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The Au/polyvinyl alcohol (Co, Zn-doped)/n-type silicon Schottky barrier devices

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ABSTRACT

Metal/polyvinyl alcohol/n-type silicon Schottky barrier (SB) devices have been fabricated in this study. The importance of this study is that PVA (Co, Zn doped) nanofiber film as an interfacial layer was formed by the electrospinning technique on n-type silicon substrate. The forward and reverse bias current–voltage (I–V) characteristics of this device were measured at room temperature. The Φ_{Bo} value of about 0.749 eV obtained from I–V characteristics indicates that the contact potential barrier exists at the interface between organic and inorganic semiconductor layer, that is, PVA/n-Si interface. The variation in the capacitance–voltage (C–V) and conductance–voltage (G/ω–V) characteristics of the Au/PVA (Co, Zn doped)/n-Si SB devices have been systematically investigated as a function of frequencies in the frequency range of 2 kHz–2 MHz at room temperature. The effects of density of interface states (N_{ss}) and series resistance (R_s) on I–V, C–V and G/ω–V characteristics were investigated. The high-frequency capacitance (C_m) and conductance (G_m/ω) values measured under reverse bias were corrected to decrease the effects of series resistance. These results show that the locations of interface states between Si/PVA and series resistance have a significant effect on electrical characteristics of the Au/PVA (Co, Zn doped)/n-Si SB devices.

1. Introduction

Recently, metal/organic semiconductor Schottky junction became an attractive as an alternate to the metal/inorganic semiconductor junction. A large number of Schottky barrier (SB) devices have been prepared and characterized using polymer with metals and semiconductors [1–20]. This has opened a new opportunity of replacing conventional inorganic devices by the organic ones. Organic interfacial layer at metal/inorganic semiconductor structures plays an important role in the determination of the main characteristics parameters of the devices. Therefore, investigating various SB devices fabricated with different types of organic interfacial layer is important for improving the electrical and optoelectrical quality of SB devices [21–28]. Polymeric interfacial layer can be sensitive probe useful in establishing process for minimizing interface states, surface damages, dislocations and contaminations that may ultimately increase the quality of devices fabricated using the semiconductor [1–4,9,10]. Of the various polymers as the interfacial layers at metal–semiconductor interface, poly(vinyl alcohol), polyaniline, poly(alkylthiophene) polypyrrole, polyophene, and poly(3-hexylthiophene) became an attractive research topic due to their potential applications and interesting properties. Especially polyvinyl alcohol (PVA) has unique chemical and physical property and it is used in industrial application [29–33].

In this work, the PVA used as an interfacial layer was selected because of its ease of processing, cost, minimizing interface states of SBDs and compatibility with Si. However, PVA is normally a poor electrical conductor; it can become conductive upon blending with some polymer. The poor conducting nature of PVA is thought to be due to the high physical interactions between polymer chains via hydrogen bonding with hydroxyl groups and the complex formation [34]. Thus, we can modify or improve the properties of PVA using reactions/interactions of hydroxyl groups with other chemical compounds [35]. Especially, electrical properties of PVA are influenced not only by the structure and nature of a dopant but also by the doping concentration and procedure [36]. The incorporation of metal salts into polar organic polymers can induce pronounced changes in various properties of the polymers [37,38]. The incorporation of metal salts, especially metal chlorides ($CoCl_2$, $CuCl_2$, and $FeCl_3$), into PVA produced intensity changes in infrared absorption bands of the polymers and resulted in a 10^6-fold increase in the electrical conductivity of the films [14]. Therefore, we doped PVA with Zn and Co composite materials [12,39–41].

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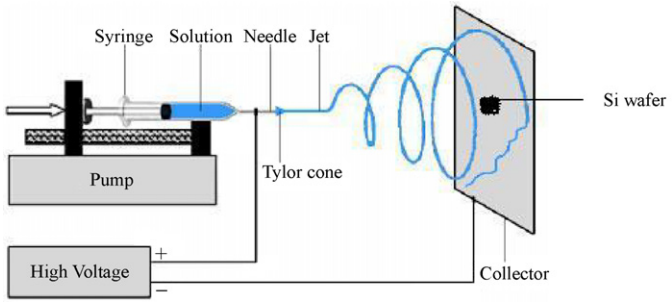

Fig. 1. Schematic representation of the electrospinning process.

After we obtained PVA (Co, Zn-doped), PVA (Co, Zn-doped) nanofibers were grown on n-type Si substrate by using electrospinning technique. The advantages of using PVA nanofiber structures as an interfacial layer are their large surface area to volume ratio and the unique nanometer scale architecture built by them [13]. Electrospun nanofibers have approximately 1–2 orders of magnitude more surface area than that found in thin films [14]. This has the advantage of high quality and well-defined interface between the PVA (Co, Zn-doped) nanofibers and n-type silicon substrate [15]. Forasmuch, the performance and electrical or photoelectrical properties of a Schottky diode are drastically influenced by the interface quality of junction [12]. The reason for the selecting electrospinning technique is that this technique utilizes electrical force to produce polymer fibers. Electrospinning process setup consists of four major components: the high-voltage power supply, the spinneret, the syringe pump and the electrically conductive collector. Syringe pump is one of the important components of the process to achieve a constant and adjustable feeding rate of the polymeric solution [23–28]. After spinning process, Au/PVA (Co, Zn doped)/n-Si SB devices were fabricated by evaporation method. The parametric characteristics of devices were calculated by the use of the current–voltage (*I–V*), capacitance–voltage (*C–V*) and conductance–voltage (*G–V*) measurements.

2. Experimental procedure

The Au/PVA (Co, Zn-doped)/n-Si SB devices were fabricated on the 2 in. (5.08 cm) diameter flat zone (1 1 1) n-type (phosphor doped) single crystal Si wafer having thickness of 350 μm with ≅0.7 Ω cm. Si wafer was first cleaned in a mix of a peroxide-ammoniac solution and then in H_2O + HCl solution for 10 min. After it was thoroughly rinsed in deionised water resistivity of 18 MΩ cm using an ultrasonic bath for 15 min, immediately high purity Au metal (99.999%) with a thickness of about 2000 Å was thermally evaporated onto the whole back side of Si wafer in the a pressure about 10^{-6} Torr in high vacuum system. In order to perform a low resistivity ohmic back contact, Si wafer was sintered at 450 °C for 5 min in N_2 atmosphere.

The PVA film was fabricated on n-type Si by electrospinning technique. A simple illustration of the electrospinning system is given in Fig. 1 [26,28].

0.5 g of cobalt acetate and 0.25 g of zinc acetate were mixed with 1 g of polyvinyl alcohol (PVA), molecular weight = 72,000 and 9 ml of deionised water. After vigorous stirring for 2 h at 50 °C, a viscous solution of PVA/(Co, Zn doped) acetates was obtained [26].

Using a peristaltic syringe pump, the precursor solution was delivered to a metal needle syringe (10 ml) with an inner diameter of 0.9 mm at a constant flow rate of 0.02 ml/h. The needle was connected to a high voltage power supply and positioned vertically on a clamp. A piece of flat aluminum foil was placed 15 cm below the tip of the needle to collect the nanofibers. Si wafer was placed on the aluminum foil. Upon applying a high voltage of 20 kV on the needle, a fluid jet was ejected from the tip. The solvent evaporated and a charged fiber was deposited onto the Si wafer as a nonwoven mat. After spinning process, circular dots of 1 mm in diameter and 1500 Å thick high purity Au rectifying contacts were deposited on the PVA surface of the wafer through a metal shadow mask in liquid nitrogen trapped oil-free ultra high vacuum system in the pressure of about 10^{-7} Torr.

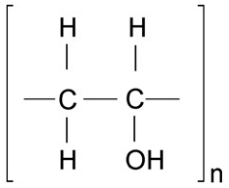

Fig. 2. The molecular structure of PVA.

Before the fabricating rectifying contact the PVA doped with different ratio of cobalt and zinc composite electrospun fiber film on Si produced was examined using SEM micrographs. Fiber formation and morphology of the electrospun Co–Zn/PVA fibers were determined using a scanning electron microscope (SEM) Quanto 400 FEI MK-2 of the PHB film was taken digitally at 20 kV. The diameter of nonwoven fibers was analyzed using ImageJ (Image Prossing and Analyzing in Java) digital image analysis programme.

The *I–V* measurements were performed by the use of a Keithley 220 programmable constant current source, a Keithley 614 electrometer at room temperature. The *C–V* and *G*/*ω*–*V* measurements were performed in the frequency range of 2 kHz–2 MHz at room temperature by using a HP 4192A LF impedance analyzer and small sinusoidal test signal of 20 $mV_{p-p.}$ from the external pulse generator is applied to the sample in order to meet the requirement. All measurements were carried out with the help of a microcomputer through an IEEE-488 ac/dc converter card.

3. Results and discussion

3.1. The properties of PVA (Co, Zn-doped) nanofiber used devices fabricating

Figs. 2–4 indicate the molecular structure, the infrared spectrum (FT-IR) and the SEM picture of PVA nanofiber respectively.

The FT-IR peaks of the PVA/Co acetate, PVA/Zn acetate and PVA/Co, Zn acetate given in Fig. 2 at about 3410, 2938, 1599, 1421,

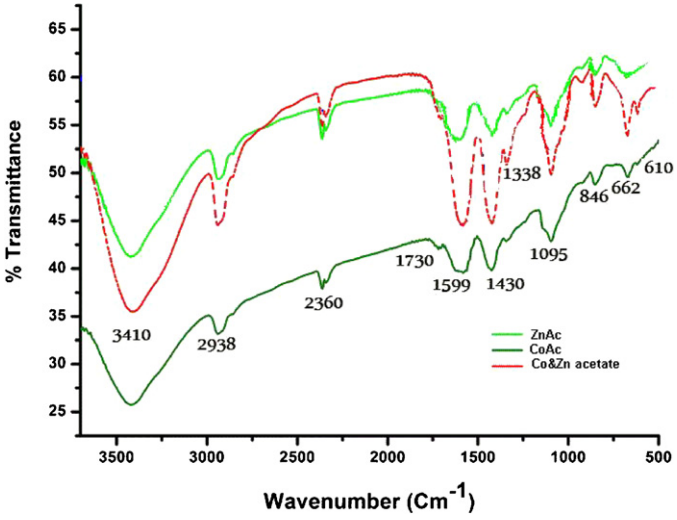

Fig. 3. The FT-IR spectra for the PVA/cobalt acetate/zinc acetate composite fibers.