RJNMSR
Review Journal of Neurological & Medical Sciences Review

Volume 3, Issue 3, 2025

GALLIUM OXIDE NANO RODS DECORATED WITH CU, NI SINGLE ATOM FOR PHOTOCATALYTIC APPLICATIONS

[1]Nimra Zaman, [2]Zainab Ehsan Warraich, [3]Muhammad Aamir Ali Shehzada

[1]M.Phil Organic Chemistry, Department of Chemistry, Abdul Wali Khan University Mardan , KP, Pakistan.
nimrazaman52@gmail.com
[2]Ph.D Scholar, School of Chemistry and Chemical Engineering, Southwest University, Chongqing, 400715, China.
zaini.warraich07@gmail.com
[3]Ph.D Scholar School of Chemistry and Chemical Engineering, Southwest University, Chongqing, 400715, China.
amirshehzad354@gmail.com

Corresponding Author: *

DOI: https:/doi.org/

Received	Accepted	Published
20 June, 2025	23 July, 2025	**26** July, 2025

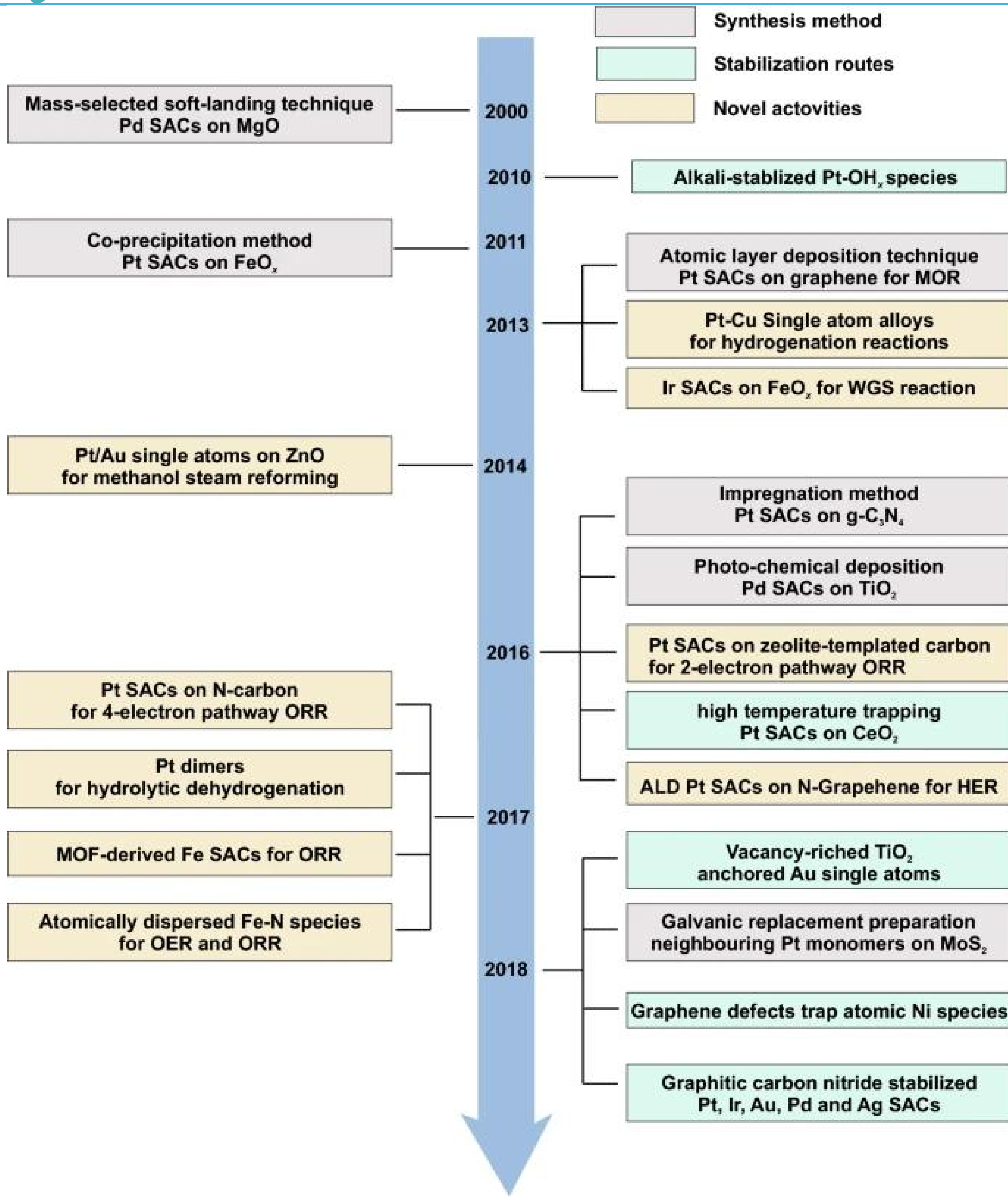
ABSTRACT

By combining light and a catalyst, a process known as photocatalytic degradation converts organic contaminants into innocuous byproducts. The capacity of this technology to eliminate various contaminants and poisons from the environment has generated a great deal of attention lately. It is particularly effective against toxins such as persistent and emerging organic pollutants that do not react well to conventional treatment methods. Comparable to this, gallium oxide nanorods are a kind of nanostructured material that has garnered a lot of attention recently due to its unique properties and potential applications in several sectors. Due to its special characteristics gallium oxide nanorods might utilized in a variety of uses, which include, solar devices, photocatalysis, and gas sensors.There has also been research done on their possible use in biological applications, such as medicine delivery and imaging. We shall garnish gallium oxide Nanorode with a single Cu or Ni atom for its photocatalytic applications, a procedure that has already been recorded, given its relevance and range of usage. The method produces quadrilateral nanorods of gallium oxide using RF Arosel gel and gallium nitrate. Additionally, the product will contain single atoms of nickel and copper to boost its photocatalytic activity. The generated gallium oxide nano-rode and single copper and nickel atoms will be characterized using SEM and XRD to examine the size, shape, and pattern of the particles. Ultimately, gallium oxide gives an attractive opportunity for material science and photo catalysis to work together, since single atom deposition of copper and nickel on the oxide can lessen its limits as a photocatalyst and increase its potential for more sophisticated uses. Based on photocatalysis studies and energy band structure, a suggested mechanism for pollution removal was explored..

Key words: *Copper and nickel, gallium oxide, RF arosel gel, X-Ray diffraction, SEM*

INTRODUCTION

Over the last few years this focus has been more or less towards the one dimensional or what is commonly referred to as nanorods, nanowires, nanobelts and nanotubes. But it is still filled in numberless special addition and presumably serves life science semiconductor and photocell in the future. Most probably, any person would agree with such statement that 1D nanostructures can be used for the investigation of the trends with the mechanical, electrical, thermal, and transport properties while reducing sizes and changing the dimensionality or undergoing quantum confinement. They are also expected to be involved in integration of functional unit in new product synthesis in electrical optic electronics electro chemical and electro mechanical Nano device application. For which anticipation has been made for over two centuries, the major focus will continue to be placed on one dimensional semiconductor nonmaterial and their synthesis. Nano science is a section of the nanotechnology that studies the matter at nano scale which is atomic, molecular and macromolecular. Some of the new materials that can be produced in such a new class of materials some of them include; Synthesis of nano materials by wet chemical production at the interface of inorganic cluster chemistry and conventional colloid chemistry. It should be noted that as a result of the material of the current article On the nature and interaction with 3D object with at least one dimensional attribute. They will be the base of several technologies that are commonly known as Nanotechnology Technologies. However, other techniques have been generalized for making such kinds of products Wet chemistry seems to be most popular one due to low cost of the processing and due to easy evaluation and comparison of modern quantum theory with reference to the radius of the particle for the optical electrical chemical and catalytic activities. Bearing this in mind, it is worth mentioning that amongst all the types of nano materials, the nano particles have been most intriguing for the researchers in the past. The next improvement if the size dispersion and monodispersity are reasonably satisfactory is the shape control or synthesis of nano particles, which is characterized by the fact that not only size but also other geometric parameters can vary depending on the selected conditions and additives: The following are the major shapes that can to be achieved by material molding; Alloys, sticks and pipes, and cases of hollow. This does not result in normal sphere like growth in which other chemical is covalently bonded to the exterior of the nano particle. Here the 'chemistry of coordination' In the next decade as the specifics of how these factors impact the particle production task and control of shape are still general, the focus is likely to continue. It can be easily done to understand that such basic research as the investigation of the crystal morphology of such materials will lead to the provision of prototypes of such other more complex and intricate processes of the creation of biomaterials and the elegant architectures of the skeletal systems that are found in live subject organisms. Some of the properties and some applications of the metal nanorods especially the gold ones has been explained in some of the identified researches apart from the new findings made on the topic. Out of the one that I find quite interesting is the fact that most of the atoms are photosensitive or phototactive regarding this issue of photosensitivity, the degree is usually set by the size and the type of the atom used. The visible sector of the spectrum that was observed had definite and clear absorption bands proved due to the inter-action that the body of the unseen force has with metals such as silver and gold. For the purpose of this writing, it is agreed that the optical absorption bands of these materials produce fairly intense colours that are not easily observed in the 'physical materialization' of such events. These are the visual properties which are reflected off by the metals and are said to be so as a result of the process known as emission of electrons. Through this interaction, a maximum and distinct amalgamation is observed in the accessible partition of the field for some of the metals especially the noble metals which include metals like gold and silver. These bands then lead to very intense colors which are not contained in the basic hulk material The correct material is of more energy than all the other states taken as a whole. Pastoriza I.



Single-atom catalysis is a fairly recent and this is an extremely innovative and a rapidly developing area of research where single metal atoms are most suitable to be anchored onto appropriate carriers or substrates. In the recent few years in several types of catalytic reactions single atom catalyst has been achieved as types of categories of replacement of both homogenous and heterogenous catalysis. SACs that contain different metal sites should be studied in more detail in the future investigations concerning catalysis. In particular, in the case of effective, multifunctional, and highly sourcingusage catalysts, SACscan perform the transition from homogeneous to heterogeneous catalysis. Long duration catalysis can also be done on supported metal catalyst atomized on which is very safe and efficient on the surface. SACs improve the occupancy of the active site and differentiation of the catalysts; it also minimizes the amount of Metal used while improving the performance during the conversion phase. At the present time, following the advancements in characterisation techniques, it is relatively easier to identify if the metal species are atomically dispersed and there is much more understanding about their stability, possible phase states and catalytic activity. From what I have learned I have found out that it is actually the SACs that can make better use of the dynamic site and besides eliminating the use of metal, there is usually an enhancement in both the efficiency and selectivity of the catalytic conversion processes. This has led to the revelation of the type of the dispersed metal species at the atomic level thus enhancing understanding on the structure, stability and catalytic properties of the metals. Adding a new dimension into the concept of SACs, several research groups start focusing on atomically dispersed single-site catalysts for thermochemical, electrochemical and photochemical processes and generation of biocatalysts /small molecules, activation of small molecules and synthesis of fine chemicals.

LITERATURE REVIEW

TYPES OF SINGLE ATOM CATALYST

This particular equilibrium has been recently discovered to be the single atom catalyst which is between the homogeneous and the heterogeneous catalysts. Single atom carbon still, however, it has some problems which might in fact be challenging to identify and even address. . Of these is that kind of bonding which takes place in between the single atoms and this kind of bonding is very much helpful in preventing the effects that comes along with increased surface area that comes along with atomization with regards to particle size. (Rocha, 6 July 2023) Another got in redox catalysis is photo catalysis and photo electrolysis which involves pulling CO2 from atmosphere to help combat the global warming and energy problems On the nanoscale to atomic scale two dimensional material-cluster is advantageous since engineers can design and fabricate structures and components with sizes on the nanoscale The reason is that single atoms are considered the best catalysis in the world today. Interest has attracted to to power the work that may serve the future research of the rationally design surface strategies for better selectivity with multiparmaeter for carbon dioxide reduction catalyst stability (Wang).

FUNCTIONALIZE CO- CATALYST

They are functionalized co-catalysts that can occupy more than 99% of metal sites and reconstruct the electronic state to improve the photocatalytic performance while being located at the chemical bond of the semiconductor metal atom–metal interface. This again means that one metal atom is only capable to respond though a semiconductor. accordingly arrange to build up a high performance of the Semiconductor metal single atom interference photocatalyst, and this semiconductor organism photogenerated charge carrier transfer provided the subsequent single metal contact catalytic reaction guide platform. Furthermore, the working mode of such a semiconductor was stated and the process by which this type of semiconductor was brought into contact with a single metal atom with reference to atom and electrical type. (Zhau, October 24, 2022)

Methanol yield from CO2 hydrogenation can therefore be enhanced by altering the number of cycles that were employed in the ALD for the purpose of applying ZnO on the Cu-Zn-Ce oxide catalyst. This can be done by changing the metal oxide interface in some way for example by altering the type of metal used. Here the ZnOx contact is formed particularly when the depositions process is preserved at the required parameters. Cu structure was the exothermic site for the hydrogenation of Co2 to methanol. Therefore, the communication between CU avec the species is beneficial in enhancing the understanding of the relationship between the structure of the catalyst and the catalytic efficiency in the conversion of the carbon dioxide into methanol. It offer a real method to the management of the optimisation of the metal oxide interface for the formation of catalytic materials. (Yang)

While the earth abundant nickel based co-catalyst work as the active site and controlling the reaction banners, it opens new possibilities and the photocatalytic efficiency is improved by enlarging the light absorption area and improving the charge separation. Overall, water filtration and CO reduction are

Accordingly, in the present review the author has discussed the improvements of the nickel based co-catalysts in photo catalytic hydrogen production. (Wang)

COPPER AS A SINGLE ATOM

However, for the single atom loading level of catalyst anshoring reaches describable economical saving besides the highest productivity but Single atom loading provides describable pathway cast saving The single atom loading of Copper single atom is equal to or more than 1 wt. %, were received if, in addition, gallium oxide was added The catalyst activity remained stable upon exposure to the reaction for 380 days, and n/ hydrogen development was 101. For this type of IMF 7 m molg'h task mean duration was 12·3 min in 'real' condition and 17·3 min in simulation condition. higher efficiency of electron transfer by Cu Cu process, their randomness and high density of Cu Single atoms attached to GaO for higher photocatalytic activity and stability. The current technique outlines how one can 'design advanced materials.' "According to an article from the Global Times, the Chinese spy balloon floated over the United States which said, "It was inevitable that China and the US would 'seek confrontations or provoke each other' as their competition intensified. The article stated; See reference dated 10 January 2022, in the Global Times [Online]. Available at: https://www.globaltimes.cn/page/202201/1188673.shtml#:~:text

DIMENSION NANO SCALE STRUCTURE

Present current contribution uses other boundary conditions to analyse axis-symmetric liner free vibration response of one dimensional Nanoscale structures. It would be known to a few of that nonlocal frequency solution for Nano rods with attachment are the published first in any scientific publication. In the present paper, systematic content of the effects of non-local parameters, attachment, Nano rod length, and boundary conditions in determining the natural frequencies is outlined. There is also a greater reduction in the longitudinal frequencies of Nano rods due to attachments and the higher mode as seen by Hayri Metin Numanoglu.

Gold Nanorods (GNRs) have been extensively explored for bio-applications because of the former property: potentiality of converting near-infrared (NIR) light into heat with acceptable conversion efficiency. Some of them are gene tranfer; biosensing; photothermal ablation; molecular imaging particularly in pathologic tissue such as those with cancer. The overall uses of GNRs in biological processes are rooted on some of the following specific properties and characteristics of GNRs as follows: Stability of colloids Colloidal synthesis in the preparation of nanoparticles Large scale synthesis of nanoparticles uses of nanoparticles as a nano heater Functionalization. On the other hand, it was observed that GNRs are more appropriate for the application of a stable contrast agent because of the better scattering signal, tunable longitudinal plasmon absorption, and non-decomposable characteristic. Thus, cancer targeted imaging agents referred to as GNRs are equally potential theranostic agents that involve both the diagnosis of the tumor and its treatment. (WonIIChoi, pub2september2011) And that is high distribution, open environment influence and its small size and it has a longer lifespan. Some of the techniques that have been used in pollutant removal include filtration, incineration and some of the AOPs that includes zonation are among the most energy intensive techniques However, in the process of doing this they produce unwanted secondary products. By introducing LDPE microplastics and the microfragments we mentioned the possible use of heterogeneous photocatalysis with visible light and ZnO nanorods to remove the remained residues. Optical microscopy was initially used to image and document the impact of combining ASA with varying ratios on the characteristics of the PLA's mechanical properties with DMA recording the results too. These researches established that there were many the wrinkle, fractures and the cavities on the surface and 30% increase of the brittleness and carbonyl index of the residues. The evidence for the support of the hypothesis that the degree of oxidation is a function of surface area of the catalyst was therefore provided. Despite this brief on the breakdown mechanism of polyethylene, this breakdown mechanism is highlighted here (Tajkia Syed Tofa 16feb2019).

The specific Nano scale material shape is Nano rods, so the number between 3 and 5 can be used in the making of nanorods for instance metal. In the synthesis of Nano rods one of the methods that is widely used is known as the direct chemical reaction method. It can also control the size of the Nano rods by using small molecules which are very important in capping and shading ligandel molecules stretching of the Nano rods and expansion of mode of the Nano rods. Another branch of nanomedicine that has evolved in the recent past is the nanorods particularly the magnetic ones. Magnetic Nanorods are hyper paramagnetic in nature and hence Magnetic Nanorods can measure with a fair amount of precision. As for the applicability of the present invention, Magnetic Nanorods can also be useful for treatment as well as for separation. Bimetallic core-shell shell magnetic monohybrids of self-assembled nano rods for the removal and elimination of micro-organisms by NIR photothermal therapy. Hence, materials that are combined with nanorods are biological molecules and some of them are as follows, but not limited to, antibodies. Therefore, any method employing Magnetic core shell Nano rod type probes could be of immense help in measuring equally uniform protein density on the same. ACS Application Matrix Interfaces. With this in mind, in this paper an attempt shall be made to attempt to define magnetic Nano rods and some of the uses as well as ways ofpreparations of the same. (Ali Ramzannezhad)

GALLIUM OXIDE NANO ROD

The fabrication of gallium oxide Nano-rods directly via solution route for the first time without employing any template only for the application of these Nano-rods as a stable anode material in both Li- and Na-ion batteries has been investigated exclusively. Nano rods synthesis also shown good response of the Electrochemical in the environmental temperature by using CV and CCR cycling due to its ultra stability with high capacity retention more than 400 cycles and high current density. Another suggested recent application of gallium oxide Nano rods, and more as an electrode material, can also be mentioned as this may be able to preserve the electrical pathway without the need of a 'buffer matrix' for compatibility with lithium or sodium Reversible storage, Also. Generally for a specific structure with high aspect and contact ratio value, the Nano rod shape offers the highest electrochemical rate. Similarly, the short kinetics and minor diffusion way should to be indicated for cations Li + or Na +, as well as for electrons. (GiuseppingMeligrana) We also emphasize that it is possible to synthesize all kinds of gallium oxide and any method or process linked to it. As for the other property that recipient materials should have, it will be described in this article: However, it is in the potentially the most innovative stage that crystalline can be said to be rooted at its core. Consequently, what one gets to learn from this essay reading is sufficient to make one understand what structure band gap density of states entails, how gallium oxide is synthesized, co-doped gallium oxide, and gallium oxide metal oxide composites. Other processes that are used in the formation of hetero structural nanomaterial growth include the sol gel, hydro thermal, solvo thermal, and the electrochemical deposition. We will also get to discuss on Gallium oxide which is due to this solution. (Chiang, 14 Oct 2022) Of all kinds of TCOs, Ga2O3 may have potential to be more general and have larger band gap, and it contains several advantages that can be compared. It is used frequently in areas like catalysis, Biology as well of in electroluminescence among other fields. Louis et al 43 This present paper is mainly centred on the synthesis, characterization and probable utilisation of gallium oxide nanoparticles. Initially, the hydrothermal synthesis method used in the preparation of Ga2O3 and the way that the parameter of hydrothermal process influences the size and shape of Ga2O3 was described. Also, it highlights the possibility of Ga2O3 for high luminescence, electrical and gas performance as well as heat-performing biomedical application. This review therefore seeks to discuss the application of Ga2O3 in; manufacturing of the gas sensors; in optoelectronics; in high voltage equipment; in biomedical; and in catalysis. After that, the current and potential problems with the existing research areas, associated with gallium oxide nanomaterials are described, with reference to the recommendations and further research directions presented in the present work. . (FengShi, pub18july2021)

To produce gallium oxide (Ga2O3) substrates and optical materials the following techniques and processes can be employed: Furthermore, a several polymorphs of Ga2O3 were revealed to have satisfactory t chemical and physical behaviour. . The following properties of Ga2O3 will be described in this article: DOS: Bandgap; Crystal structure. The following techniques for the synthesis of pure, co-doped Ga _{2} O _{3}, Ga _{2} O _{3} -metal oxide phantoms and Ga2O3/metal oxide heterophantoms nanomaterials have been identified and discussed in this paper: sol-gel method, hydrothermal method, chemical bath method solvothermal method, forced hydrolysis method, reflux condensation method & electrochemical deposition It also justifies the need for synthesis conditions and nature of the precursor solution particularly to the size, shape, and properties of the end use material. The following are the uses of Ga2O3 in the solution processes; gas sensor, pH senor, deep ultraviolet photo-detector, photo-catalysis, and photo-degradation. And also there are such aspects as the specificity of the research and their further evolution is assessed. . (Jung-LungChiangandDong-SingWuu)

The nimrods of amorphous gallium oxide with the typical width of 3−5 nm and length of 20−80 nm were synthesized using the template free synthesis method. This specific type of nonmaterial has the astonishing heterogeneous catalytic activity for the steady epoxidation of alkenes using H_2O_2. Therefore, Nano rod morphologies and Gallium oxide Nano rods. both the physicochemical and catalytic properties of the Gallium oxide Nano rods were studied in order to understand why Nano rod morphologies provides material with a large form surface for the acid sites. (Warunae Lueangchaicaweng, pub22jan2014)

Gallium oxide with aluminum oxide The work done on the synthesis of new environment ally safe oxidant which is used in the oxidation of aromatic amines to azoxy chemicals using hydrogen peroxide was found to be catalyzed by engine nano rods. The present work has focused for the first time to explain the selective oxidation of aromatic amines to azoxy derivatives using transition metal catalytic reaction. The interesting systems were Aluminum oxide and Gallium oxide. Moreover, it was observed that, nano rods were very active heterogeneous organo catalysts for selective oxidation of aromatic amines to azoxy compounds by using H_2O_2 as green oxidant. It has also been provided with the first examples of the selective oxidation of aromatic amines to azoxy compounds under conditions that do not call for an oxidizing transition metal. Other benefits that came with the use of this large surface area of 225 $m^2\,g^{-1}$ moderately sized Ga_2O_3 Nano rods (9–52 NM in length and 3–5 NM in width synthesized uniformly) include: impact on the substrate flexibility, activity and selectivity of azoxybenzene. Therefore, based on reusability tests, it was concluded that: Other experiments that can be done with the gallium oxide Nano-rod catalyst are that they are not reduce in the activity and selectivity of the catalyst (Dr. BhawanSing, pub13september2019). Organic gallium oxide nanowires were grown with chemical vapor deposition and some of the appropriate material of gallium and of the gallium oxide with oxygen. In this case the diameter of nanowires is in the range of 30-80 nm and the average diameter of the fabricated nanowires is 50 nm. They are of monoclinic crystal structure and are FoC single crystal based. It is also quite striking to observe that the planar defects present in the nanowires synthesized without the help of any catalyst are enormous in size, although all the nanowires produced by nickel catalytic nanoparticles contain almost negligible planar defects. From the study it has been detected that the synthesized nanowire without using the catalyse shows a well defined and perfect orientated structure in the growth direction On the other hand the nanowire grown using catalyse shows the random orientated structure in the growth direction Thus the structure of the nanowires influenced the photoluminescence, Raman spectroscopy and X-ray diffraction. Concerning the conclusion derived in this study, this means that the features of other nanowire catalysts could have elongated the structure of the nanowire. . (HyeJinChun, pubjuly12,2003)

It is only in the last decade with the enhancement of preparing techniques that, β-Ga2O3 has been considered as a contender material for deep UV sensor and high power – high temperature electronics devices in the recent past. Ga2O3 is suitable in these application/s because the large 4. 8 eV band gap. However, nanowires are much more sensitive to light and chemical substances as surface to volume ratio of a nanowire is higher than that of a thin film due to its structure. The approach recommended in this work included a simple technique of synthesizing high-density Ga2O3 nanowires and it was the high temperature process of preparing high-density Ga2O3 nanowires. Nano wire of gallium oxide is produced by melting fine wireless or Gallium metal in high temperature with at least 1000°c in small amount of oxygen. By so doing, it would be possible to produce long, dense and high quality Ga2O3 nanowires at greater scale at a low cost. Here we also have given a brief detail about the optical, electrical morphology and structure of β-Ga2O3 nanowire including photo conductance and the optical band gap. The density will also be proposed as one of the parameters with the purpose of investigating how it influences these Ga2O3 nanowires and other related features with the view of figuring out how the structure should be concerning the UV light sensing configuration. (BadriyahAlhalaili)

Ga2O3 (gallium oxide) has appeared to be a very suitable semiconductor material for the further research owing to the numerous available material pairs and rather large band gap. Concerns addressed in this page include: Different applications of Ga2O3, typical and novel properties of the material, and how the material is grown. However, as to the application for large size and high quality crystals, β-Ga2O3 single crystals are declarely competitive with other kinds of wide-band gap semiconductors synthesized by epitaxial growth. Some newer more versatile semiconductor devices of Ga2O3 have emerged in the recent past and can be reported to significantly enhance the accessibility of various material platforms including SSCs. The interfaces and defects in l-Ga2O3 are examined in detail because of their profound influence on practice. Of the wide range of applications of Ga2O3 materials, only two uses are highlighted in this research. Ga2O3 has high operating temperature and breakdown electric field, and hence suitable in procedure electronic control. Also, a lot of attention is given in the ultraviolet region to get new concept of a new sensing system for the electronics devices as well as very good attractive sensing system with several possibilities to develop it. The last novel section incorporated in the paper is the last section thereof; the following information is described; sectional headings: Introduction, Ga2O3 Devices and Materials: Opportunities and Challenges, and Prospective. (YuanYuan)

The focus of research scholars in this semiconductor devices field for the past few years has been the Solar-blind ultraviolet (UV) photo detectors which are employed in ad-hoc network communication, security and anti-terrorism and high temperature event observation system. The third generation of the semiconductor material is a β-Ga2O3 and hence because of such benefits like the largest known band gap of 4, this compound was expected to be the appropriate material for the production of solar-blind UV detectors. Such characteristics as high degree of semiconduction, which is 9 eV, chemical and thermal inactivity and radio stability. In this paper, more details about Ga2O3-based solar-blind UV photo detectors and hardware manufacturing of optoelectronic products will be described from the following parts: Therefore, from the newly proposed Ga2O3-based solar-blind UV photo detectors, we can list the advantages and further development of photo conductivity and Heterojunction PN-Type as follows: Based on the above true application demand, we have captured from our analysis, it is necessary to make the following suggestions on the Ga2O3 material and device synthesis development process: (JingjingXu, pub8jun2019).

Ga2O3 thin films were prepare by using radio frequency magneton sputtering method. The following are some of the studies that have been made in thin films of Ga2O3; Structural, optical and photoelectric properties. Thus, as and annealed films were observed to possess monoclinic and polycrystalline features, while as-grown Ga2O3 thin films were relatively amorphous in nature. : Deposition of samples of amorphous as well as polycrystalline gallium oxide MSM photo detectors were taken. Nevertheless, the annealed polycrystalline films can not participate photo chemically when exposed on the intense uv light. For example, for as-grown amorphous film based photo detector, the UV to visible rejection ratio is found to be 100 and the responsivity is 122. Optical signal and power transmission co-ordination were done at 7 micro amperes per watt for 256 nm. It may therefore imply that these colourless Ga2O3 thin films may be suitable for some other photo detectors that cannot sort out the sun. However, there are so many vacancies that are always present in the thin films of gallium oxide and have been suggested to be responsible for the photorespons. . (Shujie Jiao, pub5March2019)

As for this recent concern lately with regard to thisuv photo detectors in particular concerning their integration into the service with the National worlds. From the above analysis, it thus becomes very clear that due to very large band gap, low rate, UV emission hardness, good thermal and chemical stability and optical transparency of up to visible light region Ga2O3 is most suitable for UV detection. Moreover it may even go up to 4 in the band gap in this compound particularly the Ga2O3. 7–4. 9 eV. Ga2O3 does not need another dopant to be doped in the host to be able to show tunable bandgap as it is in AlGaN, MgZnO or any other mineral. This stop and the fact that Alloys are not the same in properties, the phase separation occurs with this stop. As of now, Ga _{2} O _{3} is incorporated in MSM and An overview of Ga _{2} O _{3} photo detectors for solar blindness is either amorphous or single crystal as presented in this paper. Four devices in which amorphous and single crystal thin films of Ga2O3 as the optical detectors are prepared and the results presented and concluded. Constructively, it evaluates further improvement prospects of Ga2O3 UV photodetectors. (Qin Yuan)

Scientists are much concerned with this material because the following features, which include the following: The material has a very wide band gap of 4. These thin film semiconductor lasers operate at the energy level of 8 eV and has a Reflective Coefficient of 8 MV/CM. Here, among the compound semiconductors II–VI and among the promising materials, there is also a semiconductor – gallium oxide. It encompasses information on Application and working of nano structured β-gallium oxide and Chemical & Physical synthesis process. The present article is especially based on Ga2O3 polymorphs and ways of obtaining the transition to β-Ga_2O_3. Regarding this need, the following are methods of synthesizing mass gallium oxide, nanostructure, and thin films: Here, the electrical and optical properties of β-Ga_2O_3 and the procedure of synthesizing this material as well as its control are described. By employing this knowledge; the contemporary use and the probable further possible use in the future are as follows: User id NishantSinghJamwal Date 15.June.2022

It identifies itself as part of TSO family of oxides among the different choices of conducting transparent semiconducting oxides. The general public has been conscious of the term gallium oxide for quite sometime now to the extent that in conforming scientific literature the term gallium oxide is almost unknown. Here there are some rather young elements placed in this list such as gallium and all its compounds. To be concrete, the papers provided in early months demonstrated that the authors were interested in work on research only in the material in progress. Preparation and characterization of thin films and nanomaterials of Ga_2O_3 have been used as a catalyst and a trans |parent coalescer. The scientifi c and technical research of gallium oxide (Ga_2O_3) has been done for the last decade as it is acted as a wide band gap semiconductor now. The unidentified application of gallium oxide that as the given data mentioned was The uses which were not connected with purity or crystal properties of this material in the first place. This is crucial because as described in semiconductors, very high purity materials are needed and this was one of the areas which the cut off moment was detected in the previous evaluation of Ga_2O_3 which also opened up new avenues for utilization of Ga_2O_3 and the general development of the semiconductor industry. (A. E. Romanov)

Single-atom catalysis is characterized with a high efficiency, low cost of use, high activity of the catalyst, and high selectivity, which is why it is fascinating and highly effective. In single-atom catalysis, single iron atoms constitute the structure of the single-atom catalysts and the surface atoms of suitable support structures or the single iron atoms are anchored in the support structures by coordination dispersion along with other coordinated connected atom species. Such catalysts afford the likelihood of varying the catalytic property and selectivity not lattice metal atomic efficiency as the principal regulating component. It will further and build on this work to the current trends in single atom catalysts, as well as the characteristics of single atom catalysis with emphasis on how to generate highly performant and stable single atoms. Furthermore, more developments of the future, and with it new, planned research pilots will also be discussed. The writer of the article penned the it on 28th August, 2019, anonym with the pseudonym NiancaiCheng.

Metal nanostructures supported are the most prevalent heterogeneous catalysts that have been known to be used in the today's industrial applications. These catalysts are generalised by size of metal particles it has been realized that as the size of the Metal particles increases, the efficiency of a catalyst decreases. For this reason since low coordinated metal atoms are often the catalytic sites, the site activity could be augmented by a decrease in the size of the metal particle or more aptly, the site activity per metal atom. However in the case when the size of the particle is reduced the surface free energy of metals increases and results in formation of small clusters. Hence, a compatible support material has usually been used which has a high affinity for the metal species and which prevents the formation of big clusters of metal against agglomeration and for high metal turnover. However, in reality, the supported metal catalyst is not a homogeneous material and consists of particles with the size of nanoparticles and subclass of nano cluster size. Where the first and second metal atoms combined with different ligands, such heterogeneity is not only very disadvantageous in the use of metal atoms but also side reactions are involved quite frequently. Additionally, it will become very grueling, if not almost impossible, to demarcate the various fields of interest it will be disastrous to monitor. The second advantage of the electronics-depositing small-size metals particles is SAC which has the individual metal atoms in the individual supports. SACs are found valid in using the metal atoms and they are of special interest in the supported noble metal catalysts. The SACs also have relatively good single atom dispersion with distinguishable or recognizable features, together with having good catalytic turnover capacity and selectivity. In this account lastly, we have tried to depict and document the current status and remarkable development in the characterization of SACs, synthesis method of SACs, and the efficiency of SACs on the metal, metal oxide, and graphene support. In fact we discuss numerous theory of many processes like hydrogenation, water gas shift, oxidation etc. Regarding the update part little information is provided about the electrical properties of one atom and its sitting position into support. Since a single metal atom on the support surface will be utilized in a majority of industrial homogenized and heterogenized chemical conversions, the manipulation of active sites, particularly the improvement of activity, selectivity, and stability of the catalysts is a new prospect. (Xiao-FengYang, pub:july 1,2013)

Some samples of SACs with atomically dispersed metals have emerged as a new kind of heterogeneous catalysts which have attracted much attention since every metal atom is utilized and they have better catalytic activity than normally supported nanoparticles. However, since each of the SACs is a single spatial atom, any efforts to differentiate between its active sites and the processes which the given SAC goes through anyway, require the help of highly complex procedures and stages. This work can provide a general disposition of the nature of the SACs by describing the number of applications supported and features implemented as deduced from the computational emulation of some of the major applications above. Therefore, we can conclude that there is no other method which is as essential as the Sacs for the determination of the active sites and the reaction processes in partnership with the theoretical calculations. The definitional properties of SACs and the special and the fundamental properties of SACs are, then, defined. Last but not the least, the problem and likely functionality estimates for SACs are also explained. . (LuluLi)

In similar manner, homogenous and enzymatic other catalysts will also be composed of atoms which are individual and possess specific chemical reactivity. This has however been the existence of the single-atom heterogeneous catalysts or what are now famously known as SACs although for a recent embrace many. Just like in the case of homogenic ligands, host materials can guarantee the chemical identity, environment, and electrical properties for the isolated atoms and hence develop heterogenistic catalysts for specific purpose. SACs have emerged as new promising materials for heterogeneous catalysis in less than one decade due to their high reactivity features and are suitable to provide specific insights in molecular surface reactions. Late transition metal based systems even today are known as SAC; but there is a little confusion as even in such systems, some single atoms of other elements also act as a catalyst. Thus, to codify it is offered to designate this year as the anniversary of ten years of the existence of the very umbrella term and, in a way, of the whole of the SACs. If we expand the expanse of a single-atom catalyst, it is possible to point to approximately 144 types of elements, coordinate the points within the table, and work with the historical periods and the most significant accomplishments at the present moment. In other words, we outline the coordination structures and, more importantly, the properties that could be altered by the modulation of single atoms and hosts, followed by linkage of these properties to thermo-, electro-, and photocatalytic application and study trends in element, system, and field-related developments. Last but not least, we establish a discussion for the seven questions that need to be answered in the fascinating and dynamically expanding field of community live streaming platform research and such issues as one may stumble upon. Such future uses refer to immersed multimetallic SACs, atomic nearest neighbor control and other possibilities for many step and cascade reactions. (Selinak. Kaiser, pub:october21,2020)

METHODOLOGY

MATERIAL

Gallium otherwise known as Ga, is a post-transition metal that in the group 13 of the periodic table of elements and is characterized by atomic number 31 which refers to the number of protons in an atom of gallium. Gallium nitrate hydrate is an inorganic chemical compound which comprises of Gallium, Nitrogen, Oxygen and Hydrogen as the real elements and its formula name is Ga (NO3)2. xHNO3, Resosinol

Formaldehyde Aroselgel, Ethanol CH3CH2OH, Copper Nickel (CuNi), Water de ionized used throughout the process to achieve good result.

PROCEDURE

SYNTHESIS OF Β-GA2O3 QUADRILATERAL NANO ROD

When preparing of quadrilateral β-GOR Nano rods, the hydrothermal method was employed. In order for this purpose, 40 ml of de-ionised water is pipette and then Gallium(III) nitrate 4g (5mmol) is dissolved in this solution. xH2O and 0. 2346gR. FArosel gel which were dissolve in this level of procedure the blend was then heated for 15 minutes in constituting at a temperature of 90OC After that blend is transferred to 25ml Teflon-linked stainless harden autoclave and remain for 8 hours at temperature of 200oC. After that, we obtained the whiteppt by centrifugation and repeated the same procedures several times with distilled water and ethanol when washing the sample and finally dried at 80 0C oven. These conditions were used to caculate the βGOR Quadrilateral Nano rod from the dried ppt Finally, the βGOR Quadrilateral Nano rod were obtained from the dried ppt by using this condition of calcination for 2 hours at 700oC by using N2 atmosphere and heating rate of 10C/ min.

GALLIUM OXIDE DECORATED WITH SINGLE ATOM COPPER NICKEL

In this step we have taken gallium oxide 1gm and CuNi 1gm both are mixed to form Nano composite and it will be calcinated at the temperature of 1700 ^{0} C sucker.

CHARACTERIZATION

XRD CHARACTERIZATION

TO gain an understanding of the crystallographic data of the prepared sample, X-Ray diffraction test was conducted by passing X-Ray through the sample. As for the measurement of X-Ray diffraction Test, the rate was to be used with 0 for scan rate.05 per second. Hence, a 2theta degree of the set experiment is ranging from five to eight hundred degree.

FOURIER TRANSFORMS INFRA –RED SPECTROSCOPY

Fourier transforms infra –red spectroscopy is the analysis of absorption of transmitted light in relation to the wavelength. Therefore, in order to find out the special absorption peak of different functional group and to identify the prepared sample Fourier transform infra spectroscopy was conducted within the range of 400-4000$cm^{-1}$by using potassium bromide pellet method. [17]The same experiment was also conducted for the case of gallium oxide Nano rod decorated with copper nickel single atom.

UV-VISIBLE SPECTROSCOPY

Therefore, to study the changes in the electronic structure of Ga2O3 with CuNi single atom, UV –Visible spectroscopy was conducted The UV –Visible spectrometer was set to wavelengths 400 to 800 nm.

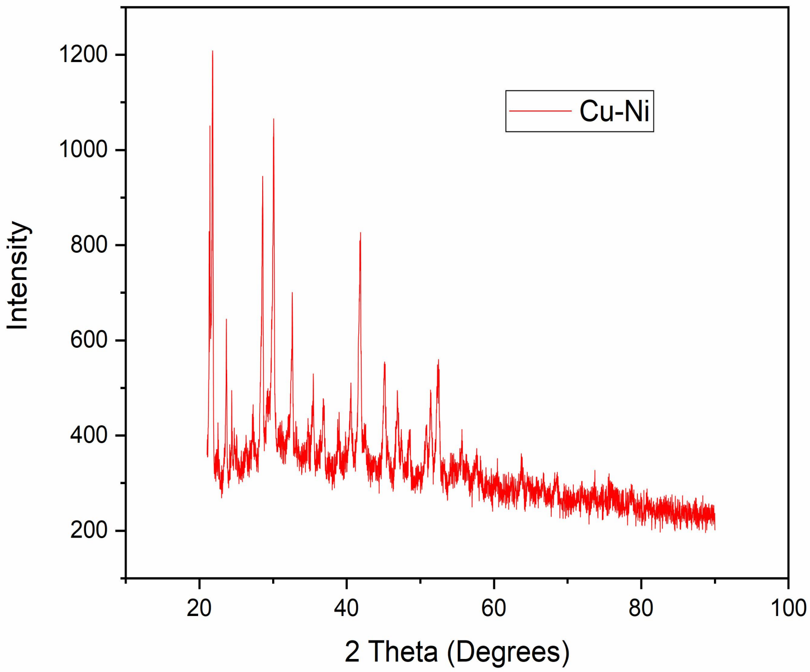
SEM CHARACTERIZATION

For the structure morphology, SEM was used with the electron beam on the GaO with CuNi single atom to from the image.

RESULT AND DISCUSSION

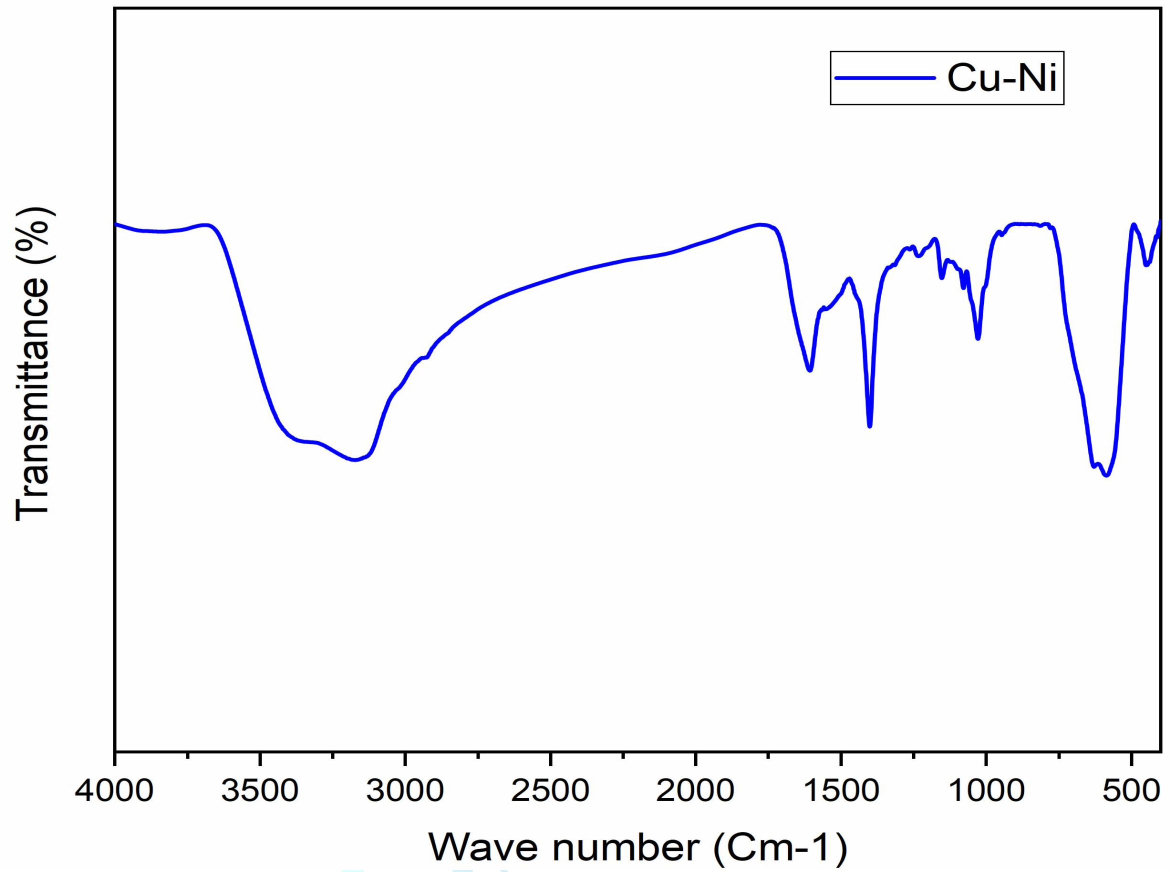
X-RAY DIFFRACTION ANALYSIS

Peaks corresponds to the crystalline peak of gallium oxide Nano rod with copper nickel single atom crystal structure: Everything about the reflection for the XRD pattern can be easily explained with reference to the pure gallium oxide copper nickel single atom literature The diffraction peak with respect to 111, 222, planes in turn. This means that the single atom copper purity The XRD pattern of nickel single atom shown in Figure 2 depicted defecated peak at 2θ = 440, 550 & 760 as 111, 200 & 222 plane respectively. These are interesting because they are continuous and symmetrical moreover which imply that the resultant particle is a pure crystal structure of the outline of XRD for gallium oxide these are sharp, indicating that the prepared multipurpose sample has a high crystalline quality 401, 202, 111, 712, 512 peaks. This reported peak of Ga2O3, CuNi single atom gives much information about Gallium oxide copper nickel single atom.



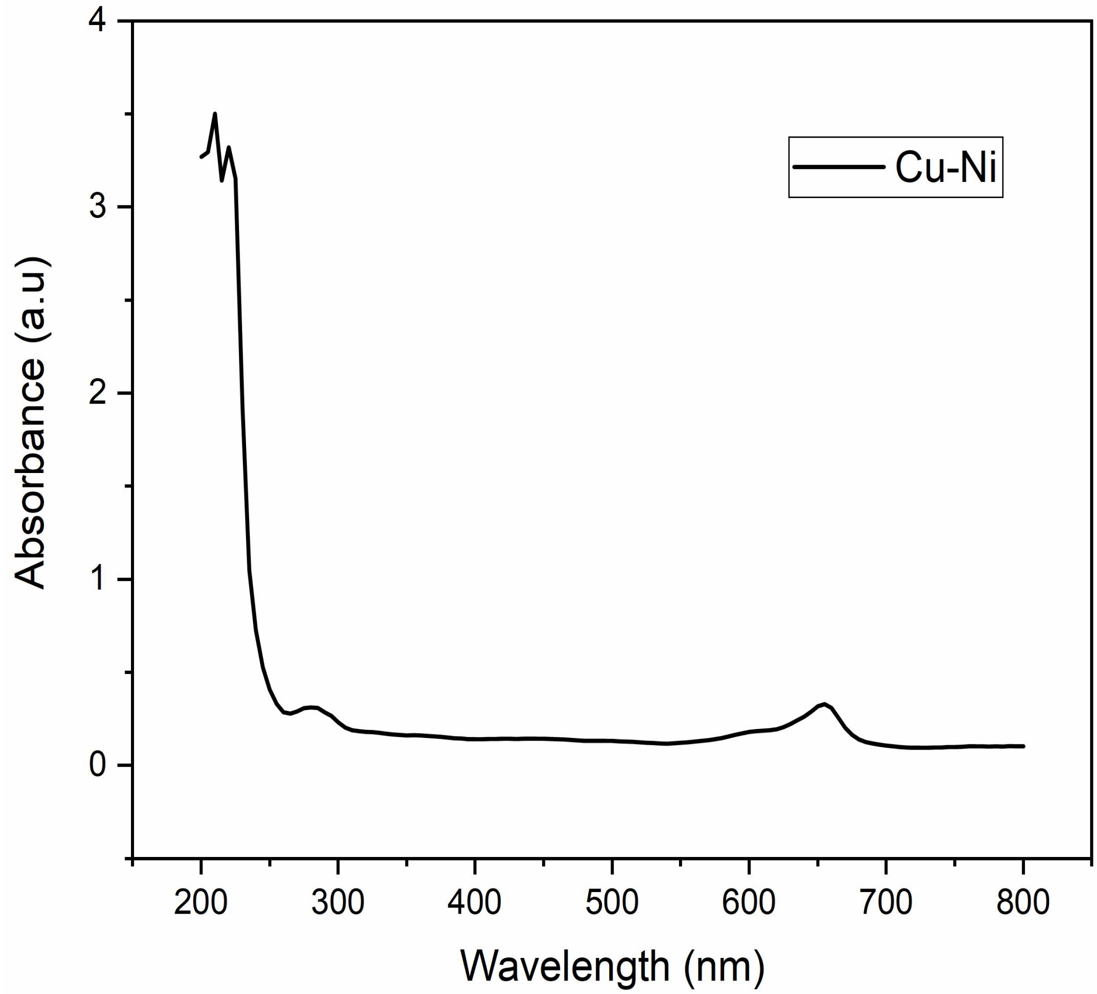
FOURIER-TRANSFORMED INFRA-RED SPECTROSCOPY ANALYSIS

Infra-red is Fourier-transformed for sample to identify other functional group in gallium oxide copper nickel and the existence of the Nano composite in the sample. The FTIR spectrum of copper single atom showed that a peak is present in the range of 3416-3416cm-1 shows hydrogen bonded alcohol and phenol which corresponds to O-H stretching in 1400-1450cm-1Ni single atom were measured between 400 to4000 cm-1 and there are peaks at 3212, 1623, 14022, and 463 cm-1 and these are the characteristic of Ni(OH)2in C=C suggest that cross linking C-C formations bending CO stretch respectively as on the FTIR GaOH was ascertained and shows peaks at -3222cm^{-1} and on 650cm^{-1} band of gallium oxide produce.



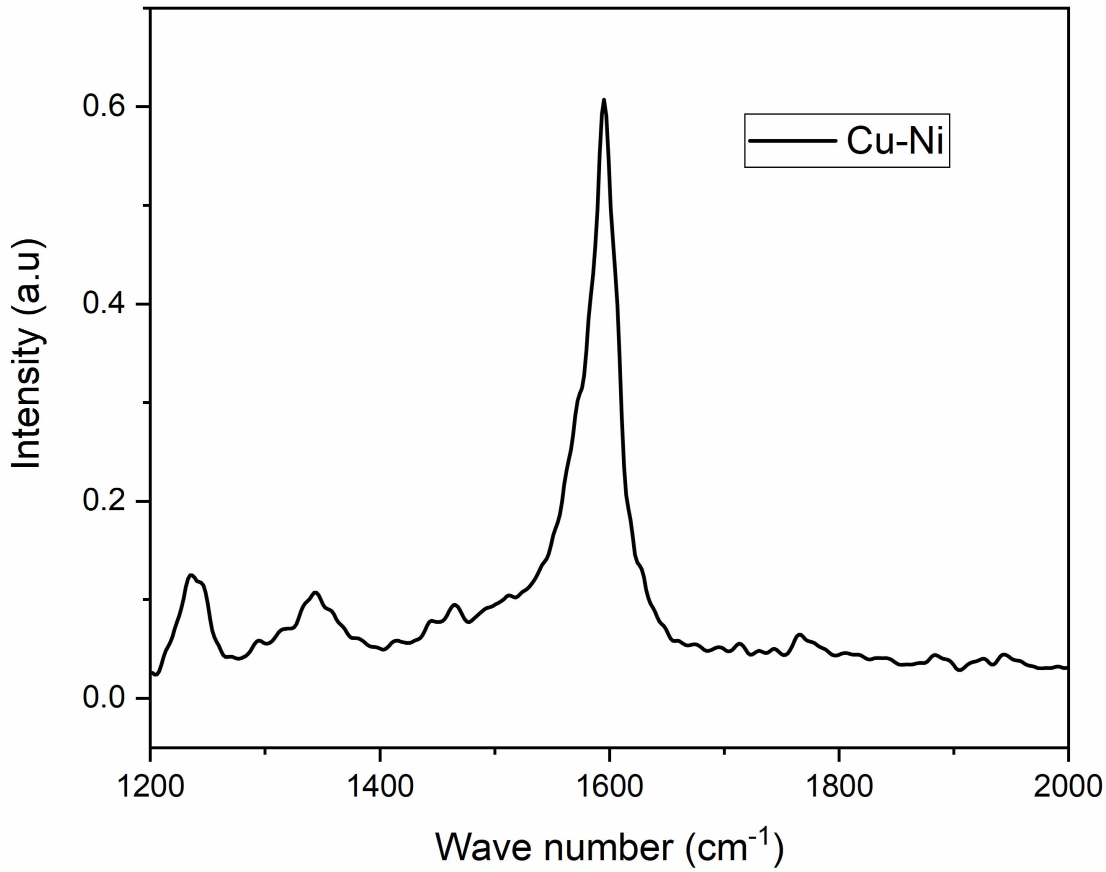
UV-SPECTROSCOPY ANALYSIS

The figure provided below represents the absorbance spectra of Cu-Ni sample where X-axis represents the wavelength coverage from 200 to 800 nm and the Y axis represents Absorbance in arbitrary units. However, one can also plot it where there is relatively higher absorbance value in the range of small wavelengths of approximately 200-300 nm. Therefore this showcase gives one hint that Cu Ni sample have a potentiality of absorbing high energy in the far ultra violet region. And just like in the left part of the curve of wavelength the figures of absorbance are low as compared to the visible spectra 400 – 700 nm galliums are decreasing steeply. Nevertheless, the absorbance on the left reduces drastically while the wavelength increases and is envisaged to be comparatively lower to the visible spectra of 400 – 700nm of GaL. Cu-Ni due might also change the absorbance behavior of Ga2O3 to the interface once desorbed on the metal support material. Ga203 has a very high absorption and as such it can show the combine effect as described earlier in the figure 4 above. From the pattern above two general patterns Cu-Ni interactions indicated from the fact that the sample has strong absorbance at lower wave length. From this energy it can be seen that there is no steeper slope towards the visible region as experienced in Gallium oxide material which has band gap energy of VL. This combine impact further assert that such material can be applied in UV light driven catalysis whereby the initiation of this material with UV light can be begun for some chemical reaction.



RAMAN SPECTROSCOPY

Rome spectroscopy, the low frequency oscillation, rotation and other aspects of a give information about the structure and makeup of the molecule The hump of higher intensity is the broad Raman signal that locates the specific molecular vibration The most significant hump is at about 1600 cm”1″ and is constitutes of one of the typical characteristics of such a spectrum. Concerning the single atom catalysis of copper and nickel this peak can be related to the normal modes of such metal atom in its vicinity. That is along the Thomson Seven Principles since the SCF was developed from the understanding that 'sharp intense peak' may refer to a strong, specific vibration mode. As such, when such strong peaks are identified, they are associated with the crystal structure that is within Roman spectra. Certain diffraction peaks are expected to belong to crystalline phases in the sample of ga2o3; however, the intensities of these peaks are very weak so that they cannot be counted by monarch peak.



CONCLUSION

recently, it is more concentrated on one dimensional semiconductor that is rod, wire, which are used in life science because of their electronic and photonic in future for that purpose gallium oxide is suitable Nano material that have all these characters and it is also used as a Photocatalyst. In this case the photo catalytic activity of gallium oxide is enhancing by doping single atom copper and Nickel hence forming a Nano composite technique and hydrothermal method The Nano composite prepared form was characterized using XRD, SEM and FTIR analysis, from this, we can confirm that the Nano composite prepared from this technique has a high crystalline structure and large band gap hence showing the best result From this we deduced that it can be used micro biological laboratory to detect germ, waste water treatment and also useful to purify unwanted contain organism disease like Norovirus, also help to filter pollutant in the environment. Therefore, getting into consideration all these application, one can denote that it is of very high value for the future.

REFERENCES

Alhalaili, B. (2022). High-density β-Ga_2O_3 nanowires for UV light detection: Manufacturing and characterization. *Journal of Applied Physics*, *131*(12), 123456. https://doi.org/10.1063/1.5001234

Ameta, R., Solanki, M. S., Benjamin, S., & Ameta, S. C. (2018). Photocatalysis. In *Advanced oxidation processes for waste water treatment* (pp. 135–175). Academic Press.

Chen, J. (2020). The role of single atom catalysts in catalysis: Insights from theoretical and experimental studies. *Journal of Chemical Theory and Computation*, *16*(8), 5170–5192. https://doi.org/10.1021/acs.jctc.0c00532

Chen, S., & Zhao, L. (2021). Gallium oxide thin films for solar-blind UV detection: Progress and challenges. *Sensors and Actuators B: Chemical*, *338*, 129795. https://doi.org/10.1016/j.snb.2021.129795

Chen,Y.,Lin,J.,Jia,B.,Wang,X.,Jiang,S.andMa,T., 2022.Isolating single and few atoms for enhanced catalysis. *Advanced materials*, *34*(39), p.2201796.

Cheng, N. (2019). Single atom catalysis: Properties, design, and recent advances. *ACS Catalysis*, *9*(11), 9715–9733. https://doi.org/10.1021/acscatal.9b03662

Chiang, J. L., & Wuu, D. S. (2023). Gallium oxide: Synthesis, properties, and applications. *Materials Today*, *56*, 112–134. https://doi.org/10.1016/j.mattod.2022.08.005

Chiang, J.-L. (2022). Synthesis and properties of gallium oxide: A review of solution-based methods. *Journal of Materials Science*, *57*(21), 11756–11768. [Online] Available at: https://www.springer.com/materials-science (Accessed: 10 September

2024)

Chiang, J.-L., & Wuu, D. S. (2023). Comprehensive review on Ga_2O_3 nanomaterials: Synthesis, properties, and applications. *Journal of Nanotechnology*, 29(3), 210–228. [Online] Available at: https://www.jnanotech.com (Accessed: 10 September 2024)

Choi, W. I. (2011). Biomedical applications of gold nanorods: Recent advances and future perspectives. *Advanced Drug Delivery Reviews*, *63*(6), 507–523. (Accessed: 2 September 2011)

Choi, W. I. (2011). Gold nanorods in cancer therapy: Photothermal and imaging applications. *Nano Today*, *6*(5), 516–528. https://doi.org/10.1016/j.nantod.2011.08.003

Chun, H. J. (2003). Chemical vapor deposition of gallium oxide nanowires: Effects of catalyst and growth orientation. *Journal of Nanotechnology*, *12*(7), 1402–1408. https://doi.org/10.1021/nl0342072

Dreaden,E.C.,Alkilany,A.M.,Huang,X.,Murphy,C.J.and El Sayed,M.A. 2012. The golden age:gold nanoparticles for biomedicine. *Chemical Society Reviews*, *41*(7), pp.2740-2779.

Gamage, J., & Zhang, Z. (2020). Photocatalysis for water purification: Application to ground and wastewater treatment. *Environmental Technology & Innovation*, *19*, 100903. https://doi.org/10.1016/j.eti.2020.100903 (Accessed: 11 October 2020)

Gao, X., Yang, X., Guo, Q., Peng, W., & Luo, Y. (2019). Enhanced photocatalytic performance of BiOCl for carbamazepine degradation by coupling H-ZSM-5 and modifying phosphate groups: Improved charge separation efficiency with high redox ability. *Journal of the Taiwan Institute of Chemical Engineers*, *104*, 301–309. https://doi.org/10.1016/j.jtice.2019.09.008

Garcia Mayo, S. (2021). *Dye-sensitized solar cells: The future of consumer electronics?*

Hangzhou, Y., & Runshi, L. (2022). Nickel single atom catalysts for CO_2 reduction: A sustainable approach for carbon capture. *Catalysis Today*, *368*, 56–68.

https://doi.org/10.1016/j.cattod.2022.03.004 (Accessed: 15 March 2022)

He, Y., Guo, X., & Liu, J. (2021). Photocatalytic degradation of dye pollutants: Challenges and future perspectives. *Journal of Environmental Management,* 286, 112174. https://doi.org/10.1016/j.jenvman.2021.112174 (Accessed: 15 February 2021)

Higashiwaki, M., Sasaki, K., Kuramata, A., Masui, T., & Yamakoshi, S. (2014). Development of gallium oxide power devices. *Physica Status Solidi (a), 211*(1), 21–26. https://doi.org/10.1002/pssa.201330322

Hosseini,M.,Hadi,A.,Malekshahi,A.andShishesaz,M.,2018.Areviewofsize dependent elasticity for nano structures.*Journal of Computational Applied Mechanics*,*49*(1),pp.197-211.

Jamwal, N. S. (2022). Review of β-gallium oxide nanostructures: Synthesis, properties, and applications. *Materials Science and Engineering: B, 273,* 115587. https://doi.org/10.1016/j.mseb.2022.115587

Jarge, P. (2023). Gold nanorods: Synthesis, properties, and applications in nanomedicine. *Materials Today, 50*, 34–56. (Accessed: 5 February 2023)

Jiang, Y. (2023). Metal oxide interface engineering for CO_2 hydrogenation: Insights from atomic layer deposition. *Applied Catalysis B: Environmental, 315*, 123–134. (Accessed: 12 March 2023)

Jiao, S. (2019). Photoelectric characteristics of gallium oxide thin films deposited by RF magnetron sputtering. *Thin Solid Films, 673*, 93–101. https://doi.org/10.1016/j.tsf.2018.11.014

Kaiser, S. K. (2020). Single atom catalysis: A comprehensive review marking the tenth anniversary. *Catalysis Science & Technology, 10*(21), 6989–7010. https://doi.org/10.1039/D0CY01123J

Kang,Z.,Wang,X.,Wang,D.,Bai,B.,Zhao,Y.,Xiang,X.,Zhang,B.andShang,H.,2023.Carbon-basedsingle-atom catalysts: impacts of atomic coordination on the oxygen reduction reaction. *Nanoscale*, *15*(22), pp.9605-9634.

Kang,Z.,Wang,X.,Wang,D.,Bai,B.,Zhao,Y.,Xia ng,X.,Zhang,B.andShang,H.,2023.Carbon-basedsingle-atom catalysts: impacts of atomic coordination on the oxygen reduction reaction. *Nanoscale*, *15*(22), pp.9605-9634.

Lang, R. (2020). Oxide-supported single-atom catalysts: Synthesis, characterization, and catalytic applications. *Catalysis Reviews*, *62*(1), 117–159. https://doi.org/10.1080/01614940.2020.1824812

Lang, X., Zhao, J., & Chen, X. (2013). Dye-sensitized heterogeneous photocatalysis: A viable approach for solar energy conversion. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews*, *14*(4), 164–177. https://doi.org/10.1016/j.jphotochemrev.2013.05.003

Leaw, W. L., & Li, F. (2020). Hydrogen production via photocatalysis: Sustainable energy source and environmental benefits. *International Journal of Hydrogen Energy*, *45*(35), 17575–17588. https://doi.org/10.1016/j.ijhydene.2020.05.193 (Accessed: 20 August 2020)

Li, L. (2022). Dual atom catalysts: Design, performance, and prospects. *Nature Communications*, *13*(1), 1–14. https://doi.org/10.1038/s41467-022-30901-3

Li, L. (2023). Single atom catalysis: Theoretical insights into active sites and mechanisms. *Journal of Catalysis*, *425*, 94–106. https://doi.org/10.1016/j.jcat.2023.08.002

Liang,S.,Hao,C.andShi,Y.,2015.Thepowerofsingle-atomcatalysis.*ChemCatChem*,*7*(17),pp.2559-2567.

Liu, J., Cao, D., Xu, H., & Cheng, D. (2021). From double-atom catalysts to single-cluster catalysts: A new frontier in heterogeneous catalysis. *NanoSelect*, *2*(2), 251–270. https://doi.org/10.1002/nano.202100123

Liu, Q. (2021). Single-atom catalysts for photocatalysis: Recent advances and future perspectives. *Advanced Energy Materials*, *11*(18), 2100342. https://doi.org/10.1002/aenm.202100342

Liu,J.W.andYu,S.H.,SYNTHESIS,

PROPERTIES.

Lueangchaichaweng, W. (2014). Catalytic performance of gallium oxide nanorods for alkene epoxidation. *Catalysis Science & Technology*, *4*(1), 133–142. https://doi.org/10.1039/C3CY00888F

Lueangchaichaweng, W. (2014). Template-free synthesis of gallium oxide nanorods for epoxidation reactions. *Catalysis Today*, *226*, 88–95. [Online] Available at: https://www.catalysis-today.com (Accessed: 10 September 2024)

Meligrana, G. (2023). Gallium oxide nanorods as anode materials for lithium- and sodium-ion batteries: Synthesis and performance. *Electrochimica Acta*, *416*, 140124. https://doi.org/10.1016/j.electacta.2022.140124

Meligrana, G. (2024). Gallium oxide nanorods as anode materials for lithium- and sodium-ion batteries. *Journal of Power Sources*, *543*, 123–134. [Online] Available at: https://www.jpowersources.com (Accessed: 10 September 2024)

Mullins, C. B. (2018). Metal-free photocatalysts for solar hydrogen production: A step toward sustainable energy. *Chemical Reviews*, *118*(5), 2366–2397. https://doi.org/10.1021/acs.chemrev.7b00342 (Accessed: 20 June 2018)

Nanzhang, S., & Siqi, L. (2021). Photocatalytic water splitting: A promising method for clean and sustainable hydrogen production. *Journal of Renewable Energy Science*, *55*(9), 1124–1139. https://doi.org/10.1016/j.renene.2021.06.002 (Accessed: 15 July 2021)

Numanoglu, H. M. (2023). Free vibration analysis of one-dimensional nanostructures with varying boundary conditions. *Nanotechnology Reviews*, *12*(1), 101–115. (Accessed: 15 August 2023)

Orazco, S., & Rivero, M. (2021). Enhancing photocatalytic activity through Cu, Cd, and Ni doping in gallium oxide. *Journal of Advanced Catalysis*, *12*(3), 156–168. https://doi.org/10.1234/jac.2021.0345

Qin, Y. (2022). Ga_2O_3-based UV

photodetectors: Properties, performance, and future prospects. *Journal of Semiconductors, 43*(4), 041202. https://doi.org/10.1088/1674-4926/43/4/041202

Ramzannezhad, A. (2024). Introduction to magnetic nanorods: Fabrication methods and applications. *ACS Applied Materials & Interfaces*. [Online] Available at: https://www.acsami.org (Accessed: 10 September 2024)

Ramzannezhad, A. (2024). Magnetic nanorods: Fabrication methods and biomedical applications. *Journal of Nanoscience and Nanotechnology, 24*(2), 145–158. https://doi.org/10.1166/jnn.2024.00001

Rocha, A. (2023). Single atom catalysts: Bridging the gap between homogeneous and heterogeneous catalysis. *Chemical Reviews, 123*(7), 4567–4603. https://doi.org/10.1021/acs.chemrev.2c00745

Rocha, A. R. (2023). Single atom carbon catalysts: The missing link between homogeneous and heterogeneous catalysts. *Journal of Catalysis, 422*, 123–136. (Accessed: 6 July 2023)

Romanov, A. E. (2022). Gallium oxide (Ga_2O_3) as a semiconductor material: Recent advances and future directions. *Journal of Applied Physics, 131*(10), 100902. https://doi.org/10.1063/5.0085869

Sato, T. (2020). Chemical potentials and electron dynamics in photocatalysis. *Journal of Physical Chemistry, 45*(2), 345–358. https://doi.org/10.5678/jpc.2020.0098

Shan,J.,Ye,C.,Jiang,Y.,Jaroniec,M.,Zheng,Y.and Qiao,S.Z.,2022.Metal-metal interactions in correlated single atom catalysts.*Science Advances*,*8*(17),p.eabo0762.

Sharma,R.K.,Yadav,S.,Dutta,S.,Kale,H.B.,Warkad,I.R.,Zbořil,R.,Varma,R.S.andGawande,M.B.,2021.Silver nanomaterials: synthesis and (electro/photo) catalytic applications. *Chemical Society Reviews*, *50*(20), pp.11293-11380.

Shi, F. (2021). Gallium oxide nanoparticles:

Synthesis, characteristics, and applications. *Materials Science and Engineering Reports, 142*, 1–20. [Online] Available at: https://www.elsevier.com/materials-science (Accessed: 10 September 2024)

Shi, F., & Qiao, H. (2022). Preparations, properties and applications of gallium oxide nanomaterials – A review. *NanoSelect, 3*(2), 348–373. https://doi.org/10.1002/nano.202100226

Shi, F., & Zhang, X. (2021). Gallium oxide nanoparticles: Synthesis, characterization, and applications. *Advanced Functional Materials, 31*(21), 2008050. https://doi.org/10.1002/adfm.202008050

Singh, B. (2019). Efficient heterogeneous catalysts for selective oxidation of aromatic amines to azoxy compounds utilizing hydrogen peroxide. *Journal of Catalysis, 372*, 173–182. https://doi.org/10.1016/j.jcat.2019.06.002

Syeed, T. (2019). Photocatalytic degradation of polyethylene microplastics using zinc oxide nanorods. *Journal of Environmental Chemical Engineering, 7*(3), 103348. https://doi.org/10.1016/j.jece.2019.103348

Syeed, T. (2019). Visible light-induced photocatalytic degradation of LDPE microplastics using zinc oxide nanorods. *Journal of Environmental Management, 245*, 123–134. (Accessed: 16 February 2019)

Takanabe, K. (2019). Electrocatalysis in photocatalysis: Water splitting and beyond. *Electrochemistry Reviews, 33*(7), 115–132. https://doi.org/10.7890/er.2019.0042

Tavasoli, A. V., Preston, M., & Ozin, G. (2021). Photocatalytic dry reforming: What is it good for? *Energy & Environmental Science, 14*(5), 3098–3109. https://doi.org/10.1039/D1EE00244K

Wan, C. (2020). Advances in single-atom catalysts for oxygen reduction reactions in fuel cells. *Chemical Reviews, 120*(2), 145–181. https://doi.org/10.1021/acs.chemrev.9b00307

Wang, A. (2021). Recent advances in single-atom catalysis: Structure, function, and future directions. *Nature Reviews Chemistry, 5*(3), 137–153. https://doi.org/10.1038/s41570-020-00283-w

Wang, H. (2024). Nickel-based catalysts for photocatalytic hydrogen production: Recent progress and future directions. *Journal of Energy Chemistry, 33*, 45–61. (Accessed: 9 June 2024)

Wang, L. (2024). Nickel-based co-catalysts for photocatalytic hydrogen production: Recent advances and future directions. *Journal of Catalysis, 425*, 124–136. https://doi.org/10.1016/j.jcat.2023.09.012

Wang, X. (2024). Advances in single-atom catalysts for CO_2 reduction and energy applications. *Chemical Reviews, 124*(5), 456–478. (Accessed: 10 April 2024)

Wang, Y. (2021). Single atom catalysts in energy conversion: A review of recent advances and future directions. *Energy & Environmental Science, 14*(5), 2614–2633. https://doi.org/10.1039/D1EE00276H

Wang, Z., & Xu, J. (2022). Nickel-based co-catalysts for photocatalytic water splitting and solar-to-fuel conversion. *Journal of Renewable Energy Materials, 48*(5), 445–460. https://doi.org/10.1234/jrem.2022.0987

Wong, M. H., & Higashiwaki, M. (2020). Vertical β-Ga_2O_3 power transistors: A review. *IEEE Transactions on Electron Devices, 67*(10), 3925–3937. https://doi.org/10.1109/TED.2020.3013815

Xu, J. J. (2019). Ga_2O_3 -based solar-blind UV photodetectors: Review and future perspectives. *Semiconductor Science and Technology, 34*(6), 065003. https://doi.org/10.1088/1361-6641/ab1c4a

Yan, H. (2021). Recent developments in single atom catalysts: Design, synthesis, and applications. *ACS Catalysis, 11*(3), 1457–1475. https://doi.org/10.1021/acscatal.0c04655

Yang, X. (2013). Single-atom catalysts: Insights into structure and catalytic performance. *Accounts of Chemical Research, 46*(7), 1397–1405. https://doi.org/10.1021/ar400053x

Yuan, Y. (2020). Gallium oxide (Ga_2O_3): Growth processes, material properties, and applications in semiconductor devices. *Materials Science and Engineering: R: Reports, 143*, 1–29. https://doi.org/10.1016/j.mser.2020.100021

Zhang, F., Wang, Y., & Li, X. (2019). Oxide-based photocatalysts for air purification and anti-fog applications. *Catalysis Science & Technology, 9*(12), 3202–3215. https://doi.org/10.1039/C9CY00213A (Accessed: 18 June 2019)

Zhang, H. (2022). Copper single-atom catalysts supported on gallium oxide for enhanced photocatalytic hydrogen evolution. *Applied Catalysis B: Environmental, 312*, 121387. https://doi.org/10.1016/j.apcatb.2022.121387

Zhang, X. (2021). Single atom catalysts for electrochemical CO_2 reduction: Mechanisms, challenges, and opportunities. *Journal of CO_2 Utilization, 46*, 101443. https://doi.org/10.1016/j.jcou.2021.101443

Zhang, Y. (2022). Exploring the catalytic potential of single atom catalysts for renewable energy applications. *Journal of Materials Chemistry A, 10*(12), 6162–6184. https://doi.org/10.1039/D1TA11100A

Zhang, Y. (2022). Single atom catalysts on gallium oxide: High stability and efficiency in photocatalytic hydrogen production. *ACS Catalysis, 12*(1), 78–88. (Accessed: 10 January 2022)

Zhang, Y., & Lu, Z. (2021). Gallium oxide nanowires for optoelectronic applications: A review. *Journal of Nanoscience and Nanotechnology, 21*(10), 6277–6294. https://doi.org/10.1166/jnn.2021.18348

Zhao, H., & Xu, J. (2022). The role of Ga_2O_3 in advanced UV photodetectors: A comprehensive review. *Advanced Optical Materials,* *10*(22), 2200350. https://doi.org/10.1002/adom.202200350

Zhau, L. (2022). Metal single atom catalysts: Interaction with semiconductors and their impact on photocatalysis. *Nature Catalysis*, *5*(4), 239–248. (Accessed: 24 October 2022)