Chapter

Introductory Chapter: Progress in Nanoporous Materials - An Introduction

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1. Introduction

The discovery of altering and prescribing properties of materials by controlling the size in the range of 1–100 nm has sparked interest in manufacturing materials from nanoscale building blocks. In accordance with the International Union of Pure and Applied Chemistry (IUPAC), the porous materials in macroscale range pose the pore sizes greater than 50 nm whereas, the mesoporous materials lie in the pore size range in between 2 and 50 nm, and the pore sizes less than ~2 nm belong to microporous materials. A unique subset of porous materials with the pore sizes ranges from 0.2 to 0.95 nm which basically called nanomaterials is popular field of considerations in many applications because they are presenting the special volume ratio of pore space to materials volume. Nanoporous materials are a type of nanostructured material that has a large specific surface area, a big pore volume, a uniform pore size, a rich surface chemistry, a significant porosity, and an ordered uniform pore structure. The well-ordered inorganic or organic frameworks support the regular, porous structure in nanoporous materials. Natural nanoporous materials are abundant in nature, but manmade nanoporous materials can also be created. These porous materials have the ability of allowing just certain compounds to pass through while blocking others [1]. The covalent organic frameworks, silicates, activated carbon, ceramics, zeolites, pillared materials, metal–organic frameworks, non-siliceous materials, aerogels, different polymers, and hybrid inorganic porous materials are examples of natural and manmade nanoporous solids. Long-range structural order or disorder can be found in nanoporous materials, which have pores ranging in size from a few nanometers to tens of nanometers. Nanomaterials including their excellent surface behavior such as high surface area and pore confinement effects are used in some applications, such as catalysis. New bottom-up techniques, such as molecular templating and intercalation, are required for the manufacturing and processing of porous materials in nanoscale range with programmable shapes and characteristics. Nanoporous materials have significant potential for the generation of new functional materials with better and tunable behaviors for use in various applications such as adsorption membranes, energy storage devices, sensors, different catalytic applications including photocatalysis, and biotechnology. The following are some of the applications of nanoporous materials that are studied in greater depth:

2. Nanoporous materials for the manufacturing of clean energy and storage

Hydrogen as a clean energy carrier is essential for future energy supply. Fossil fuels, water electrolysis, and biomass can all be used to generate hydrogen. However, hydrogen must be created in a safe and environmentally friendly manner. Nanoporous material catalysts are essential for the effective conversion of coal to hydrogen at very low-cost and the capturing of carbon compounds. The development of fuel cells, in which hydrogen is the primary fuel and converts to power with water as a byproduct, is also critical. Nanoporous materials, such as carbon nanotubes, are critical in this process and offer considerable potential as future catalysts in fuel cells. Ameen et al. used a hydrothermal approach to synthesize well-crystalline porous cobalt oxide (Co_3O_4) nanorods (NRs) for use as an electrode material in supercapacitor applications. The porous and smooth morphology of Co_3O_4 NRs was synthesized at a low calcination temperature of 300°C, but the rod morphology changed to stacks of nanoparticles at a high calcination temperature of 500°C. The surface area and pore volume of porous Co_3O_4 NRs decreased as the calcination temperature increased, according to Emmett–Teller (BET) surface area study. The porous Co_3O_4 NRs calcined at 300°C as electrode was to manufacture pseudo-supercapacitors and achieved a specific capacitance of 226.3 Fg^{-1} (at scan rate = 10 mVs^{-1}). The capacitance value is superior to Co_3O_4 NRs-500°C electrode [2]. Porous cobalt oxide (Co_3O_4) nanocubes (NCs) have also been reported by Ameen and colleagues for use in electrochemical supercapacitors. Using cyclic voltammetry in KOH electrolyte, the capacitive characteristics of porous Co_3O_4 NCs electrodes were examined, and a high specific capacitance of ~430.6 F/g was reported at a scan rate of 10 mVs^{-1}. The porous Co_3O_4 NCs demonstrated outstanding structural stability during cycling, as well as promising capacity retention, implying that porous Co_3O_4 NCs are of superior quality as electrochemical supercapacitor electrodes [3].

3. Catalyst application of nanoporous materials

Chemical and fuel production have benefited greatly from heterogeneous catalysis. To boost catalytic activity and selectivity, more efficient catalytic procedures are required. As a result, customized catalytic materials with specified microstructures are essential. Nanoporous materials are very fastidious electro catalysts for the oxidizing small-scale organic molecules such as formic acid, acetic acid, methanol and ethanol due to their relatively large surface areas, prominent surface chemistry and small specific densities. Platinum is thought to be the finest catalyst for these reactions among pure metals. Although just a quarter of the pore surface area is electrochemically accessible, the mass specific activity is equivalent to platinum catalysts. The roughness factor, which govern the area of electrochemical surface to geometric portion, is a key element in determining catalytic performance. In a nanoporous environment, reactant molecules have a longer residence time, which permits them to linger longer inside the pores and have more opportunities to collide with the electrode surface than in a nonporous environment [4]. Ameen and colleagues synthesized ZnO-flowers photocatalyst to check the application in the crystal violet (Cv) dye degradation. Cv-dye degradation was particularly fast in the as-synthesized ZnO-flowers, with a degradation rate of 96% in 80-minute time interval [5]. Polyaniline/graphene (PANI–Gr) nanocomposites were made by in-situ polymerizing aniline monomer along with Gr in another study. The photocatalytic degradation of Rose Bengal (RB) dye was achieved using the nanocomposites as an effective photocatalyst. Gr was found in PANI–Gr nanocomposites with considerable interaction/bonding between PANI and Gr, as evidenced by the absorption characteristics. The imine (-NH) of PANI and the carboxylic group on the surface of Gr sheets formed a partial hydrogen bond in the PANI–Gr nanocomposites. Under light exposure, the produced PANI–Gr nanocomposites significantly degraded the RB dye by 56% within 3 h. The inclusion of Gr sheets in PANI–Gr nanocomposites might result in substantial charge separation of photogenerated electron–hole pairs under light irradiation, was related to the significant degradation of RB dye when compared to PANI [6]. The structural and surface characterizations of nanocomposites of poly(1-naphthylamine)/SiO_2 and poly(1-naphthylamine)/TiO_2 revealed an effective connection via hydrogen bonding between –NH group in PNA and –OH in nanomaterials (SiO_2/TiO_2). Under visible light illumination, the produced nanocomposites demonstrated considerable photocatalytic activity for the breakdown of methylene blue (MB) dye. Due to the presence of efficient charge separation of photogenerated e^-–h + pairs, PNA/TiO_2 nanocomposites posed the superior MB dye degradation of 60% as compared to PNA/SiO_2 (28%) and pure PNA (9%) [7].

4. Sensor materials made of nanoporous materials

Nanoparticles and nanoporous materials have a vast surface area and are extremely sensitive to environmental changes. Sensor made of these materials are frequently employed. The sensitivity of gas sensors is determined by their surface areas, and gas sensors made of nanoporous metal oxides like TiO_2 or ZnO are being manufactured and employed to flammable gas detectors. In general, the gas sensors detect changes in electric resistivity as a function of gas concentration, and their sensitivity is proportional to surface area. Ameen et al. described a low-temperature solution method for fabricating aligned nanoporous ZnO NRs on FTO glass and using them as an electron mediator to fabricate a highly sensitivity chemical sensor for p-nitrophenylamine (p-NPA) detection in an aqueous buffer electrolyte. A high and repeatable sensitivity of ~184.26 μA mM^{-1} cm^{-2} and a quick response time of 8 s is attained by p-NPA chemical sensor based on aligned nanoporous ZnO NRs electrode. With a correlation efficiency of R = ~0.97569, the manufactured p-NPA chemical sensor had a respectable detection limit of ~53.7 M and good linearity in the region of 5–20 M [8]. Ameen and colleagues reported a modified electrode of poly (1-naphthylamine) nanoglobules for the detection of different alcohols using fabricated ultra-high sensitive chemical sensors. With a reaction time of 10 seconds, the constructed ethanol chemical sensor based on PNA nanoglobules has a high and repeatable sensitivity of ~1.66 $\mu A mM^{-1}$ cm^{-2}. The developed PNA nanoglobules-based chemical sensor had a linear dynamic range (LDR) of 0.78 mM to 50 mM, with a correlation efficiency of R = ~0.965 [9].

5. Nanoporous materials in biological applications

Because nanoporous materials are biocompatible, they can be used to create enzymatic nanomaterials which normally mimic various biological reactions. Enzymes immobilized on nanoporous materials can be utilized in biological reactors to generate pharmaceuticals, decontaminate waste, and other applications. Biosensors can be made from nanoporous materials. The electrochemically produced nanocages-augmented PANI nanowires (NCa-PANI NWs) on silicon (Si) substrate were used to create a non-enzymatic glucose biosensor. Current (I) – voltage (V), cyclic voltammetry, and amperometry measurements were used to evaluate the sensing parameters for the NCa-PANI NWs electrode. The sensing findings demonstrated that the manufactured non-enzymatic sensor responded well to glucose, with a stable, dependable, and high sensitivity value = ~156.4 mA mM^{-1} cm^{-2}, a promising limit of detection = ~0.657 M, and R = ~0.99493 [10].

6. Drug delivery using nanoporous materials

Because of its great porosity and surface area, porous silicon is an ideal material for drug delivery. Small compounds like doxorubicin have been placed into porous silicon pores as therapeutic agents. For drug delivery applications, various factors must be taken into account, including pore size, as the substance must smaller to the pore diameter for traversing the pores. Porosity is significant because the amount of medicine loaded into the pores is proportional to the capacity of the pores. This book is a valuable source of nanoporous materials for researchers interested in inventing and employing procedures to synthesis, characterize, and model nanopores in the general areas of materials science, chemical engineers, biotechnology, nanobiotechnology, biomedical engineers, and electrochemistry. This book presents the most up-to-date research on nanopores and nanoporous materials, with a particular emphasis on practical analytical applications of nanoporous materials. The major goal of this book is to provide readers in academia, industry, engineering, and biomedical disciplines with a comprehensive professional reference on nanopores. Moreover, this book provides comprehensive knowledge to readers about nanoporous materials and presents the most recent advances in a variety of domains, including synthesis, characterization, and surface modification, as well as adsorption and separation processes, biological and catalytic applications. Fundamentally, this book comprises chapter on key topics such as nanoporous materials synthesis, characterization methodologies, nanomaterials surface modification or surface functionalization, designing of novel catalyst, and nanostructure tailoring.

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