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Current Research

Opto-electronic properties of Materials, Nanoscience & Nanotechnology, Photoluminescence Spectroscopy, Solid State Physics, Light Scattering Technique for solid content & Bitumen content measurement in Tailing Pond.

Education and Research Experience

- **University of Alberta, Edmonton, Canada** December 2018- present
  Postdoc Fellow
- **Indian Institute of Technology, Kanpur** June 2018-November 2018
  Postdoc Fellow
- **Indian Institute of Technology (IIT) Indore, India** 2014-2018
  Ph.D. Research Scholar (Metallurgy Engineering & Material Science)
  Course work- CGPA- 8.3
- **Maulana Azad National Institute of Technology, Bhopal, India** 2012-2014
  M.Tech (Green Technology)
  CGPA- 9.3
- **Inderprastha Engineering College, Ghaziabad, India** 2008-2012
  BTech (Electrical & Electronics Engineering)
  Percentage- 70%
- **G. N. National Public School, Gorakhpur, UP, India** 2007
  10+2 (Physics, Chemistry, Maths)
  Percentage- 72%
- **Bethany Convent School** 2005
  10th (Science, maths, Social studies, Hindi, English)
  Percentage- 82%

Post Doc (2018-Present):

- Joined Postdoc in University of Alberta, Canada in December 2018 and currently working here. My research mainly focusses here on Development of technology for In-situ real time measurements of solids content in **Oil Sand Tailing Pond**.

  Unlike conventional method, in Canada oil/petroleum is extracted using unconventional method. Large shovels scoop the oil sand into trucks which then move it to crushers where the large clumps of earth are processed. Once the oil sand is crushed, hot water is added so it can be pumped to the extraction plant. At the extraction plant more hot water is added to this mixture of sand, clay, bitumen, and water in a large separation vessel where settling time is provided to allow the various components to separate. During separation, bitumen froth rises to the surface, where it is removed, diluted, and refined further.
  After oil/petroleum is extracted, the remaining like sand, silt, water, residual bitumen and by-products from of the hot water treatment process are called Tailings. Tailings are stored in large engineered dam and dyke facilities called tailings ponds. Tailing ponds enable water to separate from sand, clay and bitumen for re-use in bitumen extraction. Water is continuously recycled from tailings ponds back into the extraction process, reducing use of fresh water from the Athabasca River and other sources. However, it is estimated that tailings can take up to 150 years to fully dewater and settle out. There are several environmental concerns that are associated with the existence of tailings ponds. The main problem with the ponds is that they include toxic and harmful chemicals such as ammonia, mercury, and naphthenic acids. The water containing these chemicals is toxic to animals, particularly aquatic organisms. The management of tailings ponds is one of the most difficult environmental challenges associated with oil sands.
  My group is working on development of technology which would measure the amount of solid content at different depths of tailing ponds. It will help to estimate the depth from where the water can be extracted for recycling. The technology can be implemented at remote oil sands tailing ponds to measure settling of tailing in real time with lateral and depth spatial resolutions. This technology can be incorporated by oil sands industry into the overall design of their oil sands projects to deliver a more effective process and improved environmental performance. We are basically studying the processes in laser light scattering from settling particulates and gamma ray propagation in complex materials (tailings). Based on this knowledge, we will design, build and test hybrid optical-gamma ray in-situ solid content analyser systems for fluid tailings ponds.

- Joined Post Doc in IIT Kanpur from June 2018 on research topic "**Thermoelectric materials and devices**" and "**Green synthesis route of Graphene"**
  In my six-month duration work in IIT Kanpur, I was involved in various projects.
  Two major projects were thermoelectric Materials and Devices. I have synthesized pure and doped PbSe and Bi_2Te_3 using chemical synthesis route and studied its thermoelectric performance. In my research, I found out when PbSe is doped with Graphene and Bi_2Te_3 doped with Sulphur in significant amount, it gives good thermoelectric performance.
  Other project, I was involved in "Green synthesis route of Graphene using cow urine". Graphene is one of the most promising material which is being used in opto-electronics, sensors, microelectronics etc. applications. But Graphene synthesis is very challenging. Chemical synthesize route for graphene uses lots of toxic chemicals. In our work, inspite of using chemicals, we have successfully synthesized it using cow urine and Urea.

Ph.D. (2014-2018: IIT Indore)

- Thesis title: "Effect of aliovalent ion doping on structural, opto-electronic and sensing properties of ZnO".

- Synthesis of undoped and aliovalent ion ($Si^{4+}/V^{4+/5+}$) doped ZnO by Sol-gel method.

- XRD, FESEM and Raman study of the synthesized samples.

- Investigation of changes in structural parameters like strain, lattice parameters, crystallite size etc with doping.

- Analysis of the defect modification of ZnO lattice with aliovalent ion doping.

- Study of effect of aliovalent ion doping on Opto-electronic properties of ZnO.

- Understanding of the mechanism behind this changes in properties of ZnO with doping.

- Finding out the appropriate application of the material depending upon its defect modification, colour emission and opto-electronic properties.

- Application like UV sensing, Gas sensing, humidity sensing and Photocatalytic activity.

Technical Skills:

1. X-Ray Diffraction:
   a) Bruker D2-Phaser X-ray Diffractometer

2. UV-Vis Spectrometers:
   (a) Agilent cary-60 with diffuse Reflection Assembly
   (b) Ocean optics UV-Vis.

3. Fluorescence Spectrometers:
   (a) DongWoo Optron 80 K PL system
   (b) Perkin Fluorescence Spectrometers LS 55.

4. Synthesis techniques:
   Sol-gel, Solid state, Hydrothermal, Co-precipitation and wet chemical route.

5. Home-made instruments for applications like UV sensing, Light sensing set up etc.

6. Other Characterization Techniques:
   XANES, EXAFS, I-V measurements, Dielectric measurement, Raman spectroscopy, Scanning electron microscopy etc.

Other Skills/Training:

- MS Office, ORIGIN, MATLAB, GSAS, Athena and different software used for various analyses.
- One-week workshop on Indian Nanoelectronics user programs in IISC Bangalore, India in 2015.

Achievements & Awards:

- Received fellowship from Ministry of Human Resources and Development(MHRD) to Pursue my doctoral study at Indian Institute of Technology Indore, India during the period 2014-present.
- Qualified Graduate Aptitude Test in Engineering (GATE) in 2012.
- Applied in SERB-DST for fellowship for attending International conference (for oral presentation) in Rome (Applied nanotechnology and nanoscience international conference).

Publications:

- Pankaj Chamoli, **Tulika Srivastava**, Alekha Tyagi, KK Raina, Kamal K Kar, "Urea and cow urine-based green approach to fabricate graphene-based transparent conductive films with high conductivity and transparency" Materials Chemistry and Physics, 242, 122465, 2019.
- Prashant Kumar Mishra, Saniya Ayaz, **Tulika Srivastava**, Saurabh Tiwari, Ramraj Meena, Bungkiu Kissinquinker, Sajal Biring, Somaditya Sen, "Role of Ga-substitution in ZnO on defect states, carrier density, mobility and UV sensing" Journal of Materials Science: Materials in Electronics, 30, 18686-18695, 2019.
- **Tulika Srivastava**, Gaurav Bajpai, Shun Wei Liu, Sajal Biring, Somaditya Sen, "Zn1− xSixO: Reduced photosensitivity, improved stability and enhanced conductivity" 150, 42-44, 2018.
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- **Tulika Srivastava**, Aswin Sadanandan, Gaurav Bajpai, Saurabh Tiwari, Ruhul Amin, Mohd. Nasir, Sunil Kumar, Parasharam M. Shirage, Sajal Biring, Somaditya Sen, "$Zn_{1-x}Si_xO$: Improved optical transmission and electrical conductivity" Ceramics International, 43, 5668–5673, 2017.
- **Tulika Srivastava**, Gaurav Bajpai, Nidhi Tiwari, Dibyendu Bhattacharya, S. N. Jha, Sunil Kumar, Sajal Biring, and Somaditya Sen, "Opto-electronic properties of $Zn_{(1-x)}V_xO$: Green emission enhancement due to V41 state" Journal of Applied Physics 122, 025106, 2017.
- **Tulika Srivastava**, E. G. Rini, Ashutosh Joshi, Parasharam Shirage, and Somaditya Sen, "Structural Distortion and Bandgap Increment in Nanocrystalline Wurtzite Si Substituted ZnO" Journal of Nanoscience and Nanotechnology,16, 1–4, 2016.
- **Tulika Srivastava**, Sunil Kumar, Parasharam Shirage, Somaditya Sen, "Reduction of O^{2-} related defect states related to increased bandgap in Si4+ substituted ZnO" Scripta Materialia, 124, 11–14, 2016.

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- Saurabh Tiwari, Gaurav Bajpai, **Tulika Srivastava**, Srashti Viswakarma, Parasharam M. Shirage, Sajal Biring Somaditya Sen, Effect of strain due to Ni substitution in CeO_2 nanoparticles on optical and mechanical properties, Scripta Materialia, 129, 84–87., 2017.

- K Sudhakar, **Tulika Srivastava**, "Energy and exergy analysis of 36 W solar photovoltaic module" International Journal of Ambient Energy, 35, 51-57, 2014.

- Kumarasamy Sudhakar, **Tulika Srivastava**, Guddy Satpathy, Manicam Premalatha, "Modelling and estimation of photosynthetically active incident radiation based on global irradiance in Indian latitudes" International Journal of Energy and Environmental Engineering, 4, 21, 2013.

- K Sudhakar, Tulikā Śrīvāstava, Kavali Janardhan, "Matlab Modelling and simulation of solar photovoltaic panel" LAP LAMBERT Academic Publishing, 2013.

Conference proceedings/ Poster presentation:

- **Tulika Srivastava**, Gaurav Bajpai, Somaditya Sen, "Suppression and enhancement of deep level emission of ZnO on Si^{4+} & V^{5+} substitution" Journal of Physics: Conference Series, 987, 012024, 2018. (oral presentation in Applied Nanotechnology and Nanoscience International Conference (ANNIC) 18-20 October 2017 in Rome, Italy).

- **Tulika srivastava**, Gaurav Bajpai, Sunil Kumar, Parashram Shirage, Somaditya sen, "Effect of Si doping on optical & electrical property of ZnO" in 13th International Conference on Fiber Optics and Photonics, OSA Technical Digest (online) (Optical Society of America, 2016), paper W3A.88.

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- **Tulika Srivastava**, Parasharam Shirage and Somaditya Sen, “Synthesis and Characterization of Si doped ZnO nanoparticle”, Ramanujan Conclave, IIT Indore, 22-23 December 2015.

- Kavali Janardhan, **Tulika Srivastava**, Guddy Satpathy, K Sudhakar, “Hybrid solar PV and biomass system for rural electrification” Int. J. Chem. Tech. Res. ICGSEE, 5, 802-810, 2013. (International Conference on Global Scenario in Environment and Energy, ICGSEE-2013[14th – 16th March 2013] at Maulana Azad National Institute of Technology).

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Enhanced thermoelectric performance of n-type Bi_2Te_3 alloyed with low cost and highly abundant sulfur

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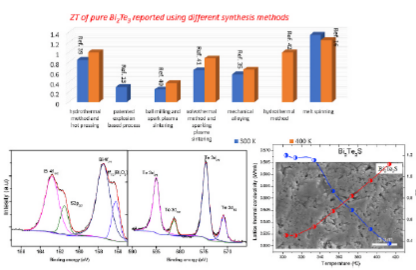
HIGHLIGHTS

- 40% reduction in thermal conductivity of S doped Bi_2Te_3 has been achieved through phonon-phonon scatterings.
- Seebeck coefficient of ~240 μV/K and lattice thermal conductivity of ~0.53 W/m K have been achieved via S doping in Bi_2Te_3.
- With the help of reduced thermal conductivity of S doped Bi_2Te_3, maximum ZT achieved is 1.12 at 413 K.
- Improved ZT has been achieved in Bi_2Te_3 by using non-toxic S dopant and low cost pressing routes.

GRAPHICAL ABSTRACT



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ABSTRACT

Bi_2Te_3 is one of the most promising thermoelectric (TE) materials. Effect of doping to decouple the electrical and thermal properties has been studied over a long decade. Here, sulfur (S), being highly abundant and non-toxic, has been used as dopant in Bi_2Te_3 material. Structural study reveals that highly doped S i.e., Bi_2Te_2S has highest dislocation density due to the enhanced point defect, which increases lattice strain. We analyzed that the combine effect of point and bulk defects significantly lead the TE performance and established a strong correlation between structure and properties. These provide a moderate Seebeck coefficient of ~240 μV/K and strong channel for scattering of low/mid frequency phonons that showed smaller lattice thermal conductivity ~0.53 W/mK (40% decrease with respect to Bi_2Te_3) for Bi_2Te_2S at 413 K. Although, there is a slight decrease in electrical conductivity with S doping but significant reduction in lattice thermal conductivity leads to an enhanced ZT value of 1.12 for Bi_2Te_2S. Enhanced ZT value for Bi_2Te_2S is rationalized by competing effect of Seebeck coefficient, electrical conductivity, and lattice thermal conductivity.

1. Introduction

The thermoelectric (TE) phenomenon stems from the fact that the charge carriers start moving in response to a temperature gradient. It is a solid-state effect, which directly converts heat into electrical energy. Promising technology of thermoelectric energy conversion from waste heat to electricity is being researched all over the world in order to optimize the efficiency. Desired properties for good performance are in

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Urea and cow urine-based green approach to fabricate graphene-based transparent conductive films with high conductivity and transparency

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Role of Ga-substitution in ZnO on defect states, carrier density, mobility and UV sensing

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Abstract

Gallium (Ga^{3+}) doped ZnO with compositions $Zn_{1-x}Ga_xO$ ($0 \le x \le 0.0468$) is prepared using the sol–gel method. ZnO Wurtzite structure having space group $P6_3mc$ is confirmed by using X-ray diffraction (XRD) measurement. The lesser ionic radii (0.62 Å) and higher charge (3+) of Gallium attracts more oxygen into the lattice and therefore a reduction in oxygen vacancies (V_O) is observed. Photoluminescence (PL) study reveals that defects present in ZnO lattice decreases with Ga substitution. This is also reflected in Urbach energy study. Enhancement in yellow emission in higher doped sample indicates the increases in oxygen interstitials (O_i). Conductivity increases due to rise of carrier concentration and mobility of the charge carriers. Interestingly p-type conduction is obtained in Ga-substituted ZnO samples. UV-sensing enhances with substitution too, i.e. photocurrent increases. However, the dark current plays crucial role in sensitivity. Reduction in oxygen vacancy, increase in oxygen interstitials and carrier recombination controls the recovery and response time.

1 Introduction

ZnO has been studied extensively in recent years for their unique properties and potential applications in electronic and optoelectronic field [1–4]. It has strong radiation resistivity, high chemical stability, low cost, and a large bandgap of ~3.37 eV at room temperature [5–8]. Furthermore, from the reported studies, defects in ZnO are an important challenge. ZnO has surface and deep level defects [9–12]. Surface defects in ZnO [13, 14] mainly comprise of oxygen and Zinc-related defects such as oxygen vacancies (V_O) [15–20], oxygen interstitials (O_i) [13, 21], Zinc vacancies (V_{Zn}) and Zinc interstitials (Zn_i) [21–24], etc.

Doping in ZnO has been tried for various reasons related to enhancement of the above properties. On such attempt is to generate a transparent conducting ZnO with p-type majority carriers. So far limited attempts have been successful. The carrier concentration and mobility needs to be drastically modified to achieve this goal. Ga^{3+} being a close neighbor of Zn^{2+} in the periodic table have similar electronic configuration and ionic radius. In the case of doping, higher valence dopant ions have a tendency of drawing more oxygen to the lattice. This results in the reduction of V_O, an introduction of O_i and other latent defects such as V_{Zn} and Zn_i. Group III (B, Al, Ga, In, etc.) [25–30] elements are mainly used to enhance its conductivity, crystallinity and optoelectronic characteristics in UV–Vis range due to their favorable elemental properties. An attempt to explore the chances of improving these parameters by Ga-substitution has been demonstrated in this work.

Ultraviolet (UV) photodetectors have been widely used in large scale area for a different purpose. Space communications, water purification, flame sensing, and early missile plume detection, etc. are some important application of UV photodetectors [3, 31–34]. Moreover, very sensitive and high-speed devices required for these applications. A variety of UV detectors are available, mainly based on

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Regular article

$Zn_{1-x}Si_xO$: Reduced photosensitivity, improved stability and enhanced conductivity

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ABSTRACT

Effect of different wavelengths (350, 380, 390, 400, 450, 550 & 650 nm) of light on surface conductivity of sol-gel synthesized $Zn_{1-x}Si_xO$ material has been observed. Enhancement in conductivity at all wavelengths of light had been attributed to enhanced charge carrier concentration with silicon doping. Reduction in sensitivity for UV and visible light wavelength indicates reduction of surface defects and deep level traps with Si^{4+} incorporation. Enhanced photo stability with Si^{4+} doping makes it an appropriate material for transparent electrodes used in various display and electronic devices.

Polycrystalline ZnO has attracted much attention due to its capability to be used as transparent electrodes for thin film transistor liquid crystal display (TFT-LCDs), organic LEDs (OLEDs), organic photovoltaics etc. [1,2]. ZnO based transparent electrodes has many evident advantages over conventional silicon based opaque electrodes like high electron conductivity, good optical transmittance, low work function, non-toxicity, and low cost [3]. Transparent electrodes are basic unit of solar cells, display devices, LEDs, etc. and therefore compromise in its properties strongly affect performance. For proper functionality of devices, ZnO based transparent electrodes should materials remain stable under the adverse condition like high humidity, high temperature, different light wavelength etc. [4]. Hence the search is on modified ZnO systems which may overcome the above criteria.

Obtaining stability of performance under illumination, i.e. being insensitive to different wavelengths of light is an important requirement [3,5]. Finding an appropriate material which remains transparent to deserved wavelengths but are not affected in terms of functionalities by the same is a challenge. With some major deficits, pure ZnO is not a good candidate in this search. The conductivity of ZnO is affected by chemisorbed oxygen molecules. ZnO usually contain surface and deep level defects which generates unwanted photo-current during light transmission and device operation. These surface defects adsorb oxygen molecules under dark condition and reduce conductivity of ZnO. Exposed to UV, oxygen molecules can be released from ZnO layer leading to an improvement of ZnO conductivity. But prolonged UV illumination can generate irreversible degradation. Deep level defects act as recombination centres for photo generated charge carriers, causing significant photo current loss [3,6,7]. To remove these defects state and obtain photo stability, different methods has been employed like doping other elements in ZnO structure, surface passivation, synthesis in special environment, etc. Si-doped ZnO has been recently shown to have improved conductivity than ZnO. The material was found to be moisture insensitive [8]. Moreover defects states were reduced [9]. In this work, effect of different wavelengths of light on conductivity of $Zn_{1-x}Si_xO$ materials has been investigated. Change in conductivity or sensitivity towards UV and visible light matches the observations made before. It also makes one understand surface defects and inter-trap states present in the material and determine photo stability. High photo stability makes this material suitable as a transparent electrode.

$Zn_{(1-x)}Si_xO$ nanoparticles, for $x = 0$, 0.013, 0.020 and 0.027, were synthesized by sol-gel method [10] (standard Pechini method) using same procedure as reported [8]. Synthesized powders were calcined at 450 °C for 6 h and then pressed into pellets. All the pellets were sintered at 500 °C for 6 h. Low temperature sintering was preferred because it is known that surface defects are higher at low temperature. A home-made setup was fabricated to observe the effect of different wavelength of light on conductivity of synthesized material as shown in Fig. S1.

Effect of different wavelength of light were examined and analysed under monochromatic light of power 20 mW at room temperature. Isolation of the system from external light ensured elimination of any secondary illumination. Repeated sequences of illumination and darkness of 10 min each were used to estimate the growth and fall of

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Vanadium substitution: A simple and economic way to improve UV sensing in ZnO

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The UV sensing in pure ZnO is due to oxygen adsorption/desorption process from the ZnO surface. Vanadium doping improves the UV sensitivity of ZnO. The enhancement in UV sensitivity in vanadium-substituted ZnO is attributed to trapping and de-trapping of electrons at V^{4+} and V^{5+}-related defect states. The V^{4+} state has an extra electron than the V^{5+} state. A V^{4+} to V^{5+} transformation happens with excitation of this electron to the conduction band, while a reverse trapping process liberates a visible light. An analytic study of response phenomenon reveals this trapping and de-trapping process. *Published by AIP Publishing.* https://doi.org/10.1063/1.5012877

INTRODUCTION

The ultraviolet detection is becoming important nowadays related to various important aspects of science/technology associated with health, environment, and even space research.[1,2] Conventional silicon based UV detectors are available. However, costly visible light filters are required for these detectors, as they are sensitive to visible light. Therefore, invention of fast, sensitive, cost-effective UV detectors is important. GaN, SiC, and diamond are promising but expensive candidates.[3–5] ZnO is abundant, inexpensive, non-toxic, and an environmentally friendly material with good thermal/chemical stability and high photoconductivity. The UV sensitivity in ZnO mainly depends upon surface defects, grain size, and oxygen adsorption/desorption properties.[6–8] Several studies of ZnO show an enhancement in UV sensing[6,8–13] due to morphological modifications. Reports suggest that doping of different materials in ZnO modifies its electronic, optoelectronic, and photoconductive properties.[14–19] Vanadium doping exhibits luminescence, and optoelectronic/photo-sensing properties. These properties arise out of defect states formation within the bandgap, which traps and de-traps electrons. In this study, the effect of vanadium doping on the UV sensing properties of ZnO is studied. A probable trap state-mediated mechanism for UV sensing is proposed.

EXPERIMENTAL

Vanadium-substituted ZnO nanoparticles ($Zn_{(1-x)}V_xO$) for x = 0 (ZV0), 0.0078 (ZV1), 0.015 (ZV2), and 0.023 (ZV3) have been synthesized by the sol-gel method (standard Pechini method). The ZnO powder was dissolved in HNO_3 (Alfa Aesar, purity 99.9%). V_2O_5 was dissolved in NH_4OH. The V-solution was added to the Zn-solution and stirred for some time for homogeneity. Citric acid and glycerol were mixed in another beaker to be used as the gelling agent. These two polymerize by releasing H_2O from OH groups (esterification) of citric acid and glycerol when heated at 70 °C for 1 h.[20] The polymeric solution was added to the Zn/V solution. Stirring and continuous heating at 70 °C were maintained on the resultant solution. Zn/V ions get attached homogeneously to the polymer solution. Gel was formed after continuous heating for ~4 h. The gels were burnt on a hot plate in ambient conditions. Decarbonization and denitrification followed upon calcination at 450 °C for 6 h. Pellets of 1 mm thickness and 13 mm diameter were pressed at 3 Tons in a uniaxial press and further annealed at 500 °C for 2 h. In all samples, two electrodes were prepared on the flatter surface of pellets using silver paste at a distance of 1.25 mm.

The structural characterization was carried out using an x-ray diffractometer (Bruker D2-Phaser). A home-made set-up was fabricated to estimate the UV light sensing of $Zn_{(1-x)}V_xO$ pellets.

Two conductive stainless-steel wires were used as connectors from the electrodes to the positive and negative terminal of Keithley (2401) meter as shown in Fig. 2(a). To ensure that no stray light can affect the experiment, the sample set-up was kept inside a dark box. A steady UV LED (light emitting diode) light source of 390 nm wavelength was focused from the top of the black box. The sample to source distance was maintained at 10 cm. This distance ensures 270 lux intensities at the surface of the sample. Five ON/OFF cycles of UV illumination were observed for each sample. Each cycle consisted of 7.5 min UV ON followed by 7.5 min UV OFF sequences. The dynamic changes in current were recorded.

RESULT AND DISCUSSION

The XRD spectra of the 500 °C heated samples revealed a dominant hexagonal wurtzite ZnO structure. Some minor reflections similar to the zinc blend were present [Fig. 1(a)].

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