METAL CHALCOGENIDE NANOSTRUCTURES FOR RENEWABLE ENERGY APPLICATIONS

Edited by
Ahsanulhaq Qurashi

Scrivener Publishing

WILEY

Metal Chalcogenide Nanostructures for Renewable Energy Applications

Edited by

Ahsanulhaq Qurashi

Scrivener Publishing

WILEY

Co-published by John Wiley & Sons, Inc. Hoboken, New Jersey, and Scrivener Publishing LLC, Salem, Massachusetts.
Published simultaneously in Canada.

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic formats. For more information about Wiley products, visit our web site at www.wiley.com.

For more information about Scrivener products please visit www.scrivenerpublishing.com.

Cover design by Russell Richardson

Library of Congress Cataloging-in-Publication Data:

ISBN 978-1-118-23791-5

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Preface

Meeting impending energy requirements by an ecologically benign approach entails scientific innovations to proficiently produce, store, transfer, and utilize enormous amounts of energy. The critical requirement to attain this goal demands to develop cost-effective materials by imparting novel intriguing features to convert maximum energy from sun and other renewable means.

Metal chalcogenide semiconductor nanostructures present the most important class of nanomaterial that provides highly anisotropic diverse morphologies, described by the efficient transport of electrons and excitons, and has been regarded as the most promising building block for nanoscale renewable energy nanodevices and nanosystems. The growth, characterization, and applications of nanostructures entreat various disciplines of science and engineering. The objective of this book is to illuminate the essentials, underlying science related to semiconductor metal chalcogenide nanostructures fabrication for potential renewable energy applications. The effect is an illustrative snapshot of the latest developments from diverse perspectives in a series of chapters based on synthesis, properties, characterization, and applications of metal sulfide, selenide, and telluride nanostructures from distinguished betrothed researchers.

This book contents are divided into three main sections.

Chapters 1–3 present an overview of increasing greenhouse emissions, recent research and substantial progress reported in the literature, covering formation of 0, 1, 2, and 3 dimensional metal sulfide, selenide, and telluride nanostructures. The application of chalcogenide materials for renewable energy conversion, which includes photovoltaics, hydrogen production, thermoelectrics, fuel cell, supercapacitors, and lithium-ion batteries and their future projections are covered in Chapter 1. The potential impact of materials for alternative energy conversion systems and various important renewable energy alternatives is anticipated in Chapters 2 and 3.

Chapters 4–7 are devoted to comprehensive synthesis of metal chalcogenide (sulfide, selenide, and telluride) nanostructures including inorganic graphenes (layered structures) by various important methods, their characterization and growth mechanism for the formation of enthralling morphologies, and various important protocols for surface functionalization of chalcogenides to improve the processability in technological applications are included in Chapters 4 and 5. The potential to engineer semiconductor nanostructures properties during and after fabrication presents an exciting realms and extensive prospect to simply improve the performance of renewable energy conversion systems. Chapters 6 and 7 provide detailed account of structural and optical properties of semiconductor chalcogenides.

Chapters 8–13 are typically covering applications of metal chalcogenides nanostructures in diverse renewable energy conversion devices. Chapter 8 presents updated works metal sulfide nanostructures for solar-driven hydrogen production through water splitting. Chapter 9 gives brief account on *hierarchical* chalcogenide nanostructures, their properties and applications in energy conversion devices. Chapters 10 and 11 are based on metal chalcogenides in photovoltaic applications. Chapter 12 focuses on theoretical work including indirect band gap calculations results and density functional theory. Chapter 13 focuses on metal telluride nanostructures for thermoelectric devices operating around room temperature.

Ahsanulhaq Qurashi
Dhahran, Saudi Arabia
August 2014

Contents

Part 2: SYNTHESIS OF METAL CHALCOGENIDE NANOSTRUCTURES

Part 1
RENEWABLE ENERGY CONVERSION SYSTEMS

1

Introduction: An Overview of Metal Chalcogenide Nanostructures for Renewable Energy Applications

Ahsanulhaq Qurashi

Center of Research Excellence in Nanotechnology and Chemistry Department, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

Abstract

In this chapter in the beginning global fossil fuel resources their current status and future anticipation and CO_2 emissions its direct and indirect consequences are presented. Also significance of materials for renewable energy conversion systems as an alternative energy source is discussed. An overview of different metal chalcogenide semiconductors and their fascinating properties is reviewed. Various important (0-, 1-, 2-, and 3-dimensional) morphologies of chalcogenide nanostructures developed by different intriguing methods are illustrated followed by their important applications in renewable energy devices and their future outlook are discussed. The new class of metal chalcogenide nanostructures and their heterostructures offer outstanding prospect for the development of cost-effective, high-performance, smart, robust, and efficient energy conversion devices.

Keywords: Metal chalcogenide nanostructures, semiconductors, renewable enrgy, metal sulphide, metal telluride and metal selenide nanostructures.

1.1 Introduction

Sustainable energy supply is essential for the profitable and societal structure of nations, and for the comfort of human lives. In the times when the demand of traditionally subjugated natural resources is surpassing supply, industrial growth has resulted in unwanted climatic changes and

**Corresponding author*: ahsanulhaq06@gmail.com

Ahsanulhaq Qurashi (ed.) Metal Chalcogenide Nanostructures for Renewable Energy Applications, (3–22) 2015 © Scrivener Publishing LLC

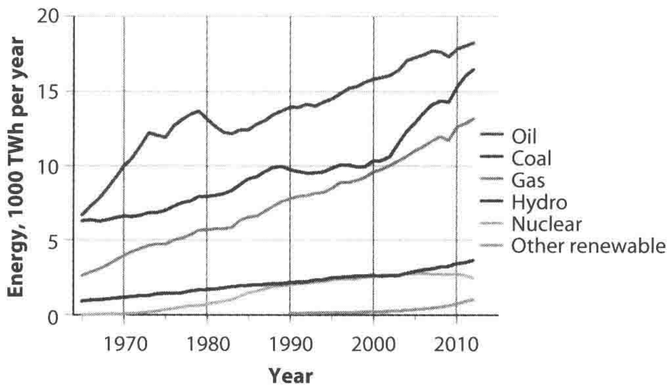

Figure 1.1 Rates of energy usage (Ref. [1]).

developing regions are contending for bigger share of restricted fuel stocks, the exploration for new methods to meet these supplies becomes more imperative. At present, more than 80% energy use is based on oil gas and coal. Figure 1.1 shows world energy usage from different sources including oil gas and coal [1]. International energy agency (IEA) data from 1990 to 2008 reveal that the average energy use per person increased 10% whereas world population increased 27% [2,3]. In the year 2008, total worldwide energy consumption was 474 exajoules (132,000 TWh) [4]. This is equivalent to an average power use of 15 terawatts (TW) ($2.0\times10^{10\ \mathrm{hp}}$) [4].

Presently, the world uses energy at a rate of approximately 4.1×10^{20} joules/yr, which is equivalent to a continuous power consumption of 13 trillion watts, or 13 TW [5]. With insistent conservation and advancement of energy efficiency measures, an increase in the Earth's population to 9 billion people escorted by fast technology expansion and economic growth worldwide, is anticipated to generate more than double the requirement for energy (to 30 TW) by 2050 [5]. Sunlight is the largest source of all carbon-neutral energy. It is estimated that more energy from sunlight strikes the Earth in one hour (4.3 × 1020 J) than all the energy being consumed on the planet in a year (4.1 ×1020J) [5].

On the other hand, fossils fuel a major source of present energy will start depleting in coming decades. According to recent studies, anticipation of fossil fuel depletion by 2050 is shown in the figure (which is carried out by peak oil and gas 2007) [6]. On the basis of these studies, it is important to understand that without viable options for supplying double or triple of today's energy use, the speedily developing world's economic, industrial, and technological prospects will be relentlessly restricted.

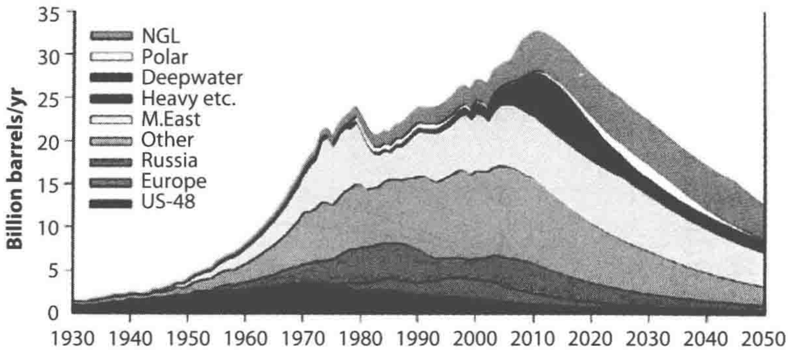

Figure 1.2 Source: Association for the Study of Peak Oil and Gas, 2007 (Ref. [6]).

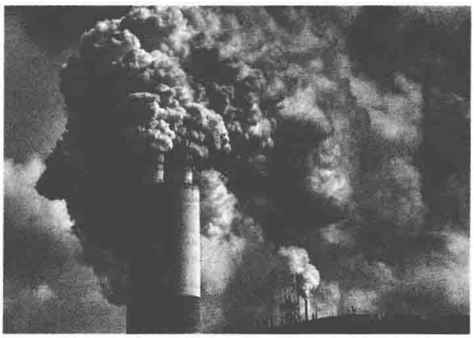

Figure 1.3 Photographic image for CO_2 emission at an industrial plant (Ref. [8]).

According to the recent report *World Energy Outlook* published by the IEA, world primary energy use will raise from 12 Gtoe (metric gigatons oil equivalent) in 2007 to 17 Gtoe in 2030, for typical yearly growth of 1.5% [6].

On the basis of IEA reports, which uses an energy production mix that comprises 80% fossil fuels, CO_2 **emissions will** increase nearly 50% between 2007 and 2030 [6]. The Intergovernmental Panel on Climate Change (IPCC) has shown that this increase could result in a 6°C elevation in temperature by the end of the century [6,7]. Figure 1.3 shows photographic image of a CO_2 emission at site of an industrial plant [8].

Carbon dioxide emissions resulting from energy production are an environmental predicament. Recent efforts to resolve the CO_2 emission include the famous summit (Kyoto Protocol) which is a UN agreement that intends to decrease harmful climate impacts signed by many countries [9]. The main deliberation of this debate was to reduce green house gases (GHGs) emission in a time framework to be monitored by

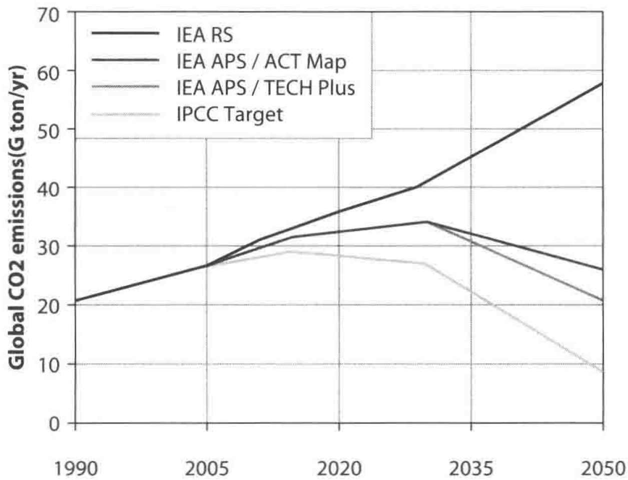

Figure 1.4 Global CO2 emissions based on IEA scenarios. Black line: the Reference Scenario (RS). Blue line: the APS from 2005 to 2030 and extrapolation to the ACT Map scenario in 2050. Red line: extrapolation from APS in 2030 to the TECH Plus scenario in 2050. Green line indicates CO2 emissions reduced by 2/3 in 2050 compared to emissions today. As such, the green line represents the IPCC target of 50–80% reduction in global CO2 emissions by 2050 (Ref. [10]).

United Nations Framework Convention on Climate Change (UNFCCC) [9]. Due to continuous unregulated industrial growth of developing and under-developed nations and struggle to attain technological progression by developed nations, air quality standards are decreasing tremendously. Figure 1.4 shows continuous CO_2 production by 2050 and effect of alternative policy scenario (APS) if the IPCC policies are implemented apolitically and meritoriously [10,11]. Very recent studies include dangerous effect of air pollution including size-dependent particulate matters (PMs) on lung cancer and cardiac diseases [12,13]. There are apparent policies adopted by developed nations as a result of tight environmental regulations to transfer substantial production of their products to under-developed and developing nations due to low manufacturing cost and high-profit margin which also enormously contribute in CO_2 emissions.

Consequently, a paramount responsibility for IEA and other international institutions arises to sternly implement global standard with respect to increasing industrial growth and regulate physically the climate changes, which can minimize its harmful effects on humans in particular and living organism in general. Considering all these important prospective of fossil fuels' depletion, increasing pollution by the massive production of energy by various conventional sources, it is essential to explore