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Activation of Silicon Implanted with Dopant Atoms by Microwave Heating

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Abstract

We report a simple heating method with a commercial microwave oven at 1000 W for 9 min with no substrate heating for activation of silicon implanted with phosphorus atoms a doze of 1x10^{15} cm^{-2}. Non destructive microwave transmittance measurement revealed a sheet resistance of 209 Ω/sq and an activation ratio of 60 %. The microwave heating also achieved recrystallization of the amorphized surface region caused by ion implantation. Typical pn diode and solar cell characteristics with the conversion efficiency of 9.3 % were obtained.

I. Introduction

Activation of semiconductor materials implanted with impurity atoms is important for fabrication of devices such as metal oxide semiconductor field effect transistors (MOS FETs), pn diodes, and solar cells [1-3]. We recently reported a simple heating method using a commercial 2.45GHz microwave oven. The microwave heating at 700 W markedly increased the minority carrier effective lifetime τ_{eff} of silicon substrates [4]. In this paper, we report activation and recrystallization of silicon substrates implanted with phosphorus atoms by using a commercial 2.45GHz microwave oven. We demonstrate the activation ratio from decrease in the sheet resistance. We also report pn diode and solar cell characteristics.

II. Experimental

20-Ωcm-p-type and 18-Ωcm-n-type 500 μm thick silicon substrates were prepared. The top and rear surfaces were coated with 100-nm-thick thermally grown SiO_2 layers. The ion implantation of phosphorus and boron atoms was conducted at 75 and 25 KeV to the top surface of p-type and n-type silicon substrates, respectively. 1.0x10^{15} cm^{-2} phosphorus and boron atoms were effectively implanted in silicon substrates, respectively. The samples were heated with microwave irradiation using a 2.45 GHz commercial microwave oven at 1000 W for 9 min. A silicon sample was sandwiched by 2.5 mm-thick glass substrates to keep heat energy during and after heating by microwave oven. The sample was then treated with 9.0x10^5 Pa-H_2O vapor heat treatment at 260^{o}C for 3 h. Activation of phosphorus and boron atoms was investigated by the 9.35 GHz microwave transmittance measurement system [5,6]. Thermally grown SiO_2 layers were subsequently removed by hydrofluoric acid. Optical reflectivity spectra were measured between 250 and 800 nm using a conventional spectrometer. They were analyzed using a numerical calculation program constructed with the optical interference effect for multi-layered structure to estimate the crystalline volume ratio [7]. Comb-type Al electrodes were formed on the top surface and whole bottom surfaces were coated with Al electrodes by vacuum evaporation. PN diode and Solar cell characteristics were measured using air mass AM 1.5 solar simulator at 100 mW/cm^2.

III. Results and discussion

Figure 1 shows sheet resistance analyzed by microwave transmissivity measurement. The sheet resistance was decreased from 433 (initial) to 141 Ω/sq by the microwave heating in the case of phosphorus implantation. On the other hand, it was decreased from 360 (initial) to 270 Ω/sq by the microwave heating in the case of boron implantation The result of Fig. 1 gave the sheet resistances of 209 and 1080 Ω/sq in the phosphorus and boron implanted surface regions, respectively. The analysis using the mobility of doped silicon concluded that 60% of phosphorus and 30% of boron atoms were activated by microwave heating, respectively. The sample was effectively heated to high temperature to move implanted phosphorus atoms for interstitial to lattice sites by microwave at 1000 W. Figure 2 shows in-depth profiles of the crystalline volume ratio of obtained by analysis of experimental spectra of samples as-phosphorus implanted and heated by microwave oven and calculated. The 10-nm-deep region from the surface was completely amorphized and the crystalline volume ratio in top 100 nm region was decreased by phosphorus implantation. On the other hand, the most of surface region was recrystallized by microwave heating. Only 6.0 nm deep region was still partially amorphized with a crystalline volume ratio of 0.7. A similar result was obtained in the case of boron implantation. Figure 3 shows the characteristics PN diode formed by phosphorus implantation and microwave heating (a) and solar cell characteristic measured using AM 1.5 solar simulator at 100 mW/cm^2 (b). The electrical current was markedly increased by positive voltage application in the dark field, while low current was observed by negative voltage application. On the other hand, high photo-induced current was measured in the case of AM 1.5 light illumination at 100 mW/cm^2, as shown in Fig. 3(a). Precise analysis of solar cell characteristic shown in Fig. 3(b) gave the short circuit current density, open circuit voltage Voc, fill factor FF, and conversion efficiency of 33.8 mA/cm^2, 0.47 V, 0.59, and 9.3 %, respectively. Those results indicate that implanted phosphorus atoms were well activated by the microwave heating and the pn junction showed the photovoltaic effect under light illumination. We will report PN junction and solar cell characteristics in the case of boron implantation in n-type silicon.

IV. Summary

We reported activation of phosphorus and boron implanted silicon substrate. 20 Ωcm p-type and 18 Ωcm n-type silicon substrate coated with thermally grown SiO_2 was prepared. Phosphorus and boron ion implantations were conducted at 75 and 25 keV with $1.0x10^{15}$ cm^{-2}, respectively. The samples was heated with a microwave oven at 1000 W for 9 min. The transmissivity of 9.35GHz microwave measurement revealed that sheet resistance of phosphorus and boron implanted regions were 209 and 1080 Ω/sq. The activation ratio of phosphorus and boron atoms were estimated to be 60 and 30 %. Analysis of optical reflectivity spectra revealed that 100 nm deep surface region was amorphized. On the other hand, microwave heating achieved recrystallization in that region. Typical pn diode and solar cell characteristics were measured. Under the condition of AM 1.5 at 100 mW/cm^2 illumination, J_{sc}, V_{oc}, FF and conversion efficiency were 33.8 mA/cm^2, 0.47 V, 0.59, and of 9.3 %, respectively.

Acknowledgements

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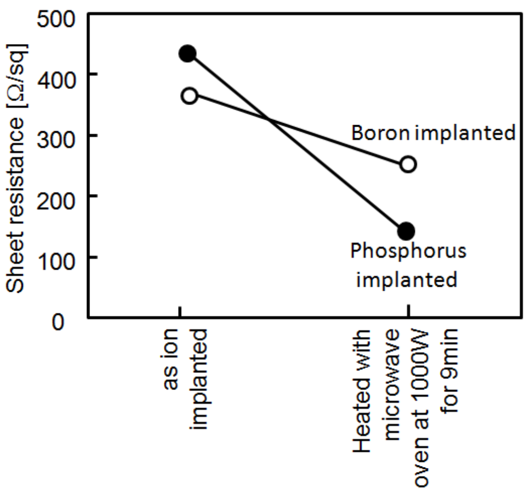

Fig. 1: Sheet resistance for samples as implanted and heated with microwave oven

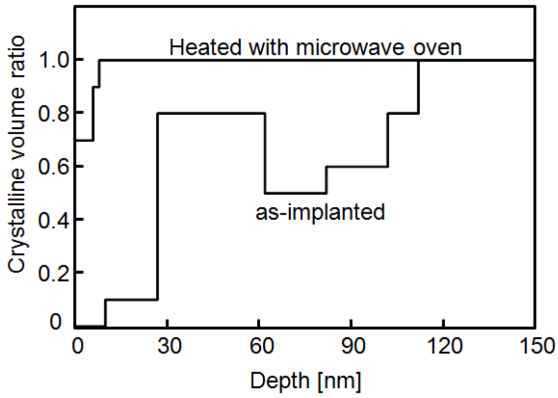

Fig.2: In-depth profiles of the crystalline volume ratio for samples as-phosphorus implanted and heated by microwave oven.

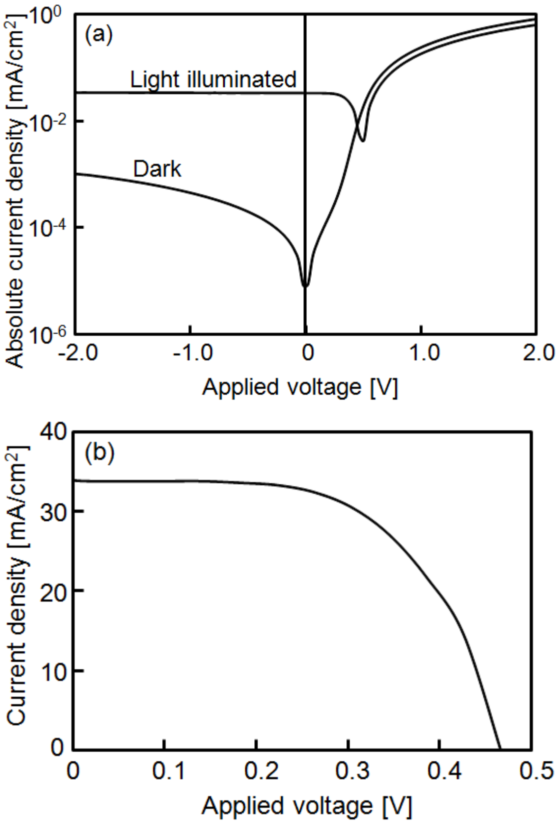

Fig.3: Characteristics PN diode formed by phosphorus implantation and microwave heating (a) and solar cell characteristic measured using AM 1.5 solar simulator at 100 mW/cm^2 (b).