Development of wireless heating system with carbon heating tubes and its application to activation of dopant atoms in silicon

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Introduction

We report development a heating system for 300-mm-diameter-sized sample with a wireless lamp of carbon heating tube (CHT) containing carbon powders with inert gas which is effectively heated to a high temperature by 2.45 GHz microwave absorption with free carrier absorption effect [1]. We also demonstrate activation of dopant atoms implanted in single crystalline silicon substrate.

Fabrication of heating equipment

The numerical calculation with a simulator constructed with the three-dimensional finite element moment method combined with the Cholesky decomposition was carried out to determine structure of the microwave cavity and CHTs that effectively absorbed the microwave power [2]. According to the simulation, The box-type cavity with no boxtop was made of stainless steel with a width, length and height of 360, 360, and 270 mm. Its base had two microwave waveguides to introduce 2.45 GHz microwave upto an intensity of 6 kW. The CHTs were fabricated with quartz tubes with 330-mm long and 6-mm diameter containing 50-μm-diameter-carbon powders at a packing density of 0.45. Ar inert gas was filled in the quartz tube at 1400 Pa. The edges of the quartz tubes were closed by thermal welding. Two quartz rods were jointed at the edges of a CHT by thermal welding to hold the CHT. 55 CHT rods were closely placed in paralell on the top of the cavity. 2.45-GHz microwave introduced from the waveguides at the bottom of the cavity traversed in the cavity and irradiated to the CHTs placed at the top of the cavity. Three dimensional Fresnel interference of microwave occurred in the cavity. The average electrical field intensity of the microwave was minimized to 15 KV/m for the shape of cavity given above because the mocrowave was effectively absorbed by the CHTs owing to free carrier abosporption effect cause by conductive carbon powders. A thermometer detecting 700 nm wavelength radiation light was used to monitor the temperature of the CHTs in real time. An infrared digital camera was also used to observe CHT heating behavior. An electrical circuit was developed to control the CHT temperature: The analog voltage signal of the thermometer is monitored in real time by a PID circuit controller which sent a signal to the power source of the magnetron to increase or decrease the microwave power for coinciding the CHT temperature with the initial temperature plan. We confirmed that the CHTs were heated to 800°C in the condition of 5.5 KW microwave irradiation.

Experimental Procedure

In order to demonstrate dopant activation, 4-inch-diameter 17-Ωcm p-type silicon substrates with a thickness of 500 μm were prepared. The ion implantation of phosphorus atoms was conducted with a dose of 1×10^{15} cm^{-2} at an acceleration energy of 70 keV to the top surface of the silicon substrate. The ion implantation of boron atoms at 20 keV was also conducted for the rear surface at a dose of 1.0×10^{15} cm^{-2}. The silicon sample was placed on the CHTs and heated by microwave at 5.5 kW for 5 min. To estimate the sheet resistivity distribution, we measured the 9.35 GHz microwave transmittance of the samples [3].

Results and Discussions

The sheet resistivity of as-implanted sample was high of 572 Ω/sq, which was determined by free carrier density of silicon bulk. Figure 1 shows distribution of the sheet resistivity in the 4 inch CHT-heat-treated substrate. The sheet resistivity uniformly decreased ranging from 49 to 58 Ω/sq. The activation ratio was estimated from 91 to 75%. This means that the sample were uniformly heated and dopant atoms were effectively activated. In this conference, we will report detail behavior of dopant activation and solar cell fabrication by this activation method.

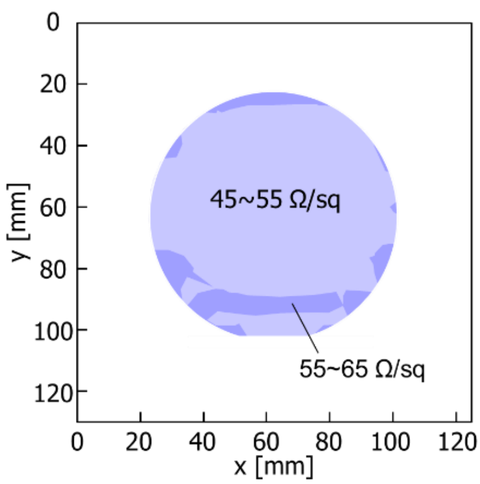

Fig. 1 Distribution of the sheet resistivity in the 4-inch substrate.

Acknowledgment

This work was partially supported by Japan Science and Technology Agency ASTEP (No. AS3015022S) and a Grants-in-Aid for Scientific Research C (No. 18K04225) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

References

[1] T. Miyazaki, G. Kobayashi, T. Sugawara, T. Kikuchi, M. Hasumi, and T. Sameshima, Proc. of Workshop on Active-Matrix Flat Panel Displays and Devices (Kyoto, 2018) pp. 1-4.
[2] T. Sameshima, T. Miyazaki, G. Kobayashi, T. Arima, T. Kikuchi, T. Uehara, T. Sugawara, M. Hasumi, I. Serizawa, IEEE Access, 2019, 7, 23798-23805.
[3] T. Sameshima, T. Motoki, K. Yasuda, T. Nakamura, M. Hasumi, T. Mizuno, Jpn. J. Appl. Phys. 54, 081302-1-6 (2015)

