better UV photodetector response.

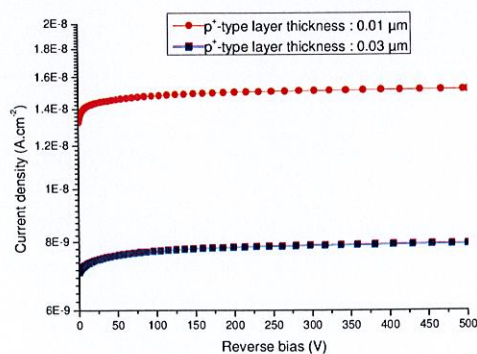


Fig.2 Current density versus reverse bias at 200 nm with a p⁺ doping concentration at $5 \times 10^{19} \text{ cm}^{-3}$

5. CURRENT-VOLTAGE

5.1. Hall effect measurements (RT)

The low thickness of Boron-implanted layers impeded any Hall effect measurement. Al-implanted photodiodes lead to the following values of carrier mobility and hole concentration, respectively : $46 \text{ cm}^2/(\text{V.s})$ and 2.8×10^{17}

cm^{-3} for samples annealed at 1700°C , $54 \text{ cm}^2/(\text{V.s})$ and $1.9 \times 10^{17} \text{ cm}^{-3}$ for samples annealed at 1650°C . Rambach *et al.* proved a better activation of Al implanted atoms for a higher annealing temperature, which increases carrier scattering and then diminishes the mobility [5].

5.2. Room-Temperature measurements

The evolution of dark currents with reverse bias is shown in Fig.3. These currents are more important with B-implanted junctions. Some B outdiffusion and/or material etching during the metallization may have partly degraded the junctions.

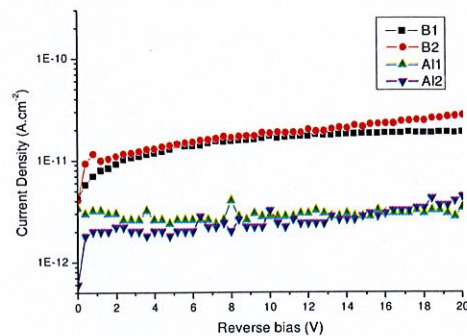


Fig.3 Dark currents of Al- and B- implanted photodiodes

Characteristics of the diodes have been measured under light, with an incident wavelength of 365 nm. Fig.4 displays the evolution of the UV/Dark current ratio with reverse bias. Again, Al-implanted photodiodes revealed better achievements, proving a ratio six times higher than for B-implanted diodes.

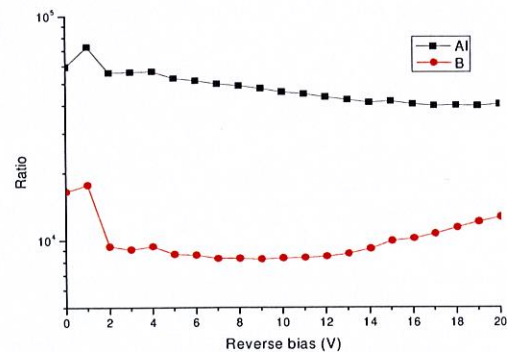


Fig.4 UV/Dark current ratio for Al- and B- implanted photodiodes

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