Contents lists available at ScienceDirect

Expert Systems With Applications

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

A harmonic estimator design with evolutionary operators equipped grey wolf optimizer

Akash Saxena[a,*], Rajesh Kumar[b], Seyedali Mirjalili[c]

[a] Department of Electrical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
[b] Department of Electrical Engineering, Malaviya National Institute of Technology, Jaipur, India
[c] Centre for Artificial Intelligence Research and Optimisation; Torrens University Australia, Fortitude Valley, Brisbane, 4006 QLD, Australia

ARTICLE INFO

Article history:
Received 28 June 2019
Revised 14 October 2019
Accepted 8 December 2019
Available online 13 December 2019

Keywords:
Grey Wolf Optimizer (GWO)
Mutation
Crossover
Harmonics
Power quality
Optimization
Algorithm

ABSTRACT

Harmonic estimation is a challenging design problem in power networks. Accurate estimation of the inter, power and sub harmonics in networks can be a helpful aspect for designing potential solutions for elimination of these harmonics. Harmonic estimation design problem has been considered as an optimization problem with the amalgamation of least square algorithm in past. In this paper, we first propose an Evolutionary Operators Equipped Grey Wolf Optimizer (E-GWO). In this proposal a sinusoidal function enabled bridging is proposed and along with this tournament selection operator and crossover and mutation operation are incorporated at position updation phase. The variant is first benchmarked on latest CEC-2017 functions and then this design problem is addressed. After a meaningful comparison with the previously published approaches, we arrive at the conclusion that proposed modifications have positive implications on the performance of GWO. Proposed harmonic designs are robust when tested with different operating conditions.

1. Introduction

Modern power system possesses consumer centric policies, hence comfort of the consumers in terms of reliability and quality of power supply are the utmost priorities of the power producers and distributors. The quality of power can be characterized as the quality of the voltage and current at distribution level rather at end user. Often the use of electronic circuits, nonlinear inductive loads and time varying loads in industry introduce harmonics in the system voltage and current. Harmonics are nothing but unwanted spectral ingredients of the distorted electrical signals. Frequency of the harmonics are the integer multiple of the fundamental frequency. These harmonics can be considered as power line pollutants that contaminate the system's fundamental voltage and current signals (Wiczynski, 2008).

These unwanted signals in the fundamental signals are catastrophic, the adverse effects of these harmonics can be observed in terms of losses in electrical systems, loss in terms of data, reduction in life span of electrical appliances, functioning of the electrical appliances and many more. The most adverse effect of the harmonics can be seen in communication networks. For example in Power Line Carrier Communication Systems (PLCCS), the communication and protection schemes are based on the measurements of receiving end and sending signals. Any harmonic in the electrical signal can affect the working of these communication channels. Regulatory bodies such as Institute of Electrical and Electronics Engineers (IEEE) and other have defined standards and regulations for harmonic levels.

Along with the power harmonics there are several adverse effects of inter harmonics namely thermal effects, telecommunication interference, erroneous firing of the apparatus which are derived from the thyristors, contamination in control signals used for protection and operation of the power devices that can results in a mal-operation of the relays and circuit breakers, frequency overload (high) of passive parallel filters and many more (Lin, 2012).

From this discussion, one can arrive on a strong conclusion that a special care is to be taken while dealing with the harmonics, hence, the studies of harmonics can be done in two directions. The first direction is to conduct analysis for accurate estimation of the harmonic levels in the power networks and second is the elimination of the harmonics by designing filters. Conservatively, discrete Fourier transform method is an efficient one for signal spectrum tracking but it possesses several drawbacks such as effect of spectral leakage and picket fence effect due to improper sampling (Lin, 2012). As it's a known fact that power system frequencies are subjected to change hence, spectral leakage cannot be avoided.

* Corresponding author.
E-mail addresses: aakash.saxena@hotmail.com, akash@skit.ac.in (A. Saxena), rkumar.ee@mnit.ac.in (R. Kumar), ali.mirjalili@gmail.com (S. Mirjalili).

https://doi.org/10.1016/j.eswa.2019.113125
0957-4174/

Applied Soft Computing Journal 75 (2019) 84–105

Contents lists available at ScienceDirect

Applied Soft Computing Journal

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

β-Chaotic map enabled Grey Wolf Optimizer

Akash Saxena [a,*], Rajesh Kumar [b], Swagatam Das [c]

[a] Department of Electrical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
[b] Department of Electrical Engineering, Malaviya National Institute of Technology, Jaipur, India
[c] Electronics and Communication Sciences Unit, Indian Statistical Institute, Kolkata, India

HIGHLIGHTS

- A bridging mechanism inspired from β function is proposed for Grey Wolf Optimizer.
- Evolved β-GWO is benchmarked on shifted and biased and CEC-2017 functions.
- Comparative analyses with variants of GWO and other algorithms are presented.
- Applications of β-GWO are reported on real problems.

ARTICLE INFO

Article history:
Received 11 June 2018
Received in revised form 20 September 2018
Accepted 24 October 2018
Available online 7 November 2018

Keywords:
β-Chaotic map
Grey Wolf Optimizer
Congress on Evolutionary Computation (CEC)
Chaos theory

ABSTRACT

The diversification (exploration) and intensification (exploitation) are two main attributes of any population-based metaheuristic algorithm. It is essential for any algorithm that in exploration phase the search space is utilized and explored properly through random behavior, on the other hand, the progression of the search in a viable direction to obtain global minima, should be performed through strategic behavior in exploitation phase. A proper balance between these two can be achieved by an adaptive mechanism in every algorithm. Robustness of an algorithm is judged by the efficacy of these two attributes along with the efficiency of the bridging mechanism. In literature, the positive impact of inculcation of chaotic sequences on the efficacy of these attributes has been reported. With this motivation, the paper presents an adaptive bridging mechanism based on β-chaotic sequence for the improvement of Grey Wolf Optimizer (GWO). The control vector of classical GWO is integrated with the β-chaotic sequence for better exploration and exploitation virtues. The new variant β-GWO is benchmarked on two benchmark suites 1 and 2 that include 12 shifted and biased functions and 29 Congress on Evolutionary Computation-2017 (CEC-2017) functions. Sensitivity Dependence of Initial Conditions (SDIC) is performed for tuning the initial parameters. The comparison of the proposed variant with other contemporary algorithms is carried out and different statistical tests are performed to judge the efficacy of the proposed variant. Further, the applicability of the proposed variant is checked with two real engineering problems namely frequency modulated sound waves parameter estimation problem and strategic bidding in the energy market. Results reveal that the proposed chaotic variant exhibits better exploration and exploitation qualities.

1. Introduction

Non-convex and black-box optimization problems involving multi-dimensional real search spaces, often pose a severe challenge to the traditional mathematical programming based solvers. In addition, some instances of such problems may not clearly define the bounds on the decision variables while involving stochastic parameters (often due to noise). These problems can be continuous, discontinuous, constrained, or unconstrained in nature. While searching the powerful paradigms to solve such hard optimization problems, the metaheuristic algorithms have been developed by the researchers for over last four decades or more. Metaheuristics, founded on the basis of simulation and mimicry of nature, provide the advantages in terms of requiring no derivative information of the function, being insensitive to initialization and being adaptive as well as simple. In contrast to the traditional problem-specific heuristic methods, these metaheuristic optimization algorithms can be applied in a black-box manner and without presuming domain knowledge about the problem at hand [1].

A metaheuristic method is a problem independent higher level heuristic method that can be employed to solve many hard optimization problems. The use of metaheuristic algorithms in real applications has increased from last few years. The metaheuristic

* Corresponding author.
E-mail address: akash@skit.ac.in (A. Saxena).

https://doi.org/10.1016/j.asoc.2018.10.044
1568-4946/

ENERGY SOURCES, PART A: RECOVERY, UTILIZATION, AND ENVIRONMENTAL EFFECTS
https://doi.org/10.1080/15567036.2019.1666937

Study of performance and emissions of a stationary DI variable compression ratio CI engine fueled with n-butanol/diesel blends using Taguchi technique: analytical and experimental analysis

Ashish Nayyar [a*], Dilip Sharma[b], Shyam Lal Soni[c], Vikas Gautam[a], Chandan Kumar[a], and Manu Augustine[a]

[a]Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India; [b]Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur, India; [c]National Institute of Technology, Uttarakhand, India

ABSTRACT

In the current work, n-butanol-diesel blends were tested on a small size agriculture-based compression ignition (CI) engine. Taguchi analysis was carried out to identify the optimum blending ratio and engine operating parameters. Experiments were conducted with n-butanol/diesel blends (10–20% by volume) by varying compression ratio (CR) (17.5–19.5), injection timing (21–25 CA btdc) and injection pressure (200–220 bar). The 20% n-butanol/diesel blend (BU20) showed better results of performance and emissions at increased CR under similar operating conditions. When engine was fueled with BU20, reduction in Smoke, NO_x (Nitrogen-oxides) and CO (Carbon-monoxide) were observed to be 49.03%, 13.68% and 5.88%, respectively, in comparison to diesel. However, HC (Hydrocarbons) were found to be higher by 11.76% for BU20 as compared to diesel.

ARTICLE HISTORY
Received 12 June 2019
Revised 2 August 2019
Accepted 29 August 2019

KEYWORDS
Emission; n-butanol-diesel blend; CI engine; Taguchi; ANOVA

Introduction

Increasing environmental pollution and cost of fossil fuels have attracted significant research attention in renewable biofuels for IC engines. The control of smoke emissions from CI engines is a major hurdle in the global aspirations of a clean environment. Use of improved fuels without structural change in engines has been observed to give good results in controlling smoke emissions (Curran et al. 2001; Rahman et al. 2013).

In CI engines, different kinds of unconventional fuels and additives like alcohols (Can, Celikten, and Usta 2004; Chen et al. 2012; Lapuerta, Armas, and Herreros 2008; Putrasaria, Nura, and Muharama 2013; Sayin 2010; Sayin, Ozsezen, and Canakci 2010), biodiesels (Klein-Douwel et al. 2009; Mohsin et al. 2014; Palash et al. 2013; Pathak et al. 2018), vegetable oils (Bayındir, Zerrakki Isık, and Aydın 2017; Corsini et al. 2015; Jain et al. 2017), gaseous fuels (Choudhary, Nayyar, and Dasgupta 2018; Gupta et al. n.d.; Rosha, Dhir, and Kumar 2018) and other oxygenated compounds (Fayyazbakhsh and Pirouzfar 2016a, 2016b; Kumar et al. 2018a, 2018b; Mccreath 1971; Ommi, Nekofar, and Pirozfar 2009; Pirouzfar, Zarringhalam Moghaddam, and Mirza 2012) can be used to control emissions. Improved fuel blends can also be prepared by adding some amount of these compounds in diesel. Out of these alternatives, oxygenated compounds are better suited because of their potential to reduce exhaust emissions without altering engine performance (Choi and Reitz 1999; Rajasekar et al. 2010; Rakopoulos et al. 2014). Most of the oxygenated compounds are renewable and hold up the local agriculture sector (Jang et al. 2012; Tutak

CONTACT Ashish Nayyar ashishnayyar@skit.ac.in Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur 302017

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ueso.

*corresponding author of this article

Energy 168 (2019) 136–150

Contents lists available at ScienceDirect

Energy

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

Modeling and experimental investigation for performance and emissions on a diesel engine using bio-oxygenated ternary fuel blends

Ashish Nayyar [a, *], Dilip Sharma [b], Shyam Lal Soni [b], Bhuvnesh Bhardwaj [c], Manu Augustine [a]

[a] Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, 302017, India
[b] Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur, 302017, India
[c] Department of Mechanical Engineering, JECRC, Jaipur, India

ARTICLE INFO

Article history:
Received 9 April 2018
Received in revised form
18 September 2018
Accepted 22 November 2018
Available online 24 November 2018

Keywords:
Emission
Diesel
Blend
Smoke
Additives
Bio-oxygenated

ABSTRACT

The increasing cost of fossil fuels as well as increasing environmental pollution has attracted research in alternative fuels and additives for improving the performance and reducing emissions of diesel engines without costly engine modifications. In the present article, an exhaustive analysis of the performance and emissions of oxygenated ternary fuel blends is done through modeling and experimental investigation to determine the optimal blending ratio of additives for reduced emissions. The Nitromethane-n-butanol –diesel blend is termed as bio-oxygenated fuel. Baseline data were generated by using diesel and a blend of 20% (v/v) n-butanol with diesel (B20). Ternary blends of Nitromethane (NM) and B20 containing 1–3% NM by volume were prepared and experiments were conducted. It was observed that 1% of Nitromethane by volume (NM1B20) gives best results for emission reduction. The overall effect of this ternary blend was reduction in smoke and nitrogen oxides (NO_x) by 61.85% and 8.07%, respectively, as compared to diesel. Moreover, the performance of ternary blend was also found to be better than the base fuels. It was thus concluded that Nitromethane-n-butanol–diesel blends can be highly effective alternatives in reducing emissions in diesel engines with a little improvement in the overall performance characteristics.

1. Introduction

The versatile diesel engine is ubiquitous in transportation and power generation applications. The increasing cost of fossil fuels and growing environmental concerns during the past few decades have attracted many researchers towards issues pertaining to alternative fuels and additives for improving performance and emissions without costly engine modifications [1–3].

It has been reported in literature that combustion improves with increasing percentage of oxygenated fuel in a blend. Alcohols are oxygenated fuels; the presence of oxygen in their molecular structure and higher volatility renders them compatible for blending with diesel [4–8].

The properties of n-butanol are very similar to that of fossil fuels. As compared to methanol and ethanol, it has a higher Cetane number, higher heating value, is less corrosive, has more calorific value and is more miscible in diesel [9–11]. N-butanol is mainly produced as a biofuel. This fact further enhances its appeal in comparison to other alternative fuels. Butanol blending up to 5% (v/v) has been found to be very effective in reducing the emissions of smoke and NO_x [12,13]. The blending of butanol (10% v/v) with vegetable oil–diesel (20:70) blends results in decreased CO_2 and HC and increased BSFC, NO_x and CO. However, the variation of HC and CO is further dependent on vegetable oil properties [14,15]. Substitution of 10% n-butanol was found to have resulted in reduction of NO_x and PM emissions at the cost of engine performance [16,17].

Experimental studies have been conducted on diesel engines at steady-state conditions with 8–24% (v/v) n-butanol-diesel and

Abbreviations: BTE, Brake thermal efficiency; BSFC, Brake specific fuel consumption; BSEC, Brake specific energy consumption; CI, Compression ignition; CN, Cetane number; CO, Carbon monoxide; CO_2, Carbon dioxide; CR, Compression ratio; DI, Direct injection; HC, Hydrocarbon; IC, Internal combustion; NM, Nitromethane; NO_x, Nitrogen oxides; PM, Particulate matter; v/v, volume/volume.

* Corresponding author.
E-mail addresses: ashishnayyar@skit.ac.in (A. Nayyar), sharmadmnit@gmail.com (D. Sharma), shyamlalsoni@gmail.com (S.L. Soni), bhuvnesh.bhardwaj@gmail.com (B. Bhardwaj), augustine.manu@gmail.com (M. Augustine).

https://doi.org/10.1016/j.energy.2018.11.098
0360-5442/

An effective teaching-learning-based optimization algorithm for the multi-skill resource-constrained project scheduling problem

Received 30 July 2018
Revised 12 October 2018
21 December 2018
27 February 2019
21 April 2019
Accepted 16 June 2019

Dheeraj Joshi
Mechanical Engineering, Swami Keshvanand Institute of Technology Management and Gramothan, Jaipur, India and Mechanical Engineering, Malaviya National Institute of Technology, Jaipur, India

M.L. Mittal
Mechanical Engineering, Malaviya National Institute of Technology, Jaipur, India

Milind Kumar Sharma
Production and Industrial Engineering, MBM Engineering College, JNV University, Jodhpur, India, and

Manish Kumar
Mechanical Engineering, Malaviya National Institute of Technology, Jaipur, India

Abstract

Purpose – The purpose of this paper is to consider one of the recent and practical extensions of the resource-constrained project scheduling problem (RCPSP) termed as the multi-skill resource-constrained project scheduling problem (MSRCPSP) for investigation. The objective is the minimization of the makespan or total project duration.

Design/methodology/approach – To solve this complex problem, the authors propose a teaching-learning-based optimization (TLBO) algorithm in which self-study and examination have been used as additional features to enhance its exploration and exploitation capabilities. An activity list-based encoding scheme has been modified to include the resource assignment information because of the multi-skill nature of the algorithm. In addition, a genetic algorithm (GA) is also developed in this work for the purpose of comparisons. The computational experiments are performed on 216 test instances with varying complexity and characteristics generated for the purpose.

Findings – The results obtained after computations show that the TLBO has performed significantly better than GA in terms of average percentage deviation from the critical path-based lower bound for different combinations of three parameters, namely, skill factor, network complexity and modified resource strength.

Research limitations/implications – The modified TLBO proposed in this paper can be conveniently applied to any product or service organization wherein human resources are involved in executing project activities.

Practical implications – The developed model can suitably handle resource allocation problems faced in real-life large-sized projects usually administered in software development companies, consultancy firms, R&D-based organizations, maintenance firms, big construction houses, etc. wherein human resources are involved.

Originality/value – The current work aims to propose an effective metaheuristic for a more realistic version of MSRCPSP, in which resource requirements of activities may be more than one. Moreover, to enhance the exploration and exploitation capabilities of the original TLBO, the authors use two additional concepts, namely, self-study and examination in the search process.

Keywords Project management, Algorithms, Scheduling, Heuristics, Optimization

Paper type Research paper

Journal of Modelling in Management
Vol. 14 No. 4, 2019
pp. 1064-1087

1746-5664
DOI 10.1108/JM2-07-2018-0108

Dynamic balancing of cleaning unit used in agricultural thresher using Jaya algorithm

Prem Singh
Swami Keshvanand Institute of Technology Management and Gramothan, Jaipur, India, and
Himanshu Chaudhary
Malaviya National Institute of Technology, Jaipur, India

Abstract

Purpose – The purpose of this paper is to propose the dynamically balanced mechanism for cleaning unit used in the agricultural thresher machine using the system of point masses.

Design/methodology/approach – The cleaning unit works on crank-rocker Grashof mechanism. To balance the mechanism, the shaking forces and shaking moments are minimized by optimizing the mass distribution of links using the dynamically equivalent system of point masses. The point mass parameters are taken as the design variables. Then, the optimization problem is solved using Jaya algorithm and genetic algorithm (GA) under suitable design constraints.

Findings – The mass, center of mass and inertias of each link are calculated using optimum design variables. These optimum parameters improve the dynamic performance of the cleaning unit.

Originality/value – The proposed methodology is tested through the standard four-bar mechanism taken from literature and also applied to the existing cleaning mechanism of the thresher machine. It is observed that the Jaya algorithm is computationally more efficient than the GA. The dynamic analysis of the proposed mechanism is simulated using ADAMS software.

Keywords Jaya algorithm, Dynamic balancing, Cleaning mechanism, Shaking force and shaking moment, Thresher machine

Paper type Research paper

1. Introduction

There are different agricultural operations, but the separation of grains from the husk and foreign materials is an essential agricultural operation. Generally, it can be done by using natural air or a mechanical fan (Simonyan and Yiljep, 2008). But natural air is limited by its speed and random direction. As a result of that, the losses of grains are higher. Moreover, the grains from the chaff and plant debris are separated using air generated by the mechanical fans (Gorial and O'callaghan, 1991a, 1991b). But these fans increase the cost, complexity of the system and labor requirement.

Therefore, the cleaning of grains can be done using a cleaning unit incorporated in a thresher machine. The thresher machine is an essential agricultural machine used by the farmers. It detaches the grains from plants with minimum effort in minimum time by the rotational motion of threshing drum with cutter and beaters as shown in Figure 1. It has three mechanisms which are feeding, threshing and cleaning mechanisms. But the cleaning mechanism plays an essential role in agriculture. It consists of three sieves which separate grains from the husk and foreign materials by the oscillating motion of sieves.

The current issue and full text archive of this journal is available on Emerald Insight at: **www.emeraldinsight.com/1708-5284.htm**

World Journal of Engineering
16/6 (2019) 702–711

[DOI 10.1108/WJE-02-2019-0048]

However, researchers have designed different mechanisms for cleaning units of thresher machine, for example, the reciprocating motion of sieves is used for cleaning the grains and driving them by the crankshaft through the connecting rod (Garvie and Welbank, 1967). The cleaning unit supported over four hinge rod is reciprocated and operated by an eccentric crank through a connecting rod (Joshi, 1981). Cam mechanism is designed for shaking of sieves (Madan Lal, 2012; Ohu *et al.*, 2015). Moreover, the cleaning process has been modelled for sorghum thresher unit (Simonyan *et al.*, 2006). Further, the grain threshing and separation have been modelled in both axial and tangential threshing units (Miu and Kutzbach, 2008). But these mechanisms require more power for their operation and also increase the cost of the machine. Also, no relevant studies on the dynamic balancing of the cleaning unit or mechanism have been published.

The unbalanced mechanism develops certain forces and moments on the frame of the machine which are defined as shaking forces and shaking moments. These forces and moments increase the vibration, driving torque, fatigues, etc., in the mechanism. The driving torque, shaking forces and shaking moments depend on the inertia, center of mass and mass of the moving link (Chaudhary and Saha, 2007a). Recently, the combined balancing of shaking forces and shaking moments is a challenging task. Therefore, many techniques have been applied to minimize the shaking forces and moments with various principles. The shaking force can be

Received 13 February 2019
Revised 23 July 2019
Accepted 21 August 2019

Journal of Science: Advanced Materials and Devices xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Science: Advanced Materials and Devices

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

Original Article

A new sustainable green protocol for production of reduced graphene oxide and its gas sensing properties

Neeru Sharma [a], Vikas Sharma [a, d], Rishi Vyas [a, e], Mitlesh Kumari [c], Akshey Kaushal [d], R. Gupta [b, c], S.K. Sharma [a], K. Sachdev [a, b, *]

[a] Department of Physics, Malaviya National Institute of Technology, Jaipur 302017, India
[b] Materials Research Centre, Malaviya National Institute of Technology, Jaipur 302017, India
[c] Department of Chemistry, Malaviya National Institute of Technology, Jaipur 302017, India
[d] Department of Physics, Indian Institute of Technology Delhi, Hauz Khas 110016, India
[e] Department of Physics, Swami Keshvanand Institute of Technology Management and Gramothan, Jaipur 302017, India

ARTICLE INFO

Article history:
Received 16 March 2019
Received in revised form
2 July 2019
Accepted 9 July 2019
Available online xxx

Keywords:
Green method
L-Glutathione
Graphene oxide
Reduced graphene oxide
Gas sensor

ABSTRACT

In this report, we report a green, rapid and scalable synthetic route for the production of reduced graphene oxide (rGO) using an environment-friendly reducing agent (L-glutathione/L-Glu) to test its feasibility for CO & NO_2 gas sensing. The structure, morphology, and thermal stability of as-synthesized rGO are investigated via Raman spectroscopy, Fourier infrared spectroscopy, X-ray diffraction, Field emission scanning electron microscope, and thermal gravimetric analysis. The L-Glu-rGO shows higher sp^2 carbon hybridization (42at.%) than graphene oxide (GO) (29 at.%). The results indicate that L-Glu-rGO exhibits good relative response at 150 °C to both gases (10 ppm of NO_2 and CO). Further, L-Glu-rGO shows a smaller response time (~10.61 s for NO_2 and ~5.05 s for CO) than GO (~16.64 s, ~11.92 s to NO_2 and CO respectively) at 150 °C, indicating the potential application of L-Glu-rGO for gas sensing.

1. Introduction

Exposure to toxic gases puts our everyday life at risk in a commercial and domestic ambiance. This has led to the development of low cost and high performing gas sensors exhibiting a low level of detection for toxic gases to address health issues. Gas sensors perform an important role in various areas viz. agriculture, medical field, electronics, aerospace, etc. Metal oxide gas sensor like Fe_2O_3, SnO_2, In_2O_3, WO_3, ZnO, TiO_2, and MoO_3 [1–9] are the most investigated ones due to their exclusive benefits such as small response time, large range of target gases, long lifetime, high sensitivity, cost efficiency, but suffer from issues such as long-term stability, and high operating temperature [10]. Nanotechnology gives liberty to cultivate the next generation gas sensing layers with improved sensitivity, selectivity, fast recovery, and smaller response time for a small concentration of gas [11]. Surface area is one of the favorable parameters which decides the sensitivity of any material. Graphene is a material contains one atom thick layer of sp^2 hybridized carbon atom, which is reported to give promising results in sensing applications due to its intrinsic electrical properties and having large surface area resulting from its nanostructure.

Graphene has been widely used for gas sensing, in energy storage devices [12,13], as transparent conducting electrode [14], in electrochemical sensors [15], ultrafiltration application on account of its unique properties *viz.* very high mobility-200,000 $cm^2 v^{-1} s^{-1}$, mechanical stiffness ~1060 GPa, excellent light transmittance ~97.7%, large surface area-2630 $m^2 g^{-1}$, and thermal conductivity ~5000 $W m^{-1} k^{-1}$ [16–18].

The graphene derivative, graphene oxide (GO), containing carbon, hydrogen, and oxygen in a varying ratio is hydrophilic and biocompatible in nature and is used in energy storage, as a biosensor, for disease detection, etc. GO is a starting point for the synthesis of high quality, cost-efficient, and large yield graphene. Reduced graphene oxide (rGO) is the best-known material as graphene derivative, having the same configuration and properties like pristine graphene, hence is suitable for electronic devices.

* Corresponding author. Department of Physics, Malaviya National Institute of Technology, Jaipur 302017, India.
E-mail address: ksachdev.phy@mnit.ac.in (K. Sachdev).
Peer review under responsibility of Vietnam National University, Hanoi.

https://doi.org/10.1016/j.jsamd.2019.07.005

Applied Nanoscience
https://doi.org/10.1007/s13204-019-01011-7

ORIGINAL ARTICLE

Investigation on the suitability of water/polyethylene glycol solutions for GO layer deposition in GO/Ag/GO films for transparent conducting electrode

Garima Makhija[1] · Vikas Sharma[2,3] · Satyavir Singh[2] · Neeru Sharma[2] · Rishi Vyas[4] · Kanupriya Sachdev[2,5]

Received: 29 November 2018 / Accepted: 9 March 2019

Abstract
A hybrid trilayered transparent conducting electrode (TCE) based on graphene oxide (GO) in the form of GO/Ag/GO multilayer synthesized using GO suspension in water and polyethylene glycol (PEG) is investigated for their suitability as TCE. The GO layers prepared from modified Hummer's method were suspended in water and EG solution separately and spin coated on a glass substrate. Ag film (~ 8 nm) was DC sputtered coated on these films before a second spin coat of GO layer to prepare two variants of trilayered structure (GO/Ag/GO). AFM/SEM images verified the smooth surface topology. Structural analysis by Raman spectroscopy showed shifting and broadening of GO peak, which represents defects/disorder with obtained I_D/I_G ratio as 0.70 and 0.98 for EG and DI water-based trilayered structure, respectively. Hall measurements concluded superior electrical and optical properties; with an average transmittance of ~ 75% in visible region, sheet resistance $R_s = 24.43\ \Omega$/sq, and high charge carrier concentration ($n = 2.11 \times 10^{22}\ \text{cm}^{-3}$) in films prepared with GO suspension in EG. The other combination prepared with DI water showed transmittance of ~ 73% and sheet resistance of 34.73 Ω/sq. X-ray photoelectron spectroscopy technique was further used to determine quantitative and chemical state information of elements by depth profile measurement of the trilayer electrode.

Keywords Graphene oxide · Transparent conducting electrode · Trilayer · Optoelectronic applications

Introduction

With the escalating demand of smart devices, the requirement of transparent conducting electrode (TCE) being a vital component in these devices (e.g., organic solar cells, OLEDs, touch screen panels, flat panels, multilayer electrodes, thin-film transistors, and defrosters) has gone manifold. A search for a candid alternative to indium–tin–oxide (ITO) has already commenced (Ellmer 2012; Aleksandrova et al. 2015) due to its high cost, scarcity of supply, and brittle nature (Yun et al. 2013; Lokanc et al. 2015). The list of such viable alternatives exhibit doped metal oxide (Jayaraman et al. 2018), multilayer TCO (Sharma et al. 2017a), metal nanowire/mesh network (Ricciardulli et al. 2018; Sepat et al. 2019), and carbon materials (Moon et al. 2013; Shekhawat et al. 2018) (carbon nanotubes and graphene) which are continually engineered to meet stringent requirements posed by new generation of optoelectronic devices. The single-layered practical devices, however, faced many bottlenecks such a slow conductivity, less stability, high junction resistance, difficulty in large-area

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s13204-019-01011-7) contains supplementary material, which is available to authorized users.

✉ Vikas Sharma
phyvikas@gmail.com

Kanupriya Sachdev
ksachdev.phy@mnit.ac.in

1 Centre for Converging Technologies, University of Rajasthan, Jaipur 302004, India

2 Department of Physics, Malaviya National Institute of Technology, Jaipur 302017, India

3 Electrical Engineering, Indian Institute of Technology Bombay, Mumbai 400076, India

4 Department of Physics, Swami Keshvanand Institute of Technology, Management and Gramothan, Jaipur 302017, India

5 Materials Research Center, Malaviya National Institute of Technology, Jaipur 302017, India

Published online: 22 March 2019