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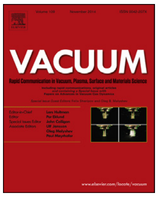

Rapid communication

Development of low-pressure high-frequency plasma chemical vapor deposition method on surface modification of silicon wafer

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ABSTRACT

Even though silicon based solar cell currently has more efficient, the dye sensitized solar cell is considerably cheaper for manufacturing because of its low cost materials and simplicity process of fabrication. In this paper, the development of plasma formed equipments for thin film material on flexible solar cell using low-pressure high-frequency plasma chemical vapor deposition method on the surface of Si wafer with the mixture of Ar gas and O_2 gas is presented. The results indicate that using this method can be possible for surface modification.

In the present, renewable energy is the new energy which becomes more important for the world. There are many energy resources producing the renewable energy, for examples; wind, solar, and biomass. Solar cell is the most popular renewable energy due to its many advantages: sunshine can shine over all area so it is the largest energy source, and can be converted directly to various types of energy. The solar cell installation has been increasing in many countries in order to support for both industrial and household [1]. As solar cell installation increase, the solar cell industrial will increase too [2,3].

Recently, most of solar cell technology that use for commercial is silicon solar cell used for commercial e.g. Mono crystalline silicon solar cell, Poly crystalline silicon solar cell or Amorphous silicon solar cell. Due to the improving of development and efficiency continuously, but using of silicon technology in solar cell production for industrial is very complicated and high cost [4]. So the dye sensitized solar cell (DSSC) becomes more interesting nowadays because of its more efficient and higher power. Besides, it has light weight, easy to install, convenience for transportation, with various shapes [5–7]. The production of dye sensitized solar cell is not complicated with low cost, but in industrial, method has to find the method that suit for mass production. However, complexity of apparatus installation and solar cell production may cause many steps and too long time in huge amount of solar cell producing.

Roll to roll (R2R) technology has been improving for higher production capacity, lower weight and lower cost [8–10]. But, Mono crystalline silicon solar cell and poly crystalline silicon solar cell cannot be used with roll to roll technology due to solid material, due to roll to roll is suitable for flexible material. Owing to flexible material such as plastic or polymer can be used with substrate for flexible dye sensitized solar cell, this will results in conductive layer of plastic or polymer for flexible dye sensitized solar cell produces thin film with roll to roll technology. Flexible dye sensitized solar cell can be applied with roll to roll technology for higher production capacity with lower cost.

Plasma Physical Vapor Deposition (PVD) and plasma chemical vapor deposition (CVD) methods are normally used together to create thin film with good quality for solar cell industrial [11,12].

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The low temperature in plasma process is appropriate in using to generate a film for flexible solar cell to avoid damage of substrate [13–16], while plasma chemical vapor deposition has to appropriate for low temperature thin film formation, however, the low efficiency of dye sensitized solar cell have to be resolved. It was reported that using oxygen plasma treatment to conduct film can reduce the Oxygen vacancies and increase the dye absorption of dye sensitized solar cell. Those are a surface solar cell modification method for higher efficiency [17,18].

In this paper, we would like to present using plasma to surface modification of flexible dye sensitized solar cell by Oxygen plasma treatment under the condition of low-pressure high-frequency plasma chemical vapor deposition method with silicon wafer. We have developed plasma equipment and reduced steps of plasma measuring by investigating radicals and characters of surface after plasma treatment process by mixture Argon gas and Oxygen gas.

In this study, the plasma CVD system has deposition *on silicon wafer* surface treatment by generating low-pressure high-frequency. Fig. 1 shown the system of low-pressure high-frequency plasma chemical vapor deposition for this research. The chamber of plasma CVD system was composed of stain steel (SUS316), and this dimension was 430 mm and 180 mm diameter and high respectively. The plasma electrode for generate plasma process was 200 mm diameter. The distance between upper and lower plasma electrodes were set at 20 mm. The showerhead and gas distribution plate have 1.0 mm diameter hole with 145 fine pores arranged in the shape of grid, the distance between each hole was 12 mm; they are attached to the upper part of the electrode. The electrode has a structure that allows the formation of uniform thin film to be formed and using for spread the vapor to form a metallic thin film in low temperature plasma. The substrate heater has been built in the lower electrode in chamber of plasma CVD system, which make the device to carry out tandem construction of thin film formation for annealing. The port for gas exhaust, which is a fundamental structure in plasma equipment was installed in the chamber on the side surface of system. Inside the chamber was maintained at constant temperature during plasma deposition by flowing cooling water onto the outer wall portion of the reactor of chamber room.

We were used Ar gas and the mixture of Ar and O_2 gas to study characteristic of surface of silicon wafer. The flow rate of Ar gas was 10 L/min and various Oxygen gas 0.1–0.6 L/min to mix various oxygen gas together. The pressure of plasma CVD system was 2.4×10^2 Pa during plasma surface treatment on silicon wafer. Heat of substrate had been controlled at not over 30 °C working temperature by water cooled on plasma chamber. Frequency at 13.56 MHz and 300 W. RF-power were used for this experimental in applying to substrate with difference gases, while the lower electrode serves as a ground, it took surface treatment 10 min by a B-doped p-type Si (100) wafer.

Fig 1 shown the plasma emission of the electrode when mixture of Ar and O_2 gas were used as the plasma gas. This figure shows the phenomenon of plasma deposition on low-pressure high-frequency plasma CVD system when the scale between each plasma electrode is 20 mm. The inset shows photograph when taken from 75 mm width eyehole under the condition of plasma deposition with plasma power: 300 W, Vacuum level: 2.4×10^2 Pa, Ar flow rate: 10 L/min and O_2 flow rate: 0.3 L/min condition in plasma deposition. From plasma reaction observation in chamber room of low-pressure high-frequency plasma CVD system, the color of plasma during deposition process was violet color.

The surface treatment of B-doped p-type Si (100) wafer was investigated by using X-ray photoelectron spectroscopy (XPS) model Shimadzu/KRATOS; AXIS-HS and contact angle meter model Kyowa Interface Science Company; Type CA-D. We observed hydrophilic properties of B-doped p-type Si (100) wafer from contact angle meter after plasma treatment by using the $\theta/2$ method and consisted of dropping 1 μL pure water droplets. The surface of silicon wafer thoroughly investigated and chemical analyzed from the existence of C1s and O1s element using XPS with Mg kα(1253.6 eV) X-ray source. For the condition of experimental of surface treatment by plasma CVD system given in Table 1.

Fig. 2 shown the action of a water droplet dropped down onto a B-doped p-type Si (100) wafer with contact angle meter using the $\theta/2$ method and pure water droplets 1 μL. In this figure showed the behavior of the water droplet on the B-doped p-type Si (100) wafer with untreated condition to clarified the radical creation state. Fig. 2(a), (b) and (c) show the behavior of the water droplet on a wafer, only Ar gas with 10.0 L/min flow rate and the mixture of Ar and O_2 gas, respectively for 10 min treatment time were used with no plasma treatment. We have found that the surface treatment with low-pressure high-frequency plasma CVD to Si wafer will make the contact angle decrease from 35.8, 8.30 and 5.96 degree after the following condition. The O_2 gas flow rate in plasma CVD system caused the angle of water droplet decreased by using contact angle meter, and the observation of changing of radical in activated Si wafer surface. The radical formation on plasma process was considered to affect relationship of the changing in the contact angle by reforming at the wafer surface. The hydrophilic properties appeared on Si wafer surface when change gas in plasma process, the OH radical and the electrons incurred different of hydrophilic properties after surface treatment by improved the surface of Si wafer.

Fig. 3 shown the C1s high-resolution spectrum obtain by the narrow scanning spectrum method when measured by XPS after

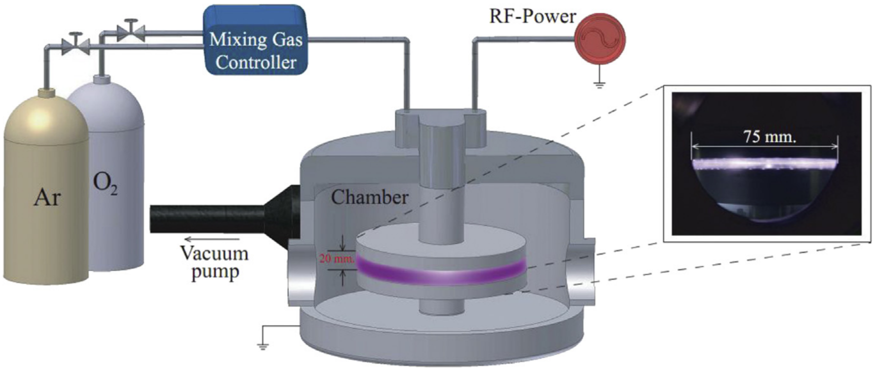

Fig. 1. The system of low-pressure high-frequency plasma CVD system and photograph during plasma deposition.