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Xenon flash lamp annealing of large area silicon photodetector

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Abstract

Xenon flash lamp with 100 μs pulse duration was used to enhance the performance of large area (1 cm^2) diffused silicon photodiodes. Leakage current, rectification, and photoresponse of silicon photodiodes after flash lamp annealing (FLA) as function of the number of shots were investigated. The experimental results show a significant improvement in photodetector properties after annealing and the best annealing condition obtained with 11 shots. No shift in peak response of photodetector is observed after FLA. Furthermore, the stability of photodiode was investigated.

Keywords: Flash lamp; Annealing; Si; Photodiode.
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1. Introduction

Pulsed–light annealing of silicon either by coherent or incoherent light is of a major importance for thermal induced regrowth process [1-3]. The performance of regrowth process is strongly depended on the pulse duration, pulse energy deposited, and the thermodynamic properties of the materials. The mechanism of annealing is independent of the coherency within certain limit of operation of the light, moreover, the incoherent light sources are cheep but have high efficiency compared to coherent sources e.g. pulsed lasers system. One of the most important advantages of incoherent sources is the large area of processing, while laser-beam profile is usually limited to a much smaller size [4]. The xenon flash lamp is a relatively efficient device or it converts 40 to 60% of the electrical input energy into radiation in the 0.2-1 μm spectral range. The wide spectral range is efficient matched to absorption spectrum of silicon [5] as shown in Figure 1.FLA is ultrarapid thermal processing technique that has great advantage over the tungsten filament ,FLA provides much steeper heating/cooling ramp rates and lower thermal budgets [6]. In this paper we have focused on the investigation of optoelectronic properties of large area p-n junction silicon photodetector after rapid thermal annealing by means of Xe flash lamp.

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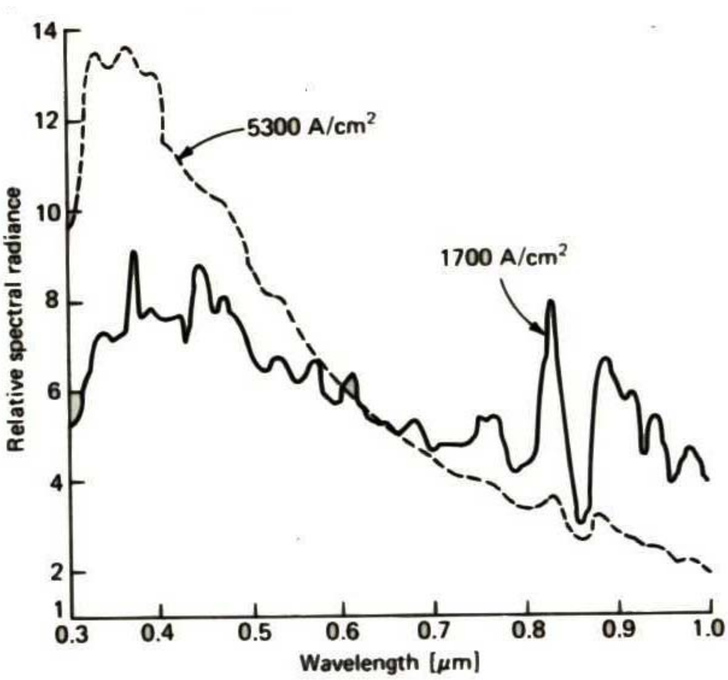


Fig. (1). Distribution of xenon lamp spectrum [5].

2. Theory

The rapid annealing processes can be divided into three groups (1) adiabatic (2) thermal flux and (3) rapid isothermal annealing. In adiabatic annealing, the energy is deposited right at the surface within the top 1 μm layer in a time too short to allow any appreciable heat loss by diffusion into material.

Heating with laser, electron beam and flash lamp fall into this category. A major difference between various thermal sources is the time scale in which the energy is delivered to the semiconductor and how it compares with the thermal response time (t) of the semiconductor defined by $t = S^2 K^{-1}$ where S is the thermal diffusion length or the sample thickness and K is the thermal diffusivity. It is obvious from the above equation, thinner layer need very short annealing time. The thermal response time varies from micro to milliseconds depending on the value of K and absorption depth α^{-1} of radiation which depends on the crystallinity and doping level of semiconductor [7].

For flash lamp annealing when light incident on Si substrate a part of light is absorbed and resulted in rise the temperature of Si substrate. The rise of the substrate temperature (T) as function of pulse number (N) can be obtained theoretically by solving the one – dimensional heat flow equation [8]:

$$c\rho\frac{\partial T}{\partial t} = I(x,t)\alpha + \frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right) \tag{1}$$

with the boundary and initial conditions:

$$\frac{\partial T(x,t)}{\partial t} = 0 \quad \text{for} \quad x = 0 \;,\; t<0$$

$$T(x,0) = T_o = 298k \quad 0 \le x \quad d < \ , \ t = 0 \tag{2}$$

Where c is the heat capacity, ρ the density, α is the absorption coefficient, K the thermal conductivity, $I(x,t)$ is the intensity of flash lamp within substrate at time t and depth d .

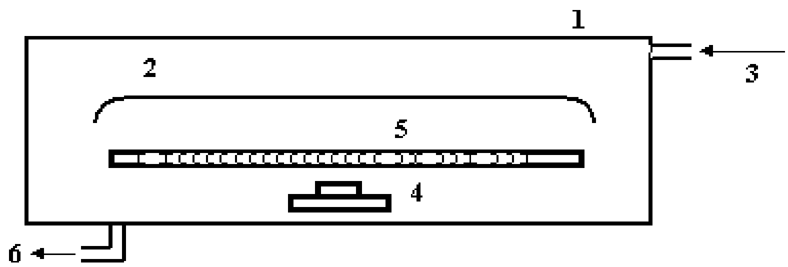
For single pulse the flash lamp intensity within substrate can be obtained by

$$I(x,t) = (1-R)I_{\circ}(t)\exp(-\alpha x) \tag{3}$$

Where is the substrate light reflectivity, $I_{\circ}$ the intensity of incident light pulse (square wave)

3. Experiment

In this study, we used a single crystal of 1cm^2 p-type silicon polished wafers having (111) orientation with electrical resistivity of (3-5) Ω.cm. To form p-n junction phosphorus atoms were diffused into silicon using $POCl_3$ source at 850 ^oC for 1hr. Four point probe measurements have been used to determine the sheet resistance R_S. Xenon flash lamp annealing system with 11 cm length and 4 mm bore diameter was employed with number of shots (N= 5, 11, 20) with pulse repetition frequency of 1 shot/s with energy density around 0.5 J/cm^2. The duration of light pulse was measured by an oscilloscope using silicon photodiode and the duration of pulse was measured and found to be 100 µs (FWHM) which represent annealing time. Four point probe system was used to measure the sheet resistance. Fig.(2) shows the apparatus of annealing system used in this experiment. After annealing electrical ohmic contacst were made by deposition of Al and Au-Sb films on p-type and n-type respectively using thermal resistive technique. Thin layer of TiO_2 antireflecting coating was deposited on n-type layer through mask by electron gun technique. Finally, the samples were mounted on special package. To investigate the photoresponse of photodiodes before and after flash lamp annealing (FLA), a calibrated monochromator in the spectral range of 400-1100 nm has been used.



1.Stainless steel cell 2. Reflector 3. Inlet gas 4. Si photodiode 5. Flash lamp 6. To vacuum pump.

Fig. 2: Schematic diagram of FLA system.

4. Results and Discussion

Fig. 3 reveals the electrical sheet resistance R_s before and after FLA, a pronounced decreasing in the R_S of n-type region after annealing up to 11 shots was observed. This effect can be attributed to the semi-complete activation of dopants resulted form dissolved the precipitation of phosphorus [9-10]. Increasing annealing shots leads to increases R_S, this is probably due to dopant diffusion and junction degradation. This is because of diffusion of impurities to the depth > junction depth X_J (X_J = 0.3 μm).

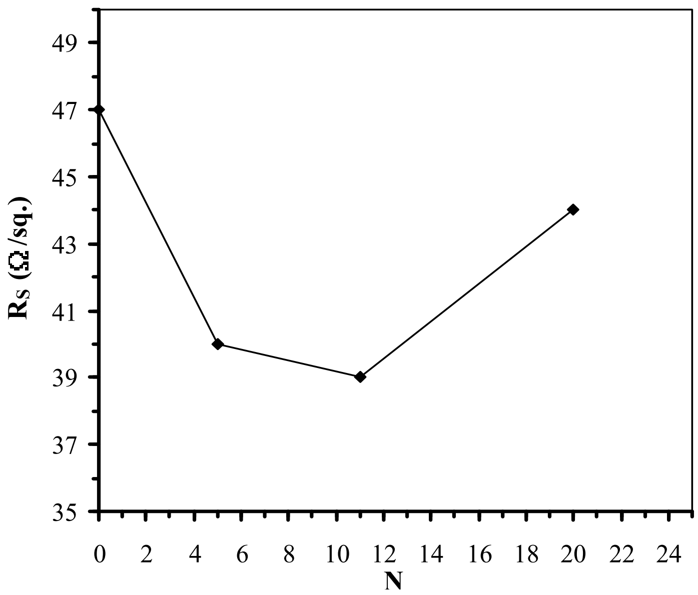


Fig. 3: R_S vs N plot.

The effect of FLA on the I-V characteristics of photodiodes under dark condition is depicted in Fig. (4), it is clear that improvement of I-V be profile and rectification ratio at 1V were achieved. The maximum rectification obtained after annealing with 11 shots as shown in Fig. 5.

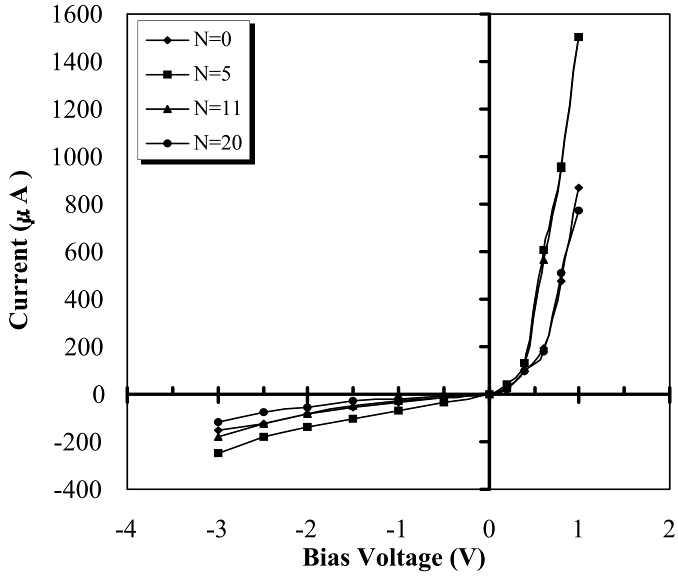


Fig. 4: I-V curve under dark condition.

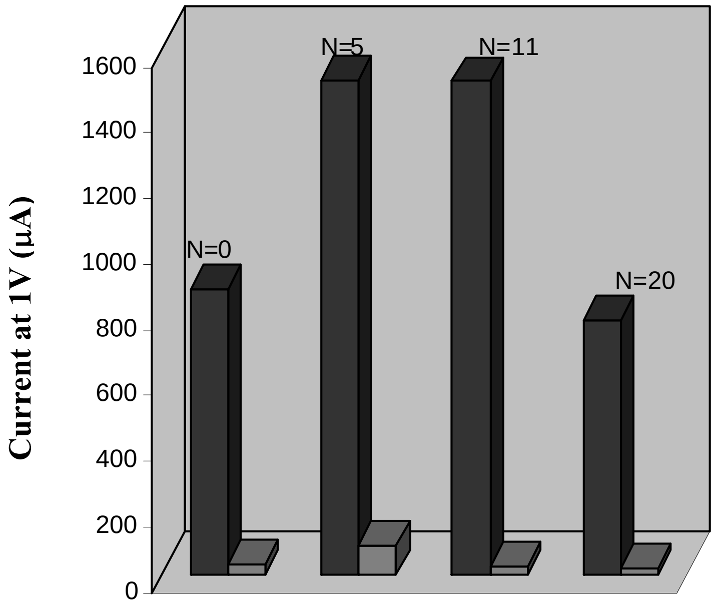


Fig. 5: Histogram for forward and reverse currents at 1V.

Furthermore, the leakage current I_S determined from I-V forward plot was decreased after FLA up to 11 shots as presented in table (I). This result can be ascribed to flatten the dopant profile, high activation of impurities, minimal redistribution, and low concentration of defects [11-13]. These results agree with those obtained by Lee *at.al* [14].Annealing with higher shots leads to increasing the saturation current because of visible cracks formation and due to diffusion of dopants and increasing the junction depth [15].

Table 1: I_S as function of N.

N	**I_S (μA)**
0	16
5	12
11	11
20	20

The enhancement in photoresponse spectrum under zero bias voltage after flash lamp annealing was realized as shown in Fig. 6. This improvement may be related to the minimization of structural defects and due to electrical activation of dopants. This result agree with that in Ref.[16]. On the other hand, the optimum photocurrent of photodiode reaches its highest value after annealing with 11 shots.

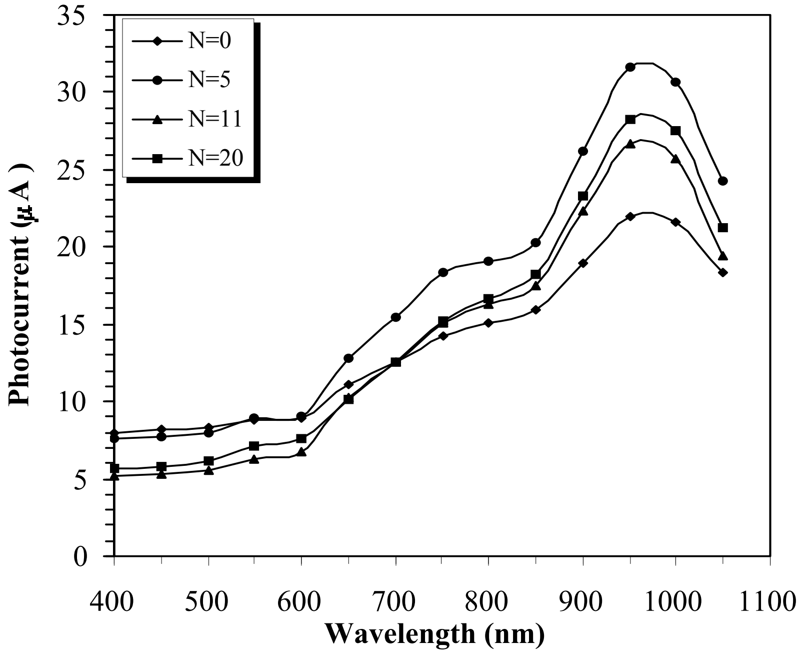


Fig. 6: Photoresponse spectrum of photodiodes.

For higher shots the photocurrent degraded probably because of the increasing of junction depth and the recombination centers induced by multiple shots. It is noticed that no significant effect of external bias on photoresponse of photodiode. On the other hand, no remarkable shifting in peak response was noticed after FLA. No significant variation of electrical and photorsponse characteristics of annealed photodiodes are observed after three months of storing in normal ambient.

5. Conclusion

It has been conceded that pulses from a simple single xenon flash lamp with selected conditions can be used to improve the optoelectronic properties of low cost large area silicon photodiodes. The electrical activation of dopants after FLA plays a positive role in improvement the photoresponse and junction characteristics of photodiode.

The method used in this study has the advantages of simplicity, large area treatment, low cost, high throughout, good uniformity and reproducibility. The effect of FLA on the spatial uniformity and response time of photodiode is under way.

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