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Controlled Synthesis of Ag@Polythiophene Nanocables by Ion Adsorption Technique

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Abstract

Ag@Polythiophene nanocables were synthesized by Ion Adsorption Technique. In this approach, the pre-synthesized Ag nanowires were dispersed in aqueous solution of copper acetate and the Cu²⁺ ions adsorbed onto the surface of Ag nanowires. These nanowires were then redispersed in aqueous solution of thiophene. The adsorbed Cu²⁺ ions oxidized thiophene monomer to polymerize into uniform polythiophene sheath outside Ag nanowires. Thus, it has transformed pre-synthesized Ag NWs into polythiophene Nanocables (NCs). The morphology of pristine Ag NWs and Ag@polythiophene NCs were characterized by scanning electron microscopy (SEM), which showed sheathing effect

at Ag NWs and indicated the successful coating over its surface. Optical and electronic properties were determined by UV-Vis spectroscopy and PL spectroscopy. The functional groups were determined by Fourier transform infrared spectroscopy (FT-IR). The peaks at 1482 cm⁻¹, 1625 cm⁻¹, 1223 cm⁻¹, 825 cm⁻¹ and 722 cm⁻¹ confirmed the polythiophene coating on Ag NWs. Furthermore, the thermal stability was monitored by thermogravimetric analysis (TGA) which showed enhanced thermal stability of Ag@Polythiophene nanocables as compared to pristine Ag NWs.

Keywords: Ag@Polythiophene, Nanocables, Polypyrrole

1. Introduction

Nanomaterials are the materials with a particle size of less than 100 nm in at least one of its dimension. Nanomaterials have distinct physical, chemical, electrical and magnetic properties due to their nanoscale size, which sets them apart from minuscule atoms, molecules and macroobjects. (B. Zhang, 2018) [63] the size reduction causes the properties of a macroscopic substance to dramatically change to some extraordinary characteristics. (Asha & Narain, 2020) [4]. Thus, the extraordinary properties of nanomaterials are the result of this high surface area to volume ratio phenomenon. In general, nanomaterials are classified on the basis of their dimensionality, morphology, state and chemical makeup. (Gleiter, 2000) [14] These materials can be further divided into four kinds based on their dimensionality and overall shape such as zero Dimensional (0D) Nanomaterials, one Dimensional (1D) Nanomaterials, two Dimensional (2D) Nanomaterials and three Dimensional (3D) Nanomaterials.

Zero dimensional (0D) nanomaterials have all of their dimensions at the nanoscale. Spherical nanomaterials, cubes, nanorods and quantum dots are included in zero dimensional nanomaterials. (Saleh, 2020) [49] One dimensional (1D) nanomaterials have two dimensions in the nanoscale. Nanowires and nanofibres are part of one-dimensional nanomaterials. The two-dimensional (2D) nanomaterials have only one dimension in the nanoscale. Thin films, nanoplates and nanocoatings are examples of 2D nanomaterials.

Nanomaterials having various dimensions beyond 100 nm fall under the category of three dimensional (3D) nanomaterials. (Pokropivny & Skorokhod, 2007) [45], (Aversa, Modarres, Cozzini, Ciancio, & Chiusole, 2018) [5] for example fullerenes, polycrystals, pillars and layer skeletons. (Asghari, Jahanshiri, Imani, Shams-Ghahfarokhi, & Razzaghi-Abyaneh, 2016) [3], (Shiau et al., 2018) [52].

At the vanguard of nanoscience and nanotechnology, nanowires represent a significant and diverse class of 1D nanostructures. In most cases, nanowires are single crystalline, highly anisotropic, insulating and/or metallic nanostructures that are produced by rapid growth along one axis. (Lieber & Wang, 2007) [32] Nanowires are structures with unrestricted lengths and

thicknesses of tens of nanometers or less. Nanowires are extensively used in memory devices, transistors, optoelectronics, advanced composite materials, quantum devices, biomolecular nanosensors and field emitters.

There are two basic approaches for synthesizing nanowires such as top-down approach and bottom-up approach. In a top-down approach, a large piece of a material is divided into smaller bits using several techniques, including lithography and electrophoresis. Basically, it refers to cutting or splitting bulk material into nano-sized materials. (Lupu, 2010) [36] The bottom-up approach discusses the combination of atoms or molecules to form bulk material. According to bottom-up synthesis approach, nanostructures are synthesized on the substrate when atoms are stacked onto each other to form crystal planes. The crystal planes are further stacked on the top of one another to produce nanostructures. (Sofiah, Samykan, Kadirgama, Mohan, & Lah, 2018) [53]. Today's synthesis methods are largely based on bottom-up strategies. In order to produce nanostructures with fewer deformities, more uniform chemical compositions and better short- and long-range ordering, the bottom-up method is preferred over the top-down method. (García, Batalla, & Escarpa, 2014) [13], (Mijatovic, Eijkel, & Van den Berg, 2005) [38].

Nanowires can be synthesized using different methods including vapour-liquid-solid growth method, solution phase synthesis, electrodeposition in nanoporous templates, electrospinning and chemical etching. (Rawtani, Sajan, Twinkle R, & Agrawal, 2015) [47]. Different methods for the synthesis of nanowires are depicted in Fig 1.1.

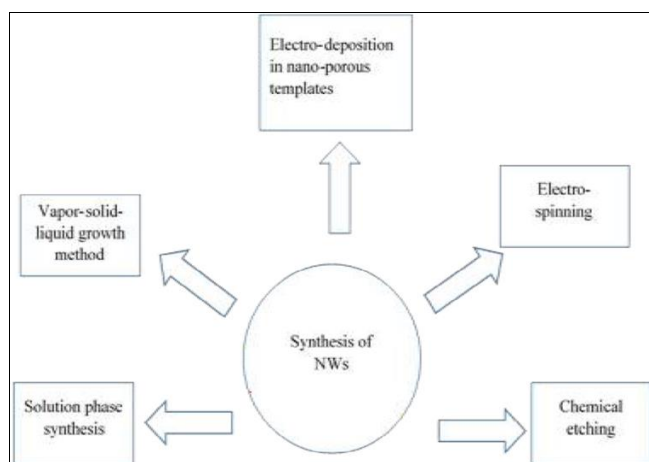


Fig 1.1: Various Methods for Synthesis of Nanowires

There are numerous different types of nanowires, including metallic nanowires (such as Ni, Au, Ag, and Pt), semiconducting nanowires (such as InP, GaN, and Si), insulating nanowires (such as TiO₂ and SiO₂) and molecular nanowires (e.g. organic DNA or inorganic). (Lupu, 2010) [36].

Metallic nanowires have garnered significant attention in the field of nanomaterial science due to their exceptional features such as high electrical and thermal conductivity, good mechanical flexibility, high aspect ratio and excellent optical transparency. (Shah & Xiong, 2019) [51]. In order to understand the stretchability and flexibility of electronics, conductive components of these devices should have deformable and bendable characters. Although indium tin oxide (ITO) has been extensively used in these devices due to its low sheet resistivity and high optical transparency, the

scarcity of indium and ITO's brittleness substantially limited its use resulting in a pressing need to create new conductive materials. Due to their high flexibility and conductivity, carbon nanotubes (CNT), graphene and metal grids have been used in the LED, bendable touchscreens and flexible solar cells as a substitute of the ITO. Since the conductivities of the CNT and graphene depend on their fabrication process, their use in many fields is restricted by their facile agglomeration and low dispersibility in solution. The metallic nanowires i.e. silver nanowires (AgNWs) and copper nanowires (CuNWs) possess the properties to meet these requirements due to their excellent conductivity, flexibility, transparency and simplicity in the operation process. (Jiu & Suganuma, 2016) [26]. Silver is one of the most sought-after metals with high thermal and electrical potential. Although silver has a high conductivity, it has more sophisticated applications when constructed in a 1D nanoscale. Silver is capable to enhance the optical as well as electrical properties of polymer composites. To get a wide range of applications in photonics, electronics, chemical sensing and imaging, catalysis etc., silver nanowires are constantly gaining attention due to their unique potential features.

In electronics, silver nanowires are used in manufacturing advanced, transparent and conductive films due to high electrical conductivity (L. Hu, Kim, Lee, Peumans, & Cui, 2010) [20], best optical features (Sun, 2010) [56], high transparency (Song *et al.*, 2013) [54] and mechanical flexibility. (Yun *et al.*, 2012) [61] Silver nanowires are extensively used in manufacturing electronic, photonic and sensing devices as an interconnected component. The silver nanowires are the important components used in the manufacture of touch screens for mobile phones, tablets and laptops. (Kuang *et al.*, 2011) [30] Silver nanowires are also used in making electric filters to kill bacteria in water.

Silver nanowires can be synthesized using different strategies such as polyol process, solvothermal method, photoreduction technique, ultraviolet irradiation, electrodeposition process, DNA template method and wet chemical method. Among all, polyol method is considered as an ideal method for the synthesis of Ag nanowires due to its low cost, high productivity and simplicity of operation. In this method, silver nitrate is reduced by a polyol i.e. ethylene glycol (EG). The EG acts as a reducing agent as well as a solvent. The polyvinylpyrrolidone (PVP) as an assistant agent is used to synthesize Ag nanowires by the polyol reduction method. It prevents agglomeration and directs anisotropic morphology of Ag NWs. A small amount of NaCl is also added to facilitate the growth of Ag NWs.

Based on chemical composition, the metal nanocables are classified into different types that includes metal-metal nanocables, metal semiconductor nanocables and metal polymer nanocables.

Nanocomposites are the substances that incorporate nanoscale particles into a matrix of conventional substance. Properties like mechanical strength, toughness and electrical or thermal conductivity significantly enhance as a result of the incorporation of nanoparticles. The two components by which nanocomposites are formed are matrix and reinforcement. The matrix is the component that is present in large proportions and the reinforcement is the component that is encoded between the matrix to enhance its mechanical performance and reinforcement is the nanosized material which in turn improve the properties of the

material. Over the past decade, electronics have performed significantly better due to inorganic/organic nanocomposites. One of these is the category in which the organic part is polymer such as polythiophene, polypyrrole, polycarbazole etc. and the inorganic part is metal nanowires. In Ag@Polythiophene nanocomposite, Ag NWs are embedded in the polythiophene matrix. Compared with pure polythiophene, these nanocomposites perform well in sensing, optoelectronics and catalytic capabilities. (Telipan, Pîslaru-Dănescu, Lungulescu, Ion, & Marinescu, 2021) [59]. The optical, chemical, electrochemical and physical properties of these nanocomposites also depend on their electrical properties. The most commonly used polymers, polypyrrole and polythiophene have a conductivity of 1 S/cm and their conductivity is 4-5 times less than that of metals like silver and gold. To increase the conductivity of these polymers, their composites are formed. Therefore, for the synthesis of composites, inorganic materials such as silver are coated with an organic material i.e. a polymer. Among the noble metals, silver is of great importance for composites due to its high electrical conductivity as 5.6×10^5 S/cm and easy availability. In general, polymer produces various shapes such as globules, microspheres, nanofibers, nanotubes and various other nanostructures. (Sapurina & Stejskal, 2010) [50] Silver is also available in various forms, such as nanowires, nanorods, nanotubes, nanoparticles and nanofibres. (Nadagouda & Varma, 2007) [41].

Polythiophene is a conducting material with efficient electrochemical performance and is widely used as a coating material on various substrates. Super hydrophobic polythiophene has been used as a coating material to protect the stainless steel from corrosion. (de Leon, Pernites, & Advincula, 2012) [11]. The PTh-coated NaFePO₄ electrode improved the electrochemical performance of Na-ion batteries. (Ali *et al.*, 2016) [2] Similarly, the electrochemical performance of the LiFePO₄ electrodes is improved with coating of polythiophene. (Bai, Qiu, Wen, & Han, 2010) [7] Polythiophene can also be used to coat silver nanowires. In nanotechnology, polythiophene is considered a very important coating material because of its special electrical properties. Nano hybrid materials are formed by combining polymers with various organic or inorganic materials. Polythiophenes and their nanocomposites are gaining importance and being used as the conducting materials in the industries and in a wide range of potential applications including light emitting diodes, supercapacitors, chemical/optical sensors, display devices, transistors, photovoltaics/solar cells, rechargeable batteries etc. (Gnanakan, Rajasekhar, & Subramania, 2009) [15].

Polythiophene is usually synthesized by electrochemical as well as chemical oxidative-polymerization methods. The commonly recognised mechanism for the oxidative polymerization of thiophene involves the formation of radical cations followed by radical-radical coupling to produce the oligomers.

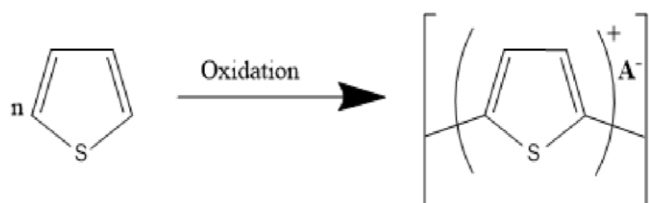


Fig 1.2: General Mechanism of Thiophene Polymerization

In chemical synthesis of polythiophene, thiophene monomer is treated with anhydrous FeCl₃. The oxidative polymerization occurs in three steps. In the first step, radical cations (C₄SH₄⁺) are produced by oxidation of thiophene monomer. In the second step, radical-radical coupling occurs between two radical cations followed by deprotonation and a dimer species (bithiophene) is formed. The last step is chain propagation in which the dimer species is reoxidized and couples with other radical cations to produce an undoped polymer. (AL-Refai, Ganash, & Hussein, 2021) [1] The mechanism of thiophene polymerization is shown in Fig 1.3.

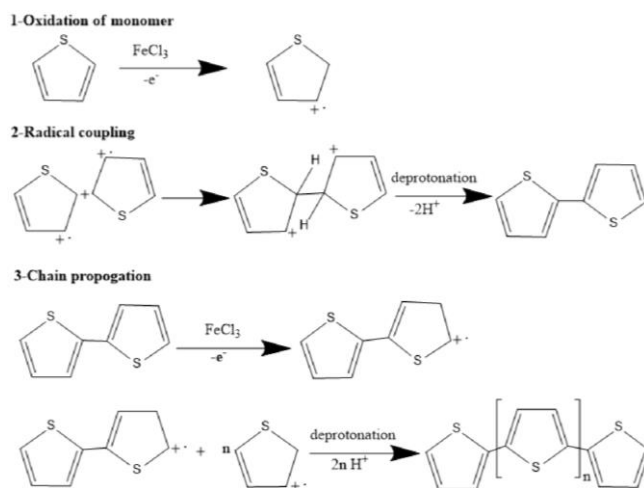


Fig 1.3: Mechanism of Thiophene Polymerization

Jung *et al.* (2010) used a simultaneous one-pot approach of polymerizing 3,4-ethylenedioxythiophene (EDOT) and reducing Ag(I) acetate into neutral Ag to create Ag/poly(3,4-ethylenedioxythiophene) (PEDOT) nanocomposites. The Ag/PEDOT nanocomposites were reported to have formed as a core-shell structure that kept Ag nanoparticles evenly distributed in the PEDOT polymer with high surface area and good electrical conductivity. Using galvanostatic discharge/charge and cyclic voltammetry, they explored electrochemical properties. The Ag/PEDOT nanocomposites' charge capacity during the first cycle was 291 mAh/g and it peaked at 209 mAh/g during the 20th cycle, outperforming all other samples. The Li ions transmission is facilitated by the shape of Ag/PEDOT nanocomposites, which leads to improved electrochemical performance due to adequate charge transfer in the interface and feasible mass transport. The samples' discharge-charge characteristics were assessed at the current densities of 0.5 mA/cm² and voltage ranges of 0.02 to 2.8 V. At a scan rate of 0.05 mV/s, the cell's CV was conducted over the voltage range of 0 to 2.8 V. The one-pot reduction approach was used to create Ag/PEDOT core-shell nanocomposites for an anode material in order to enhance the material's high surface area. The PEDOT acts as an effective buffering agent for Ag particles, preventing Ag particle agglomeration while also enhancing Ag particle dispersion and increasing Ag particle stability. (Jung & Lee, 2011) [27]. Jing You *et al.* (2011) [60] examined how silver nanoparticles affected the photocurrent production of a polythiophene-fullerene photovoltaic film. First, Ag nanoparticles layer was fabricated on the surface of ITO glass. Then, P3HT-PCBM thin films were fabricated on the surface of the Ag

nanoparticles layer by the spin-coating. They verified that Ag nanoparticles enhance the photocurrent signals in organic photovoltaic systems. (You *et al.*, 2011) [60]. S. Irandoost *et al.* (2013) reported the synthesis of PTh/Ag₂O nanocomposite by the chemical polymerization method through the oxidation of the monomer by FeCl₃/H₂O₂ in aqueous media. The coreshell structure of the PTh/Ag₂O nanocomposite was confirmed by the SEM and XRD experiments. (Irandoost & Eis) [21]. Janusz Szeremeta *et al.* (2014) [58] investigated the spectral dependence of the effect of silver nanoparticles (Ag NPs) on the photoconductivity of thin films made of poly (3hexylthiophene) (P3HT). They determined the photoconductivity enhancement in P3HT films doped with Ag NPs as a function of the excitation wavelength. (Szeremeta, Nyk, & Samoc, 2014) [58]. Bagheri *et al.* (2016) [6] created a nanocomposite of polythiophene and silver (PTh/Ag) using chemical oxidative polymerization in the presence of anhydrous ferric chloride and used it as the required sorbent for headspace needle trap extraction. They found that the PTh moiety contributes to the hydrophobic and π - π interactions whereas the Ag NPs within the polymeric structure may be responsible for the greater specific surface area and sorption capacity. The created nanocomposite was easily applied to the separation of a few chosen PAHs from several water samples. (Bagheri, Banihashemi, & Jelvani, 2016) [6].

2. Experimental

2.1 Materials

The chemicals used in the experiments were polyvinylpyrrolidone (PVP), silver nitrate (AgNO₃), ethylene glycol (EG), sodium chloride (NaCl), copper (II) acetate-1-hydrate (C₄H₈CuO₅), thiophene (C₄H₄S), hydrogen peroxide (H₂O₂), sodium dodecyl sulfate (SDS), ethanol, acetone and distilled water. All the chemicals used were purchased from Sigma Aldrich.

2.2 Synthesis of Ag Nanowires

The Ag nanowires were synthesized by polyol reduction method. In this method, a two necked round bottom flask containing 10 mL ethylene glycol (EG) was placed in an oil bath and preheated at 160 °C and continuously stirred for one hour. Then, 0.1 M NaCl (0.00585 g) in 1 mL EG, 0.1 M silver nitrate (0.0849 g) and 0.1 M PVP (0.0555 g) were dissolved in 5 mL of ethylene glycol in separate beakers and sonicated for appropriate dissolution. In the preheated ethylene glycol, 1 mL of NaCl solution was added. After 15 minutes of continuous heating and stirring, dropwise AgNO₃ solution were injected. After that, both the solutions (i.e., solution of AgNO₃ and PVP) were simultaneously and slowly injected to the EG solution. A pink solution appeared from the colorless EG solution, which turned greyish after few minutes. The temperature of reaction mixture was dropped to 150 °C during this process of addition that again maintained to 160 °C after complete injection. The reaction mixture was heated and stirred continuously for 1 hour at 160 °C. The reaction was stopped and cooled down at room temperature. After formation of Ag NWs, the product was washed with acetone (1 time) and ethanol (3 times) through centrifugation at 3000 rpm.

2.3 Fabrication of Ag@Polythiophene Nanocables

The as-synthesized silver nanowires were dissolved in 20 mL of 0.1M copper acetate (0.399g) aqueous solution by

ultrasonication for 20 minutes. The treated nanowires were separated by the centrifugation and then re-dissolved in 20 mL of distilled water along with 0.5 mL of thiophene monomer in a round bottom flask. This reaction mixture was magnetically stirred for 48 hours at room temperature. After the reaction stopped, final product was isolated by the centrifugation at 6000 rpm and repeatedly washed with ethanol and dried. Fig 2.1 shows schematic representation of synthesis of Ag@Polythiophene nanocables.

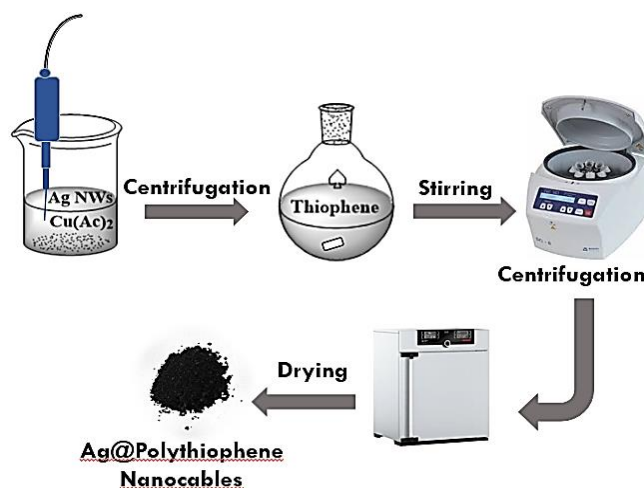


Fig 2.1: Schematic representation of synthesis of Ag@Polythiophene nanocables

2.4 Characterizations

After the synthesis of samples, various techniques were used to determine their shape and properties. For this study, SHIMADZU UV 1800 spectrophotometer was used to determine the absorbance of as-prepared samples. Its wavelength ranges from 200-800 nm. SHIMADZU RF-6000 Spectro Fluorophotometer was used to study the photoluminescence. Ethanol was used as the solvent in the solution of the analysis. The Fourier Transform Infrared Spectroscopy (FTIR) was used to identify functional groups of compounds. The SHIMADZU IRAffinity-1S was used to obtain the FTIR spectrum. For topographical survey and elemental composition of as-synthesized samples scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDX) was used. The FESEM NOVA MIRA3XMM instrument was used to collect SEM and EDX data. PerkinElmer thermogravimetric analyzer 4000 was employed in nitrogen environment with temperature range 25°C to 700°C.

3. Results and Discussion

The morphological studies of Ag NWs and Ag@Polythiophene nanocables were carried out using SEM analysis. The SEM image of Ag NWs is shown in Fig 3.1 (a) while Fig 3.1 (b) shows EDX spectrum of Ag NWs that tells elemental composition of as-prepared sample. The surface of silver nanowires is smooth having diameter around 85 nm. Fig 4.1 (c) shows SEM image of polythiophene coated silver nanocables and Fig 3.1 (d) depicts EDX spectrum of Ag@Polythiophene Nanocables. The polythiophene coating gives nanocables a rough and shinning appearance. The diameter of silver nanowires was increased after coating. The thickness of polythiophene sheath was about 25-30 nm, so the overall diameter of Ag@Polythiophene nanocables was appeared to be 110 nm.

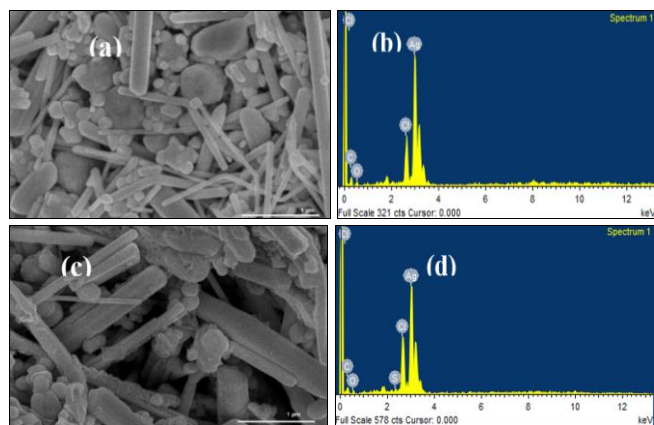


Fig 3.1: SEM image and EDX Spectrum of (a),(b) Ag NWs (c),(d) Ag@Polythiophene Nanocables

The FT-IR spectra of Ag NWs and Ag@Polythiophene nanocables is shown in Fig 3.2(a,b). In Fig 4.2(a), the absorption peak around 1300 cm^{-1} corresponds to C-N stretching vibration. The peaks at 1650 and 2922 cm^{-1} are attributed to -C=O and -C-H stretching vibrations respectively. The broad peak at 3438 cm^{-1} can be assigned to OH stretching vibration which indicates the presence of hydroxyl groups. In Fig 3.2(b), the peaks at 1482 cm^{-1} , 1625 cm^{-1} , 1223 cm^{-1} , 825 cm^{-1} and 722 cm^{-1} confirmed the polythiophene coating on Ag NWs. The peak at 1482 cm^{-1} is due to the asymmetric vibration of polythiophene. The peaks at 1223 cm^{-1} and 825 cm^{-1} are due to in plane and out of plane C-H aromatic bending vibrations of thiophene ring. The peak at 722 cm^{-1} is attributed to the C-S bending mode. The peak at 1625 cm^{-1} is due to the aromatic C=C stretching band.

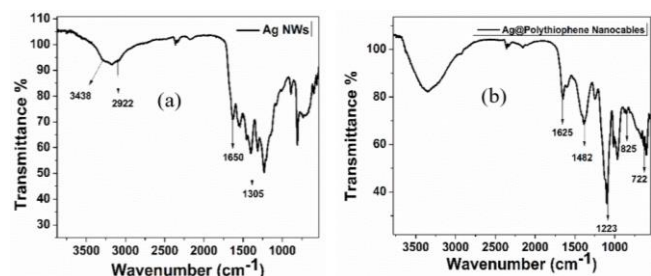


Fig 3.2: FTIR Spectra of (a) Ag NWs (b) Ag@Polythiophene NCs

The UV-Visible spectroscopy was used for the structural characterization of the Ag NWs and polythiophene coated silver nanowires. The Fig (3.3a) shows the spectrum of Ag NWs synthesized by the polyol method. The two relatively sharp peaks were observed at 357 nm and 382 nm which correspond to the transverse mode of Ag NWs. The increase in the intensity of the peaks in the spectrum shows an increase in the length of Ag nanowires. The Fig (3.3b) depicts the UV-Vis absorption spectrum of Ag@Polythiophene nanocables. When polythiophene is coated on the surface of Ag nanowires, the absorption intensity of Ag nanowires is reduced and there is a red shift due to the coating. When polythiophene is applied to the surface of Ag nanowires, the peak intensity decreases and a red shift appears due to the coating. Confirmation of the infrastructure of Ag@Polythiophene nanocomposites is done by observing a decrease in peak intensity and red shift in the peaks. The UV-Vis spectra of Ag NWs and Ag@Polythiophene nanocables are shown in Fig 3.3.

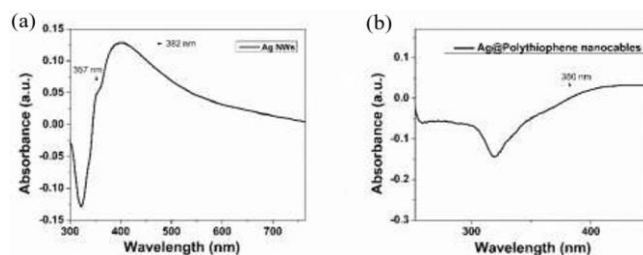


Fig 3.3: UV-Vis spectrum of (a) Ag NWs (b) Ag@Polythiophene nanocables

In order to determine the photoluminescence study of the as-prepared samples, these samples were excited at the wavelength at which they show maximum absorption and wide emission after the excitement. The Fig (3.4a) and (3.4b) shows the PL spectrum of Ag nanowires and Ag@Polythiophene nanocables respectively. The Ag nanowires were excited at the wavelength of 382 nm and it shows emission peak at 365 nm . The Ag@Polythiophene nanocables showed emission peak at 375 nm .

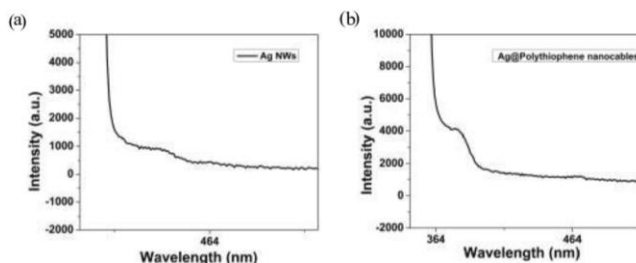


Fig 3.4: PL Spectra of (a) Ag NWs (b) Ag@Polythiophene NCs

The thermal stability of Ag NWs and Ag@Polythiophene nanocables was investigated by thermogravimetric analysis analyzer. For this purpose, the samples were heated under a constant flow of nitrogen gas in the temperature range $25\text{--}800\text{ }^{\circ}\text{C}$ at a heating rate of $10^{\circ}\text{C}/\text{min}$. The thermogram images of Ag NWs and Ag@Polythiophene nanocables are depicted in Fig 3.5 (a,b). Fig 3.5 (a) shows thermogram of Ag nanowires. It shows gradual weight loss till $200\text{ }^{\circ}\text{C}$ which may be due to the presence of small molecules like water. However further weight loss is due to the degradation of PVP present in Ag NWs. Fig 3.5 (b) shows thermogram of Ag@Polythiophene nanocables. It can be clearly seen in the graph that the sample is thermally stable till $200\text{ }^{\circ}\text{C}$. It means small molecules have been removed after washing the sample. The sharp weight loss between $200\text{--}300\text{ }^{\circ}\text{C}$ indicate that the polymer sheath outside nanowires was thick which degraded sharply on heating. However, further gradual weight loss shows enhanced thermal stability of Ag@Polythiophene nanocables as compared to pristine Ag NWs.

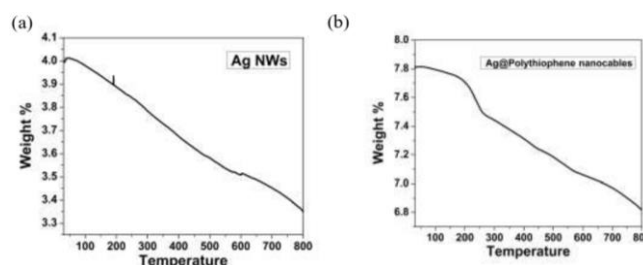
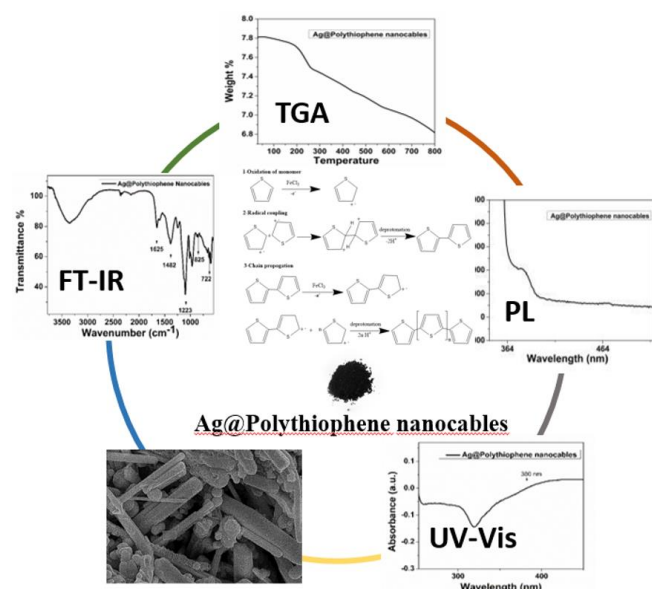


Fig 3.5: Thermogram of (a) Ag NWs (b) Ag@Polythiophene NCs

4. Conclusions

Ag@Polythiophene nanocables were successfully synthesized using ion adsorption technique. First, silver nanowires were synthesized using polyol reduction method. These nanowires were then dispersed in aqueous solution of copper acetate which adsorbed Cu^{+2} ions on the surface of silver nanowires. The nanowires were then redispersed in aqueous solution of thiophene. The adsorbed Cu^{+2} ions oxidized the thiophene monomer and polymerized it into uniform polythiophene sheath outside silver nanowires. In this way, the silver nanowires were successfully transformed into Ag@Polythiophene nanocables. The morphology of prepared nanocables was confirmed by SEM images. The diameter of nanocables was increased upto 25-30 nm which showed that polythiophene is successfully coated on the surface of silver nanowires. The synthesis of Ag@Polythiophene nanocables was also confirmed by UV/VIS spectroscopy and PL spectroscopy. The UV/VIS spectroscopic result showed a red shift in wavelength in case of Ag@Polythiophene nanocables which is due to the conjugation in polymer chain. The functional groups present in Ag@Polythiophene nanocables were determined by fourier transform infrared spectroscopy (FT-IR). The peaks at 1482 cm^{-1} , 1625 cm^{-1} , 1223 cm^{-1} , 825 cm^{-1} and 722 cm^{-1} confirmed the polythiophene coating on Ag NWs. Furthermore, the thermal stability was monitored by thermogravimetric analysis (TGA) which showed enhanced thermal stability of Ag@Polythiophene nanocables as compared to pristine Ag NWs. Thus, it is concluded that Ag@Polythiophene nanocables have been successfully synthesized using ion adsorption technique.

5. Graphical Abstract



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