ION IMPLANTATION EFFECTS IN FULLERENE C_{60} FOR PHOTOVOLTAIC APPLICATIONS

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Introduction

Ion implantation is one of the key processes used for the introduction of the controlled amounts of impurities into semiconductors. C_{60} is known for its electrically insulating nature. The conductivity of fullerenes and other carbon-based materials could be altered by the ion implantation technique. In general, during the low energy ion implantation, the nuclear energy loss is found to dominate over the electronic energy loss whereas in the case of high-energy heavy ion irradiation, the electronic energy loss dominates over the nuclear energy loss. In the case of fullerene C_{60}, the role of ion beam at low energy ion implantation is to displace the carbon atoms of the fullerene molecules (each molecule has 60 carbon atoms) from its position and to subsequently introduce lattice damage in the fullerene thin films. The electronic energy deposition in C_{60} leads to a polymerization of the fullerene molecules where as nuclear energy deposition leads to the complete the transformation of fullerene molecules to amorphous carbon. Ion implantation in C_{60} has recently attained an enormous interest due to its structural transition thereby leading to dramatic changes in their physical properties. The effects of ion implantation onto the fullerene thin films have been reported [1-3]. There are a few reports available on the increase in the conductivity of the films subjected to low energy ion implantation of various species [4,5]. Enhancement of the conductivity of the fullerene films during implantation and thereby using the films for photovoltaic applications is thought to be important despite the structural transition. Though there are lots of literatures available in this direction, there is hardly any detailed work on the fabrication of the photovoltaic device structures using the boron ion and phosphorous ion implanted films. In this report, we present the structural, electrical properties of the ion-implanted films, and also the attempt to fabricate the solar cell structure out of boron ion implanted films.

Experimental Details

Boron doped and phosphorous-doped Si (001) wafers grown by Czochralski (Cz-Si) (100) were used as the substrates for the deposition of the fullerene thin film. Before depositing the fullerene thin film on the polishing side of the wafer, Al film was deposited at the backside followed by annealing in nitrogen atmosphere for 15 minutes at 425 deg C. The ohmic contact at the back surface of the device was thus made. On the front polishing surface of the silicon wafer, the fullerene thin film was deposited at room temperature by using the molecular beam epitaxy (MBE) method. The film deposition was carried out at a pressure of 10^{-8} torr. Emitter contacts were made by using the silver paste on the top surface of the ion implanted fullerene thin film. The illuminated current voltage (J-V) curve was measured using an AM (air mass) 1.5 solar simulator.

Results and Discussion

Raman and Fourier Transform Infra Red (FTIR) measurements were carried out on the boron and phosphorous ion implanted fullerene films deposited on the silicon wafer and the measurements indicate the possible transformation of the crystalline C_{60} phase to a:carbon. These results were reported elsewhere [3]. The structural transition is due to the fragmentation of the bukky balls to individual carbon atoms during the ion implantation [4].

The room temperature resistivity of the undoped fullerene thin films is reported to be as high as about 10^{10}-ohm cm. It is observed that the conductivity of the films during boron and phosphorous on implantation has dramatically increased. The typical enhancement of conductivity in the boron-implanted films is given in Fig.1. The conductivity enhancement is due to the disintegration of the carbon atoms during the process of ion implantation despite the contribution from the doping ions. Temperature dependence of conductivity in the case of boron and phosphorous ion implanted films was measured and found to be semiconductor nature as the conductivity is found to increase with temperature. The variable range hopping mechanism was verified by fitting the resistivity data of the implanted thin films with $T^{-1/4}$. The ion implanted C_{60} turned amorphous carbon is found to have a reduction in the optical gap [6]. Structural transition, enhancement in conductivity and changes in the optical gap are thus found to occur in the ion implanted films. Hot probe measurements on the boron and phosphorous implanted fullerene films indicate the p and n type semiconducting behavior. We have successfully fabricated the device out of boron and phosphorous ion implanted films whose conductivity and band gap have been tailored during the process of ion implantation.

Figure 2 shows the schematic structure of the fabricated solar cell. Multiple boron ion implantation with energies in the range of 50 ~ 80 keV into C_{60} films of thickness of about 300 nm has been carried out in order to realize uniform boron distribution in the films. The ideality factor n and series resistance Rs evaluated are 2.3 and 370 ohms. Especially, Rs is found to be improved using B-ion implantation compared to R_s(35,000 ohms) of the undoped n-C_{60}/p-Si heterojunction solar cells reported previously by the authors [7]. This cell has an active area of about 0.25 cm^2, shows an open circuit voltage of 0.17 V, short-circuit current density Jsc of 0.33 mA/cm^2, fill factor of 0.415. The conversion efficiency of the solar cell (Fig.3) is reported to be 0.02% that is about 3 orders higher than that of the undoped cell [7]. Though the efficiency of the boron ion implanted films is three orders of magnitude higher than the undoped one, the lower efficiency is due to the series resistance of the carbon layer. Due to the increase in the series resistance, the open circuit voltage and short circuit current are very small.

With the n type conducting phosphorous ion implanted fullerene thin films of thickness of about 230 nm and p type Si, we have similarly fabricated solar cell device structures and the device efficiency along with the fill factor (FF), open cicuit voltage (V_{oc}), short circuit current (I_{sc}) and the series resistance of the devices are listed in table 1. The light illuminated J-V characteristic of the cell fabricated is given in Fig 4. The efficiency of the cell due to the multiple energy ion implantation is found to be about 0.01 %. The efficiency of the devices fabricated by us may not be encouraging for the commercial applications but it is worth doing more fundamental studies on these devices to understand the effect of the ion implantation effects of carbon-based materials.

Conclusion

The possibility of device fabrication out of ion implanted C_{60} film and Si is demonstrated in this paper. The efficiency of the device in the multiple energy boron and phosphorous ion implanted C_{60} film /n-Si and p-Si hetero junction is found to be 0.01 % under AM 1.5 conditions. The larger series resistance and the ion implantation induced lattice defects are the main reasons for the low efficiency of this heterojunction device.

Acknowledgements

We acknowledge Mr. Misawa of Semiconductor center for his help during this work. The Japan Society supported this work for the Promotion of Science as a program entitled Research for the Future (JSPS- RFTF97P00902): Study of new carbon based materials for solar cells).

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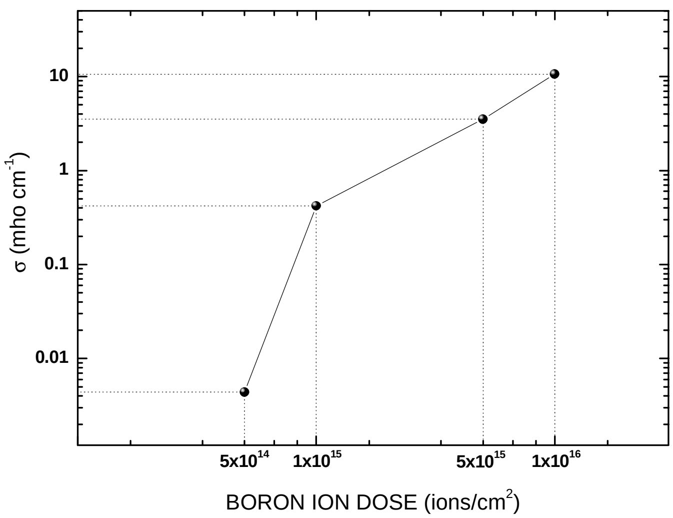

Fig. 1 Conductivity vs boron ion dose

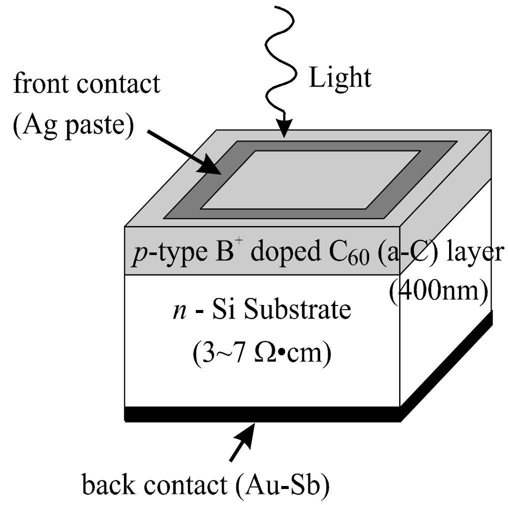

Fig 2 Schematic figure of the cell

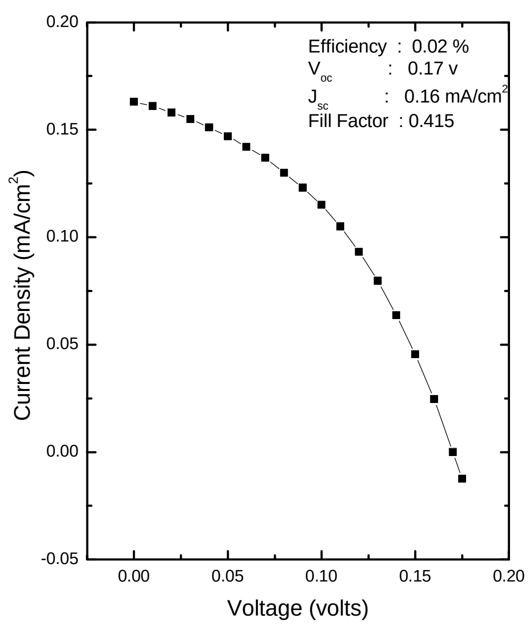

Fig. 3 Illuminated J-V curve of boron ion implanted C_{60} film/n-Si

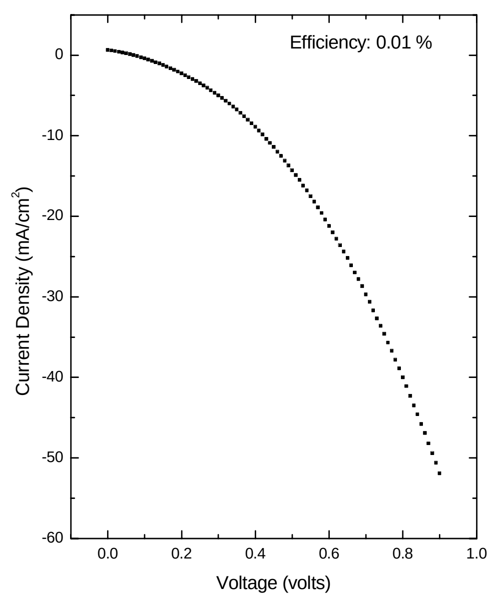

Fig.4 Illuminated J-V curve of phosphorous ion implanted C_{60} film /p-Si

TABLE - I

Various device conditions and their corresponding photovoltaic parameters

Condition	Efficiency	Open Circuit Voltage (V_{oc})	Short Circuit Current (mA/cm^2)	Fill Factor	Series Resistance ohms cm^2
80 keV $1x10^{15}$ P^+/cm^2 Phosphorous Implanted C_{60}	2.5 $x10^{-4}$ %	6.14 $x10^{-2}$	0.016	0.26	400
80 keV $1x10^{16}$ P^+/cm^2 Phosphorous Implanted C_{60}	2.2 $x10^{-3}$ %	7.41 $x10^{-2}$	0.120	0.25	100
Multiple Energy (80,60,40 kV), $1x10^{16}$ P^+/cm^2 implanted C_{60}	0.01 %	7.1 $x10^{-2}$	0.640	0.28	25