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Temperature dependent dielectric properties of Schottky diodes with organic interfacial layer

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The dielectric properties of Au/PVA(Co,Ni-doped)/n-Si Schottky diodes (SDs) have been studied in the temperature range of 80-400 K. In this study, polyvinyl alcohol (PVA) film was used as an interfacial layer between metal and semiconductor. The dielectric constant (ε'), dielectric loss (ε''), dielectric loss tangent (tan δ) and the ac electrical conductivity (σ_{ac}) obtained from the measured capacitance and conductance are studied for Au/PVA(Co,Ni-Doped)/n-Si SDs. Experimental results show that the values of ε', ε'' and tanδ were found a function of temperature. The ac electrical conductivity (σ_{ac}) of Au/PVA(Co,Ni-Doped)/n-Si SDs is found to increase with temperature.

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1. Introduction

In recent years, considerable attention was given the fabrication and electrical characterization of organic semiconductor devices due to their unusual electrical and optical properties and their ease of fabrication and processing. Particularly conducting polymers have generated a great interest owing to most attention for possible application in molecular electronic devices because of their unique properties and versatility [1-4]. Among the various conducting polymers, poly (vinyl alcohol) (PVA) which is a water-soluble polymer produced industrially by hydrolysis of poly (vinyl acetate) became an attractive research topic due to their potential applications and interesting properties by chemists, physicists and electrical engineers alike) [5-7]. PVA has been used in fiber and film products for many years. It has also a widespread use as a paper coating, adhesives and colloid stabilizer. Recently, metal/organic semiconductor Schottky diodes became interesting as an alternate to the metal/inorganic semiconductor junction because investigating various Schottky diodes fabricated with different type interfacial layer is important for understanding of the electrical and dielectric properties of Schottky contacts [8-10].

In this study PVA film was used as an interfacial layer between metal and semiconductor. PVA doped different ratio of Cobalt and Nickel was produced and PVA / (Co, Ni) nanofiber film on n-type silicon semiconductor were fabricated by the use of electrospinning technique. Electrospinning process utilizes electrical force to produce polymer fibers. However, the main aim of this study is to try to determine the temperature dependent electric and dielectric properties of Au/PVA(Co, Ni-Doped)/n-Si structures and the variation of dielectric constant (ε'), dielectric loss (ε''), loss tangent (tanδ) and ac electrical conductivity (σ_{ac})have been investigated as a function of temperature and voltage.

2. Experimental

The Au/PVA (Co,Ni-doped)n-Si SDs were fabricated on the 2 inch (5.08 cm) diameter flot zone (111) n-type (phosphor doped) single crystal Si wafer having thickness of 350 μm with ≅ 0.7 Ωcm. Si wafer first was cleaned in a mix of a peroxide- ammoniac solution and then in H_2O+ HCl solution in 10 minute. After it was thoroughly rinsed in deionised water resistivity of 18 MΩcm using an ultrasonic bath for 15 min, immediately high purity Au metal (999.999 %) 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. 0.5 g of cobalt acetate and 0.25 g of nicel acetate was mixed with 1g 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, Ni) acetates was 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 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 traped oil-free ultra high vacuum system in the pressure of about 10^{-7} Torr.

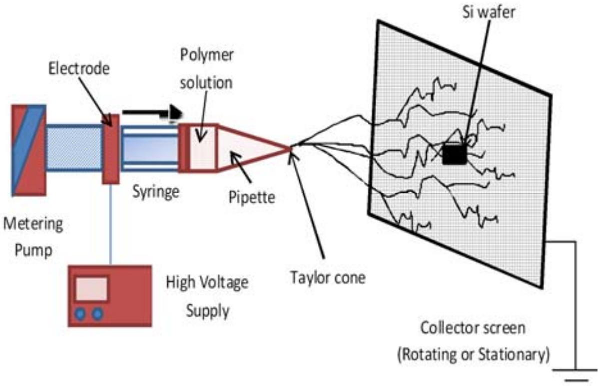

Fig. 1. Schematic representation of the electrospinning process.

The *C-V* and *G/w-V* measurements were performed in the temperature range of 80-400 K at 1 MHz by using a HP 4192A LF impedance analyzer and small sinusoidal test signal of 20 $\text{mV}_{\text{p-p.}}$ from the external pulse generator is applied to the sample in order to meet the requirement. The sample temperature was always monitored by using temperature-controlled Janis vpf-475 cryostat, which enables us to make measurements in the temperature range of 77-450 K. All measurements were carried out with the help of a microcomputer through an IEEE-488 ac/dc converter card.

3. Results and discussion

ε', ε'', $\tan\delta$, σ_{ac} and electric modulus were evaluated from the knowledge of capacitance and conductance measurements for Au/PVA (Co,Ni-doped)n-Si SD in the temperature range of 80-400 K. The complex permittivity can be written [11] as

$$\varepsilon^* = \varepsilon' - i\varepsilon'' \tag{1}$$

where ε' and ε'' are the real and imaginary of complex permittivity of the dielectric constant, and *i* is the imaginary root of $\sqrt{-1}$. The complex permittivity formalism has been employed to describe the electrical and dielectric properties. In the ε^* formalism, in the case of admittance Y^* measurements, the following relation holds

$$\varepsilon^* = \frac{Y^*}{j\omega C_o} = \frac{C}{C_o} - i\frac{G}{\omega C_{o_i}} \tag{2}$$

where, *C* and *G* are the measured capacitance and conductance of the device, ω is the angular frequency ($\omega = 2\pi f$) of the applied electric field [11]. The real part of the complex permittivity, the ε', at the various temperatures is calculated using the measured capacitance values at the strong accumulation region from the relation [12],

$$\varepsilon' = \frac{C}{C_o} = \frac{C\,d_i}{\varepsilon_o A} \tag{3}$$

where $C_0 = \varepsilon_0 A/d_i$ is capacitance of an empty capacitor, *A* is the rectifier contact area of the structure in cm^{-2}, d_i is the interfacial layer thickness and ε_o is the electric permittivity of free space (ε_0 = 8.85x10^{-14} F/cm). In the strong accumulation region, the maximal capacitance of the structure corresponds to the insulator capacitance ($C_{ac} = C_i = \varepsilon' \varepsilon_o A / d_i$). The imaginary part of the complex permittivity, the ε'', at the various frequencies is calculated using the measured conductance values from the relation,

$$\varepsilon'' = \frac{G}{\omega C_o} = \frac{G d_i}{\varepsilon_o \omega A} \tag{4}$$

$\tan\delta$ can be expressed as follows [11,12],

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \tag{5}$$

σ_{ac} of the dielectric material can be given by the following equation [12],

$$\sigma_{ac} = \omega C \tan\delta (d / A) = \varepsilon'' \omega \varepsilon_o \tag{6}$$

The complex impedance (Z^*) and complex electric modulus (M^*) formalisms were discussed by various authors with regard to the analysis of dielectric materials [13]. Analysis of the complex permittivity (ε^*) data in the Z^* formalism ($Z^* = 1/Y = 1/i\omega C_0 \varepsilon^*$) is commonly used to separate the bulk and the surface phenomena and to determine the bulk dc conductivity of the material [14]. Many authors prefer to describe the dielectric properties of these devices by using the electric modulus formalize [15]. The complex impedance or the complex permittivity ($\varepsilon^* = 1/M$) data are transformed into the M^* formalism using the following relation [13,14]

$$M^* = i\omega C_o Z^* \tag{7}$$

or

$$M^* = \frac{1}{\varepsilon^*} = M' + jM'' = \frac{\varepsilon'}{\varepsilon'^2 + \varepsilon''^2} + j\frac{\varepsilon''}{\varepsilon'^2 + \varepsilon''^2} \tag{8}$$

The real component M' and the imaginary component M'' are calculated from ε' and ε''.

The temperature dependence of ε', ε'', $\tan\delta$ at different frequencies for MIS Schottky diode is shown in Fig. 2(a), (b) and (c), respectively. As the temperature rises, imperfections/disorders are occurred in the lattice and the mobility of the majority charge carriers (ions and electrons) increases. The combined effect gives rise to a rise in the values of ε' and ε'' with rising temperature. This may be possible due to both the ion jump and the orientation and space charge effect resulting from the increased concentrations of the charge carriers [16,17]. Furthermore, the increase in temperature induced an expansion of molecules which causes some increase in the electronic polarization and hence an increase in the ε' and ε'' of the dielectric material [16-19]. The variation of the ε', ε'' and $\tan\delta$ with temperature is a general trend in ionic solids. It may be due to space charge polarization caused by impurities or interstitials in semiconductor and polymeric interfacial layer. Furthermore in narrow band semiconductors, the charge carriers are not free to move but are trapped causing a polarization. By increasing temperature, the number of charge carriers increases exponentially and thus produces further space charge polarization and hence leads to a rapid increase in the dielectric constant ε' [18].

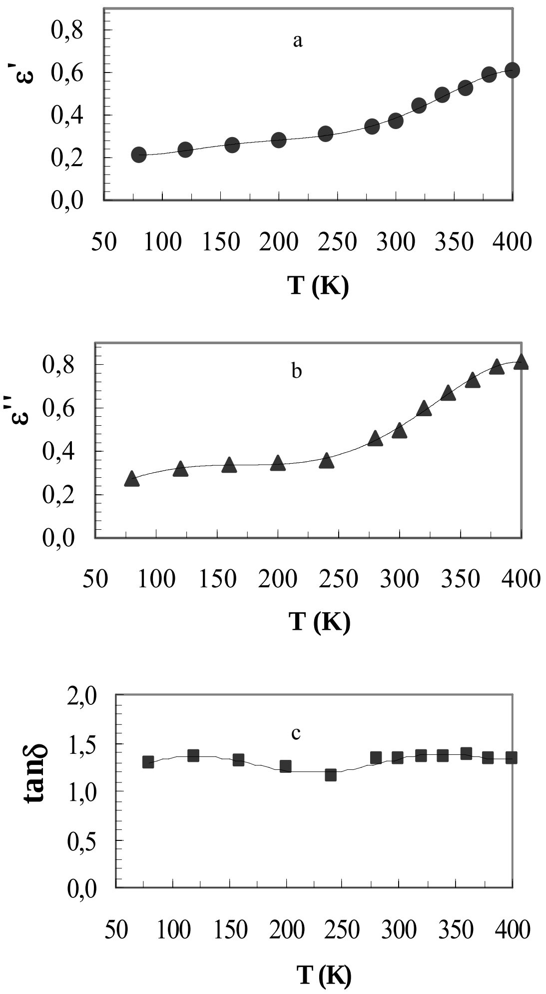

Fig. 2. Temperature dependence of the (a) ε' (b) ε'' and (c) $\tan\delta$ of Au/ PVA(Co, Ni-doped)/n-Si structure.

Fig. 3 shows the temperature dependence of the ac electrical conductivity measured at a constant frequency of 1 MHz. It is clear that the conductivity increases with temperature. Similar results have been reported in the literature [16,18,21]. It is suggested that the process of dielectric polarization in Au/PVA (Co,Ni-doped)n-Si SDs structure takes place through a mechanism similar to the conduction process. The increase in the electrical conductivity at low temperature is attributed to the impurities, which reside at the grain boundaries [12,17,22]. These impurities lie below the bottom of the conduction band and thus it has small activation energy. This means that the contribution to the conduction mechanism comes from the grain boundaries while it mainly results from the grains for higher temperature. The real component M' and the imaginary component M'' are calculated from ε' and ε''.

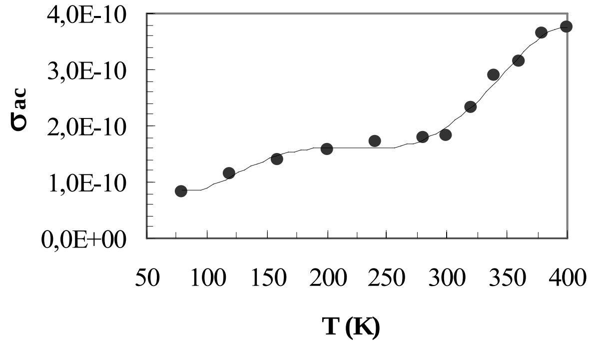

Fig. 3. Temperature dependence of ac electrical conductivity (σ_{ac}) of Au/ PVA(Co, Ni-doped)/n-Si structure.

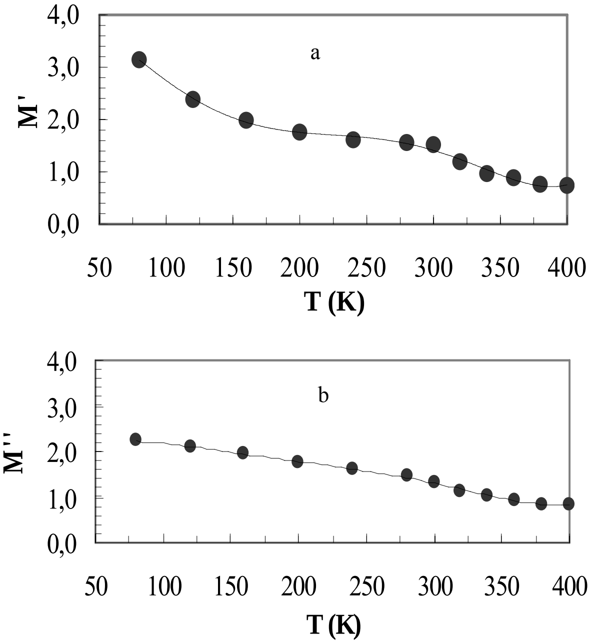

Fig. 4. (a) The real part M' and (b) the imaginary part M'' of electric modulus M^* vs temperature for Au/ PVA(Co, Ni-doped)/n-Si structure.

Fig. 4(a) and (b) depict the real part of M' and the imaginary part of M'' of electric modulus M^* versus temperature for MIS Schottky diode at 1MHz. As can be seen in Fig 4 (a) and (b) M' and M'' decrease with increasing temperature.

4. Conclusions

In this study, we were used PVA material in replacing SiO_2 as interfacial layer at metal semiconductor interface due to its easy processing, cost and high dielectric constant. Dielectric properties of Au/PVA(Co, Ni-Doped)/n-Si SD have been reported in detail from *C-V* and *G/w-V* measurements in the temperature range of 80-400 K at 1 MHz. The analysis of experimental dielectric characteristics of Au/ PVA(Co,Ni-Doped)/n-Si SD have shown that the values of real part of ε', ε'', $\tan\delta$ and σ_{ac} of Au/PVA(Co,Ni-Doped)/n-Si SD depends on the temperature. The behavior of dielectric properties especially depends on polymeric interfacial layer, the density of space charges, and temperature. Therefore, it can be concluded that the accuracy and reliability of semiconductor devices with Schottky contact depend on the type and thickness of interfacial layer, fixed surface charge.

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