



OFET Transistor with Polyvinyl chloride/ NiO Nano Composite

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Available online at: www.isca.in, www.isca.me

Received 25th November 2013, revised 1st February 2014, accepted 21st October 2014

Abstract

We have tried to study the electrical and nanostructural properties of polymer-based materials in corporation NiO (Nickel oxide) in concentrations of 0.2%, 0.4% and 0.8% by weight of PVC (polyvinylchloride) polymer, in NiO/PVC nano composite with using X-ray diffraction (XRD), scanning electron microscopy (SEM) and atomic force microscopy (AFM) techniques. The contact point of NiO/ PVC is of importance due to its ohmic and Schottky contacts. The obtained results indicated that the NiO/PVC sample with 5 g NiO and 0.02g PVC (equivalence to 0.4 % PVC) in weight synthesis at 80 °C temperature has higher dielectric constant, better morphology, less roughness surface, less leakage current, and thus has the potential to be succeeded as a good gate dielectric material for the future of OFET (Organic Field Effect Transistor) devices.

Keywords: Nano hybride composite, PVC, NiO, sol-gel method, OFET.

Introduction

In the last decades, people¹⁻³ have studied the development of organic field effect transistors (OFETs) because OFETs are inexpensive to prepare, are easily fabricated over large areas, and are amenable to solution processing. Previous studies have reported various gate dielectric materials for OFET transistors and metal-oxide-semiconductor (MOS) with very small dimension^{4,5}. Indeed, the effective oxide thickness of SiO₂ dielectrics in current MOSFET (metal-oxide-semiconductor field effect transistor) is down to 1 nm, which is approximately 3 monolayer and close to the physical limit, resulting in high gate leakage currents due to the quantum tunneling effect, tunneling and light atom penetration through the film. These problems cause performance degradation in electronic material in those novel architectures are required for the next FET devices⁶⁻⁸.

Over the past few decades, people have studied to solve FET device problems, and to find an alternative gate dielectric. They have been investigated high-k dielectric materials, such as HfO₂⁹, Al₂O₃, TiO₂, La₂O₃¹⁰⁻¹³ and Ta₂O₅¹⁴ as a buffer insulator. These dielectric materials could not been used as a good gate dielectrics due to unwanted intermediate layer (SiO₂) between silicon substrates and high dielectric constant materials. Researchers have tried to study organic-inorganic hybride composites, as well. Therefore in recent years, metallic oxide and organic material hybride nanocomposite have attractive extensive interest for their unique properties in various fields (such as catalytic, electronic and quality factors)^{15,16}, in comparition with their bulk counterparts. Nickel oxid (NiO) has demonstrated excellence when being used as a catalyst and dielectric materials¹⁷⁻¹⁹. Due to the different effects in terms of volume, quantum size, surface, and macroscopic quantum tunnel, nano-sized NiO particles are expected to possess many

improved properties over those of bulk and micrometer-sized particles. On the other hand Polyvinyl chloride through their properties was used in the various fields widely. NiO/PVC can be made softer, more flexible and less leakage, tunneling currents, boron diffusion through the gate dielectric by the PVC²⁰.

We found that the NiO/PVC sample with 5 g NiO and 0.02 g PVC (equivalence to 0.4% PVC) in weight synthesis at 80 °C temperature has higher dielectric constant, better morphology, less roughness surface, less leakage current and can be thus used as a good gate dielectric for the future of OFET (Organic Field Effect Transistor) devices. This sample as a promising gate dielectric material can be used in advanced applications, with tunable electrical properties for fabrication of sub-micron and microscale electronic devices.

Methodology

In the present work we used sol-gel method for NiO/PVC synthesis. Nickel Nitrate hexahydrate [Ni(NO₃)₂.6H₂O] with water solvent was used as the metallic precursors for the nanocrystallites. Tethra hydro foran [THF] was used as solvent Polyvinyle chloride [PVC]: 5g nickel nitrate hexahydrate was dissolved in 50 mL distilled water for 20 min under stirring at 80 °C. 0.6 g sodium hydroxide was added to the above solution to adjust the PH value from 10-7. Thus 0.01 g PVC (equivalence to 0.2% weight of Nickel Nitrate hexahydrate) was added to 0.3 mL THF. PVC Solution was added drop wise to the first solution. For the other percent of PVC (0.4%, 0.8%), the experiment was repeated with the same condition. The green resultant sol was stirred continuously for 24h. Finally, the stabilized sol was changed to gel. The gel being dried in an oven at 80 °C for 24 h and finally a polymeric precursor was gained. Then it was milled and finally powdered.

Results and Discussion

XRD pattern, SEM images, AFM techniques (atomic force microscopy) and I-V curves are shown in figures-1 through 4.

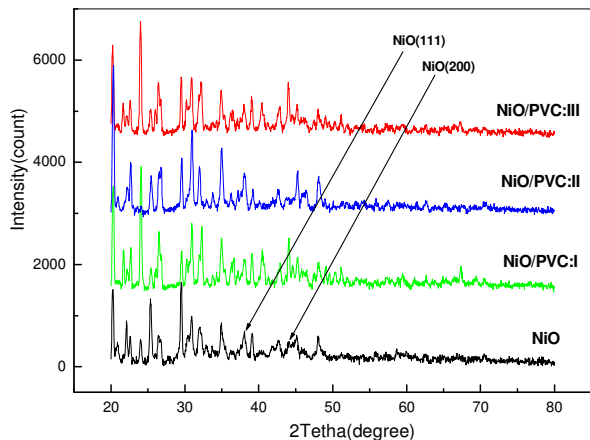
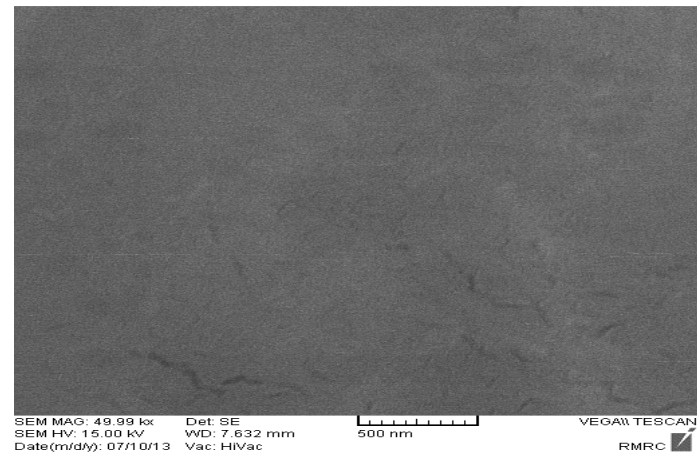
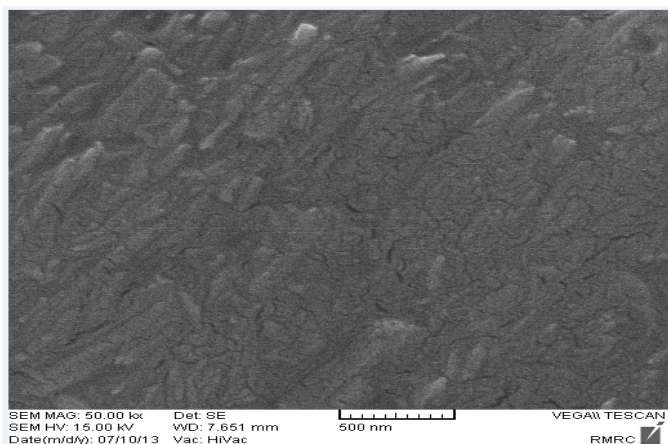


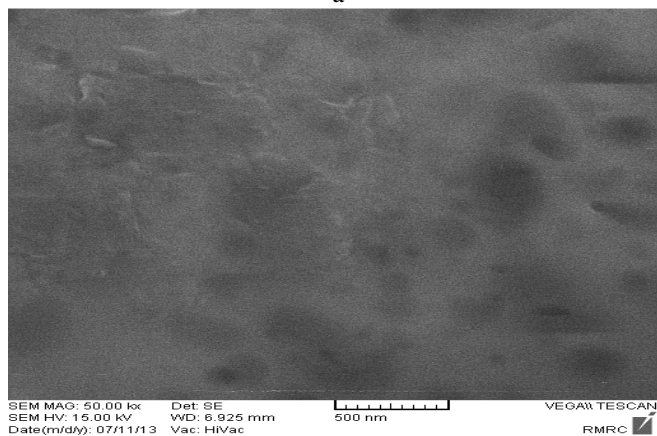
Figure-1
XRD Patterns of NiO and NiO/PVC nano hybrid composite with different content of PVC



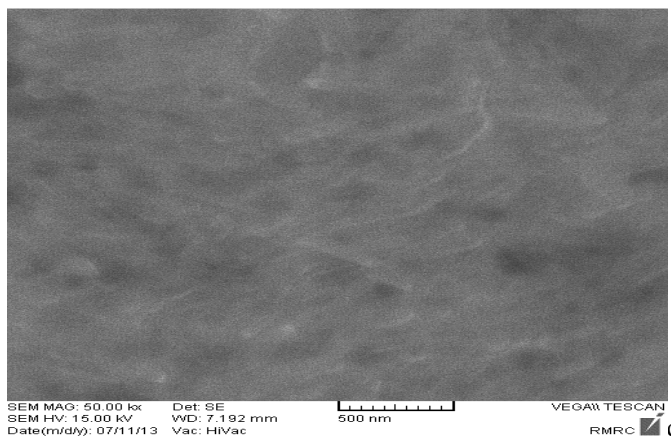
a



b



c



d

Figure-2
SEM images of: (a) NiO, (b) NiO+0.2%PVC, (c) NiO+0.4%PVC, (d) NiO+0.8%PVC

Table-1

Roughness factors of NiO and NiO/PVC samples obtained with Nanosurfe software

Sample	NiO	NiO+0.2% pvc	NiO+0.4% pvc	NiO+0.8 %pvc
S _v	6.45 nm	58.5nm	4.49nm	4.91nm
S _z	5.75nm	52.7nm	3.56 nm	3.88 nm
S _a	914pm	5.81nm	474 pm	537 pm
S _q	1.12nm	8.48nm	597pm	656 pm

Table-2

C, k, Q_F,R and D_F of NiO/PVC samples

Sample	Q _F	D _F	R(MΩ)	C(Pf)	K
NiO+0.2%PVC	0.969	1.032	6.435	173.5	52
NiO+0.4%PVC	0.983	1.017	0.937	3.35	56
NiO+0.8%PVC	0.453	2.207	1.528	9.7	29.2

Table-3

Sextic function coefficients for NiO/PVC samples

Sample	Function coefficients(×1.0E+4)					
	a	b	c	d	e	f
NiO+0.2%PVC	-1122	852.6	-231.8	30.8	-1.9	0
NiO+0.4%PVC	38304	-19443	3825	-364	17	0
NiO+0.8%PVC	10204	-10143	2541	-328	-2.3	0

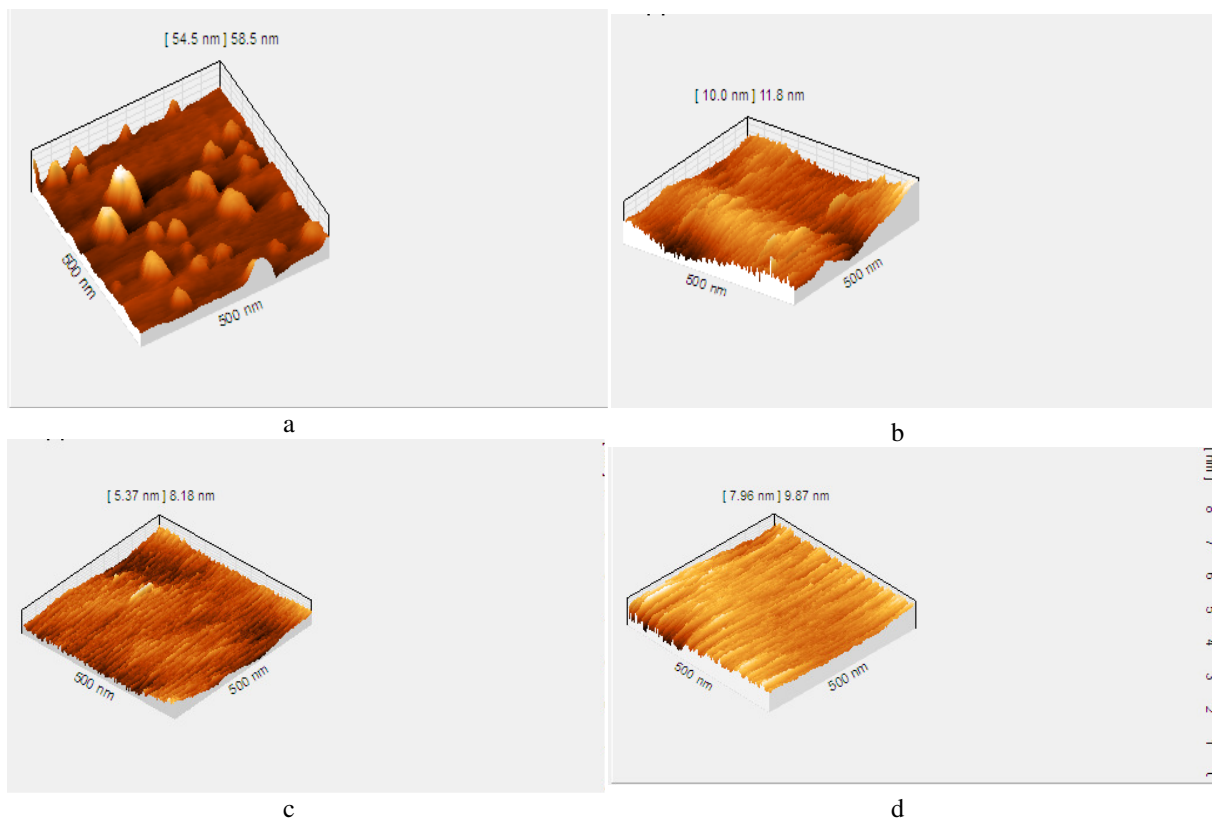


Figure-3
 AFM topography images (3-D), (a), (b), (c) and (d) of NiO, NiO+0.2% PVC , NiO+0.4% PVC and NiO+0.8% PVC nanocrystallit, respectively

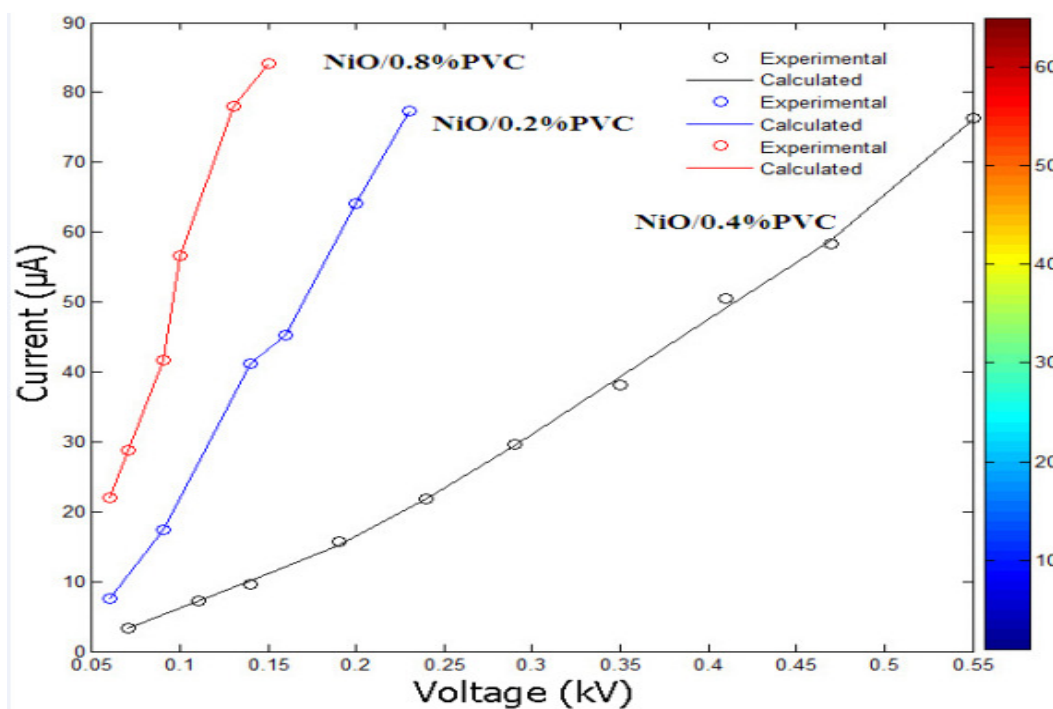


Figure-4
 The I-V curves of NiO/PVC samples

The crystalline structures and the size of the nanocrystallites were determined by using X-ray technique. Figure-1 shows the

concentration effect of PVC content on the diffraction pattern of the investigated NiO and NiO/PVC nano hybride composite. As the PVC content in the nano hybride composite increased, nano hybride composite were formed in more different polycrystalline phases. This indicates that the addition of PVC causes a decrease in the degree of crystallinity of the NiO/PVC complex. Thus it indicates that the polymeric films are composed of a combination of semicrystalline and amorphous phases. Corresponding to figure-1, for NiO+0.4%PVC sample, respect to others (0.2, 0.8) % PVC content, intensity of peaks of the XRD spectrum, increased generally and shifted to higher 2θ occasionally. According to the Scherrer's equation, meaning the size of nanoparticles is smaller than that the other samples.

$$D = \frac{K\lambda}{\beta \cos\theta} \quad (1)$$

Where D, λ , β and θ are mean crystallite dimension, X-ray wavelength, FWHM (in radians) and Bragg angle, respectively and $K=0.94$.

Furthermore, the SEM images of the NiO and NiO/PVC samples in figure-2 reveals no recognizable crystal grains, but with signs severe brittle fracture on the worn surface, in Figure-2, a and b, nano hybride composite are being formed smooth surfaces continuously.

According to the SEM images of NiO and NiO/PVC, when PVC content in NiO/PVC nano hybride composite increase to 0.4%, the surface formed more smooth than the other PVC content. It is clear that the number of trapping of charge carrier decrease, and we can result that mobility (μ) of carriers increase with reducing the trapping. In agree with formula $\sigma = q(n\mu_e + p\mu_p)$, conductivity increase with the mobility too.

Figure-3 exhibit AFM topography images (3-D) of NiO and NiO/PVC nano hybride composite, with different concentration of PVC, synthesized at 80°C. It is clear that when the content of PVC increase in NiO/PVC nanocomposite, nano hybride composite is being formed a smooth surface, that in agree with to SEM images. From the table-1 the roughness parameters and the average roughness, S_a , of nano hybride composites are obtained. It is clear that uniform surface is formed in nano hybride composite synthesized.

The Roughness Average (S_a), Mean Value (S_m) and Root Mean Square (S_q) that are calculated from the data, are defined with the following formula:

$$S_a = \frac{1}{N} \sum_{i=0}^{N-1} |z(x_i)|, \quad S_m = \frac{1}{N} \sum_{i=0}^{N-1} z(x_i), \quad S_q = \sqrt{\frac{1}{N} \sum_{i=0}^{N-1} (z(x_i))^2}$$

In parallel to above studies, nano hybride composite in the AFM images, showed similar surface roughness which agree with electrical properties of the NiO/PVC nano hybride composite.

Figure-4 shows the I-V curves for NiO/PVC (with different content of PVC) samples, were annealed at 80°C. From I-V curve, we found that the contact point of NiO/ PVC is of importance due to its ohmic and Schottky contacts. With the results of table-2 we found that the higher dielectric constant has obtained for NiO/PVC sample with 0.4% PVC that prepared at 80°C.

Electrical conductivity of NiO/PVC nano hybride composite was also studied at 80°C. The electrical conductivity can be expressed in the simplest form, equation-1²¹.

$$\sigma = \sigma_0 \exp\left(-\frac{E_a}{kT}\right) \quad (1)$$

Where: σ is the conductivity ($\sigma = \frac{j}{E}$), E_a is the activation energy, corresponds to the energy difference between the donor level and the conduction level. σ_0 is a temperature independent factor.

The area under the I-V curves of NiO/PVC nanocrystallites dielectric is proportional to power ($P = VI$). The average value of current, \bar{I} , can be obtained. The obtained results presented in table-2, capacitance (C), dielectric constant (K) and quality factor (Q_F) and dissipation factor (D_F) that are defined in following are changed with adding PVC content.

$$P = \int I dv \quad (2)$$

$$\bar{I} = \frac{P}{\Delta V} \quad (3)$$

Higher Q_F value indicates a lower rate of energy loss respect to the stored energy of the capacitor as demonstrated in equation-4,

$$Q_F = 2\pi \times \frac{\text{Energy stored}}{\text{energy dissipated per cycle}} \quad (4)$$

D_F value defined with equation-5 give the loss-rate of energy of capacitor and varies with the dielectric material as presented in table-2.

$$D_F = 1/Q_F \quad (5)$$

Mathematically, the expression for current density according to poole- frenkel model can be written as,

$$J = AT^2 \exp \frac{1}{K_B T} \left[\left(\frac{57.7 \text{ eV}}{Kd} \right)^{\frac{1}{2}} - \phi_t \right] \quad (6)$$

Where: K is the dielectric constant of the film, d is electrode spacing in Å, ϕ_t is the depth of the trap potential well, K_B is the Boltzmann constant and A (Richardson constant) is 120 A/cm² k². Poole-Frenkel effect has been observed due to the trap levels originated from defect levels, indicate that adsorbed oxygen atoms present in the grain boundary regions can change the nano structural (electrical properties). The obtained results show the NiO/PVC nano hybride composite with 0.4% PVC has maximum value of dielectric constant could be synthesized.

It obviously reveals that the I-V trend is a sextic function behavior given by

$$I = aV^6 + bV^5 + cV^4 + dV^3 + eV^2 + fV + g \quad (7)$$

Coefficients a, b, c, d, e, f and g have specified in table-3.

Conclusion

In the present work, the electrical properties of the NiO/PVC nano hybride composite prepared by sol-gel method were studied. XRD analysis revealed that as the PVC content in the nanohybride composite increase, generally peaks intensity increased and shifted. From the XRD pattens, it is clear that the sample has amorphous structure which can reduce the leakage and tunneling currents. Higher value of dielectric constant, K in equation-6 strongly indicates the lower leakage current through the gate dielectric, as shown in table-2, NiO+0.4% PVC has higher dielectric constant. Since the permittivity value of NiO+0.4% PVC dielectric is higher than that other presented sample therefore, it can be introduced as a good gate dielectric material for the next OFET generation.

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