Fabrication of crystalline silicon solar cells by rapid heating with carbon heating tube

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Introduction

We have proposed a heating system with a lamp of carbon heating tube (CHT) for rapid thermal heating [1]. The CHT consists of 2-μm-diameter-carbon powders with a 0.1-g weight in quartz tubes with 60-mm long and 4-mm inner diameter with a packing density of 0.08. It is heated to 1279°C by irradiation of 2.45 GHz microwave at 200 W. Moreover, we also achieved the control of the CHT temperature with a home-made proportional integral differential (PID) feedback circuit which regulated the magnetron power source using a signal of the thermometer. In this paper, we report solar cells fabrication by the CHT heating system with different temperatures controlled by the PID system.

Experimental

We prepared 4-inch-diameter 17-Ωcm n-type silicon substrates with a thickness of 500 μm with 100-nm-thick thermally grown SiO_2 layers. The ion implantation of boron atoms was conducted with a dose of $2x10^{15}$ cm^{-2} at an acceleration energy of 25 keV to the top surface of the silicon substrate to achieve the location of the boron peak concentration at the interface of the SiO_2 layer and silicon substrate. Boron atoms at 1.0 x 10^{15} cm^{-2} were effectively implanted in the silicon substrates. The ion implantation of phosphorus atoms at 75 keV was also conducted for the rear surface with an effective dose of 1.0 x 10^{15} cm^{-2}. The silicon substrate was cut to four pieces for activating implanted regions. A sample piece was placed in the heating system just below the CHT. The sample piece was moved at 0.12 mm/s in the normal direction just below the CHT to heat whole area of a sample piece. The CHT temperature was controlled by PID feedback method. The three conditions of CHT temperature were carried out at 1000, 1100 and 1200 °C. After heating, the thermally grown SiO_2 layer was removed using hydrofluoric acid. To estimate the sheet resistivity and effective minority carrier lifetime τ_{eff}, we measured the 9.35 GHz microwave transmittance of the samples [2]. Comb-type Al electrodes were formed on the top surface and the rear surface was entirely coated with Al electrodes by vacuum evaporation. 100-nm-thick AlO_x layer was subsequently deposited on the top surface as anti-reflection layer. The samples were heated in H_2O vaper at 0.8 MPa at 230°C for 3 h to decrease defect states in the doped regions. The electrical current density as a function of applied voltage (J–V) was measured in dark and under illumination of air mass (AM) 1.5 light at 0.1 W/cm^2.

Results and Discussions

Figure 1 shows (a) the sheet resistivity and (b) τ_{eff} as a function of CHT heating temperature. Although the sheet resistivity of as-implanted sample was high of 626 Ω/sq due to the carriers in the silicon bulk, it decreased from 215 to 146 Ω/sq as the heating temperature increased from 1000 to 1200 °C. The τ_{eff} of as-implanted sample was 1.05 x 10^{-5} s. It increased from 3.37 x 10^{-5} to 2.03 x 10^{-4} s as the heating temperature increased from 1000 to 1200 °C. Figure 2 shows solar cell characteristics. The AM 1.5 light illumination caused the typical photovoltaic characteristic for every sample. The highest values of the short circuit current density, open circuit voltage, fill factor, and conversion efficiency of 39 mA/cm^2, 0.55 V, 0.69, and 14.71% were obtained in the case of 1200°C heating. These results indicate that the CHT heating has a capability of activating boron and phosphorus implanted regions and reducing the recombination defect states.

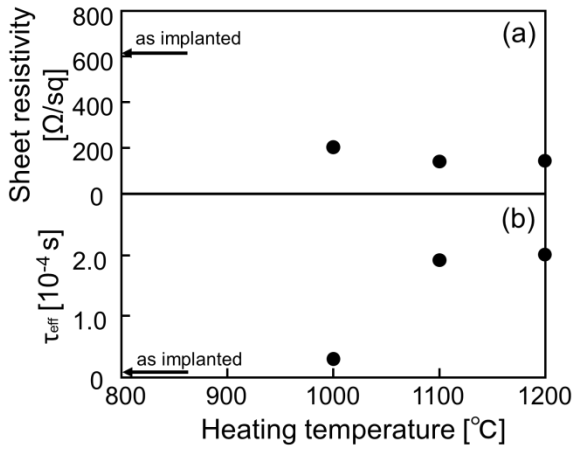

Fig.1 (a) Sheet resistivity and (b) τ_{eff} as a function of CHT heating temperature.

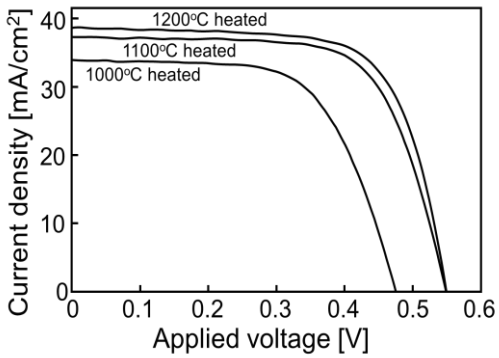

Fig.2 Solar cell characteristics under the illumination of AM 1.5 light at 0.1 W/cm^2.

Acknowledgment

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