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# A comparative electric and dielectric properties of Al/p-Si structures with undoped and Co-doped interfacial PVA layer

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## ABSTRACT

In this study, Al/p-Si structures with undoped and Co-doped PVA interfacial layer called  $S_1$  and  $S_2$  were fabricated and their both electrical and dielectric properties were compared by using 300 kHz capacitance–voltage ( $C-V$ ) and conductance–voltage ( $G/\omega-V$ ) measurements at room temperature. Experimental results show that both  $C$  and  $G$  or dielectric constant ( $\epsilon'$ ), dielectric loss ( $\epsilon''$ ) values were found as strongly function of applied bias voltage especially at inverse and accumulation bias regions. It was found that the value of  $R_s$  considerably decreases with doping Co metal contrary to conductivity especially in the forward bias region. Such behavior can be attributed to the lack of free charges in pure PVA. The imaginary part of dielectric modulus ( $M''$ ) gives two peaks for  $S_1$  corresponding to enough reverse and forward biases and passes from a minimum at about zero bias. Also, it is clear that the minimum of the  $M''$  for  $S_2$  coincides with the maximum of the  $M''$  for  $S_1$  at zero bias. As a result, Co-doped PVA considerably improved the performance of structure. In addition, loss tangent ( $\tan\delta$ ), ac conductivity ( $\sigma_{ac}$ ) and real part of the electric modulus ( $M'$ ) were obtained and compared each other.

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## 1. Introduction

Polymeric materials have attracted much attention in both academic and industrial research fields as a consequence of their wide applications. Therefore, polymer electronics has attracted considerably interest in the last decades with the discovery of conducting polymers. The substantial attentiveness has given the production and electrical characterization of organic electronic devices such as metal-semiconductor (MS) and metal-polymer-semiconductor (MPS) type Schottky barrier diodes (SBDs) [1–8]. The use of polymers as dielectrics or interfacial layer between metal and semiconductor has attracted attention

in science and technology within the last decade [9–15]. Amongst them polyvinyl alcohol (PVA) has excellent film forming, emulsifying, and adhesive properties with low melting point for the fully hydrolyzed and partially hydrolyzed grades. Although it is also a good insulating material with low conductivity, but their conductivity can be increased by doping some metals such as nickel (Ni), and zinc (Zn), cobalt (Co) [16,17]. Therefore, metal doped PVA or other polymer materials can be used as an interfacial layer to reduce inter-diffusion at M/S interface [14,15].

Dielectric measurements such as the real ( $\epsilon'$ ), and imaginary ( $\epsilon''$ ) parts of complex dielectric constant and loss tangent ( $\tan\delta = \epsilon''/\epsilon'$ ) are drastically affected by the presence dopant/dopants metal in the polymer [18,19]. It is well known PVA has a very high dielectric strength ( $> 1000$  kV/mm), good charge storage capacity, and dopant-dependent electrical and optical properties [20].

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Electrical and dielectric properties of PVA are influenced not only by dopant structure and nature but also by doping concentration and procedure [21,22]. The performance of MS and MPS and similar devices are also considerably influenced by the production processes, the thickness of polymer layer and its homogeneity, surface charges or interface traps/states ( $N_{ss}$ ) localized at M/S interface, series resistance of device ( $R_s$ ). In the real MIS, MPS, and other structures, the localized interface states ( $N_{ss}$ ) exist at semiconductor/insulator interface and the device behavior is different from ideal situation due to existence of the  $N_{ss}$  and  $R_s$  [13,23]. The effect of dipoles at the interface on dielectric properties is also important. Usually, the polarization can be classified in four categories namely: electronic ( $\alpha_e$ ) atomic/ionic ( $\alpha_a$ ), oriental/dipolar ( $\alpha_o$ ) and interfacial ( $\alpha_i$ ) [24–26] and each polarization mechanism involves a short range motion of the charge and contributes to total polarization of the material. Among them electronic polarization may be occurred at very high frequencies ( $f > 10^{15}$  Hz). Atomic polarization may be occurred between  $10^{10}$  and  $10^{13}$  Hz. On the other hand, dipolar polarization can occur in intermediate or high frequencies ranges of 1 kHz–1 MHz due to their longer relaxation time and may originate from the existence of permanent orient-able dipoles, impurities and surface charges or this locations [24–26]. The interfacial polarization is more sensitive especially in the low frequencies ( $f \leq 1$  kHz) [27]. Our measurements carried out 300 kHz. Therefore, last two types of polarizations may be dominant in our dielectric calculations. Especially, the interfacial polarization occurs when mobile charge carriers are impeded by a physical barrier that inhibits charge migration. Thus, the charges pile up at the barrier producing a localized polarization of the materials [27]. According to Tung [28], at a polycrystalline M/S interface, the bonding geometry likely changes from place to place, leading to a locally varying interface dipole. Therefore, the measured BH then reflects some weighted average of this interface dipole. So the Schottky dipole is assumed to arise from the polarization of interface bonds.

In this study, to comparative both the electrical and dielectric properties and ac electrical conductivity of Al/p-Si structures with undoped and Co-doped interfacial PVA layer called (Sample:  $S_1$ ) and (Sample:  $S_2$ ) were fabricated on the same wafer. The variation of both electrical and dielectric properties of these structures including dielectric constant ( $\epsilon'$ ), dielectric loss ( $\epsilon''$ ), loss tangent ( $\tan\delta$ ), ac electrical conductivity ( $\sigma_{ac}$ ) and real and imaginary parts of electric modulus ( $M'$  and  $M''$ ) have been investigated over the applied bias voltage for 300 kHz at room temperature and compared each other. The experimental  $C-V$  and  $G/\omega-V$  measurements were carried out in the wide range of voltage ( $-5$  V to  $6$  V) by using an HP4192 A impedance analyzer at room temperature.

## 2. Experimental procedures

The Al/p-Si structures with and without Co-doped PVA interfacial layer were produced on p-type (B-doped) single crystal Si wafer with (1 1 1) float zone,  $350 \mu\text{m}$  thickness,  $0.04 \Omega \text{ cm}$  resistivity. First semiconductor wafer was cleaned

in a mix of a peroxide-ammoniac solution and also in  $\text{H}_2\text{O} + \text{HCl}$  solution in 10 min. Si wafer was well rinsed in de-ionized water with  $18 \text{ M}\Omega \text{ cm}$  resistivity at ultrasonic bath for 15 min and then high purity Au (99.999%) with  $\sim 2000 \text{ \AA}$  was thermally evaporated atop the back side of Si at about  $10^{-6}$  Torr. To ensure a low resistivity ohmic contact, Si wafer was also annealed at  $450^\circ\text{C}$  for 5 min in dry nitrogen ( $\text{N}_2$ ) atmosphere. With undoped and Co-doped thin PVA film were produced on the p-type Si by electro-spinning method. 0.5 g of cobalt acetate was mixed with 1 g of polyvinyl Alcohol (PVA). After vigorous stirring for 2 h at  $50^\circ\text{C}$ , a viscous solution of with and without Co-doped PVA acetates were obtained.

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 in the perpendicular on a clamp. A piece of flat aluminum foil was placed 15 cm below the tip of the needle to collect the nano-fibers. By implementing a high bias voltage (20 kV) on the needle, a fluid jet was ejected from the tip. After electro-spinning process, rectifier contacts with 1 mm in diameter and  $1500 \text{ \AA}$  thick high purity Al was deposited on the PVA surface through a metal shadow mask in high vacuum system at  $10^{-6}$  Torr. The value of native  $\text{SiO}_2$  and Co-doped PVA interfacial layers thickness ( $d_i$ ) were obtained the interfacial layer capacitance at strong accumulation region ( $C_i = \epsilon' \epsilon_0 A / d_i$ ) as  $25.14 \text{ \AA}$  and  $54.5 \text{ \AA}$ , respectively.

The  $C-V$  and  $G/\omega-V$  measurements were carried out for 300 kHz at room temperature by using a HP 4192 A LF impedance analyzer between  $-5$  V and  $6$  V dc voltages by 50 mV steps. At the same time, a small ac signal  $40 \text{ mV}_{\text{p-p}}$  is applied to the sample in order to meet the requirement. All of these measurements were carried out with the help of a microcomputer through an IEEE-488 AC/DC converter card in the Janes-475 cryostat at about  $10^{-3}$  Torr to avoid from any external noise or other effects.

## 3. Results and discussions

The forward and reverse-bias  $C$  and  $G/\omega$  measurements of the Al/p-Si structures with undoped and Co-doped PVA interfacial layer called  $S_1$  and  $S_2$  were carried out at room temperature and given in Fig. 1(a) and (b), respectively. As can be seen in Fig. 1(a), the  $C-V$  plot of the  $S_2$  for 300 kHz gives two peaks which are corresponding to the inversion and accumulation region. First peak especially can be attributed to a particular density distribution of  $D_{it}$  at M/S interface near the energy band gap of Si. The other especially can be attributed to the existence of  $R_s$  and interfacial Co-doped PVA layer. At the same time, the  $C-V$  plot of the  $S_1$  for 300 kHz shows that capacitance increases with increasing voltage and gives a peak at depletion region due to the charges at traps [29,30]. On the contrary  $C-V$  plots, the  $G/\omega-V$  plots show nearly a U shape behavior for both of the structures. It is easy to see that the values of the  $G/\omega-V$  are  $5.85 \times 10^{-9}$  F for  $S_1$  and  $6.85 \times 10^{-8}$  F for  $S_2$  at  $-5$  V,  $3.67 \times 10^{-10}$  F for  $S_1$  and  $1.27 \times 10^{-8}$  F for  $S_2$  at zero voltage, and  $1.66 \times 10^{-8}$  F for  $S_1$

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