Impact of SRFE process on electrical properties of P-N photodetector

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Abstract. Semiconductor properties change from soft radiation flash exposure process (SRFE) will present in this paper. Semiconductor device use with radiation application and always degrade because impact from radiation will damage on device structure. Currently, the defects from radiation cannot explain all of impact to electrical properties because has wind range in several application. However, this paper will present influent from Roentgen radiation on P-N photodetector device by expose for few second and low energy. The radiation will expose on device for many time to reach target time and will control distance between radiations machine and devices. Forward current of device after SRFE process has changed in positive way by build in potential (V_{bi}) decrease around 0.2V and forward current increase around 4 orders.

Keywords: P-N photodetector, SRFE process, energy band gap, COMSOL, series resistance

1. Introduction

In principle of semiconductor ability can control by atom doping, temperature and mechanism properties. This material has energy band gap not over 4eV that higher than metal material. The energy band gap (E_g) is the energy between conduction band and valence band. Electron has to get energy same of energy band jump to conduction band. However, researcher try to change and adjust semiconductor material for support many application such as transistor, solar cell and detector. Process for device fabrication has several step and always generate defects and change mechanism of substrate [1]. The defects will influent to device performance such as decrease lifetime [2] and change properties. Many research try to explain by electrical characteristics of devices such as DMOSFET has early breakdown due to poor reliability. [3]

Defects in semiconductor device generate by many case. Silicon wafer is one of case for defects generate such as point defect, plan defects and spatial defects shown in Figure. 1 [4]. Moreover, fabrication process also generate defect by high energy doping process, thermal doping process and rapid thermal annealing (RTA) [5]. Although, device has defect in mechanism but some of defect not impact to properties to much, power device focus on higher breakdown if has small defects will not impact to performance.

Ion implantation is one of process in semiconductor device fabrication. This process use for doping atom on substrate with high energy. The damage from this process can generate defects or create cluster in...
substrate. Therefore, the device will pass annealing for treatment after this process and also help atom diffuse into silicon substrate. The goal of this paper will using SRFE process change properties of semiconductor device by expose for few second. Soft radiation may induce some of defect, on the other hand, may help to treatment electrical properties of device as well.

![Figure 1](image1.png)

Figure 1. Example defects in semiconductor device (1) point defects, (2) dislocation defects. [6]

2. Experimental procedure

2.1. Fabrication process and device structure

Device will fabricate by using CMOS technology. The silicon substrate type is n-silicon shown in Figure 2. The process flow show in below:

- Deposited oxide cover and also etching to open active area
- Doped phosphorus by ion implantation technique with high energy 120 keV by dosage $1 \times 10^{16}$ cm$^{-2}$ on back side for ohmic contact
- Doped boron in active area same technique and energy with backside
- Diffuse platinum on backside of device and diffusion by RTA technique for 6 hours with high temperature
- Create metal (Al) both side then annealing treatment by TA technique
- By the final will die device prepare for testing

![Figure 2](image2.png)

Figure 2. Device structure after fabricate.
2.2. Simulation
Simulation results will generate by using COMSOL semiconductor program. By using device fabrication condition same actual and export results to study on the effect from fabrication process and also substrate mechanism.

2.3. Experimental and device measurement
Device after fabrication process will measure current-voltage (I-V) characteristics. Voltage bias provided from 0 to 1V by step 0.02V. Then, device will expose radiation by SRFE process. The radiation exposed to device by many times for few second and measure I-V characteristics. SRFE process on device shown in Figure 3.

![Figure 3. SRFE process on semiconductor device.](image)

3. Results and Discussions
Figure. 4 shows a results of doping concentration profile by COMSOL simulation. Doping atom after ion implantation high concentrate around surface and will drive in to substrate by using RTA technique.

![Figure 4. Concentration profile of doping atom.](image)

By on surface has damage from doping ion implantation and may generate trapping center. The diffusion profile has high concentration deep to device structure around 7 µm after RTA process. By the surface has decrease concentration before RTA then atom will diffuse to substrate. Although doping atom diffuse to substrate mechanism but them will decrease concentrate once deep much more range [7].
Temperature and time are the main factor for diffusion range. If anneal device with high temperature and take long time atom will get kinetic energy and drive through deep range of substrate. However, atom will always generate more defects and cluster in substrate mechanism if using high temperature and take long time. This investigation will study by control which energy and time are optimize for RTA process. [8, 9]

Doping atom diffusion range profile shown in Figure. 5 by the correlation of profile relate with Figure. 4. The center of doping point has high concentrate and also has defect in this area by atom behavior. The atom will expand diffuse to substrate by non-direction depend on kinetic energy from RTA process and also host mechanism. The potential of diffusion from self-diffusion and RTA process will generate many kind of defects such self-diffuse may generate point detects and RTA with high temperature will break silicon bond then doping atom can create defects.

Forward current characteristics of device before SRFE has current around $10^{-5}$A and after SRFE current increase around 4 orders at 1V bias shown in Figure. 6. By after SRFE current show $10^{-1}$A that show different results with radiation effect in the past. However, effect of SRFE on forward current team may from this process cure defect and also decrease series resistance of device.
The series resistance ($R_s$) is significant impact to downward curvature of forward bias characteristics of device. Series resistance use for observed dominate in forward current, the current-voltage relation base on Shockley equation can be explain by equation below:

$$I = I_0 \left[ \exp \left( \frac{q(V_A - IR_s)}{\eta KT} \right) - 1 \right]$$  \hspace{1cm} (1)

Where $I$ is measured current, $V_A$ is the voltage applied across PN junction and parallel resistance ($R_s$) of driving diode, $q$ is electronic charge, $\eta$ is diode ideality factor that can describe PN junction departure from ideal diode performance, $K$ is Boltzmann's constant, and $T$ is device temperature. \[10\]

4. Experimental procedure

From previous results of radiation influence will decrease device performance and also reduce device lifetime. In this paper has present the effect from fabrication process by simulation which process impact to device performance such as diffusion process. Ion implantation is an importance technique for diffusion and also huge impact to substrate mechanism. SRFE process use for expose on photodetector after fabricate for few second with low energy. However, SRFE can increase device performance by increase forward current from $10^{-5}$ to $10^{-1}$A, 4 orders and also change build in voltage reduce around 0.2V. Although, SRFE take few second on device and dose may optimize for device treatment.

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