Surface Thermal and Electric charge of PN Diode Expose by Soft Radiation Flash Exposure

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Abstract: In this study present the effect of soft radiation flash exposure (SRFE) to forward bias current-voltage (I-V) of PN diode by using COMSOL simulation program. The results show surface thermal and electric charge while expose by radiation with flash exposure technique. Series resistance (R_s) increase around 2 times and close to idea case after expose by radiation, the radiation will impact to bulk defect and reduce surface recombination. SRFE induce temperature on surface and deep into silicon bulk. The value of R_s increase with increase expose time. The changing of R_s becomes independent from radiation dose at high forward bias voltage.

1. Introduction

Ion implantation is one of technique use for doping atom with high energy and short time more than thermal doping. This technique can control the concentration of atom for doped in semiconductor material by calculate time and energy [1]. However, ion implantation can generate defects in substrate because high energy. After doping process will follow by RTP (rapid thermal process), this technique can push doping atom deep to substrate and treatment properties of device.

RTP usual in manufacturing of semiconductor device by heat substrate with high temperature around 1000-1200 °C just few second. This process should careful about wafer temperature brought down by slowly due to wafer structure has effect if temperature down quickly such as dislocations and wafer break. RTA (rapid thermal annealing) is the process in RTP using for treatment damage from ion implantation [2]. This technique quite different from furnace annealing (FA) because time for RTA just few minute. In principle, RTA can reduce damage from several process from device fabrication but cannot destroy big cluster in substrate structure [3].
Radiation technique use for change characteristics of semiconductor for long time such as β-beta [4], photon [5], neutron [6] and Roentgen [7]. Radiation can change the properties of material by generate trapping, defects and treatment. Generally, high radiation always use for create trapping in silicon material structure to change switching time but it can generate unpredicted defects that will impact to device performance. The simulation program use in this paper is COMSOL multiphysics.

COMSOL is tool use simulate design and investigate the effect in semiconductor device. The option for COMSOL multiphysics use for considerate performance of semiconductor device and predict the device characteristics [8].

In this paper, we will investigate to use SRFE for treatment and improve performance of semiconductor device base on silicon substrate after pass several process in wafer and fabrication process. SRFE will use for study in this experiment with short time expose on device after fabrication. However, we will show the effect of atom implantation in silicon substrate by simulation.

2. Experimental
The processes of P-N diode were show in the picture. The wafer was cleaned with an ultra-sonic wash to remove organic contaminants. The diode process module consists of (i) the deposition of the oxide covered substrate and the dry-etching oxide of the active area, (ii) the implantation of phosphorus at an energy of 120 keV and dosage of 1x10¹⁶ cm⁻² for ohmic contact on the backside wafer, (iii) the implantation of boron at the same energy (iv) create platinum layer on the backside and diffusion at 850°C for 6 hours (v) create 1 µm thickness of Aluminum layer at both side and anneal at 400°C for 30 min. Finally, the fully assembled chip was installed onto a prototype circuit board (PCB) before the finishing. After fabrication process the diodes were irradiated by SRFE with few second. The current-voltage (I-V) characteristics of the PN diode were measured at room temperature by bias voltage from 0 to 1 V, step 20 mV [9].

![Device structure after fabrication](image)

**Figure 1.** Device structure after fabrication

The simulation by COMSOL will leverage PN diode fabrication process. The results can explain effect of some process from wafer and fabrication process to semiconductor device performance. From model of PN diode design will show diffusion range and effect of SRFE temperature while expose.

3. Results and discussions
From the results show forward current-voltage characteristics of PN diode before and after SRFE process. Figure 2 shows build in voltage ($V_{bi}$) of device, $V_{bi}$ of non-SRFE around 0.4V but after SRFE
process $V_{th}$ has increased to 0.5V. SRFE process may impact to device structure due to when expose radiation on device will generate thermal and radiation penetrate into device mechanism. [10]

Figure 2. Forward current of PN diode (a) non-SRFE, (b) SRFE

Figure 3 shows semi-log forward bias I-V characteristics, the results show significant change after SRFE. Forward current before SRFE process show around $10^{-5}$A, on the other hand, current after pass SRFE process around $10^{-3}$A (0.6 to 1V). In principle, forward current deviate considerable due to the effect from series resistance. 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 [11]:

$$ I = I_0 \left[ \exp \left( \frac{q(V_{A}-1)R_s}{n \kappa T} \right) - 1 \right] $$

(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.

**Figure 3.** Forward current-voltage between non-SRFE and SRFE process

Series resistance increase 2 orders after SRFE, the process may help treatment device such as reduce insulator resistance and reduce defects in silicon bulk [12]. Radiation may destroy defect or cluster from wafer and fabrication process. SRFE has low impact to junction and mechanism due to low energy and shot time expose. However, SRFE has optimize energy and time to improve PN diode as show by forward current results [13].

**Figure 4.** Effect of radiation generate thermal on PN diode

**Figure 5.** Thermal effect in doping area of PN diode while SRFE process
Figure 4. Shows radiation generate effect on device by the simulation results show temperate occur on active area. The results can confirm radiation has 2 kind of effect while expose on device are temperature but not high.

Figure 5 shows the thermal generate while expose radiation on top of PN diode. The high temperature impact to junction deposition. Red color has high temperature and slightly decrease to silicon bulk. The picture show impact of temperature focus on deposited area, this area doped with n+ and may generate defects. However, temperature not impact to this area to much because temperature around 200 °C by few second but the significant by SRFE from radiation penetrate to device structure. Radiation influence to defect in device, the explanation of this effect in a basic of radiation dependence of minority carrier lifetime and build conductivity of device [14]. The variety of SRFE effect on PN diode characteristics obtained in this work indicate rather complex dependence of diode characteristics on SRFE process.

4. Conclusions
In summary, we have observe the effect of SRFE on the forward I-V characteristics. A new results classify the effect from radiation by different are temperature and radiation particle has been publish in this work first time. All our results show effect of SRFE reduce series resistance that show in forward current increate around 2 orders. SRFE influence direct to defects in device, radiation may change or remove some of defects by several process while fabricate.

The most of important for this observe is radiation not damage to device while use with optimum time and dose. We can use this study begin start to use SRFE process for enhance semiconductor performance not only silicon base and we can simulate by change material and design as well.

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