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Vinod Kumar Jain
Sunita Rattan
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Recent Trends in Materials and Devices

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Preface

The emerging development in the field of materials and devices are some of the most important factors in driving the growth of a nation's economy because of its potential contribution to manufacturing processes and innovative products. It is heartening to see that how during the past few years, the niches for research in the area of material science and technologies have multiplied exponentially and how the material scientists are contributing to global progress in the field.

The conference was organized with the aim to provide a common forum for eminent scientists, technologists, entrepreneurs, and scholars from various disciplines to present their work and discuss the latest advances and innovations in this exciting area of research. Materials science remains intrinsically interdisciplinary and the integration of different disciplines of sciences and outcome of R&D efforts from laboratory to practical devices was one of the focal themes of this conference wherein our faculty and students were exposed to the latest advancements in these fields. The conference provided an opportunity for the participants to interact and develop collaborative partnership.

The Book "*Recent Trends in Materials and Devices*" comprises of scientific contributions from different veins of semiconductors, composites, polymeric materials, devices, and the other related technologies. The contributions have been made by different researchers and eminent scientist from all over the world, who presented their papers in this International Conference on the Recent Trends in Materials and Devices, 2015. In view of the great efforts and initiative of the Government of India, especially the "Make in India" program, most of the NRI & PIO scientists, academicians, and technocrats are willing to help our country especially in research & development in the area of materials and devices leading to product development and production. The chapters include various latest and significant topics i.e. *Semiconductor Materials and Devices, Smart Materials, Polymeric Materials, Sensors, Photovoltaics and Energy Storage, Optoelectronics, Nanotechnology and Nanomaterials, MEMS and NEMS, and Emerging Technologies.*

Part I of the book gives the cutting-edge technologies in the field of *Nanotechnology and Nanomaterials*. It includes the latest findings of eminent scientists discussing the thermal characterization of SWCNT and tungsten oxide-based nanomaterials; Carbon the future of nanomaterials; antireflection properties of nanoparticles assist black silicon for 3rd generation solar cells; dye removal using nanocellulose; thermos-physical properties of nanoparticle-enhanced phase change materials for thermal energy storage; silicone nanowire based transistors; surface engineering of colloidal quantum dots; graphene nanoballs; water splitting; nanocomposites; nanomaterial based sensors; and a lots more. The latest work in the field of *Optoelectronics* is compiled in Part II, such as structural and optical properties of single crystalline cerium-doped ZnO thin films; tailoring the band structures of GaSb and $InP_{1-x}Bi_x$ for LASERS, photodetectors, etc.; efficient metal clad optical waveguide polarizer. Part III includes the pioneering and front-line outcomes in the arena of *Photovoltaics and Energy Storage*, from the research work of various eminent scientists and young researchers. The contributions comprises of effect of silver nanoparticles as surface plasmonic layer to enhance efficiency of 3rd generation solar cells; graded index antireflection coating for efficient solar cells; dye-sensitized solar cells; photonic crystals as reflection and diffraction gratings for light trapping; synthesis of Cu_2ZnSnS_4 (CZTS); analysis of SnS nanolayer on ZnO nanowires; MWCNT for energy storage/conversion devices; etc. Part IV comprises the latest findings on *Sensors*, which includes the work such as Lossy Mode Resonance Sensor; Dual Dielectric p-MOSFET as Cumulative Gamma Dose Sensor. The contributions in the trust area of *Polymeric Materials* are discussed in Part V, which contains polymer nanocomposite films for energy storage applications; polymer separator for energy storage devices; efficient nano-filler embedded polymeric films; polypropylene/glass fiber composites for low cost orthotic aid. Part VI includes *Semiconductor Materials and Devices*, where the latest observations have been discussed on properties of nanocrystalline PbS films; Synthesis and properties of inorganic organic chloride-based perovskite; design, simulation, and analysis of 4×1 Mux at 90 nm CMOS. Further, in Part VII the cutting-edge researches from various eminent scientists and young scholars have been reported. It includes the clean energy harvesting using rare-earth magnet and ferro-fluid; findings on nonvolatile memory device applications; strengthen properties of cast Cu–Al alloys processed by cryorolling; twist grain boundary phases in liquid crystals; capping-ligand effect on colloidal CIGSe nanocrystals for thin film solar cell applications; and more findings. In the last, Part VIII includes the latest outcomes of various *Emerging Technologies*, such as novel design of fractal antenna; Nematic liquid crystal; and Carbon nanotube FET-based inverter. These contributory papers were full of new scientific knowledge, thought provoking ideas, skills, brain storming discussions, and exchange of ideas. Through this, every latest findings and researches will go ahead to our scientific world.

We are sure that all the latest results and findings reported here will be useful to the young researchers and scientists working in these areas.

These conference-related papers and the rich scientific-knowledge exchanged the result from the efforts of a large team of people who volunteered their time to serve the ICRTMD conference. We are indebted to all of them for their assistance and support. It is not possible to thank all of these individuals, but we would like to thank, on behalf of the ICRTMD 2015, a number of people who made particularly significant contributions.

The editors wish to place on record our appreciation to Dr. Ashok K. Chauhan, Chief Patron—ICRTMD 2015 and Founder President, Amity University, Noida for his continuous guidance and encouragement to organize this important conference. Editors are also highly thankful to Dr. Balvinder Shukla, Vice Chancellor, Amity University, for her tremendous support, in making this conference a success event. Our sincere thanks and gratitude goes to Dr. Sangeeta Tiwari, Dr. R.S. Pandey, Dr. Prashant Shukla, and all the members of International Conference on the Recent Trends in Materials and Devices, 2015 (jointly organized by Amity Institute for Advanced Research and Studies (AIARS) and Amity Institute of Applied Sciences (AIAS), Amity University, Noida), for their support in organizing this conference.

Noida, India

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Part I
Nanotechnology and Nanomaterials

Thermal Characterization of Single-Walled Carbon Nanotubes and Tungsten Oxide-Based Nanomaterials via Raman Spectroscopy

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Abstract The thermal characterization of single-walled carbon nanotubes (SWCNTs) and tungsten oxide (WO_3)-based nanomaterials through the use of Raman spectroscopy is the primary aim of this study, and is focused mainly on the applications of SWCNTs for energy storage and $WO_3$for toxic gas sensing, respectively. In the case of SWCNTs, the properties relevant to their performance obtained via resonant Raman spectroscopy were thermal expansion and thermal conductivity through the exploitation of the latter property's relationship to the thermal behavior of the Raman G^+-band of SWCNTs. In the case of the tungsten oxide-based nanomaterials, the responses of the various Raman signature peaks to different external stimuli, such as temperature variation, humidity changes, and toxic gas exposure, under controlled conditions were investigated.

1 Introduction

Resonance Raman spectroscopy has become one of the most common techniques in the characterization of single-walled carbon nanotubes (SWCNT) and other nanomaterials. It is possible to obtain rich detailed Raman spectra from samples with

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little to no work in the way of sample preparation, in contrast to more expensive scanning probe methods, e.g. AFM and TEM. Understanding of the thermal expansion properties of carbon nanotubes provides potential insight into the process of storing thermal energy in these materials. Meanwhile, metal oxide gas sensors work by bringing about a change in conductivity in the sensor due to gas exposure caused by the chemisorption of oxygen. We have investigated these processes in which molecules are adsorbed into the metal oxide lattice structure with the goal of understanding how the Raman spectral features change as a result of varying conditions, especially temperature effects. The Raman spectroscopy data (Fig. 1) were recorded using a ThermoFisher DXR (532 and 780 nm) Smart Raman spectrometer and a Renishaw inVia Raman Microscope (514 nm).

2 SWCNT Experimental Details

This section first presents a novel robust and simple method of estimating the purity levels of bundled SWCNT samples based on Raman spectroscopy [1]. This method of carbon nanotube content estimation relies on the linear variation of the tangential mode G^+ Raman peak with temperature, where the sample heating is provided by increasing the laser power at the sample location.

By calibrating the Raman-based methods with purity estimates of high quality SWCNT samples via direct transmission electron microscopy (TEM) characterization, Terekhov et al.[1], were able to show that the slope of the G^+ band vs laser power density directly correlates with the amount of nanotube content present in one's sample. It was also noted in [1] that there were three different regions, each exhibiting a different slope in the G^+ frequency versus laser power density graphs (Fig. 2). The first region occurs for very low laser power levels, where the sample is not heated by the laser, resulting in an essentially flat level portion of the graph. In the second intermediate region, the slope value increases slightly, showing a noticeable departure of the G^+ peak from the graphite value of 1592 cm^{-1}; and finally in the third region at very high laser powers the nanotube sample is ablated at the laser spot and the shape of the G^+ band no longer changes [1]. The stretching out of the first region of the G^+ peak vs laser power plot occurs for SWCNT samples of higher purity, or stated another way, samples with more nanotube content present compared to other materials, such as amorphous carbon and metallic catalyst particles, have much longer initially flat first regions on plots of the G^+ peak frequency vs laser power. Also, since the thermal conductivity of the SWCNT sample is directly proportional to the slope of the G^+ band vs laser power density as shown in Eq. (1), we have yet another material property that is critical to the performance of SWCNT-based energy storage applications that can be characterized via Raman spectroscopy [2]. In Eq. (1), T is the sample temperature, F_0 is the laser power density, κ is the effective thermal conductivity of the sample, and d is the laser beam diameter.

$$2(\Delta T)\kappa = \sqrt{\pi} d \times F_0 \quad (1)$$

3 WO_3 Experimental Details

In this section, we will discuss the Raman spectroscopy research on metal oxide gas sensors, mainly WO_3 variants, and how their Raman spectral features undergo changes based on increasing/decreasing temperatures, primarily focused on the 25–200 °C temperature range using 780 nm wavelength laser excitation. We have previously studied the behavior of temperature increases in the range 30–160 °C [3]. In this paper we discuss the effects of lowering the temperature, going from 190 to 30 °C, and the different effects the cycles have on the Raman spectral features of tungsten oxide.

We have focused our investigations strictly on the monoclinic form of WO_3 on a silicon substrate. The main features for monoclinic WO_3 are seen around ~807, ~716, and ~271 cm^{-1}, which correspond to the stretching of O–W–O bonds, stretching of W–O and the bending of O–W–O, respectively. Figure 1 illustrates the Raman spectral signature of WO_3 for 532 nm (top) and 780 nm (bottom) laser excitation wavelengths, respectively. Several other Raman peaks can be seen corresponding to other vibrations of W–O and O–W–O bonds. The peak around ~1550 cm^{-1} corresponds to OH–O and W–OH, which is a result of humidity effects on the sample. A complete listing of peak assignments as related to multiple WO_3 features can be found in our previously published study [3].

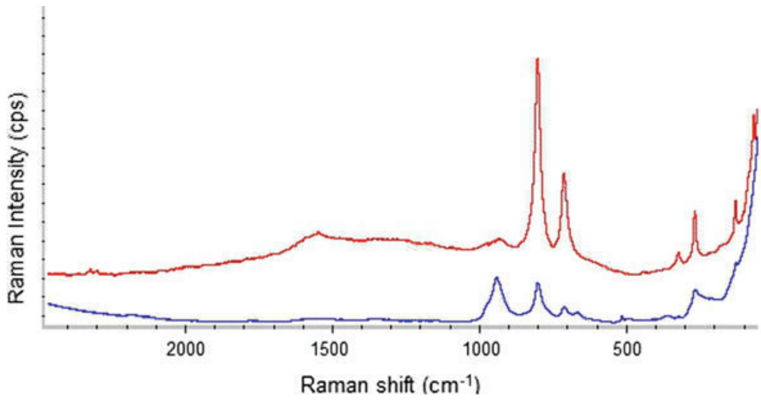

Fig. 1 Raman Spectrum of WO_3 at 30 °C using 532 nm wavelength (*top*) and 780 nm (*bottom*)