UV-light Mediated Green Synthesis of Silver Nanowires and Their Catalytic Degradation Potential Against Methyl Orange

Faisal Ali  
The University of Lahore - New Campus  
Zahid Ali  
The University of Lahore - New Campus  
Ghulam Mooinuddin  
The University of Lahore - New Campus  
Umer Younas  
The University of Lahore - New Campus  
Muhammad Parvaiz  
The University of Lahore - New Campus  
Faiza Hassan  
The University of Lahore - New Campus  
Hafiz Muhammad Yasir  
The University of Lahore - New Campus  
Adnan Ashraf  
The University of Lahore - New Campus  
Muhammad Waqas Ishaq (✉️ mwaqasmayo@mail.ustc.edu.cn)  
USTC: University of Science and Technology of China  

Research Article

Keywords: Photocatalytic degradation, Ag nanowires, Methyl orange dye, Psidium guajava

DOI: https://doi.org/10.21203/rs.3.rs-648387/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.  
Read Full License
Abstract

In the present study, a simple and eco-friendly method for the synthesis of silver nanowires (Ag-NWs) has been reported. *Psidium guajava* seed extract was used as a reducing agent for silver nitrate solution at 70 °C temperature under continues UV-irradiation, for the production of Ag-NWs. Silver nanowires were initially characterized by using UV-visible and FTIR spectrophotometer. Synthesis of nanowires and involvement of functional groups was confirmed by FT-IR spectra. The morphology and particle size of synthesized Ag-NWs was determined using Field Emission Scanning Electron Microscopy (FESEM) and X-ray diffraction (XRD). XRD results revealed cubic phase morphology of Ag-NWs. Nanowires were found having 12-8 μm length and 300-500 nm diameter. In addition, catalytic potential of the sample for degradation of methyl orange dye (MO) was tracked spectrophotometrically. The results exposed that; bio-synthesized silver nanowires were found having excellent morphological features as well as impressive catalytic potential.

1. Introduction

Heavy metals, organic and un-natural dyes cause countless serious complications to human health and eco-system, however, manipulation of such chemicals are unescapable due to their widespread applications in diverse meadows of science and technology. With the hasty growth of industries for instance ore mining, textile industries, paper and paint industry, fertilizers and pesticide industries etc., an extensive aggregate of dyes, heavy metals and pigments are predisposed afterward the industrial progressions (Mance, 2012). The effluents commencing from such industries are discharged-off into natural-surfaces and ground-water resources. These toxic-effluents amends the composition of surface-water and consequently sound effects to the healthiness of living-beings. With the passageway of time, pigments and dyes available in water submit yourself to degradation chemically and transformed to supplementary hazardous toxic-chemical entities (Chang & Chen, 2009). Finally, these heavy metals and dyes possibly will indirectly or directly enter the food-web and originate unadorned toxic-impacts on surroundings. Thus, it is lethal to become aware of and reduce such engineering-wastes from water.

There are numerous techniques reported previously for the treatment of unnatural-dyes filthy-water. These comprise that, catalytic reduction (Begum et al., 2018), photo-catalytic degradation (Saeed, Ahmad, Boddula, ul Haq, & Azhar, 2018), advance oxidation routes (Qiu et al., 2017), membrane matrices (Fersi, Gzara, & Dhabhi, 2005), bio-remediation (Mani & Kumar, 2014), adsorption (Chongmin Liu, Wu, Tran, Zhu, & Dang, 2018). Amongst them, reductive squalor by employing nanocatalyst partake been pragmatic on broad-spectrum for the treatment of dyes in aqueous solutions prior to its proficiency, clean dispensation, and cost effectiveness (Hassan et al., 2011; Hu et al., 2015). Reduction of such dyes by nanocatalyst transfigure them to gamely biodegradable out-puts, that be able to further processed on requirement (Hassan et al., 2011). Metal based nanocatalyst for such reduction feedback mainly count on noble metals, like Ag and Au (P. Wang et al., 2008; Yasin, Liu, & Yao, 2013) in line for their extraordinary stability and high specific area. Thus, starved of appropriate surface stabilizers, these nanocatalysts endures aggregation, which can primarily domino effect of degradation of their catalytic-activities and lifetime.
Therefore, this is vitally important to stabilize nanocatalyst with accurate-ligands to enhance its efficiency and life-span. Several routes for preparing metal nanoparticles have been developed i.e., co-precipitation (Kim, Kim, & Lee, 2003), hydrothermal synthesis (Daou et al., 2006), sol-gel method (Chao Liu, Zou, Rondinone, & Zhang, 2001), inert gas condensation (Pérez-Tijerina et al., 2008), laser ablation (Amendola & Meneghetti, 2009), sputtering (Rane, Kanny, Abitha, & Thomas, 2018), template synthesis (Sreeram, Nidhin, & Nair, 2008), and biological synthesis (Devi et al., 2013). However, biological synthesis is the hot choice with advantages over physical and chemical methods as it is quick, eco-friendly, highly stable, and cost-effective. Biological synthesis does not acquire any culture growth and does not produce toxic residues to contaminate the atmosphere (Kulkarni & Muddapur, 2014).

Catalytic reduction mainly depends upon the morphology (Sun, 2010) and surface area of the nanostructures (Das & Soni, 2017) i.e., nanoparticles (Yousaf, Mehmood, Ahmad, & Rafi, 2020), nano-rods (Sawant & Sawant, 2020), nano-spheres (Ramya, Jyothi, Vardhan, Gopal, & Desai, 2020), nanotubes (Nadagouda, Speth, & Varma, 2011) and nanowires (Goh et al., 2012). Among them nanowires have grabbed the prime focus of the material scientists due to their excellent features like surface area, microporous structural features, highest contact area with adsorbate surfaces (Z. Wang, Liu, Chen, Wan, & Qian, 2005). Lin Bao et al. has reported the synthesizes of nanowires via green approach by using poly-vinyl acetate (PVA) polymer back-bone as a stabilizing agent due to the lower stability of Ag-nanowires (Ag-NWs) (Luo, Yu, Qian, & Gong, 2006). Many serious attempts have been made to enhance the stability of Ag-NW by using stabilizers like polymer matrices (PVA, PPy EG, and glucose) (Zhu et al., 2016), ITO glass electrode base (Sim et al., 2016) and electrostatic charge stabilizers (Yang et al., 2011). The synthesis of Ag-NW via a facile, green and eco-friendly routes without any external stabilizers and prolonged shelf-life is still a great challenge for the scientists (Guo, Chen, Wang, Jiang, & Wang, 2020).

Herein, we are reporting a facile and green approach to synthesize the Ag-Nanowires (Ag-NW) by using Psidium guajava seed extract to stabilize the nanowires, without any external stabilizers like ITO-glass electrode, electrostatic charge which was the classical approach to synthesize the nanowires. The plant seed extract by dissolving 0.1 g of the dry and finely divided form in 100 mL water at 60°C for 50 minutes followed by the vacuum filtration and used as a precursor for the reduction of silver ions. Then freshly prepared 0.1 mM solution of AgNO$_3$ was taken in conical flask. The addition of 5 mL of Psidium guajava seed extract was done to AgNO$_3$ under continues stirring and UV-irradiation of 265 nm wavelength white light, and stirred the reaction mixture for 4 hours. This is first effort to synthesize Ag-NW via a green, eco-friendly and template free pathway, with greater stability of Ag-NW.

2. Materials And Methods

2.1. Materials

Silver nitrate was acquired from Merck, Germany, sodium hydroxide (NaOH) and sodium borohydride (NaBH$_4$) was obtained from Sigma Aldrich, UK. The methyl orange dye was purchased from Fisher,
Pakistan Ltd. All chemicals were in analytical grade and used without further purification. Double deionized water was used throughout the analysis.

2.2. Preparation of *Psidium Guajava* Seeds Extract

*Psidium guajava* seeds were collected washed and dried in oven around 60°C till 48 hours. Ground the *Psidium guajava* seeds in grinder and filtered with mesh sieved of 0.40 micron and stored in Eppendorf tube. The 0.1 g of the *Psidium guajava* seeds in 100 mL distilled water were heated in a conical flask with constant stirring at 60°C temperature for 50 minutes (Sharma et al., 2021). The filtration was carried out to separate the plant extract with vacuum filtration apparatus. Freshly prepared plant extract was used for the further experiments (Sathiyavimal et al., 2021).

2.3. Synthesis of Silver Nanowires

A solution of AgNO₃ of 0.1 mM concentration was prepared by dissolving AgNO₃ in deionized water. In a classic green-synthesis practice, *Psidium guajava* seeds extract was used to reduce and cap the Ag ions. 5 mL of *Psidium guajava* seeds extract was added into the aqueous solution of AgNO₃ under standard conditions. The mixture was constantly stirred at 70°C in a homemade UV-lamp containing a single wavelength of 265 nm of white light for four hours by using magnetic stirrer. The color change from milky white to yellow and finally orange was showing the formation of the silver nanowires. Ag-nanowires were obtained on filtration and followed by calcination at 50°C for 30 minutes (Scheme 1 and Fig. 1).

2.4. Catalytic activity of MO dye

Catalytic-degradation of MO dye was supervised over UV/Vis spectrophotometer using Psidium Guajava seed extract's stabilized Ag-NWs. The degradation was done by time dependent kinetic studies with constant 3 minutes' time interval. 0.4 mL quartz cuvettes were utilized during all reactions. 0.6 mL of 17.6 mM constant concentration of NaBH₄ was used for the optimized model reaction as well as for both factors study. For catalyst Ag-NWs dosage factor, 0.4 mL of different concentrations of Ag-NWs (0.64 to 3.84 mg/mL) were used. Similarly, 1.6 mL of MO dye having concentration ranges from 0.062 to 0.102 mM were used for MO dye's factor study. All the reactions follow Pseudo first order reaction with Langmuir-Hinshelwood mechanism (LHM) as the 200% more NaBH₄ was used in contrast with MO dye.

\[
\ln \left( \frac{A_t}{A_0} \right) = -k_{obs} t \quad (\text{NaBH}_4 \gg\gg \text{MO dye})
\]

Reaction mixture without Ag-NWs was observed over UV/Vis spectra ranges from 300–800 nm as reference to compare with reaction mixture containing Ag-NW's UV/Vis spectra for the confirmation of Ag-NWs.

3. Characterization Of Ag-nws

The fabrication of AgNWs was preliminarily established by recording the absorbance in UV/Vis spectra at a range of 300–800 nm. The change in Surface Plasmon Resonance (SPR) of nanoparticles in the
dispersion was recorded using UV/Vis spectrophotometer by CECIL-Aquarius 7400 ce UK. The XRD patterns of Ag-nanowires were collected on Bruker AXS-D8 Advanced X-Ray diffractometer with Cu Ka radiations of $\lambda = 1.5406 \text{ Å}$ and scanning angle $2\theta$ over the range of $10–80^\circ$. Crystallite size was calculated by using Scherer Equation $CS = K\lambda/\beta \cos \theta$, where $CS$ is the crystallite size, constant $K = 0.94$, $\beta$ is the full width at half maximum (FWHM), $(\beta = \text{FWHM} \times \pi/180)$, $\lambda = 1.5406 \times 10^{-10}$ and $\cos \theta = \text{Bragg}$ angle. Fourier Transformation Infrared Spectroscopy (FTIR) was used to characterize the nanoparticles using the powder sample by ATR in the range of $400–4000 \text{ cm}^{-1}$. Scanning electron microscopy (SEM) images were recorded using FEI-NOVA-450 Nano-SEM (FE-SEM) by USA. The functional group determination was carried out by utilizing Alpha-II FTIR-ATR by BRUKERS Internationals (USA).

4. Results And Discussion

UV-visible spectroscopy is a convenient, preliminary, and indirect method for characterization of Ag-NWs based on optical properties called surface plasmon resonance (SPR) (Pathak & Singh, 2020). The Ag-nanowires bands occur at 435.0 nm with progressive increase in absorbance for 30 minutes (Fig. 2) (Chung et al., 2021). From this spectrum, it is clear that there is no peak in Psidium Guajava seed's curve which illustrates the absence of Ag-NWs. But, the peak in AgNWs-Guajava curve confirmed the creation of nanowires of Ag with wide size distribution. (Parente et al., 2020).

4.1. FTIR spectra of Ag NWs

FTIR spectrum of as-prepared Ag-NWs was conceded to pinpoint the biomolecules accountable for the reduction and capping of silver ions (Fig. 3). The existence of peaks at 3341.8, 2927.4 and 1234 cm$^{-1}$ may perhaps be due to $\text{N-H}$ stretching of the secondary amine and its salts and primary amine, respectively. The peak 3341.8 cm$^{-1}$ shrink in case of silver due to interaction $\text{OH}$ group of nanowires with amines. The peaks around 2197.4 cm$^{-1}$ and 1619 cm$^{-1}$ affirms the presence of $\alpha$, $\beta$-substituted unsaturated ketones. Two peaks observed at 2161.3 cm$^{-1}$ and 2009.4 cm$^{-1}$ conrmed the iso-cyanate and thio-cyanate functionalities, respectively. The peaks at 1735 cm$^{-1}$ and 1647 cm$^{-1}$ confirm the presence of ortho-substituted six-membered lactone. The $\text{OH}$ bending of $\alpha$, $\beta$-unsaturated carboxylic was recorded at 1419.6 cm$^{-1}$. Secondary amine its salts and $\alpha$, $\beta$-unsaturated carboxylic acts as reduced silver nitrate to silver ions also work as a capping agent and stabilizes the Ag-NWs (Le et al., 2021).

4.2. Scanning Electron Microscopy

Morphology and surface properties of the product was determined by field emission scanning electron microscopy (FE-SEM) (Fig. 4). It is evident that the product has wires i.e., morphology mainly formed and stabilized due to the action of unsaturated linear ketones. The well separated wires have $\sim 12 – 8 \text{ µm}$ length and $\sim 500 – 300 \text{ nm}$ diameter. This unique morphology results an excellent surface area expansion, mainly responsible for the brilliant catalytic reduction of the organic dyes. The performance of a catalyst chiefly dependent on surface area, stability, surface charge, and shape of the molecules of a catalyst. Amongst them surface area and shape have shown more powerful role for the adsorption and
reduction of the adsorbed entities in photocatalysis phenomena as mentioned in previous works (Satsangi, 2020).

### 4.3. XRD analysis of Ag-NWs

As-obtained Ag-NWs were further characterized by X-ray diffraction method to elucidate the crystal structure and crystallite size (Fig. 5). The fingerprint pattern has four typical diffraction features corresponds to (111), (200), (020), (220), and (131) planes, and all the four peaks might be indexed to standard cubic phase of silver (JCPDS-870720) (Nagasundari, Muthu, Kaviyarasu, Al Farraj, & Alkufeidy, 2021). The final product owes 100% purity as there was no peak detected for reflection, mainly corresponds to nitrate ions and other impurities. The peak intensity profile was individual of simple cubic construction of Ag-nanowires. The size of Ag-NWs was determined by using Debye-Scherrer equation-1 (Lim, Marks, & Rowles, 2020).

\[
\text{Particle size (D)} = \frac{kD}{\beta \cos \theta}
\]

is the crystalline size, \(k\) is the wavelength of x-ray used, \(b\) is the full width at half maximum light of the maximum intensity peak and \(h\) is the Bragg’s angle. The crystallite size of the synthesized Ag-nanowires is estimated \(\sim 19.63\) nm.

### 5. Catalytic Reduction Of Methyl Orange (Mo)

Methyl Orange (MO) is widely used as an indicator as well as a textile dye (azo-dye) for dying of textile fabrics (Carolin, Kumar, & Joshiba, 2021). The reduction of MO was calculated by using freshly prepared Ag-NWs in excessive NaBH\(_4\). The rate of reduction of methyl orange without catalyst in the presence of NaBH\(_4\) is very slow (Fig. 6-a). This poor performance is due to the presence of high energy barrier of mutually repulsive interactions between the borohydride anion and methyl orange ion, which should be overcome only by catalyst (Wu et al., 2020). Moreover, in the presence of catalyst only no reduction occurs due to the same interactions as mentioned above (Fig. 6-b). However, in the presence of catalyst and NaBH\(_4\), reduction of azo-dye takes place (Model reaction). Initially, NaBH\(_4\) and catalyst will adsorb on the surface of the dye and then reduction reaction will proceed at faster rate. The characteristic peak of MO solution was recorded \(\sim 458\) nm and catalytic reduction was observed by a sharp decline in intensity merely in 25 minutes (Fig. 6-c).

### 6. Kinetic Studies

#### 6.1. Effect of Catalyst dosage

The effect of concentration of catalyst-dosage was determined by changing the amount of Ag-NWs from 0.60–3.84 mg/mL (Fig. 7-a). The rate of reaction increases fasts from 0.60–1.28 mg/mL because the adsorption takes place exponentially in the start of reaction due to the presence of active sites. Later on
the reaction rate becomes slow from 2.56–3.84 mg/mL due to the occupation of the available active sites (Rodwihok et al., 2020). The effective degradation out of all the adsorbent’s concentration was monitored at 1.28 mg/mL by the help of \( k_{\text{obs}} \) graph plotted between \( k_{\text{obs}} \) vs concentration of Ag-NWs, while keeping the NaBH\(_4\) concentration (17.6 mM) and MO-dye (0.082 mM) constant.

It is evident from the Fig. 7-b, that from 0–5 minutes’ reaction was started with a very slow speed as there are molecules moving towards the surface of Ag-NWs and speed-up from 6–20 minutes due to their interaction at the surface of catalyst, then ultimately reaches to completion after 20–25 minutes. The inset graph shows the negative slopes which used for the determination of \( k_{\text{obs}} \) (Shan et al., 2020).

6.2. Effect of MO dye

Figure (8-a) illustrates the graph between \( k_{\text{obs}} \) on ordinate and concentration of MO-dye on abscissa, while keeping catalyst dosage (1.28 mg/mL) and NaBH\(_4\) (17.6 mM) constant. This graph explains that initially \( k_{\text{obs}} \) value remains constant while, at 0.082 mM its concentration increases to maximum \( k_{\text{obs}} \) value. Which is due to the maximum adsorption of incoming MO-dye’s molecules on the surface of catalytically enhanced by Ag-NWs. This point is fruitful in optimization of reaction. After this concentration the decrease in \( k_{\text{obs}} \)’s value is due to the excessive amount of MO-dye molecules on the surface of limited Ag-NWs. Here the double layer adsorption occurs on the surface of Ag-NWs, which restricts the effective adsorption.

MO dye’s concentrations were taken, ranges from 0.072 to 0.102 mM with 0.010 mM difference. Figure 8-b shows the induction, reaction and completion times of the catalytic reaction between MO-dye and NaBH\(_4\) on the surface of Ag-NWs. As, the concentration of MO-dye increases, while keeping the concentrations of Ag-NWs and NaBH\(_4\) constant, the time of degradation increases (Ramos, Luyo, Sánchez, Gomez, & Rodríguez, 2020). The reason behind this factor is the constant concentration of Ag-NWs, which illustrates the limitation of surface active sites for incoming reactants (Raj, Singh, Trivedi, & Soni, 2020b). The figure inset (6) shows the negative slopes for finding the apparent rate constant for Pseudo first order reaction following Langmuir-Hinshelwood mechanism (LHM) (Kumari & Meena, 2020).
Table 1
Comparison of time duration of MO-dye degradation by NW and nanoparticles.

| Reduction Source                      | Nanostructures (NS) | Dimensions of (NS)        | Time (minutes) | Ref.                                      |
|---------------------------------------|---------------------|---------------------------|----------------|-------------------------------------------|
| *Lavandula angustifolia* plant extract | Nanowires           | 100 µm (L) 60–130 nm (d) | 60–130         | (Villalpando, Saavedra-Molina, & Rosas, 2020) |
| *Terminalia arjuna* leaf extract      | Nanoparticles       | 10–15 nm                  | 29             | (Raj, Singh, Trivedi, & Soni, 2020a)      |
| *Nervalia zeylanica* leaf extract     | Nanoparticles       | 34 nm                     | 60             | (Vijayan, Joseph, & Mathew, 2019)         |
| Ag@AgBr                               | Nanowires           | 54 nm                     | 160            | (Y. Wang, 2016)                          |
| Ag@Cu$_2$O                           | Nanowires           | 10 µm (L) 100 nm (d)      | 140            | (Xiong et al., 2014)                     |
| *Psidium guajava* seed extract        | Nanowires           | ~19 nm                    | 25             | This Work                                 |

**Conclusion**

The Ag-NWs were successfully fabricated using AgNO$_3$ as precursor and *Psidium guajava* seed extract under continuous irradiation of UV light. The extract strongly acted as reducing as well as stabilizing agent. UV-visible spectra confirm the formation of the Ag-NWs. The average crystallite size of Ag-NWs was 19.63 nm and morphology were cubic face having 12-8 µm length and internal diameter of 300-500 nm. Synthesized Ag-NWs was then used for catalytic degradation MO-dye, NaBH$_4$ and Ag-NWs. The reaction completed in 25 minutes and kinetic studies of the data confirmed pseudo first order reaction. Hence, *Psidium guajava* seed extract can be used for the synthesis of Ag-NWs. The authors recommended that Ag-NWs can be exploited for degradation of azo-dyes that can be a good tool for treatment of water from textile industry.

**Declarations**

**Ethical Approval**

All the data and information in this manuscript original and not been published in any other Journal before this.

**Conflict of Interest**

Author declares no conflict of interest with anyone.
Consent to Participate

Not applicable.

Consent to Publish

Authors are willing to publish this data.

Authors Contributions

Faisal Ali: Synthesized and characterized the compounds. Zahid Ali: Data curation, Writing – original draft. Ghulam Mooin-ud-din: Theoretical calculation and Writing – theoretical part.

Umer Younas: Final formatting and cross-review. Muhammad Pervaiz: Software validation. Faiza Hassan: Dye-degradation studies. Hafiz Muhammad Yasir: Technical support. Adnan Ashraf: Discussion on theoretical results. Muhammad Waqas Ishaq: Conceptualization, Methodology.

Funding

There is no funding for this project.

Availability of data and materials

All original data and materials are available on demand.

References

1. Amendola V, Meneghetti M (2009) Laser ablation synthesis in solution and size manipulation of noble metal nanoparticles. Physical Chemistry Chemical Physics 11(20):3805–3821
2. Begum R, Farooqi ZH, Naseem K, Ali F, Batool M, Xiao J, Irfan A (2018) Applications of UV/Vis spectroscopy in characterization and catalytic activity of noble metal nanoparticles fabricated in responsive polymer microgels: a review. Critical reviews in analytical chemistry 48(6):503–516
3. Carolin CF, Kumar PS, Joshiba GJ (2021) Sustainable approach to decolourize methyl orange dye from aqueous solution using novel bacterial strain and its metabolites characterization. Clean Technol Environ Policy 23(1):173–181
4. Chang Y-C, Chen D-H (2009) Catalytic reduction of 4-nitrophenol by magnetically recoverable Au nanocatalyst. J Hazard Mater 165(1–3):664–669
5. Chung DCK, Lin ES, Peng L, Jiang X, Ong JW, Abid HA,.. . Ng TW (2021) Efficient drop reactor processing of methylene blue degradation with silver nanowire catalysts. Colloids Surf A 610:125749
6. Daou T, Pourroy G, Bégine-Colin S, Greneche J-M, Ulhaq-Bouillet C, Legaré P,.. . Rogez G (2006) Hydrothermal synthesis of monodisperse magnetite nanoparticles. Chemistry of materials 18(18):4399–4404
7. Das R, Soni R (2017) Synthesis and surface-enhanced Raman scattering of indium nanotriangles and nanowires. RSC Adv 7(51):32255–32263

8. Devi TP, Kulanthaivel S, Kamil D, Borah JL, Prabhakaran N, Srinivasa N (2013) Biosynthesis of silver nanoparticles from Trichoderma species

9. Fersi C, Gzara L, Dhahbi M (2005) Treatment of textile effluents by membrane technologies. Desalination 185(1–3):399–409

10. Goh MS, Lee YH, Pedireddy S, Phang IY, Tjiu WW, Tan JMR, Ling XY (2012) A chemical route to increase hot spots on silver nanowires for surface-enhanced Raman spectroscopy application. Langmuir 28(40):14441–14449

11. Guo Z, Chen Y, Wang Y, Jiang H, Wang X (2020) Advances and challenges in metallic nanomaterial synthesis and antibacterial applications. Journal of Materials Chemistry B 8(22):4764–4777

12. Hassan SS, Solangi AR, Agheem MH, Junejo Y, Kalwar NH, Tagar ZA (2011) Ultra-fast catalytic reduction of dyes by ionic liquid recoverable and reusable mefenamic acid derived gold nanoparticles. J Hazard Mater 190(1–3):1030–1036

13. Hu H, Xin JH, Hu H, Wang X, Miao D, Liu Y (2015) Synthesis and stabilization of metal nanocatalysts for reduction reactions—a review. Journal of Materials Chemistry A 3(21):11157–11182

14. Kim YI, Kim D, Lee CS (2003) Synthesis and characterization of CoFe2O4 magnetic nanoparticles prepared by temperature-controlled coprecipitation method. Physica B 337(1–4):42–51

15. Kulkarni N, Muddapur U (2014) Biosynthesis of metal nanoparticles: a review. Journal of Nanotechnology, 2014

16. Kumari P, Meena A (2020) Green synthesis of gold nanoparticles from Lawsonia inermis and its catalytic activities following the Langmuir-Hinshelwood mechanism. Colloids Surf A 606:125447

17. Le NTT, Trinh BT, Nguyen DH, Tran LD, Luu CH, Hoang Thi TT (2021) The physicochemical and antifungal properties of eco-friendly silver nanoparticles synthesized by Psidium guajava leaf extract in the comparison with Tamarindus indica. J Cluster Sci 32:601–611

18. Lim DJ, Marks NA, Rowles MR (2020) Universal Scherrer equation for graphene fragments. Carbon 162:475–480

19. Lin S-Y, Tsai Y-T, Chen C-C, Lin C-M, Chen C-h (2004) Two-step functionalization of neutral and positively charged thiols onto citrate-stabilized Au nanoparticles. J Phys Chem B 108(7):2134–2139

20. Liu C, Wu P, Tran L, Zhu N, Dang Z (2018) Organo-montmorillonites for efficient and rapid water remediation: sequential and simultaneous adsorption of lead and bisphenol A. Environ Chem 15(5):286–295

21. Liu C, Zou B, Rondinone AJ, Zhang ZJ (2001) Sol–gel synthesis of free-standing ferroelectric lead zirconate titanate nanoparticles. J Am Chem Soc 123(18):4344–4345

22. Luo L-B, Yu S-H, Qian H-S, Gong J-Y (2006) Large scale synthesis of uniform silver@carbon rich composite (carbon and cross-linked PVA) sub-microcables by a facile green chemistry carbonization approach. Chemical communications(7), 793–795
23. Mance G (2012) Pollution threat of heavy metals in aquatic environments. Springer Science & Business Media
24. Mani D, Kumar C (2014) Biotechnological advances in bioremediation of heavy metals contaminated ecosystems: an overview with special reference to phytoremediation. Int J Environ Sci Technol 11(3):843–872
25. Nadagouda MN, Speth TF, Varma RS (2011) Microwave-assisted green synthesis of silver nanostructures. Acc Chem Res 44(7):469–478
26. Nagasundari SM, Muthu K, Kaviyarsu K, Al Farraj DA, Alkufeidy RM (2021) Current trends of Silver doped Zinc oxide nanowires photocatalytic degradation for energy and environmental application. Surfaces Interfaces 23:100931
27. Parente M, van Helvert M, Hamans RF, Verbroekken R, Sinha R, Bieberle-Hutter A, Baldi A (2020) Simple and Fast High-Yield Synthesis of Silver Nanowires. Nano Lett 20(8):5759–5764
28. Pathak AK, Singh VK (2020) SPR Based Optical Fiber Refractive Index Sensor Using Silver Nanowire Assisted CSMFC. IEEE Photonics Technol Lett 32(8):465–468
29. Pérez-Tijerina E, Pinilla MG, Mejía-Rosales S, Ortiz-Méndez U, Torres A, José-Yacamán M (2008) Highly size-controlled synthesis of Au/Pd nanoparticles by inert-gas condensation. Faraday discussions 138:353–362
30. Qiu F, Tang R, Zuo X, Shi X, Wei Y, Zheng X, ... Xu P (2017) A genome-wide association study identifies six novel risk loci for primary biliary cholangitis. Nature communications 8(1):1–8
31. Raj S, Singh H, Trivedi R, Soni V (2020a) Biogenic synthesis of AgNPs employing Terminalia arjuna leaf extract and its efficacy towards catalytic degradation of organic dyes. Sci Rep 10(1):9616. doi:10.1038/s41598-020-66851-8
32. Raj S, Singh H, Trivedi R, Soni V (2020b) Biogenic synthesis of AgNPs employing Terminalia arjuna leaf extract and its efficacy towards catalytic degradation of organic dyes. Sci Rep 10(1):1–10
33. Ramos PG, Luyo C, Sánchez LA, Gomez ED, Rodriguez JM (2020) The Spinning Voltage Influence on the Growth of ZnO-rGO Nanorods for Photocatalytic Degradation of Methyl Orange Dye. Catalysts 10(6):660
34. Ramya E, Jyothi L, Vardhan PV, Gopal NSR, Desai NR (2020) Optical and biomedical applications of eco-friendly biosynthesized silver nano spheres using zingiber officinale root extract. Nano Express 1(1):010021
35. Rane AV, Kanny K, Abitha V, Thomas S (2018) Methods for synthesis of nanoparticles and fabrication of nanocomposites. In: Synthesis of inorganic nanomaterials. Elsevier, pp 121–139
36. Rodwihok C, Wongratanaphisan D, Tam TV, Choi WM, Hur SH, Chung JS (2020) Cerium-oxide-nanoparticle-decorated zinc oxide with enhanced photocatalytic degradation of methyl orange. Applied Sciences 10(5):1697
37. Saeed M, Ahmad A, Boddula R, Haq ul, A., & Azhar A (2018) Ag@ Mn x O y: an effective catalyst for photo-degradation of rhodamine B dye. Environ Chem Lett 16(1):287–294
38. Sathiyavimal S, Vasantharaj S, Veeramani V, Saravanan M, Rajalakshmi G, Kaliannan T, . . . Pugazhendhi A (2021) Green chemistry route of biosynthesized copper oxide nanoparticles using Psidium guajava leaf extract and their antibacterial activity and effective removal of industrial dyes. Journal of Environmental Chemical Engineering 9(2):105033
39. Satsangi N (2020) Synthesis and characterization of biocompatible silver nanoparticles for anticancer application. J Inorg Organomet Polym Mater 30(6):1907–1914
40. Sawant VJ, Sawant VJ (2020) Biogenic capped selenium nano rods as naked eye and selective hydrogen peroxide spectrometric sensor. Sensing Bio-Sensing Research 27:100314
41. Shan R, Lu L, Gu J, Zhang Y, Yuan H, Chen Y, Luo B (2020) Photocatalytic degradation of methyl orange by Ag/TiO2/biochar composite catalysts in aqueous solutions. Mater Sci Semicond Process 114:105088
42. Sharma Y, Kawatra A, Sharma V, Dhull D, Kaushik S, Yadav JP, Kaushik S (2021) In-vitro and in-silico evaluation of the anti-chikungunya potential of Psidium guajava leaf extract and their synthesized silver nanoparticles. VirusDisease, 1–6
43. Sim H, Bok S, Kim B, Kim M, Lim GH, Cho SM, Lim B (2016) Organic-Stabilizer-Free Polyol Synthesis of Silver Nanowires for Electrode Applications. Angew Chem Int Ed 55(39):11814–11818
44. Sreeram KJ, Nidhin M, Nair BU (2008) Microwave assisted template synthesis of silver nanoparticles. Bull Mater Sci 31(7):937–942
45. Sun Y (2010) Silver nanowires–unique templates for functional nanostructures. Nanoscale 2(9):1626–1642
46. Vijayan R, Joseph S, Mathew B (2019) Green synthesis of silver nanoparticles using Nervalia zeylanica leaf extract and evaluation of their antioxidant, catalytic, and antimicrobial potentials. Part Sci Technol 37(7):809–819. doi:10.1080/02726351.2018.1450312
47. Villalpando M, Saavedra-Molina A, Rosas G (2020) A facile synthesis of silver nanowires and their evaluation in the mitochondrial membrane potential. Materials Science Engineering: C 114:110973. doi:https://doi.org/10.1016/j.msec.2020.110973
48. Wang P, Huang B, Qin X, Zhang X, Dai Y, Wei J, Whangbo MH (2008) Ag@AgCl: a highly efficient and stable photocatalyst active under visible light. Angew Chem Int Ed 47(41):7931–7933
49. Wang Y (2016) Synthesis of plasmonic Ag@AgBr nanowires as highly efficient sunlight photocatalyst. J Mater Sci: Mater Electron 27(10):10122–10127. doi:10.1007/s10854-016-5087-z
50. Wang Z, Liu J, Chen X, Wan J, Qian Y (2005) A simple hydrothermal route to large-scale synthesis of uniform silver nanowires. Chemistry–A European Journal 11(1):160–163
51. Wu T, Kou Y, Zheng H, Lu J, Kadasala NR, Yang S, . . . Gao M (2020) A novel Au@Cu2O-Ag ternary nanocomposite with highly efficient catalytic performance: towards rapid reduction of methyl orange under dark condition. Nanomaterials 10(1):48
52. Xiong J, Li Z, Chen J, Zhang S, Wang L, Dou S (2014) Facile Synthesis of Highly Efficient One-Dimensional Plasmonic Photocatalysts through Ag@Cu2O Core–Shell Heteronanowires. ACS Appl Mater Interfaces 6(18):15716–15725. doi:10.1021/am502516s
53. Yang C, Gu H, Lin W, Yuen MM, Wong CP, Xiong M, Gao B (2011) Silver nanowires: from scalable synthesis to recyclable foldable electronics. Advanced materials 23(27):3052–3056

54. Yasin S, Liu L, Yao J (2013) Biosynthesis of silver nanoparticles by bamboo leaves extract and their antimicrobial activity. J Fiber Bioeng Inform 6(6):77–84

55. Yousaf H, Mehmood A, Ahmad KS, Raffi M (2020) Green synthesis of silver nanoparticles and their applications as an alternative antibacterial and antioxidant agents. Materials Science Engineering: C 112:110901

56. Zhu J, Kan C, Wu Y, Wan J, Han M, Wang G (2016) A novel discovery of growth process for Ag nanowires and plausible mechanism. Journal of Nanomaterials, 2016.

Figures

Figure 1

Milky white solution (a), Orange colored Ag-Nanowires (b), Ag-NW powder oven dried (c)
Figure 2

Ag-NWs confirmation with UV/Vis spectra and comparison with Psidium guajava UV-visible spectroscopy

Figure 3

FTIR comparison of Psidium guajava and Ag-NWs
Figure 4
FE-SEM images of Ag-NWs stabilized Psidium guajava seeds (a, b) length of nanowires ~8-12 μm and (c, d) average diameter ranges between 300-500 nm

Figure 5
XRD pattern of Ag-NWs

Figure 6

Reaction monitoring over UV/Vis; in the absence of catalyst (a), in the absence of NaBH4 (b) and Model reaction at optimized conditions; NaBH4 = [17.6 mM], MO = [0.082 mM], Ag-NW (catalyst) = [1.84 mg/mL]
**Figure 7**

Effect of Ag-NWs-Catalyst dosage for kinetic study at 0.60, 1.28, 2.56, 3.84 mg/mL concentrations, NaBH4 = 17.6mM, Ag-NWs = 1.84 mg/mL (a) and kobs determination (b)
Figure 8

Effect of MO dye for kinetic study at 0.062, 0.072, 0.082, 0.092, 0.102 mM concentrations, NaBH4 = 17.6 mM, Ag-NWs = 1.84 mg/mL (a) and observed-rate constant determination (b)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Scheme01.png