Physica B: Condensed Matter 546 (2018) 93–98

Contents lists available at ScienceDirect

Physica B: Condensed Matter

journal homepage: www.elsevier.com/locate/physb

Preparation of mixed copper/PVA nanocomposites as an interface layer for fabrication of Al/Cu-PVA/p-Si Schottky structures

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ARTICLE INFO

Keywords:
Cu-doped PVA)
Ultrasound-assisted
MPS structures
Electrical parameters
Energy dependent profile of N_{ss}

ABSTRACT

In this study, simple ultrasound-assisted method was used for prepare the composite of (Cu-doped PVA) interfacial layer between metal and semiconductor (Al/p-Si). The scanning electron microscopy (SEM) images of the prepared (Cu-doped PVA) nanocomposites have shown an uniform fish scale shape, which are about 100 nm long and several tens of nm in width. Both the Al/p-Si (MS) and Al/(Cu-PVA)/p-Si (MPS) structures were fabricated on the same Si wafer to investigate the effect of this polymer layer on the electrical characteristics by using the current-voltage (I-V) and capacitance/conductance-voltage (C/G-V) measurements at room temperature. The values of reverse-saturation current (I_o), ideality factor (n) and zero-bias barrier height (Φ_{Bo}) were obtained from the liner part of the forward bias I-V plot as 6.6×10^{-10} A, 3.67 and 0.84 eV for MS structure and 1.82×10^{-8} A, 4.18 and 0.76 eV for MPS structure, respectively. MPS structure has a good rectifier behavior with low leakage current in comparison to the MS structure. The high values of n was attributed to the barrier inhomogeneity at Al/p-Si, special density distribution of N_{ss} at (Cu-PVA)/p-Si interface and both the existence of native SiO_2 and deposited of (Cu-doped PVA) interlayer at M/S interface. The energy dependent values of N_{ss} were obtained from the forward bias I-V data and they ranged from the 1.85×10^{13} $eV^{-1}cm^{-2}$ (0.60 eV -Ev) to 7.40×10^{13} $eV^{-1}cm^{-2}$ (0.40 eV - Ev) for MS structure and 9.81×10^{12} $eV^{-1}cm^{-2}$ (0.67 eV -Ev) to 5.26×10^{13} $eV^{-1}cm^{-2}$ (0.47 eV -Ev) for the MPS structure. Experimental results show that the (Cu-PVA) interlayer can be successfully used instead of traditional insulator layer because of the saturation of dangling bonds.

1. Introduction

The research in the field of preparation and synthesis of nanomaterials has become attractive due to the increasingly applications in different technologies [1,2], but the nanoscale the physicochemical properties depend strongly on the size of the particles due to quantum confinement effect. These properties are often based on the high surface area to volume ratio, which derives from the small size [3,4]. There are numerous types of stabilizers that have been used as capping agent for stabilizing nanostructures [5,6]. Among them the copper nanoparticles (Cu) are of great interest because of their distinctive structural, magnetic, thermal, optical, antimicrobial and electrical conducting properties and widely used in catalysts [7], antifouling agents [8], solar energy [9], biosensors [10] electronic and optical devices [11] and so on. The synthesis of Cu nanostructures in polymer has several advantages compared to other agents such as solubility, their ease of processing, control of nanoparticles growth and less toxicity [12]. There are various techniques which are involved to prepare Cu nanostructures such as micro emulsion [13], Laser ablation [14], microwave irradiation [15], wet chemical [16], ionic liquid [17], electrochemical [18] and thermal treatment [19]. Among these methods, ultrasound-assisted method is very simple and it has some distinctive benefits because of low instrument cost and lower crystal formation temperature. It involves ultrasound irradiation (UI) of the precursor during the preparation. UI has been used extensively to produce a broad range of novel materials with interesting properties due to the interesting physio-chemical effects of ultrasonic waves in aqueous media.

There are many studies to improve the performance or quality of the

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https://doi.org/10.1016/j.physb.2018.06.019
Received 4 June 2018; Received in revised form 16 June 2018; Accepted 18 June 2018
Available online 23 July 2018
0921-4526/

metal-semiconductor (MS) type Schottky barrier diodes (SBDs) by using an interfacial insulator or polymer-organic layer in the last two decades [20–24]. Especially high-dielectric organic interfacial layer with and without a metal doped has drown more attention due to its low-cost, low-weight, flexibility and easy processing. Due to significant properties of organic materials with and without doping materials such as Ni, Bi_2O_3, BaTiO, ZnS, Zn, Co, Cu and Graphene, MS structures have been replaced by MPS structures [2,25–28]. Especially Cu-polymer composites are applied as a basic material for electronic applications. The electrical, optical and dielectric properties of MPS structures are influenced by various factors including its thickness, interface layer and homogeneities, interface/surface states (D_{it}/N_{ss}), series and shunt resistances of them, fabrication processes, applied bias voltage, sample temperature, frequency, radiation, doping concentration atoms [29,30]. Especially, the formation of barrier height (BH) at M/S interface and conduction mechanisms are more influenced from these factors [24,29–35].

In this study, firstly the simple ultrasound-assisted method has been used for preparation of Cu nanostructure in presence of PVA and it was used/inserted as an interfacial between Al and p-Si to perform Al/(Cu-PVA)/p-Si (MPS) structures. Secondly, the electrical properties of these MPS structures are compared with the Al/p-Si (MS) structures by using the current-voltage ($I - V$), capacitance-voltage ($C - V$) and conductance-voltage ($G/\omega - V$) measurements to see the effect of (Cu-PVA) interfacial layer at room temperature.

2. Experimental

2.1. Preparation of Cu-PVA composite

Analytical grade and pure precursors were used without further purification in all reported experiments. 5% PVA solution was prepared by dissolving granular powder PVA in double distilled water under heating at 85 °C and magnetic stirring for 2 h. The resulting transparent viscous PVA solution was left for several hours at room temperature to cool and gel formation. In the next step, 0.5 g of copper metal powder was added to 10 ml of 5% aqueous PVA solution to form a Cu-PVA composite material, and then the solution was kept in the exposure of ultrasonic waves at a frequency of 23 kHz for 15 min. Finally well-dispersed Cu-PVA products were obtained.

2.2. Fabrication of Al/Cu-PVA/P-Si structure

The Al/Cu-PVA/p-Si structure was fabricated on p-doped (p-Si) single crystalline Si wafer with (100) orientation, with approximately 300 μm thick and 1–10 Ω cm resistivity. For cleaning procedure of Si substrate, hot acetone (55 °C) was utilized for 10 min on the surface of Si substrate, then Si wafer was immersed in methanol and then rinsed in double distilled water for several times. After the cleaning step, the Si wafer was etched in a hot solution of H_2O, NH_4OH and H_2O_2 (65:13:13 v/v), then again rinsed in double distilled water. Si wafer was etched in a solution of H_2O:HF (24:1 v/v) and again rinsed in double distilled water. In the next step of fabrication of MPS structure, for deposition of a good ohmic contact, the p-Si wafer was kept in a high vacuum thermal deposition chamber. The high purity (99.999%) aluminum (Al) material was utilized for deposition as a target material. Aluminum thin film with a thickness of approximately 1500 Å was thermally evaporated at a pressure of approximately 10^{-6} Torr using a tungsten filament onto the entire back side of the p-Si wafer. Then, the sample was annealed at 500 °C to obtaining a good ohmic contact. Afterward, Cu-PVA film was deposited on p-Si using a spin coating method and then the film was kept at room temperature to dry. Finally, for fabrication of rectifier contact, again using the same coating system for ohmic contact, the highly pure of Al dots with 2 mm diameter (0.0314 cm^2) and approximately 1500 Å thickness were deposited on the Cu-PVA composite/p-Si. The fabricated MPS structure is ready for electrophysical characterizations.

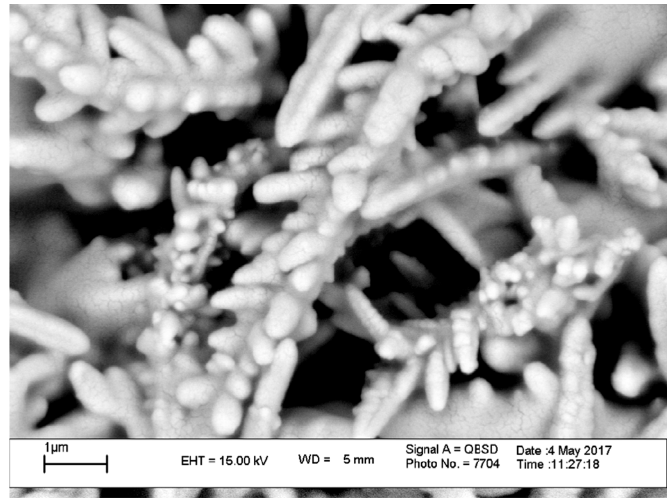

Fig. 1. SEM image of copper nanostructures.

3. Results and discussion

3.1. Structural and optical properties

Fig. 1 shows the SEM image of Cu nanostructures prepared by ultrasound-assisted method in presence of PVA as a capping agent material. The fine branches on the surface of the feather-like nanostructure, which are about 100 nm long and several tens of nanometers in width are shown in the SEM image. Fig. 2 shows the UV–Vis spectroscopy spectrum of Cu nanostructures in presence of PVA in wavelength range 200–500 nm. The optical absorbance edge of prepared sample was blue shifted from that of the bulk form. The broadening of the absorbance spectrum due to the quantum confinement effect of nanostructures. When the quantum confinement effect occurs the blue shift in energy is observed. The band gap energy is found to be particle size dependent and increases with decreasing particle size.

3.2. Forward and reverse bias I–V, $C - V$ and $G/\omega - V$ characteristics

3.2.1. Current-voltage characteristics

Fig. 3 shows the semi-logarithmic forward and reverse biases I–V plots of the Al/p-Si (MS) and Al/(Cu –PVA)/p-Si (MPS) type Schottky structures at room temperature. As can be seen from the Fig. 3, for both MS and MPS type structures the LnI–V plots have a relatively good rectifier behavior, but the rectifying rate ($RR = I_F/I_R$ at ± 5 V) for MPS type is 18 times higher than MS structure. Furthermore, the comparatively high value of RR is observed in the Al/(Cu -PVA)/p-Si (MPS) type

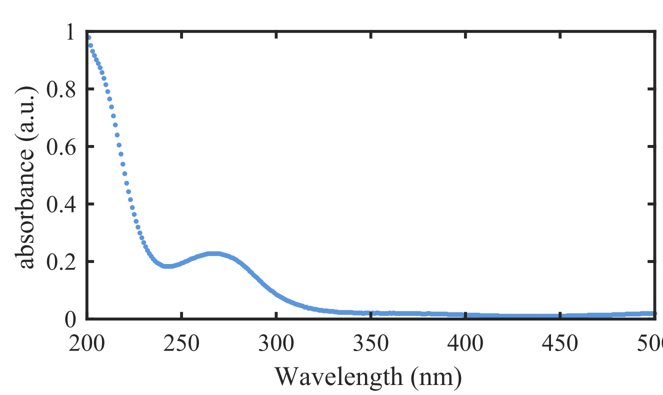

Fig. 2. UV–Vis spectrum of the prepared Cu nanostructures.