Investigation the Effect of Soft X-ray Flash Exposure on PN Diode

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Abstract. In this paper will present the properties of PN diode before and after expose by radiation. Although, radiation help to improve the performance of semiconductor device but still has some damage in device structure. In previous article I have showed performance improve after expose by soft radiation. The device is exposed by low frequency X-ray radiation (soft radiation flash exposure: SRFE) technique with few second for several times. In principle of PN diode after fabrication will has defects from process such as ion implantation, doped and silicon wafer process. The results show temperature while SRFE expose on device that generate high temperature on surface and silicon boundary that may the optimize energy and expose time for treatment damage of PN diode.

1. Introduction
Semiconductor device use for component in many application [1-3]. One of reason, semiconductor device still important and has demand for current technology due to researcher always improve and create new device [4]. As we know, company like Intel and Texas instrument still spend a lot of money for laboratory in development and design. Not only research in silicon they investigate another material, gas and deep into bulk quantities [5].

PN diode is most of popular structure for semiconductor device. This structure not complicate for fabricate and can apply to use with many application such as control switching time [6], lighting LED [7] and DC power supply [8], etc. PN diode can use both reverse and forward bias, reverse bias use for power device and forward use in high speed detector or switch. In generally, device performance reduce from several process of device fabrication. Silicon wafer process has defect while growth silicon ingot and also in device fabrication [9-10].

Radiation treatment is one of way to repair damage in semiconductor device [11-12]. As we know that radiation has high energy and it will generate some of defects in substrate bulk [13]. In previous of my article has published, the electrical properties of device change after expose by SRFE.

The goal of this paper will analysis the effect of radiation on properties of PN diode such as carries concentration and thermal effect in device.
2. Experimental procedure
PN diode was fabricated on thin silicon with high purity (intrinsic). (a) clean n-type silicon, thickness 300 µm, resistivity 7-20 Ω·cm with DI water and ultrasonic for 5 mins, (b) doped platinum on back side of substrate, (c) annealing by using RTA process at 800 oC for 5 mins, (d) coating Al on top of silicon, (e) photolithography and open active area, (f) sintering with 500 oC in nitrogen environment, (g) the last step for checking adhesion on metal contact by using 3M sticker stick with contact and pull off. The device after fabricate show in below: [14]

![Device after fabrication process](image)

Figure 1. Device after fabrication process

Figure 1 shows device structure after fabrication by several process. The investigate effect of SRFE on device properties was prepared by CMOS fabrication technology and simulate by COMSOL simulation program [15]. Devices test condition are expose by SRFE 3 seconds for 40 times. The electrical properties current-voltage (I-V) of device measured by HP4156B with bias from -10 to 1 V, step 0.1 V. Capacitance-voltage (C-V) use same measurement by sweep voltage -10 to 0 V, step 0.1 V [16].

In principle of semiconductor, the electrical change due to mechanical properties of device change from several reason such as high thermal annealing for reduce electron trap, laser annealing and high energy radiation expose annealing (200 MeV by continuous). All technique try to treatment damage from several process and would like to improve performance of semiconductor device but not all technique success in laboratory.

In this paper investigate the effect from SRFE to PN diode with Pt atom doped. SRFE use energy around 50 keV with few second by several time of exposure. Radiation will expose to device for 3 seconds by 40 times. However, this paper will provide simulation results effect of ion implantation and SRFE temperature in device [17]. The concentration in junction depth can calculate by

\[
N(W) = \frac{C^3}{qK_0A^2dC/dV} = \frac{2}{qK_0A^2d(1/C^2)/dV}
\]

Using the identity

\[
d\left(\frac{1}{C^2}\right)/dV = -\left(\frac{2}{C^3}\right)dC/dV
\]

Where A is the area of device, N is doped density, A is the dc bias, W is the space-charge region, \(\varepsilon\) is the permittivity of free space
3. Results and discussion

Figure 2 shows the experimental semi-log forward and reverse bias of the PN diode with Pt atom doped. By generally, the physical mechanism of semiconductor device could induce leakage current after expose by radiation [18] but in our results show reverse current not generate radiation-induce leakage current effect (GRILE). However, forward-current show significant different between before and after SRFE process.

![Figure 2. The experimental of forward and reverse bias, current-voltage (I-V) characteristics of PN diode with Pt atom doped.](image)

Figure 3 shows the leakage current with reverse bias voltage, leakage increase when depletion region expand to deep level of substrate bulk. However, graph show that leakage current decrease after SRFE process around 1x10^{-10}A. Although, current not decrease by significant number but show good trend for this study. In case of results, SRFE may impact to defects by several reason such as destroy defects cluster [19], change kind of defects [20] or reduce defects in silicon bulk [21]. However, we
will analysis carrier concentration compare between before and after for confirm impact of SRFE in reverse current condition.

![Figure 4. COMSOL simulation results of SRFE temperature generate in PN diode](image)

Temperature of SRFE in PN diode show in Figure 4, the picture show surface has high temperature then slightly decrease deep to substrate around 6-8 µm (refer from diffusion range after RTA process). In principle of SRFE it should be penetrate to all of device thickness due to the device has thick around 300 µm and temperature may cure device like thermal annealing. Kind of generate from SRFE impact to device are thermal and radiation. Surface thermal impact to grain boundary same of thermal annealing in furnace or RTA process although we don’t know how much temperature occur while SRFE process. Moreover, SRFE will has another effect to the characteristics of device, the radiation will destroy defects and treatment device properties not only generate thermal on surface. In this paper confirm SRFE condition is good for treatment of PN diode.

![Figure 5. Carrier concentration of PN diode before and after SRFE process by reverse bias](image)

Figure 5 shows carrier concentration of diode while reverse bias. From the Figure show when reverse bias 0 to -2 V, the carrier concentration not different between before and after SRFE. While concentration slightly decrease at -2 to -3.5 V around 4x10¹³ (1/cm³), then increase at bias -5 to -6 V around 6x10¹³ (1/cm³). When we calculate depletion width at -2 to -3.5 V is the junction range between doped area and silicon bulk. Mean SRFE will impact to this area if we refer from Figure 4. From Figure 4 the temperature has high in red area around 7-8 µm (-2 V by depletion region range). After -6 bias voltage, the concentration between before and after are same trend.
4. Conclusion
There are 2 points to be made about the results presented here. First, SRFE have clear dependence on the reverse bias of PN diode. For 2 cases of SRFE generate to device are temperature and radiation penetrate silicon bulk. Leakage current slightly decrease by SRFE and the concentration at junction depth change and we will analysis by more results to investigate more detail of the effect from SRFE. However, the results are complicated that is not clear whether these effect impact only surface or all bulk of silicon, or not.

Second point, forward current after SRFE show significant change close to ideal case of PN diode theory. The current before SRFE show trend out from ideal case, it may from many reason but SRFE can treatment device properties. From the results of reverse and forward bias show that SRFE can improve performance of diode.

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5. References
[1] EL-Hang L and Kyoungwan P 2000 Mat Sci Eng B-Adv vol 74 p 1-6
[2] Mark A R 2000 A rchitectures for Molecular Electronics Computer p 386-426
[3] Satoshi K Hitoshi U Julien P and Mariko S 2018 Power Electronics Device Application of Diomand
[4] Jose M Philippe G Xavier P Amador P T and Jose R 2013 IEEE Trans Power Electron vol 29 p 2155-2163
[5] Vasile V N and Alexandru C O 2010 CAS 2010 Proceeding (Romania)
[6] Saijun M Tao W Xi L Jelena P and Jan A F 2016 6th Electronics System-Integration Technology Conference (ESTC, France)
[7] Bruno G 2016 Cr Phys vol 18 p 453-461
[8] Denis F 1998 Introduction to Power Electronics p 125-148
[9] Elenore L Jordi V Williried F and Mustapha L 2016 Energy Procedia vol 92 p 845-851
[10] Florian E Daniel C Davide C Marcello C Mariluz P Hon A O Hermann F and Gernot K 2016 Procedia CIRP vol 67 p 368-373
[11] Cullis A G 1985 Rep Prog Phys vol 48 p 1155-1233
[12] Shwetabh P Vedansh D and Shubham D 2017 International Journal of Advance Research in Electrical, Electronics and Instrumentation Engineering vol 6 p 4016
[13] Summers G P Burke E A Shapiro P Messenger S R and Walters R J 1993 IEEE Trans. Nucl Sci vol 40 p 1372-1379
[14] Narong S Itsara S and Preecha P Y 2016 Far East Journal of Electronics and Communications vol 16 p 443-449
[15] Gaurav S and Roy P 2016 Sensing and Bio-Sensing Research Vol 4 p 57-60
[16] Itsara S Surada U Surasak N and Preecha P Y 2012 Opt Express vol 20 p 12640
[17] Narong S Itsara S and Preecha P Y 2016 Far East Journal of Electronics and Communications vol 16 p 451-458
[18] Fred S G William L H 1961 Nucl Instr Meth vol 12 p 249-262
[19] Miaomiao J Penghui C Sidney Y and Michael P S Acta Mater vol 155 p 410-417
[20] Michael W David F Andrea B Yongqiang W Peter H and Daniel K 2018 Mater Des vol 160 p 1148-1157
[21] Via F L Severino A Anzalone R Bongiorno C Litrico G Maucci M Schoeler M Schuh P and Wellmann P 2018 Mat Sci Semicon Proc vol 78 p 57-68