빛에 의한 Cz 실리콘 기판의 carrier lifetime 감소에 대한 연구

이지연*, 이수홍**

성진세미텍 (주) 태양전지 연구 개발 센터*, 세종대학교 전략에너지 연구소**

Investigation of the Carrier Lifetime of Cz-Si after Light Induced Degradation

Ji Youn Lee*, Soo Hong Lee**

Photovoltaics R&D Center, Sungjin Semitech Co*.,

Strategic Research Energy Center, Dept. of Electronics Engineering, Sejong University**

Abstract

The carrier lifetime of boron doped Cz silicon samples after light induced degradation could be improved by optimized rapid thermal processing (RTP). The important five different parameters varied in order to investigate which parameter is important for the stable lifetime after light induced degradation, τ_d. The plateau temperature and the plateau time influenced on the lifetime after light induced degradation. Especially, the plateau temperature showed a strong influence on the stable lifetime. The optimal plateau temperature is approximately 900 ℃ for a plateau time of 120 s. The stable lifetime increased from 15 μs to 25.5 μs. The normalized defect concentration, N_t^*, decreased from 0.06 μs^{-1} to 0.037 μs^{-1} by RTP-process.

Key Words : Passivation, SiO_2, SiN_x, RTP, Solar cells

1. INTRODUCTION

At present, about 99 % of all semiconductor devices are produced on monocrystalline silicon. About 95 % of all single crystal silicon is grown according to the Czochralski (Cz) technique [1]. Especially, Cz silicon material is of major importance not only for semiconductor device fabrication, but also for solar cells. Czochraski (Cz) solar cells have a share of 40 % of the world-wide solar cell production. The cost per Cz wafer is about three times lower than that of FZ. Cz wafers can be treated at high temperature (>1000 ℃) and show high efficiencies well above 20 % on solar cells [2]. Unfortunately, an initial degradation at the Cz solar cell efficiency by illumination or carrier injection was observed [3]. The efficiency degrades by 3-4 % relativity within 10 hours illumination using of 1 cm boron doped material [4]. The degradation follows an exponential law and depends on the illumination intensity.

In this work we tried to find an optimal process for Cz-Si wafer in rapid thermal processing (RTP) which is introduced to a low thermal budget due to very high heating and cooling rates of the order of 100 ℃/s and a short process time. For this aim we used the design of experiment (DOE) [5] in order to analyze the influence of process parameters on the lifetime systematically. The important five process parameters are varied and observed which parameter has the significant influence on the stable lifetime without any external gettering.

2. EXPERIMENT

2.1 Sample preparations and Carrier Lifetime measurement

Boron-doped Cz-Si wafers with a resistivity of 1.06 Ωcm, 350 μm thickness and 5x5 cm^2 in size were used for this experiment. The oxygen content $[O_i]$ of this Cz material is $5x10^{17}$ cm^{-3} and the stable effective lifetime after degradation by illumination is 15 μs as measured on SiN_x passivated reference samples.

After the RTP cleaning the wafers are deposited with SiN_x in order to protect the bulk against external contamination from the furnace. The wafers are processed in RTP. The SiN_x layer is etched off using an optimized plasma etch step [7] and a new SiN_x layer is deposited. Subsequently, the effective lifetime before light-induced degradation, τ_o, is measured directly after a forming gas anneal (FGA) step at 425 ℃ for 25 min. The wafer is then illuminated with white light of an intensity of 100 mW/cm^2 (1 sun) for 30 h. And finally the stable effective lifetime, τ_d, is measured.

2.2 Design of Experments (DOE)

In this work we have used design of experiments (DOE) in order to find the main parameter which gives a strong effect on the carrier lifetime after light induced degradation. DOE is a statistical method for an analysis of experimented data. In the classical case only one parameter is varied and the other parameters are fixed, one by one in order to study the effect of parameters. Therefore, in the case of using many parameters it needs many runs and much time. Moreover, when this method is used, the interactions between all each parameters are failed to address.

The contrary, in DOE all parameters are varied simultaneously according to the systematical setting form. Therefore, DOE method can be obtain information not only about the main effects of the factors but also about any interactions among them. Also the number of runs can be minimized [6].

A two-level factorial design was chosen in this study which consists of at only two values, high and low. Five process parameters as factors are used in DOE: plateau temperature ($T_{plateau}$), plateau time ($t_{plateau}$), heating rate (R_{up}), cooling rate (R_{down}) and cooling point temperature ($T_{cooling\ pt}$) Table 1 indicates the total list of two-level factors for DOE. '-'and '+' indicate low and high value of each parameters.

Table 1. Total lists of variable factors and response value for design of experiment (DOE)

Variable	dimension	low (−) value	high (+) value
$T_{plateau}$	℃	850	1050
$t_{plateau}$	s	30	120
R_{down}	℃/s	1	50
R_{up}	℃/s	10	100
$T_{cooing\ Pt.}$	℃	750	820
Response value	μμs		

3. RESULTS AND DISCUSSION

Fig. 1 shows the stable effective lifetime (τ_d) after light induced degradation with respect to 17 different process parameters. In the case of an RTP treatment at 850 °C for 120 s, τ_d is increased drastically by 60 % from 15 μs to 24 μs (a5-a8) almost independent of the ramping conditions.

The wafers (a9-a10, a13-a14) with a slow cooling rate at 1050 ℃ in RTP have higher stable effective lifetimes than the wafers treated with fast cooling rate (a11-a12, a15-a16). If high cooling rates are applied, the stable effective lifetime is 50 % lower compared to the non-RTP- treated reference sample.

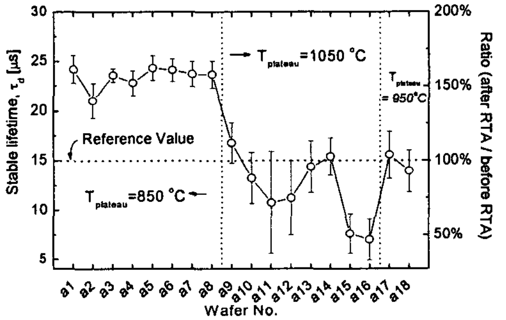

Fig. 1. The stable effective lifetime of boron-doped Cz silicon wafer after RTP-processing

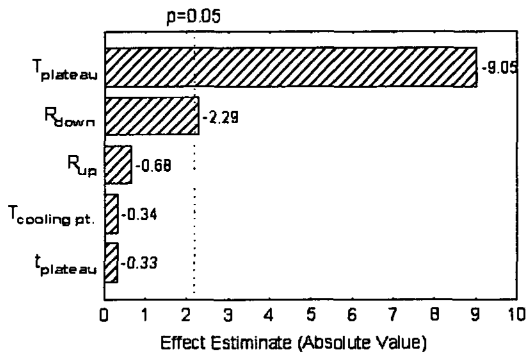

Fig. 2. *The pareto chart of standardized effects through* $2^{(5-1)}$ design of experiments

These facts can be seen well in Fig. 3 which shows the pareto chart of standardized effects through $2^{(5-1)}$ experimental design. 'p=0.05' indicates a statistical probability, In the effect estimate value of parameters the minus '-' means that the effect lifetime decreases with an increase in parameters. Firstly, the plateau temperature has a strong correlation on the stable effective lifetime. Secondly, the cooling rate (R_{down}) has some effect on the stable effective lifetime which stems from the wafers treated at 1050 ℃. The other parameters seem to be negligible, since they are below the statistical significance.

We have shown that the plateau temperature has a very significant effect on the stable lifetime. For a further optimization the parameters of the a5 run are chosen which have given the best stable effective lifetime in Fig. 1. The plateau temperature is varied between 700 ℃ and 1050 ℃ while the other parameters fixed.

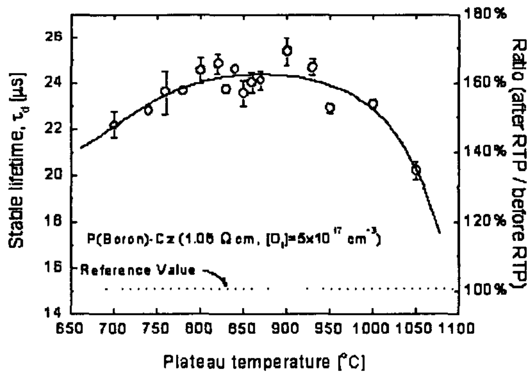

Fig. 3. Evolution of the stable effective lifetimes after degradation as a function of the temperature for SiN_xcoated Cz-Si samples

Fig. 3 shows the dependence of the stable effective lifetime in Cz-Si on the plateau temperature in the range from 700 ℃ to 1050 ℃ for 120 s. The non-RTP-treated reference wafer shows a stable effective lifetime of 15 μs. All RTP-processed wafers have a lifetime higher than the reference wafer. 100 % on the right side in Fig. 3 represents the stable effective lifetime of the non-RTP-treated reference sample. The highest improvement of fairly 80 % (from 15 μs up to 25.5 μs) can be observed at

900 ℃. On the other hand, after rapid thermal processing at 1050 ℃ a stable effective lifetime is reduced to 82.3 % compared to this optimum value. However, at this high temperature an improvement compared to the initial value is also observed.

assumption that the metastable defect is completely deactivated after the annealing at 200 ℃ and is completely activated after an illumination for 30 h under 100 mW/cm^2 (1 sun) and all additional defects possibly contained in the material are not affected by the anneal/illumination cycle.

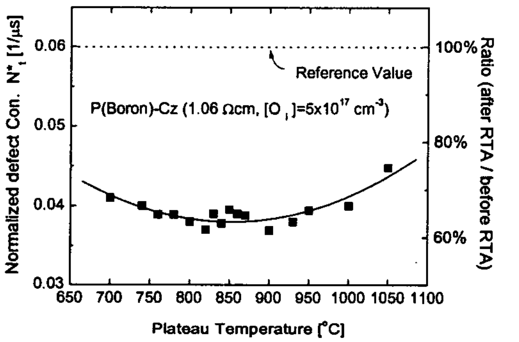

Fig. 4. Normalized defect concentration, N^*_t

Fig. 4 shows the normalized defect concentration after rapid thermal processing. The normalized defect concentration of the non-RTP-treated reference sample is 0.06 μs^{-1}. N^*_t is strongly reduced from 0.06 μs^{-1} to 0.037 μs^{-1} due to RTP at 900 ℃. Thus, it is possible to improve the stable effective lifetime and reduce the normalized defect concentration by rapid thermal processing. This reduction is somewhat smaller for temperatures higher than 950 ℃.

4. CONCLUSION

In this study, we have investigated the potential of RTP to reduce the metastable defect in Cz-Si. The dependence of the stable effective lifetime after degradation on the process parameters has been studied using a design of experiment. The plateau temperature is the most important parameter with respect to the stable effective lifetime. The optimal plateau temperature was approximately 900 ℃ with a plateau time of 120 s. This led to an improvement of the stable effective lifetime of 1 cm Cz-Si by a factor of 2 without any external gettering. Also, the normalized defect concentration reduces at high temperatures process by RTP. This improvement of the stable lifetime due to the optimized high temperatures process by RTP can be observed for Cz materials.

ACKNOWLEDGEMENT

The author would like to thank Dr. Stefan Glunz for fruitful discussions in Fraunhofer ISE in Germany.

REFERENCE

1. W. Zulehner,, Mater. Sci. Eng. B, 7-15 (2000)
2. J. Knobloch,. S. W. Glunz, D. Biro, and W. Warta,,25th IEEE PVSC, 1996. Washington DC, USA, 405, (1996)
3. V.G. Weizer, et al., J. Appl. Phys., **50**(6), 4443, (1979).
4. S. W. Glunz, S. Rein, W. Warta, and J. Knobloch,. Proc. 2nd WCPEC, Vienna, Austria, 1343, (1998).
5. STATISTICA for Windows. Vol. IV. 1984, Tulka OK, USA: Industial Statistcis, Sta. Soft Inc.,(1984).
6. G.E.P. Box, W. G. Hunter and J. S. Hunter, Statistics for experiments, New York: John Wiley and Sons, (1978).