C-7-6

Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp702-703

Activation of Silicon Implanted with Phosphorus and Boron Atoms by Microwave Rapid Annealing

Shunsuke Kimura, Masahiko Hasumi, Kosuke Ota, and Toshiyuki Sameshima
Tokyo University of Agriculture and Technology
2-24-16 Nakamachi, Koganei, Tokyo 184-8588, Japan
Phone: +81-423-88-7109 E-mail: tsamesim@cc.tuat.ac.jp

Abstract

We report rapid thermal annealing by microwave heating associated with carbon powders, which effectively absorbed 1000 W microwave and were heated above 1000°C at 15 s. We demonstrate activation and recrystallization of boron and phosphorus implanted silicon substrates. Sheet resistivity was decreased to 61 Ω/sq by the microwave annealing. Optical reflectivity spectra demonstrate recrystallization in the implanted regions. Typical diode and solar cell characteristics with the conversion efficiency of 13.3 % were obtained.

1. Introduction

Activation of semiconductor materials implanted with impurity atoms is important for fabrication of devices such as metal oxide semiconductor field effect transistors (MOSFETs), pn junction diodes, and solar cells [1, 2]. Rapid heating is an attractive method for activating a semiconductor with a low thermal budget for fabricating these devices at a low cost. We have developed a simple heating method using a commercial 2.45 GHz microwave associated with carbon powders [3]. The microwave heating achieved activation of ion implanted silicon and increase in the minority carrier lifetime τ_{eff} [4]. In this paper, we report temeprature increase beheivior of microwave heating, activation and recrystallization of silicon implanted with phosphorus and boron atoms by the microwave heating for 20 s. We also report the change in sheet resistivity, and pn diode and solar cell characteristics.

2. Experimental

20-Ωcm n-type 500-μm-thick silicon substrate was prepared. The top and rear surfaces were coated with 100-nm-thick thermally grown SiO_2 layers. The ion implantations of boron and phosphorus atoms were conducted at 25 and 75 keV to silicon top and rear surfaces, respectively, as shown in Fig.1(a). 1.0×10^{15} cm^{-2} boron and phosphorus atoms were conducted. The sample was subsequently heated with microwave irradiation using a 2.45 GHz commercial microwave oven at 1000 W for 20 s, as shown in Fig.2. The silicon substrate was completely covered with 2 μm sized carbon powders with a weight of 1 g. Temperature of carbon powders was measured using radiation thermometer through a hole at the front door of the microwave oven. Sheet resistivity was investigated by the 9.35 GHz microwave transmittance measurement system [5]. Optical reflectivity spectra were measured to investigate the crystalline state in the implanted surface region. Then, thermally grown SiO_2 layers were removed by hydrofluoric acid. Comb-type Al electrode was formed on the boron-implanted surface and whole phosphorus-implanted surface was coated with Al electrode by vacuum evaporation, as shown in Fig.1(c). PN diode and solar cell characteristics were measured using air mass AM 1.5 solar simulator at 100 mW/cm^2.

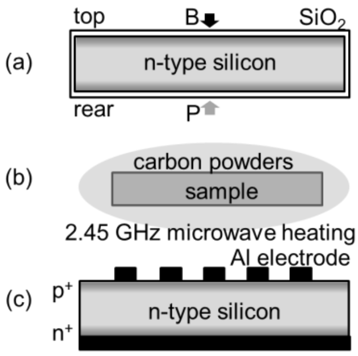

Fig. 1 Schematic sample fabrication steps of (a) boron and phosphorus ion implantations, (b) activation by microwave heating, and (c) SiO_2 etching followed by Al electrode formation.

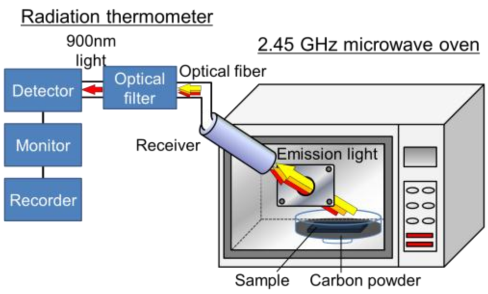

Fig. 2 Schematic image of microwave heating and thermometry system.

3. Result and discussion

Figure 3 shows change in temperature of carbon powders during the 1000-W-microwave irradiation. The picture in the inset of fig. 3 shows photo of black body radiation of heated carbon powders. Carbon powders was rapidly heat-

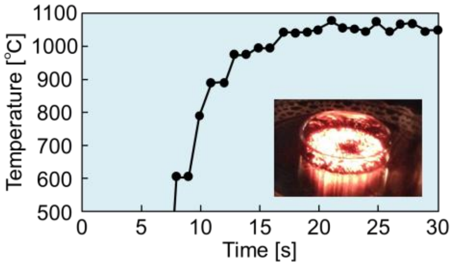

Fig. 3 Change in temperature of carbon powders during the 1000 W microwave irradiation.

ed above 1000°C at 15 s and the temperature increased to 1070°C for 20 s because of effective absorption of microwave power. The sheet resistivity of sample were decreased from 180 (as-implanted) to 61 Ω/sq by the microwave heating at 1000 W for 20 s because of the increase in the carrier density in boron- and phosphorus-implanted regions as shown in Fig. 4. Figure 5 shows optical reflectivity spectra for boron- (a) and phosphorus-implanted (b) surfaces. For the as-implanted sample, optical reflectivity spectrum of boron implanted surface had low E_1 and E_2 peaks at 370 and 280 nm, respectively, and that of phosphorus implanted surface had no peak in ultraviolet region because of amorphization by the implantation. For both surfaces of the microwave annealed sample, sharp E_1 and E_2 peaks appeared. These results clearly indicate that the surface regions were recrystallized by the 20-s-microwave annealing. Numerical estimation revealed that the as-implanted sample had low crystalline volume ratios of 0.07 and 0.00 in 3- and 34-nm-deep boron and phosphorus implanted surface regions, respectively [6]. The microwave heating increased the crystalline volume ratio to 0.99 and 0.93 in those regions. Figure 6 shows (a) PN diode and (b) solar cell characteristics measured using AM 1.5 solar simulator at 100 mW/cm^2. Typical diode characteristics were observed in the dark field. On the other hand, high photo-induced current was observed in the case of AM 1.5 light illumination, as shown in Fig.6(a). Solar cell characteristic shown in

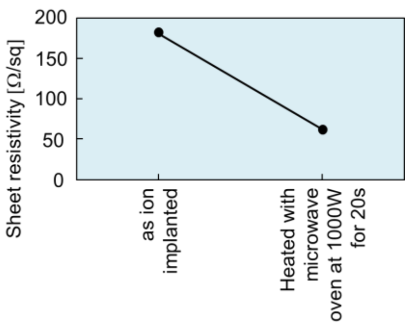

Fig. 4 Sheet resistivity for the sample as implanted and heated with microwave.

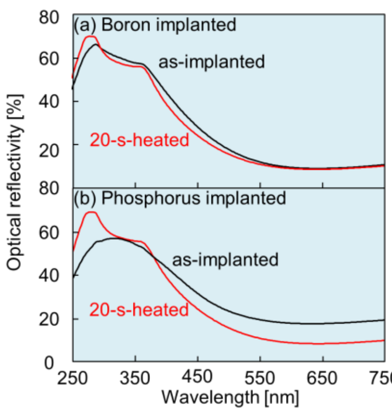

Fig. 5 Optical reflectivity spectra for boron- (a) and phosphorus-implanted (b) surfaces.

Fig.6(b) gave the short circuit current density J_{SC}, open circuit voltage V_{OC}, fill factor FF, and conversion efficiency of 37.6 mA/cm^2, 0.54 V, 0.66, and 13.3 %, respectively. Those results indicated that pn junction was well formed by the microwave heating at 1000 W for 20 s and that the present method has a possibility as a rapid annealing method in semiconductor device fabrication.

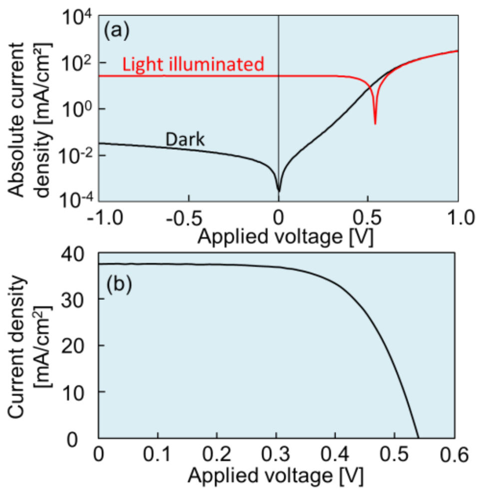

Fig.6 pn diode (a) and solar cell characteristics (b) measured using AM 1.5 light illumination.

4. Conclusion

We reported activation and recrystallization of boron and phosphorus implanted silicon substrate by microwave rapid heating. 20 Ωcm n-type silicon substrate coated with thermally grown SiO_2 was prepared. Boron and phosphorus ion implantation were conducted to top and rear surfaces with 1.0x 10^{15} cm^{-2}, respectively. The sample covered with carbon powders was subsequently heated by 2.45 GHz microwave oven at 1000 W for 20 s. Carbon powders was heated above 1000 °C within 15 s. The microwave heating decreased sheet resistivity from 180 to 61 Ω/sq. Optical reflectivity spectra indicated that microwave heating achieved recrystallization in ion implanted region. Typical diode and solar cell characteristics were measured. Under AM 1.5 light at 100 mA/cm^2 illumination, J_{SC}, V_{OC}, FF, and conversion efficiency were 37.6 mA/cm^2, 0.54 V, 0.66, and 13.3 %, respectively.

Acknowledgements

This work was partly supported by Grants-in-Aid for Scientific Research C (No. 25420282) from the Ministry of Education, Culture, Sports, Science and Technology of Japan and Japan Science and Technology Agency A-STEP (No. AS2621088J).

References

[1] K. Ueda and M. Kasu, Jpn. J. Appl. Phys. 49, 04DF16 (2010).
[2] A. Shima and A. Hiraiwa: Jpn. J. Appl. Phys. 45 (2006) 5708.
[3] M. Hasumi, T. Nakamura, S. Yoshidomi, and T. Sameshima, Jpn. J. Appl. Phys. 53 (2014) 05FV05-1-6.
[4] T. Sameshima, R. Ebina, K. Betsuin, Y. Takiguchi, and M. Hasumi, Jpn. J. Appl. Phys. 52 (2013) 011801
[5] T. Sameshima, T. Nagao, S. Yoshidomi, K. Kogure and M. Hasumi, Jpn. J.Appl. Phys. 50 (2011) 03CA02-1-8
[6] T. Sameshima, Y. Matsuda, Y. Andoh, and N. Sano, Jpn. J. Appl. Phys. 47, 1871 (2008).