www.amlett.com, www.vbripress.com/aml, DOI: 10.5185/amlett.2015.5917

Published online by the VBRI Press in 2015

# Structural and electrical properties of selfstanding polyaniline films modified with gold nanoparticles

## Sonika Thakur, Anupinder Singh, Lakhwant Singh<sup>\*</sup>

Department of Physics, Guru Nanak Dev University, Amritsar 143005, India

\*Corresponding author. Tel: (+91) 9914128822; E-mail: lakhwant@yahoo.com

Received: 27 March 2015, Revised: 21 June 2015 and Accepted: 26 June 2015

## ABSTRACT

Self-standing polyaniline (Pani) films modified with gold nanoparticles (Au NP's), where Au NP's are added in different successive weight percents, have been synthesized by conventional chemical polymerization technique. An in-depth investigation of the structural and electrical characteristics of prepared films has been conducted using various characterizations. The X-ray diffraction (XRD) validates the presence of Au NP's in Pani and the results are supported well by energy dispersive X-ray analyzer (EDX). The field emission scanning electron microscopy (FESEM) clearly shows thorough dispersion of Au NP's in the amorphous host matrix with minor aggregation. The Fourier transform infrared red (FTIR) studies give the information of possible chemical interaction between the nanoparticles and polymer which is in good agreement with charge transfer mechanism proposed in the manuscript. The temperature dependent dc electrical conductivity has been observed to depend strongly on the nanoparticle loading and follows Mott's three-dimensional variable range hopping (3D VRH) conduction mechanism. Parameters obtained from Hall Effect measurements are of same order as is calculated by dc measurements which indicates a very good corroboration of results. Higher ac conductivity, dielectric constant and dielectric loss of nanocomposites have also been observed as compared to that of pure Pani. Copyright © 2015 VBRI Press.

Keywords: Gold nanoparticles; polyaniline; nanocomposites; electrical properties.

## Introduction

Conducting polymers have found considerable interest in modern technology because they possess the characteristic chemical and mechanical properties of organic polymers with unique electrical properties similar to that of metals and semiconductors [1]. Polyaniline has proved to be a most useful and robust conducting polymer for application purposes. It has numerous advantages like ease of synthesis, wide range of tunable electrical and optical properties, low cost, environmental stability and processability in ambient conditions [2-6]. The incorporation of different types of metal nanoparticles into the conducting polymer is reported in the literature [7-12]. Among the various metal nanostructures, Gold nanoparticles have been the focal point for attention because of their particular electrical, optical, thermal, catalytic, and biocompatible properties [13-15]. It is possible to synthesize specific novel materials having both organic and inorganic characteristics by introducing metal nanoparticles into conducting polymer matrix [16]. These composite materials are expected to exhibit several collaborative properties between the organic polymer and metal nanoparticles and hence making them promising candidates for applications in several fields especially in catalysis, biosensors, sensors, memory devices, electrochromic devices [17-26]. Pani occurs in various insulating forms, the fully oxidized pernigraniline base (PNB), semi oxidized emeraldine base (EB) and fully reduced leucoemeraldine base (LEB), depending on its oxidation state. The EB form of Pani differs from PNB and LEB in the sense that its conductivity can be transformed from insulating form to a conducting form by doping with acids or metal nanoparticles. It is mostly soluble in 1-methyl-2pyrrolidinone (NMP). The self-standing film of EB form can be easily obtained from its NMP solution through slow controlled evaporation of the solvent. Therefore in the present paper, EB form of Pani has been selected to prepare self-standing films modified with gold nanoparticles. The synthesis and characterization of Pani/Au nanocomposites using diverse synthetic methods and analysis techniques is well documented. Venditti et al [27] prepared composite material by means of an osmosis based method. Ali et al [28] employed two-step electrochemical synthesis method for synthesis of Au nanoparticles decorated polyaniline nanofibers. Gupta et al [29] reported the preparation of composite of polyaniline nanorod with gold by chemical oxidative method. Bogdanovic et al [30] applied an interfacial method to produce composites containing polyaniline and gold nanoparticles. Mallick et al [31] synthesized one-dimensional gold-polyaniline composite materials and reported optical, microscopic and low

temperature electrical properties of the composite networks. However, ingrained limitations associated with these methods were unavoidable, for example, complex process control, cost-ineffective and risk of contamination. In the present research work, conventional polymerisation has been adopted to get self-standing films of Pani consisting of gold nanoparticles. The chosen method is economical, cost effective, has negligible risk of contamination and provides good quality self-standing films. Different research groups have tried hard to maximize the performance of nanocomposite based device. To achieve this objective, it is increasingly important to have a detailed understanding of the underlying mechanism responsible for the structural and electrical changes of the resulting polymer/metal nanocomposite. The present work demonstrates a comprehensive study of the transport mechanism in selfstanding sheets of Pani/Au nanocomposites. The interest behind this investigation is to study the typical changes in electrical properties of Pani when gold nanoparticles are dispersed in it.

### Experimental

#### Material synthesis

The materials used for synthesis were aniline monomer, ammonium per oxy disulfate (APS), 1-methyl-2pyrrolidinone (NMP), gold nanoparticles (particle size ~100 nm) and hydrochloric acid (HCl), all obtained from Aldrich and used as received without any further purification. Doubly distilled water was used during the whole experiment. The oxidative polymerization of aniline monomer using 0.25 M APS as an oxidizing agent was adopted for preparing green colored conducting emeraldine salt form [32]. The conducting salt so obtained was converted to insulating EB form by dipping it in 0.1M ammonia solution for 4-5 h. This base form was filtered through Buchner funnel after washing with copious amount of distilled water, 1M HCl acid and acetone. The shinning copper-brown colored precipitates were dried and crushed into fine powder. This powder was dissolved in NMP solvent and filtered. For making nanocomposite films, the gold nanoparticles of concentration 0.30%, 0.60% and 1.0% by weight were added in the above solution and sonicated. The resulting solutions were placed in a convection oven for 24 h at 60-70 °C to cast self-standing films of Pani and Pani/Au nanocomposite (thickness ~30 um). The labeling of prepared samples is tabulated in Table 1.

Table 1. Composition	and coding of	the prepared samples.
----------------------	---------------	-----------------------

Sample Code	Polyaniline (wt %)	Gold NP's (wt %)
S <sub>0</sub>	100	0
S <sub>0.30</sub>	99.7	0.30
S <sub>0.60</sub>	99.4	0.60
<b>S</b> <sub>1.0</sub>	99.0	1.0

#### **Characterizations**

The X-ray diffraction of the films was carried out on a Bruker AXS D8 diffractometer. The structural changes were studied using Varian 660 IR FTIR spectrometer in the range 4000-400 cm<sup>-1</sup>. The surface morphology and

elemental composition of the samples were examined using Carl Zeiss Supra 55 field emission scanning electron microscope (FESEM) equipped with 50 mm sq., oxford instruments X-mas energy dispersive X-ray analyzer (EDX). The dc conductivity measurements were performed by standard four probe method in the temperature range of 80-350K using Keithley 2612A System source meter and Lake Shore 340 temperature controller. Hall measurements were taken using Ecopia Hall effect measurement system (HMS-3000 VER 3.51.5) at room temperature using the Van der Pauw configuration. For dc and Hall measurements, samples were made conducting by dipping them in 1M HCl solution. Dielectric measurements were carried out using fully automatic Hewlett Packard 4284A precision LCR meter in the frequency range 20 Hz-1 MHz at room temperature. The contacts were made on the samples using silver paste.

#### **Results and discussion**

#### X-ray diffraction

**Fig. 1** shows the XRD patterns of pure Au nanoparticles, Pani (S<sub>0</sub>) and Pani/Au nanocomposite films (S<sub>0.30</sub>, S<sub>0.60</sub>, and S<sub>1.0</sub>). A broad amorphous hump or halo at about 20° in all the samples is assigned to the parallel periodicity of Pani **[33]**. All other characteristic peaks at  $2\theta$ = 38°, 44.4°, 64.5°, 77.5°, and 81.8° found in **Fig. 1(b-d**) represent Bragg's reflections, respectively, from (111), (200), (220), (311) and (222) planes of the face centered cubic lattice phase of gold (JCPDS no-04-0784). **Fig. 1(e)** shows the XRD pattern of pure gold nanoparticles. The strong (111) Bragg reflection indicates highly oriented crystalline character of the gold particles. Average crystallite size calculated from (111) diffraction peak using Debye–Scherrer's equation is ~100 nm for Au NP's.



Fig. 1. X-Ray diffraction pattern of Pani (S $_0$ ) and Pani/Au films (S $_{0.30}$ , S $_{0.60}$ , and S $_{1.0}$ ).

#### FT-IR analysis

In order to determine the possibility of interactions among gold nanoparticles and Pani, FTIR spectroscopy has been performed and is presented in Fig. 2. All characteristic absorption bands for the EB form of Pani [32, 34] are observed in Fig. 2(a). These characteristic bands of Pani can also be identified in the infrared spectra of the nanocomposite films in Fig. 2(b-d) affirming the formation of Pani in all samples. The bands at 1239 and 1274 cm<sup>-1</sup> indicate C=N and C-N stretching modes, while the bands at 1482 and 1584 cm<sup>-1</sup> refer to C=C stretching deformations of benzoid (N-B-N) and quinoid (N=Q=N) units, respectively. The bands at 1167 cm<sup>-1</sup> and 832 cm<sup>-1</sup> are identified as C-H in-plane and C-H out-of-plane bending, respectively. The bands at 3281 cm<sup>-1</sup> attribute to N-H stretching. The C=O stretching band observed at 1672 cm<sup>-1</sup> suggests that the Pani film consists of residual NMP solvent [32]. Though there is no drastic modification in the peak positions has been observed for Pani and Pani/Au nanocomposites but a gradual change in the intensity of peaks is well observed with addition of Au nanoparticles. It is observed that as the concentration of gold nanoparticles increases, there is change in intensity of some specific bands at 1239 and 1584 cm<sup>-1</sup> associated with C=N and C=C respectively. It results due to stretching of the quinoid ring, illustrating that gold nanoparticles and Pani have some sort of interaction between them. Therefore, it is presumed that Au NP's may be situated nearby to the imine nitrogen of quinoid ring of Pani. These results validate the proposed conduction mechanism in Pani/Au nanocomposites (Scheme 1) discussed later.



Fig. 2. FTIR spectrum of Pani (S $_0$ ) and Pani/Au films (S $_{0.30}$ , S $_{0.60}$ , and S $_{1.0}$ ).

#### Scanning electron microscopy

The SEM images of Pani and Pani/Au composite materials are exhibited in Fig. 3. It has been noticed from Fig. 3(a) that the surface of pristine polyaniline film is smooth and featureless. Fig. 3(b-d) displays the uniform dispersion of gold nanoparticles (bright spots) in the amorphous host matrix with minor aggregation. Wide ranges of particle/cluster size are observed having long dimensions on the order of a few micrometers and short dimensions on the order of 90 nm [35]. The number of agglomerates has been increased with increasing Au NP's concentration in the Pani. This may be attributed to the temperature dependent Brownian motion of nanoparticles in solution. If the particle concentration is high, particles may repeatedly collide, eventually leading to irreversible aggregation and precipitation in the given samples. Fig. 3(e) demonstrates the EDX spectrum of  $S_{1,0}$  sample. Carbon, oxygen, nitrogen, and chlorine are obtained from the Pani structure. Gold peak in the spectrum implies the presence of gold nanoparticles in the polyaniline. The coupled information from SEM and EDX supports the genuine nanocomposite formation with Pani and Au nanoparticles.



Fig. 3. FESEM micrographs of (a)  $S_{0,}$  (b)  $S_{0,30}$ , (c)  $S_{0,60}$ , (d)  $S_{1,0}$  samples and (e) EDX spectrum of  $S_{1,0}$  sample.

#### Temperature dependent dc conductivity

To find the influence of different concentrations of gold nanoparticles on the charge transport mechanism in the Pani, the dc conductivity  $\sigma_{dc}$  of the samples has been inspected in the temperature range 80-350 K. Fig. 4

displays the variation of  $\sigma_{dc}$  with temperature. The room temperature conductivity varies between 15 and 398 Sm<sup>-1</sup> with addition of gold NP's. The  $\sigma_{dc}$  increases with increasing temperature suggesting a semiconducting behavior for all the samples. To examine the conduction mechanism, several models are applied for the conductivity data. Fig. 4(a) presents ln  $\sigma_{dc}$  versus 1000/T plot which gives a moderate fit to the data for the whole temperature range studied. However, perfect fit to the experimental results is given by Mott's three-dimensional variable range hopping (3D VRH) model as shown in Fig. 4(b). Therefore, the observed conductivity of the films may be associated with the hopping of electrons along and between the molecular chains. Such a situation has been well described by Mott [36] through the movement of electronic charge carriers. Each time an electron moves between the polymer chains, an electron just below the Fermi level jumps normally to a state just above it with average hopping energy W and transfers from one chain to the adjacent chain. The wave functions of these polymer chains overlap with each other. Accordingly the electrical transport along the molecular chain might be easier than between the chains in Pani/Au films.



Fig. 4. Variation of dc conductivity as a function of (a) 1000/T and (b) T<sup>1/4</sup> of Pani (S<sub>0</sub>) and Pani/Au films (S<sub>0.30</sub>, S<sub>0.60</sub>, and S<sub>1.0</sub>).

According to Mott's three-dimensional variable range hopping (3D VRH) model, the conductivity in three dimensions is given by

$$\sigma_{dc}(T) = \sigma_0 \exp\left(\frac{T_0}{T}\right)^{\frac{1}{4}} \tag{1}$$

where,  $T_0$  is the characteristic temperature, which can be interpreted as an energy difference between localized states and  $\sigma_0$  is the conductivity at infinite temperature. Both can be calculated using the formulae

$$T_0 = \frac{\lambda \alpha^3}{kN(E_F)} \tag{2}$$

$$\sigma_0 = e^2 R^2 v_{ph} N(E_F) \tag{3}$$

where,  $\lambda \approx 18.1$  [36] is a dimensionless constant,  $\alpha^{-1} \approx 1.1$  nm [37] is the coefficient of exponential decay of the localized states involved in the hopping process, *k* is Boltzmann's constant,  $N(E_F)$  is the density of states at the Fermi energy level, *e* is the electronic charge,  $v_{ph}$  is a phonon frequency (~10<sup>13</sup> Hz) and *R* is the hopping distance between two sites can be given as

$$R = \left[\frac{9}{8\pi \alpha k T N(E_F)}\right]^{\frac{1}{4}}$$
(4)

The average hopping energy W can be evaluated by the following relation

$$W = \frac{3}{4\pi R^3 N(E_F)} \tag{5}$$

The values of  $T_0$ , R, W and  $N(E_F)$  as evaluated from above equations are listed in **Table 2** and are in good agreement with the values reported earlier [**36-39**]. The variations of Mott's parameters with the increase of Au NP's concentration provide an acceptable explanation for the enhancement of conductivity of Pani/Au films. The obtained results fulfill the Mott's requirement  $\alpha R >> 1$  and W>> kT for conductivity by hopping to distant sites.

**Table 2.** Mott's parameters such as Characteristic temperature  $(T_o)$ , hopping distance (R), average hopping energy (W), density of states at Fermi energy level N(E<sub>F</sub>) and Electrical parameters obtained from Hall Effect measurements such as carrier concentration (n), mobility ( $\mu$ ), Hall resistivity ( $\rho$ ), Hall coefficient (R<sub>H</sub>) for different Pani/Au samples.

Parameters	$S_0$	S <sub>0.30</sub>	S <sub>0.60</sub>	S <sub>1.0</sub>
T <sub>o</sub> (K)	1.84x10 <sup>7</sup>	$1.47 \text{x} 10^7$	4.6x10 <sup>6</sup>	8.7x10 <sup>6</sup>
R <sub>hop</sub> (nm) at 300K	6.45	6.13	4.60	5.39
W (meV)	102	97	72	85
N (E <sub>F</sub> ) cm <sup>-3</sup> eV <sup>-1</sup>	8.76x10 <sup>18</sup>	1.07x10 <sup>19</sup>	3.42x10 <sup>19</sup>	1.8x10 <sup>19</sup>
αR	5.9	5.6	4.2	4.9
n (cm <sup>-3</sup> )	9.17 x 10 <sup>17</sup>	2.30 x 10 <sup>18</sup>	1.11 x 10 <sup>19</sup>	5.33 x 10 <sup>18</sup>
$\mu$ (cm <sup>2</sup> V <sup>-1</sup> sec-1)	2.55	3.38	9.75	4.07
$\rho \left( \Omega \; cm \right)$	2.66	0.80	0.05	0.28
$R_{\rm H}(m^2C^{-1})$	6.81	2.71	0.56	1.17

#### Hall effect measurements

The Hall resistivity ( $\rho$ ) as a function of nanoparticle concentration has been measured at room temperature. The results are summarized in **Table 2** along with Mott's parameters. The Hall coefficient ( $R_H$ ) decreases by a factor of ~10 on increasing metal concentrations from 0 to 1.0 %. Carrier concentration (n) and mobility ( $\mu$ ) increases at the same rate as the decrease in  $R_H$  towards higher gold particle concentration. Electrical parameters, such as n and  $\rho$  obtained from Hall measurements are of the same order as is calculated by dc measurements, indicating confirmation of the results obtained.

#### Dielectric constant and dielectric loss

The variation of the dielectric constant,  $\varepsilon'$ , and dielectric loss,  $\varepsilon''$ , versus frequency for pure Pani and different Pani/Au nanocomposites is shown in **Fig. 5**. The dielectric constant,  $\varepsilon'$ , and dielectric loss,  $\varepsilon''$ , have been calculated from the measured values of capacitance (C) and dissipation factor (tan  $\delta$ ) obtained from LCR meter using the relations

$$\varepsilon' = \frac{Cd}{A\varepsilon_0} \tag{6}$$
$$\varepsilon'' = \varepsilon' \tan \delta \tag{7}$$

where, d and A is the thickness and area of the investigated samples respectively, and  $\mathcal{E}_0$  is the permittivity of free space. It is evident from the plot that both  $\varepsilon'$  and  $\varepsilon''$  decrease with increased frequency.



**Fig. 5.** Variation of dielectric constant with frequency of Pani ( $S_0$ ) and Pani/Au films ( $S_{0.30}$  and  $S_{1.0}$ ). Inset shows frequency dependence of dielectric loss factor of Pani ( $S_0$ ) and Pani/Au films ( $S_{0.30}$  and  $S_{1.0}$ ).

The frequency dependence of  $\varepsilon'$  and  $\varepsilon''$  is due to the interfacial polarization of the material. This polarization arises essentially due to existence of polar and conductive regions dispersed in an insulating matrix. The mobile charges accumulate at the interfaces and there is formation of large dipoles on metal particles or clusters. When the applied field frequency is less, the electric dipoles adjust according to the field direction and polarization increases. Hence,  $\varepsilon'$  shows large values in low frequency regime [40]. However, at high frequencies, the variation of field is too

fast that the dipoles can no longer pursue the applied field, results in decrease in  $\varepsilon'$ . It can be identified from **Fig. 5** that the incorporation of gold NP's enhances the dielectric constant of the S<sub>0.30</sub>, and S<sub>1.0</sub> samples dramatically in comparison to S<sub>0</sub> under the same conditions. The  $\varepsilon''$  follows the similar trend. The improved dielectric constant of nanocomposite suggests its increased ability to store electric potential energy under the impact of alternating electric field.

### AC conductivity

The ac conductivity  $\sigma_{ac}$  can be obtained from  $\varepsilon'$  and  $\tan \delta$  using the relation

$$\sigma_{ac} = \omega \varepsilon_0 \varepsilon' \tan \delta \tag{8}$$

where,  $\omega = 2\pi f$  is the angular frequency. The room temperature frequency dependence of the ac conductivity of S<sub>0</sub>, S<sub>0.30</sub>, and S<sub>1.0</sub> is given in **Fig. 6**.



Fig. 6. Frequency dependence of ac conductivity of Pani ( $S_0$ ) and Pani/Au films ( $S_{0.30}$  and  $S_{1.0}$ ).

In the present study, the ac conductivity is analyzed by the power law equation given by Pollock and Geballe [41]

$$\sigma_{ac} \propto \omega^s \tag{9}$$

where, s is the index used to understand the type of conduction mechanism dominant in amorphous materials. The value of s for given samples lie between 0.5 and 1. It indicates a hopping mechanism is dominant in the given samples. As shown in **Fig. 6**, the  $\sigma_{ac}$  of  $S_{0.30}$  and  $S_{1.0}$  is higher than that of  $S_0$ . The following mechanism is proposed for explaining the increase in  $\sigma_{ac}$  of Pani with introduction of gold nanoparticles. There is an electric field induced charge transfer taking place between the Pani and the gold nanoparticles [**42**]. When a sufficient electric field is applied, the electron lone pair that resides on the imine nitrogen of the Pani may gain adequate energy to overcome the interface between the Pani and the Au nanoparticles and shifted onto the gold nanoparticles (**Scheme 1**).



**Scheme 1.** Schematic representation depicting charge transfer between the polyaniline and gold nanoparticles in Pani/Au nanocomposites.

After losing a lone pair of electrons, the EB form of Pani will become fully oxidised. At this state, the Pani film will compose predominantly of quinoid groups and hence so many imino moieties which may have earlier been occupied are available for complex formation with the gold nanoparticles. This may temporarily dope the film. Therefore, the conductivity of nanocomposite will increase dramatically. The homogenous dispersion of gold nanoparticles in Pani (as shown in FESEM images) additionally helps in improving the ac conductivity of Properly dispersed composite materials. metal nanoparticles increase electronic tunneling through gold nanoparticles [43]. However conductivity decreases in more heavily doped polyaniline films with gold nanoparticles. This is because of the formation of agglomerates due to self-binding property of gold nanoparticles in polymer matrix at higher concentration, which hinders the movement of electrons.

#### Conclusion

Self-standing films of Pani/Au nanocomposites have been successfully synthesized using a physical process with negligible risk of chemical contamination. Confirmation of the presence of gold nanoparticles in polyaniline is obtained by XRD and EDX. FTIR confirms that the addition of gold nanoparticles does not change the backbone structure of Pani. SEM analysis show homogenous distribution of gold nanoparticles in the Pani matrix with minor aggregation. The conductivity measurement done at 80-350 K obeys the three dimensional Mott's variable range hopping among localized states for non-interacting carriers. The conductivity of the samples gets enhanced with introduction of metal fractions. The parameters obtained directly from room temperature Hall measurement are in good agreement with that of dc measurements. The dielectric properties of nanocomposite material are also enhanced with respect to pure Pani.

#### Acknowledgements

The authors acknowledge Dr. Asokan, IUAC, New Delhi for extending some of the experimental facilities for this research.

#### Reference

- Qazi, T.H.; Rai, R.; Dippold, D.; Roether, J.E.; Schubert, D.W.; Rosellini, E.; Barbani, N.; Boccaccini, A.R.; *Acta Biomater.*, 2014, 10, 2434.
   DOI: <u>10.1016/j.actbio.2014.02.023</u>
- Duboriz, I.; Pud, A.; Sens. Actuators, B, 2014, 190, 398.
   DOI: 10.1016/j.snb.2013.09.005
- Pramodini, S.; Poornesh, P.; Sudhakar, Y.N.; Kumar, M.S.; *Opt. Commun.*, **2013**, *293*, 125.
   **DOI:** 10.1016/j.optcom.2012.11.088

- Min, Y.; Liu, Y.; Poojari, Y.; Wu, J.C.; Hildreth, B.E.; Rosol, T.J.; Epstein, A.J.; *Synth. Met.*, **2014**, *198*, 308.
   **DOI:** <u>10.1016/j.synthmet.2014.10.035</u>
- Niu, H.; Qin, S.; Mao, X.; Zhang, S.; Wang, R.; Wan, L.; Xu, J.; Miao S.; *Electrochim. Acta*, **2014**, *121*, 285.
   **DOI:** <u>10.1016/j.electacta.2013.12.059</u>
- 6. Ali, Y.; Kumar, V.; Sonkawade, R.G.; Dhaliwal, A.S.; *Adv. Mat. Lett.*, **2012**, *3*, 388.
- **DOI:** 10.5185/amlett.2012.6358 7. Ali, Y.; Kumar, V.; Sonkawade, R.G.; Dhaliwal, A.S.; *Vacuum*, **2013**, *90*, 59.
- **DOI:** <u>10.1016/j.vacuum.2012.10.001</u>
- Kumar, V.; Ali, Y.; Sharma, K.; Kumar, V.; Sonkawade, R.G.; Dhaliwal, A.S.; Swart, H. C.; *Nucl. Instrum. Methods Phys. Res., Sect. B*, 2014, 323, 7.
   DOI: <u>10.1016/j.nimb.2014.01.009</u>
- Mishra, Y.K.; Mohapatra, S.; Chakravadhanula, V.S.K.; Lalla, N.P.; Zaporojtchenko, V.; Avasthi, D.K.; Faupel, F.; J. *Nanosci. Nanotechnol.*, 2010, 10, 2833.
   DOI: <u>10.1166/jnn.2010.1449</u>
- 10. Park, D.H.; Kim, M.S.; Joo, J; Chem. Soc. Rev., **2010**, *39*, 2439. **DOI:** <u>10.1039/B907993A</u>
- Ali, Y.; Sharma, K.; Kumar, V.; Sonkawade, R.G.; Dhaliwal, A.S.; *Appl. Surf. Sci.*, **2013**, 280, 950.
   **DOI:** <u>10.1016/j.apsusc.2013.05.116</u>
- Ali, Y.; Kumar, V.; Sonkawade, R.G.; Dhaliwal, A.S.; Swart, H.S.; Vacuum, 2014, 99, 265.
   DOI:10.1016/j.vacuum.2013.06.016
- Yu, Q.; Shi, M.; Cheng, Y.; Wang, M.; Chen, H.Z.; Nanotechnol., 2008, 19, 265702.
   DOI: 10.1088/0957-4484/19/26/265702
- Avasthi, D.K.; Mishra, Y.K.; Singhal, R.; Kabiraj, D.; Mohapatra, S.; Mohanta, B.; Gohil, N.K.; Singh, N.; *J. Nanosci. Nanotechnol.*, 2010, 10, 2705.
   DOI: <u>10.1166/jnn.2010.1433</u>
- Mohapatra, S.; Mishra, Y.K.; Avasthi, D.K.; Kabiraj, D.; Ghatak, J.; Varma, S.; J. Phys. D: Appl. Phys., 2007, 40, 7063.
   DOI: 10.1088/0022-3727/40/22/030
- Kooti, M.; Kharazi, P.; Motamedi, H.; J. Taiwan Inst. Chem. Eng., 2014, 45, 2698.
- DOI: <u>10.1016/j.jtice.2014.04.006</u>
  Patil, U.V.; Ramgir, N.S.; Karmakar, N.; Bhogale, A.; Debnath, A.K.; Aswal, D.K.; Gupta, S.K.; Kothari, D.C.; *Appl. Surface Sci.*, **2015**, *339*, 69.
  DOI: <u>10.1016/j.apsusc.2015.02.164</u>
- Wang, Z.; Yuan, J.; Li, M.; Han, D.; Zhang, Y.; Shen, Y.; Niu, L.; Ivaska, A.; *J. Electroanalytical Chem.*, 2007, 599, 121.
   DOI: <u>10.1016/j.jelechem.2006.09.021</u>
- Yang, W.; Liu, J.; Zheng, R.; Liu, Z.; Dai, Y.; Chen, G.; Ringer, S.; Braet, F.; *Nanoscale Res. Lett.*, **2008**, *3*, 468.
   **DOI:** <u>10.1007/s11671-008-9182-9</u>
- Bao, S.; Du, M.; Zhang, M.; Zhu, H.; Wang, P.; Yang, T.; Zou, M.; *Chem. Eng. J.*, **2014**, *258*, 281.
   **DOI:** 10.1016/j.cej.2014.07.078
- Mazeiko, V.; Minkstimiene, A.K.; Ramanaviciene, A.; Balevicius, Z.; Ramanavicius, A.; *Sens. Actuators, B.*, **2013**, *189*, 187. DOI: <u>10.1016/j.snb.2013.03.140</u>
- Tseng, R.J.; Huang, J.; Ouyang, J.; Kaner, R.B.; Yang, Y.; Nano Lett., 2005, 5, 1077.
   DOI: <u>10.1021/nl0505871</u>
- Chen, W.-K.; Hu, C.-W.; Hsu, C.-Y.; Ho. K.-C.; *Electrochim. Acta*, 2009, 54, 4408.
- **DOI**: <u>10.1016/j.electacta.2009.03.017</u> 24. Fu, X.; Jia, C.; Wan, Z.; Weng, X.; Xie, J.; Deng, L.; *Org., Electron.*, **2014**, *15*, 2702.
- DOI: <u>10.1016/j.orgel.2014.07.040</u>
  25. Ali, Y.; Kumar, V.; Dhaliwal, A.S.; Sonkawade, R.G.; *Adv. Mat.*
- *Lett.*, **2013**, *4*, 368. **DOI**: <u>10.5185/amlett.2012.9422</u>
- 26. Radhapyari, K.; Khan, R.; *Adv. Mat. Lett.*, **2015**, *6*, 13. **DOI**: <u>10.5185/amlett.2015.5607</u>
- Venditti, I.; Fratoddi, I.; Russo, M.V.; Bearzotti, A.; *Nanotechnol.*, 2013, 24, 155503.
   DOI: 10.1088/0957-4484/24/15/155503
- 28. Ali, Y.; Kumar, V.; Sonkawade, R.G.; Shirsat, M.D.; Dhaliwal, A.S.; Vacuum, **2013**, 93, 79.

**DOI:** <u>10.1016/j.vacuum.2013.01.007</u>

- Gupta, K.; Jana, P.C.; Meikap, A.K.; *Solid State Sci.*, **2012**, *14*, 324.
   DOI: <u>10.1016/j.solidstatesciences.2011.12.003</u>
- Bogdanovic, U.; Vodnik, V.V.; Ahrenkiel, S.P.; Stoiljkovic, M.; Marjanovic, G.C.; Nedeljkovic, J.M.; *Synth. Met.*, **2014**, *195*, 122. DOI: <u>10.1016/j.synthmet.2014.05.018</u>
- Mallick, K.; Witcomb, M.; Scurell, M.; Strydom, A.; J. Phys. D: Appl. Phys., 2009, 42, 095409.
   DOI: 10.1088/0022-3727/42/9/095409
- Afzal, A.B.; Akhtar, M.J.; Nadeem, M.; Hassan, M.M.; *J. Phys. Chem. C*, **2009**, *113*, 17560.
   **DOI:** <u>10.1021/jp902725d</u>
- Kumar, A., Banerjee, S.; Saikia, J.P.; Konwar, B.K.; *Nanotechnol.*, 2010, 21, 175102.
   DOI: <u>10.1088/0957-4484/21/17/175102</u>
- 34. Li, G.; Zhang, Z.; *Macromolecules*, 2004, *37*, 2683.
  DOI: <u>10.1021/ma035891k</u>
- Mack, N.H.; Bailey, J.A.; Doorn, S.K.; Chen, C.; Gau, H.; Xu, P.; Williams, D.J.; Akhadov, E.A.; Wang, H.; *Langmuir*, 2011, 27, 4979.
   DOI: 10.1021/la103644j
- Singh, R.; Narula, A.K.; Tandon, R.P.; Mansingh, A.; Chandra, S.; J. Appl. Phys., 1996, 79, 1476.
   DOI: 10.1063/1.360987
- Singh, R.; Arora, V.; Tandon, R.P.; Chandra, S.; Mansingh, A.; J. Mat. Sci., 1998, 33, 2067.
   DOI: 10.1023/A:1004358800788
- Dutta, K.; De, S.; De, S.K.; J. Appl. Phys., 2007, 101, 093711.
   DOI: 10.1063/1.2724824
- Campos, M.; Jr, B.B.; J. Phys. D Appl. Phys., 1997, 30, 1531.
   DOI: <u>10.1088/0022-3727/30/10/021</u>
- Kaur, N.; Singh, M.; Singh, A.; Awasthi, A.M.; Singh, L.; *Phys. B*, 2012, 407, 4489.
- DOI: <u>10.1016/j.physb.2012.07.052</u>
  41. Pollak, M.; Geballe, T.H.; *Phys. Rev.*, **1961**, *122*, 1742.
  DOI: <u>10.1103/PhysRev.122.1742</u>
- 42. Goswami, L.; Sarma, N.S.; Chowdhury, D.; J. Phys. Chem. C, 2011, 115, 19668.
   DOI: 10.1021/jp2075012
- Gurta, K.; Jana, P.C.; Meikap, A.K.; Synth. Met., 2010, 160, 1566.
   DOI: 10.1016/j.synthmet.2010.05.026

# **Advanced Materials Letters**

Copyright © VBRI Press AB, Sweden www.vbripress.com

## Publish your article in this journal

Advanced Materials Letters is an official international journal of International Association of Advanced Materials (IAAM, <u>www.iaamonline.org</u>) published by VBRI Press AB, Sweden monthly. The journal is intended to provide topquality peer-review articles in the fascinating field of materials science and technology particularly in the area of structure, sysnthesis and processing, characterisation, advanced-sate properties, and application of materials. All published articles are indexed in various databases and are available download for free. The manuscript management system is completely electronic and has fast and fair peer-review process. The journal includes review article, research article, notes, letter to editor and short communications.

