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Optical Properties from Energy of Polyaniline Transparent Conductive Thin Film

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Abstract: *Polyaniline thin film was synthesized at temperatures of 28ºC, by in situ oxidative polymerisation with ammonium peroxidisulphate [$(NH_4)_2S_2O_8$] at equimolar of aniline (C_6H_5-NH_2) to oxidant ratio and 1M hydrochloric acid (HCl) on substrate of soda lime glasses and post treated via water bath with organic solvents such as propanol, ethanol, chloroform and diethyl ether. The resulting PANI thin film was characterized by techniques such as: UV-Visible Spectroscopy. The optical transmission and reflectance spectra have been found in the visible wavelength range 300-800 nm for different compositions of polyaniline thin films. Moreover, the effects of organic solvents on prepared polyaniline in the parameters such as transmittance, reflectance, optical energy gap (E_{opt}), refractive index, absorbance, absorption coefficient and extinction coefficient have been investigated and evaluated. And the polyanilines with Chloroform and diethyl ether were found to have higher optical transmittance, while the polyanilines with propanol and ethanol were found to have lower optical transmittance.*

Keywords: *Transmittance, Reflectance, Energy Band Gap, Absorption coefficient, Extinction Coefficient and Refractive index*

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1.0 Introduction

During the last decade, there has been widespread interest in conjugated polymers with conductive and semiconductive properties suitable for applications in electronics and various related fields. (Salma, 2012; Alias *et al*., 2013). Among the conducting polymers, polyaniline is emerging as the material of choice for many applications (Khan and Khalid, 2010; Kim *et al*, 2011). The interest in this conducting polymer stems from the fact that most ring- and nitrogen-substituted derivatives can be readily synthesized, and each of the derivatives can exist in different oxidation states at the molecular level, such as leucoemeraldine base (LEB), emeraldine base (EB) and pernigraniline base (PN) (Amrithesh, 2009; Cornelius *et al*., 2015). Furthermore, they can be enhanced by doping with doped with different dopants through redox or non-redox processes (Xiong, 2010; Xian, 2011).

Polyaniline emeraldine base (EB) is reported to have two main structural units, that is, benzoic diamine and quinoid diimine (Kuestan, 2013; Miroslava *et al*., 2013). The emeraldine base state of polyaniline benzenoid diamine units is a region of Highest Occupied Molecular Orbit (HOMO) or bonding orbital, known as valence bands, while the quinonoid diimine units are a region of Lowest Unoccupied Molecular

Orbit (LUMO) or antibonding orbital known as conduction bands (Amrithesh, 2009; Li and Li, 2011). These properties, combined with the fairly high conductivity after doping, their ease of synthesis, satisfactory and processing environmental stability, low synthetic cost, high performance of electrical property, easiness to handle, high thermal stability, insolubility, low resistivity and the relatively low cost of the starting materials strongly suggest their significant potential for technological applicability (Stejskal and Gilbert, 2002; Yilmaz, 2007). Polyaniline has several scope of applications, including solar energy conversion, rechargeable batteries, electrochromic displays, electrochemical sensors, capacitors, photovoltaic and LEDs organic semiconductors (Vivekanandan *et al*., 2011).

Salman (2012), stated that the major problems relating to successful utilization of the PANI are poor mechanical properties and low solubility in aqueous and organic solvents. Improvement of polyanline properties is achieved either by forming composites and nanocomposites of aniline, or blending with commercially available polymers or inorganic materials which will offer better mechanical, electrical and optical properties, stability and processability (Sharma *et al*., 2014).

Yilmaz, (2007); Amrithesh, (2009); Zhao, (2010) reported that some deposition techniques, such as solution casting, spin coating, plasma polymerization, oxidative chemical polymerization, electrochemical, and thermal evaporation are employed to get conductive polyaniline in thin film form. However, in this work PANI films has been prepared from anilinium chloride through *in situ* chemical polymerization using ammonium peroxodisulphate on glass slides of soda lime (Pavlina *et al*., 2011). This method has been reported to yield stable, adherent, uniform and hard films with good reproducibility by a relatively simple process. The waste products from this method are reversible by deprotonation. Soda lime glass was used as substrate for deposition of the PANI thin film due to its resistance to the chemical reaction, and its adhesive nature between organic compounds, which enables uniformity in the growth of films on the substrates, thereby resulting in qualitative film formation. Although it has been reported that PANI thin films can also be grown on substrates such as FTO glass, quartz, and plastic, without involving bulk equipment and time-consuming at room temperature, (Zhao, 2010; Qidong *et al*., 2011).

Although polyaniline thin films have been widely studied for their electrical and optical properties, there is still limited understanding of how post-deposition treatment with different organic solvents influences the optical characteristics such as transmittance, reflectance, refractive index, absorption coefficient, and energy band gap. Most previous studies have focused on synthesis methods and doping effects, but the systematic evaluation of solvent-induced modifications on optical performance remains underexplored.

This study aims to synthesize polyaniline thin films via in situ oxidative polymerization, followed by post-treatment with organic solvents, and to evaluate the resulting optical properties using UV-Vis spectroscopy. Specifically, the work investigates how solvent type affects parameters including transmittance, reflectance, energy band gap, refractive index, absorbance, absorption coefficient, and extinction coefficient.

Understanding the role of solvent treatment on the optical behaviour of polyaniline thin films is significant for tailoring their performance in optoelectronic and photonic applications. By identifying solvent conditions that enhance transparency and optimize band gap properties, this research provides insights for improving the design of conducting polymer-based devices such as solar cells, sensors, and display technologies. Hydrochloric acid (HCl) was selected as a dopant based on its excellent cationic sources for electrical and optical properties and the presence of lightweight dopant ions (Cl^-, ions). HCl doped PANI possesses higher electric conductivity, when compare with other protonic acids such as orthophosphoric (H_3PO_4), sulphuric acid (H_2SO_4) and nitric acid (HNO_3) (Amrithesh, 2009; Miroslava *et al.*, 2013). The choice of ammonium peroxodisulphate [$(NH_4)_2S_2O_8$], as oxidant, is based on its excellent salt content for easy conversion of emeraldine base (EB) into emeraldine salt (ES) (Miroslava *et al.*, 2013; Cornelius *et al.*, 2015). The post deposition treatment was applied using organic solvents such as propanol, ethanol, and diethyl ether in the water bath process (Kim *et al*.,2011).

2.0 Materials and Methods

2.1 Materials

Soda lime glass slides, beakers, stainless basin, electric balance, electric blowing dryer, tong, vessels, programmable electrical boiler, stop watch, patria dishes and thermometer, ammonium peroxodisulphate [$(NH_4)_2S_2O_8$]-(BDH 98%), hydrochloric acid (HCl)-(BDH,37%), aniline (C_6H_5-NH_2), propanol (C_3H_7OH)-(BDH, 99%), Ethanol (C_2H_6OH)-(BDH, 99%), Chloroform ($CHCl_3$)-(BDH, 99%), diethyl-ether ($C_4H_{10}O$)-(BDH, 99%), sulphuric acid (H_2SO_4) –(BDH, 98%), chromic acid (H_2CrO_3)-(BDH, 99%) and distilled water (H_2O)

2.2 Methods

2.2.1 Preparation of Polyaniline Thin Film

PANI thin films were prepared through *in situ* chemicals oxidative polymerization at room temperature on the Soda lime glass substrate (Skytec microscopic glass slide of area 25.4 *mm* X 76.2 mm, Thickness-1.0 *mm* and Refractive index -1.52), which were sucked chemically (i.e. in saturated solution of concentrated H_2SO_4 dissolved in concentrated chromic acid) for 24 hours, washed and cleaned with 100 *ml* of distilled water 4 times and dry with blowing dryer at room temperature. After which, solutions of aniline in concentrated hydrochloric acid (HCl) and strong oxidizing agent (ammonium peroxodisulphate) at room temperature were used. The method is based on the arrangement of 5 glass slides parallel inside a vessel with aid of paper sell tape, to avoid double face deposition of the glass slides and mixing of two solutions: (i) 0.1M aniline (C_6H_5-NH_2; 3.72 g) solution was dissolve in 1 M hydrochloric acid (HCl; 1.46g) which served as a source of cationic and ionic, in a beaker, A, and thoroughly stirred for 2 minutes. And (ii) 0.1M ammonium peroxodisulphate [$(NH_4)_2S_2O_8$; 9.12g] was dissolved in 10ml of distilled water, which served as an oxidizing agent in a beaker B and thoroughly stirred for 2 minutes. After the mixing of both solutions the polymerization of the aniline was proceeded by poured both solutions inside beaker A and beaker B simultaneously unto vessel contained 5 glass slides for polymerization reaction and deposition to take placed which is signal by the green colour of the reaction solution, the time for the first round polymerization reaction are 5 minutes and after which the sell tape on second face of glass slides is gradual removed and with aid of holder the glass slides were cleaned and washed with 0.05M HCl and dry with electrical blowing dryer machine and all process was repeated for the second round, but polymerization reaction are 7 minutes for second round. And this makes the total time 12 minutes for the first and second round polymerization reaction. The repeating process is carried out to give effective deposition of PANI thin films onto the surface of the glass slides in term of thickness and uniformity. However, Stejskal and Gilbert (2002), observed that washing PANI precipitate with 0.2M HCl removes residual monomers, oxidants, and its decomposition products. The treatment with HCl acid solution provides a more uniform protonation of PANI with chloride counter ions. Fig. 1 below shows the PANI thin films deposited on the soda lime glass substrates, the chemical reaction equation and structure at the end of the polymerisation reaction.

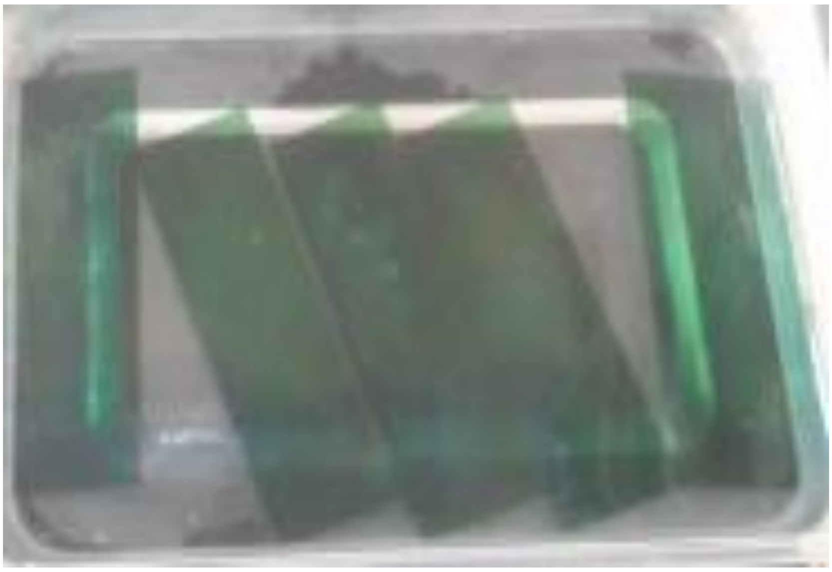

Plate1: Deposited Polyaniline thin films

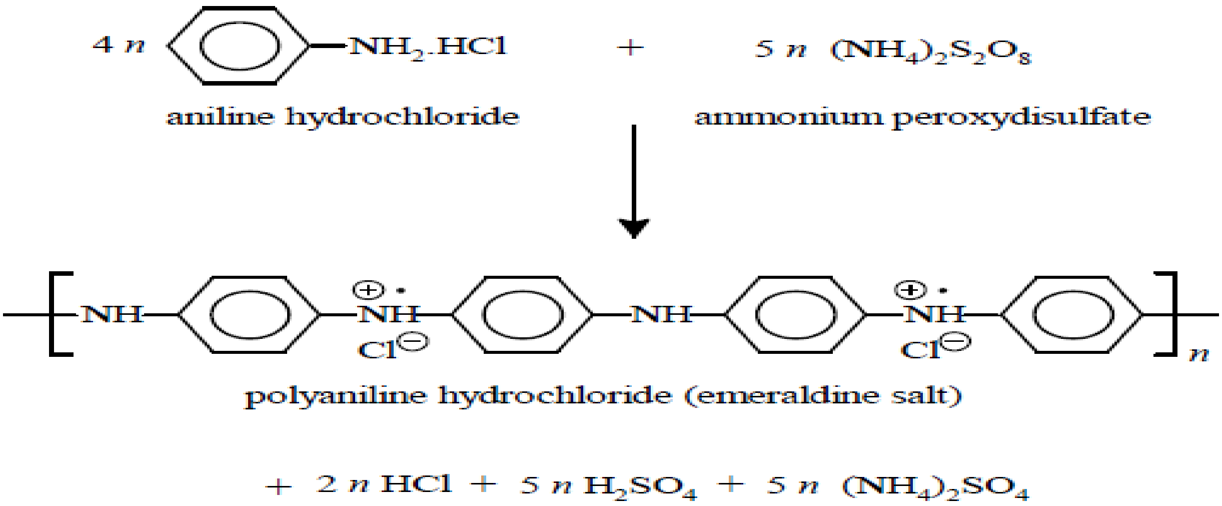

Fig. 1: Polymerisation reaction of aniline dope hydrochloric acid (HCl) (Yilmaz, 2007; Amrithesh, 2009; Miroslava *et al*., 2013)

2.2.2 Water Bath (Post Deposition Treatment)

The method of annealing and exposing 4 samples out of 5 deposited on glass slides was carried out with 4 different organic annealing solvents such as propanol, ethanol, chloroform and diethyl ether through the water bath method. This is done by measuring 200 ml of water into a stainless basin with a flat cycler tray. And four beakers were washed, and cleaned with distilled water and dried with electrical blowing dryer, were use in housing 4 samples and 10ml of each of the 4 different annealing solvents is measured and poured into each beaker; that is propanol in first beaker, ethanol in second beaker, chloroform in third beaker, and diethyl ether in forth beaker and all the 4 beakers are covered tightly and placed inside the basin contained water and flat tray, which is later transferred to the top of the programmable boiler for heating at constant temperature of 100°C for 2 hours. This is the temperature of boiling water. One glass slide with pure PANI thin film is left as a control sample without exposed to vapour of the organic solvent. Ameen *et al*., (2011) reported that annealing with organic solvents through the water bath will help to remove excess organic acids or impurities, completely converted PANI thin films to polyaniline salts to achieve relatively high-quality organic semiconductor film for higher electrical and optical properties.

2.2.3 Characterisation Techniques for the Deposited PANI Thin Films

The dried green coloured product in the form of thin films is characterised using UV-Vis spectrophotometric (Avantes UV-Visible Spectrophotometer) technique to determine Optical.

3.0 Results and Discussion

The optical properties of the prepared polyaniline (PANI) thin films, both untreated and solvent-treated, were studied using UV–Vis spectroscopy. Table 1 summarizes the transmittance, reflectance, absorbance, absorption coefficient, extinction coefficient, refractive index, and optical band gap values of the films.

Table 1. The Summary for Optical Properties of the PANI Thin Films

Samples ID	Transmittance (%)	Reflectance (%)	Absorbance (A) ×10^{-1}	Absorption coefficient (α) ×10^{6}	Extinction coefficient (k) ×10^{-2}	Refractive Index (n)	Optical Band Gap (eV)
PANI-Propanol	33.20	3.75	4.789	3.56	15.58	1.48	2.5
PANI-Ethanol	31.19	1.79	5.060	3.76	16.46	1.31	2.4
PANI-Chloroform	51.30	3.99	2.899	2.15	9.41	1.50	2.8
PANI-Diethyl	39.83	2.19	3.998	2.97	13.00	1.35	2.7
Pure-PANI	24.52	3.79	6.105	4.54	19.87	1.48	2.3

The solvent-treated films showed significantly improved transmittance compared with the untreated PANI film (24.52%). The chloroform-treated film recorded the highest transmittance (51.30%), followed by diethyl ether (39.83%), propanol (33.20%), and ethanol (31.19%). This trend indicates that chloroform and diethyl ether promote better transparency of PANI films, which is beneficial for optoelectronic applications requiring high optical clarity. Reflectance values were generally low (1.79–3.99%), suggesting that most incident light penetrated the films rather than being reflected.

Pure PANI exhibited the highest absorbance (6.105×10^{-1}) and absorption coefficient (4.54×10^{6} cm^{-1}), reflecting its strong light absorption in the visible region. Solvent treatment reduced absorbance, particularly in the chloroform-treated film (2.899×10^{-1}, $\alpha = 2.15 \times 10^{6}$ cm^{-1}). This reduction in absorption correlates with increased transparency, as the films absorb less light and transmit more.

The extinction coefficient followed a similar trend to absorbance, with pure PANI having the highest value (19.87×10^{-2}). Solvent treatment decreased k values, with chloroform again yielding the lowest (9.41×10^{-2}). A lower extinction coefficient indicates reduced optical losses, making chloroform-treated PANI films more suitable for optical device applications.

The refractive indices ranged from 1.31 to 1.50. The ethanol-treated film had the lowest refractive index (1.31), whereas chloroform and pure PANI films had higher values (1.50 and 1.48, respectively). Variations in n reflect structural modifications induced by solvent annealing, which influence light propagation through the films.

The band gap values increased with solvent treatment compared with pure PANI (2.3 eV). Chloroform-treated PANI exhibited the widest band gap (2.8 eV), followed by diethyl ether (2.7 eV), propanol (2.5 eV), and ethanol (2.4 eV). The widening of Eg after solvent treatment suggests improved ordering and reduced defect density in the polymer chains, which enhances semiconducting behaviour.

The results demonstrate that organic solvent treatment significantly influences the optical behaviour of PANI thin films. Chloroform and diethyl ether treatments were particularly effective in enhancing transparency, reducing absorption, lowering extinction losses, and widening the band gap. These modifications are advantageous for optoelectronic and photonic applications such as solar cells, light-emitting devices, and transparent conductive coatings, where both high transmittance and an appropriate band gap are essential.

3.1 Transmittance Spectra

Fig. 2 shows the optical transmittance spectra of PANI-propanol, PANI-ethanol, PANI-chloroform, PANI-diethyl ether, and pure PANI.

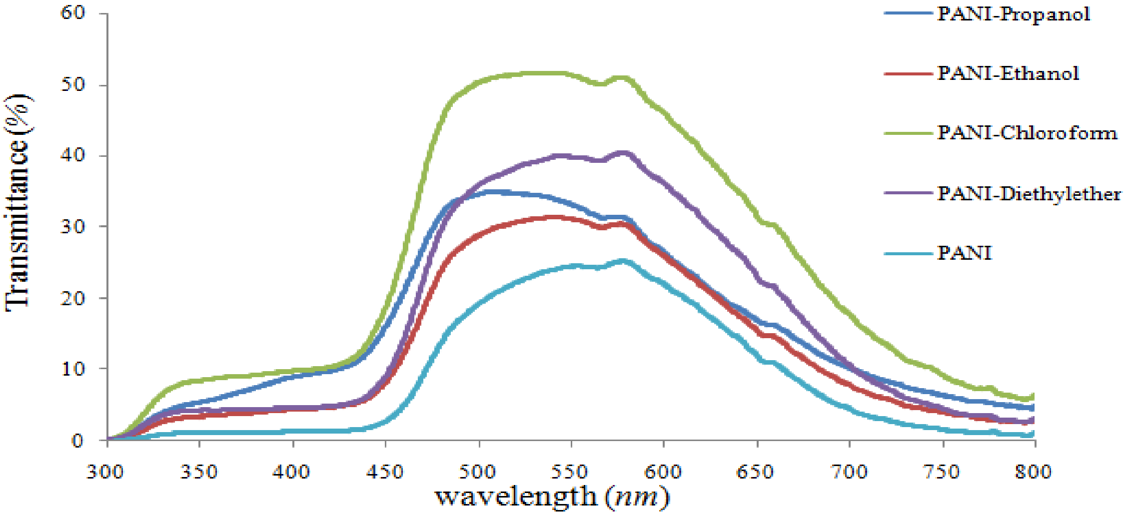

Fig. 2: Transmittance spectra of PANI and samples exposed to organic solvents.

The average transmittance was estimated by taking the average of the transmittance at the visible wavelength range of 300 – 800 *nm.* The visible region with high transmittance could be assigned to the π-π* transition of the benzenoid ring and the quinoid ring transition. That is, charge transfer from the Highest Occupied Molecular Orbit (HOMO) of the benzenoid ring refers to as the valence band to the Lowest Unoccupied Molecular Orbit (LUMO) of quinoid ring is referred to as the conduction band. And is a transition of the π-π* energy gap in the conducting polymers. And the bands depend on the overall oxidation state of the polymers (Vivekananda *et al.*,2011; Sharma *et al*, 2014).

The transmittance spectrum of polyaniline salt doped with HCl shows bands at 533 *nm* and 571 *nm* with higher intensity. And a characteristic band for polaron-π* transition appeared at 437 *nm*, indicating that the resulting PANI emeraldine salt was in a doped state. And this is also in agreement with the report by Kuestan (2013) and Pavlina *et al.* (2011). PANI-chloroform shows the highest transmittance intensity of 51.30%, followed by PANI-Diethyl-ether with intensity 39.83%, PANI-Propanol with intensity 33.20%, PANI-Ethanol with intensity 31.19% and pure PANI with intensity 24.52% respectively.

The variation in transmittance with substrates is principally due to the interference phenomenon between air film and film substrate interference, which could be related to the variation in substrates' organic solvents. However, the highest intensity in

PANI-Chloroform and relatively higher intensity in PANI-Diethyl ether could be due to the better crystallinity. And this implies that the benzenoid and quinonoid units in the PANI-Chloroform and the PANI-diethyl ether are more orderly arranged, without any unfavourable clustering. It was found that the quinonoid unit quenches the optical transmission due to the intrachain energy dissipation (Amerithesh, 2009; Song and Ning, 2014). The higher transmittance may be due to the higher extent of π-conjugation couple with a more orderly arrangement of the benzenoid and quinonoid units, which might favour the formation of an exciton Islam *et al*., 2013). Another possible reason responsible for higher optical transmission in PANI-chloroform may be due to the presence of the excess lighter dopant ions (Cl$^-$). Although PANI-diethyl ether does not have lighter dopant ions (Cl$^-$), the slightly better transmittance may be attributed to its properties such as low electrical dipole moment and low dielectric constant, which may also enhance the formation of the excitons in its chain.

PANI-propanol and PANI-ethanol also tend to show slightly high optical transmission. These may be due to the electron-donating groups such as NH in polyaniline and electron-withdrawing groups such as C=O in both propanol and ethanol. Amerithesh (2009) reported that the combination enhances the π-electron mobility, so as both propanol and ethanol content increase in Composites the combination probability and hence the π-electron mobility increase further, and this favours the formation of singlet exciton, the singlet exciton states so formed decay radiatively to the ground state, resulting in enhanced optical transmission (Ansari, and Keivani, 2006).

On the other hand, the characteristic of the polar solvents, such as the miscibility with water, higher dielectric constant and as well as higher dipole moment effect π electron mobility in PANI-propanol and PANI-ethanol and these may decrease optical transmission, because of the disorder arrangement in quinonoid and benzenoid structures of polymers (Song and Ning, 2014).

Pure PANI shows the lowest optical transmission intensity of 24.52%, despite the presence of light dopant ions. This may be attributed to the excess organic acid (an impurity) in polyaniline salts or residual monomers, oxidants and their decomposition product and resulting in such decreases, π electron mobility, and thereby lowering the optical transmission of pure PANI (Kuestan, 2013).

3.2 Reflectance Spectra

The average reflectance was estimated by taking the average of the reflectance within the visible wavelength range of 300 - 800 *nm*. The average reflectance was estimated to be 3.99%, 3.79%, 3.75%, 2.19% and 1.79% respectively, for substrates of PANI-propanol, PANI-ethanol, PANI-chloroform, PANI-diethyl ether and pure PANI(Fig. 3).

There are small differences between the reflectance spectra of PANI (EB) films and PANI films exposed to organic solvents. Both pure PANI (EB) and PANI samples exposed to organic solvents exhibit peaks at 465 and 571 and 778 *nm*, quite close to the reported values (Qiang *et al*., 2003; Xia *et al*., 2012). From Fig.3 it was observed that peaks at 465, 571 and 778 *nm* corresponds to π- π* transition and exciton band formed due to charge transfer from the highest occupied molecular orbital (HOMO) centered on the benzenoid rings to the lowest unoccupied molecular orbital (LUMO) centered on the quinonoid rings (Hameed *et al.*, 2010; Al-Salhi *et al.*, 2011).

It could be observed that there is a lower average reflectance intensity for the five samples and with slight differences in their values. This is because most organic materials absorb much radiation of light and reflect less, as source of their feeding also depends on light for living. It may also be attributed to the uniform substrate temperature during deposition, which reduce the optical reflectance spectrum of pure PANI and the PANI samples exposed to the vapour of the organic solvents, as a similar case occurred of lower intensity in the optical transmittance spectra of five samples and this is in agreement with Hameed *et al.* (2010). Other factors which may contribute to the lower reflectance intensity could be related to physical and chemical properties of the acids used, such as volatility, miscibility or immiscibility, dielectric constant, dipole moment and contents of either lighter or heavier ions in those acids.

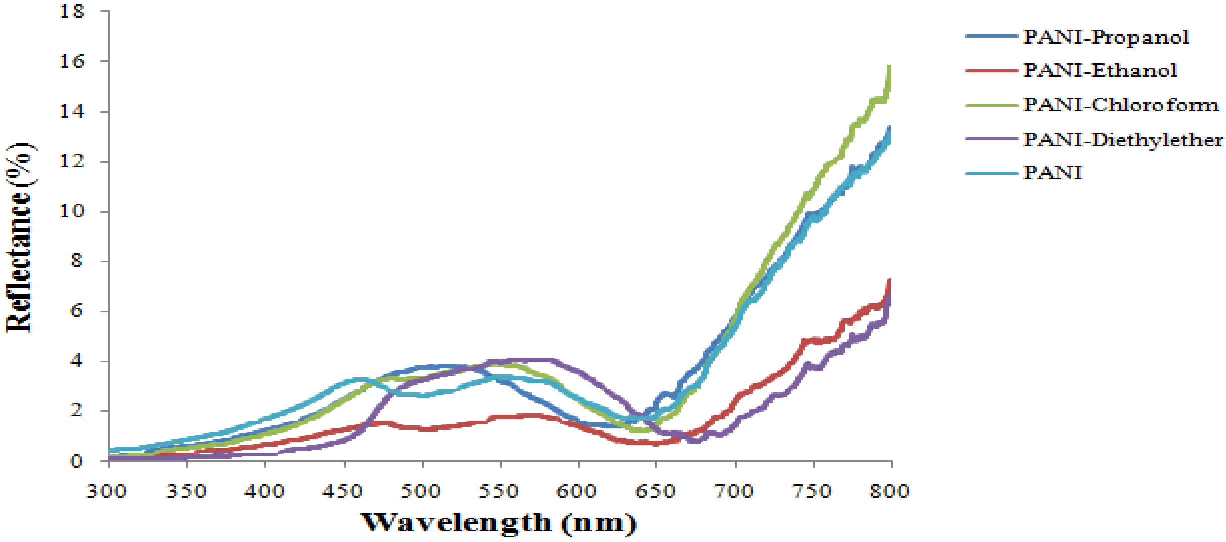

Fig. 3: Reflectance spectra of PANI and PANI samples exposed to organic solvents.

3.3 Optical Energy Band Gap

Fig.4 shows the optical band gaps of the investigated materials. From the work of Amrithesh (2009) and Alias *et al.* (2013), the optical absorption for non-crystalline materials is given by the Tauc's and Davis–Mott model and is used to determine optical energy band gap

$$(\alpha h v)^n = \beta(hv - E_{opt}) \qquad (1)$$

where β is a constant, α is absorption coefficient, hv is the photon energy and n is the exponential constant index. The exponential constant index is an important parameter that describes the type of electronic transition. There are four types of transition in amorphous materials that can be represented with n. The values of index n are commonly 1/3, 1/2, 2/3, and 2 for indirect forbidden, indirect allowed, direct forbidden, and direct allowed transitions, respectively.

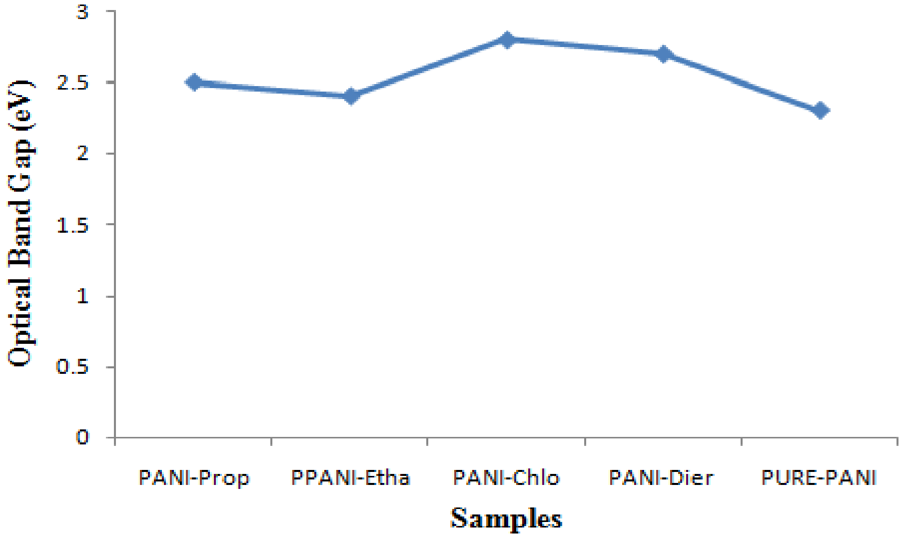

Fig. 4: Plot of optical band gap of pure PANI and PANI with organic solvents

From Fig. 4, it is evident that all samples have one allowed direct optical energy gap. The optical energy band gap is observed to increase in the range of 2.3 to 2.8 eV for PANI and PANI organic solvents simultaneously. And this is in agreement with the report of Lee *et al*. (2011) that most semiconducting polymers are found to have a band gap in the range of 1.5~3eV, allowing stable optical excitations and mobile charge carriers that make them suitable for optoelectronic devices. It has been found that energy decreases with increasing the concentration percentage of PANI. The addition of PANI above 10% increases the degree of disorder then selective absorption of the photon energies of incident light that such energy is devoted to breaking up and hence deforming of partially crystalline structure of the polymers Salma (2012) and has such result in low value of optical energy band gap in pure PANI. However, the addition of vapour of the organic solvents results into a high value of optical energy band gap in PANI-chloroform, and this could be due to the modification in the structure of polyaniline by the vapour of chloroform.

In undoped PANI, the optical band gap equals the energy separation between the band edges, but on doping, the donor electrons occupy states at the bottom of the conduction band, since the Pauli principle states that no two electrons have all their quantum numbers identical (Xia *et al*., 2012). That is each orbital can be occupied by at most one electron. This applies to electrons in atoms, molecules or solids. The bands formed from the highest occupied molecular orbital (HOMO) are the lower energy levels, also referred to as the valence band. Similarly, bands formed from the lowest unoccupied molecular orbital (LUMO) are the higher energy levels, also referred to as the conduction band. The difference between the two levels produces the band gap (Caseri, 2000; Ahmad *et al*., 2010). The band gap difference of the poly-aniline thin film and PANI thin films exposed to the vapour of organic solvents could be due to the variation in grain boundaries formation and imperfections in the polycrystalline thin films. The atomic structure at the grain boundary is different from that in the grain, which leads to larger free carrier concentrations (free electron concentration) and the existence of potential barriers at the boundaries, leading to the formation of an electronic field and hence an increase of the band gap. This is consistent with the results of (Xia *et al*. 2010; Xia and Ouyang, 2011). Zhao (2010) also reported that the band gap difference between the HCl dope PANI film and bulk aniline is due to the grain boundary, the stress and the interaction potentials between defects and host materials. The increase in band gap could be attributed to the partial filling of the conduction band of PANI thin film, resulting in a blocking of the lowest states. According to the Burstein-Moss effect, the band gap would increase with increasing carrier concentration (Alias *et al*., 2013). Doping of PANI with HCl acid increases the carrier concentrations, thereby blocking the lowest state in the conduction band owing to the filling up of low-energy levels by the conduction electrons, thus increasing the band gap. The enhancement of band gap also ensures that HCl acid was successfully doped in the aniline thin films. This is in agreement with Song *et al.* (2014). The increase in the band gap could be attributed to quantum confinement, which has primarily two consequences. Due to the presence of double bonds in conjugated polymers, each atom contains an unpaired electron in the p orbital. These two orbitals overlap to form a π bond. The quantum mechanical overlap of these orbitals results in splitting into two discrete energy levels. Due to the interaction of "n" number of orbital "n" states form. For large values of "n", the energy states are close enough together to form a continuous system of electronic states along the backbone, a band of allowed energies. This is in agreement with the report of Bejbouj (2010).

3.4 Absorption coefficient

The absorption coefficient α is related to the absorbance A based on the Lambert-Beer law that is;

$$\propto(\lambda) = \frac{2.303A}{x} \qquad (2)$$

where x is the sample thickness, where A is the absorbance and constant 2.303 is = ln10

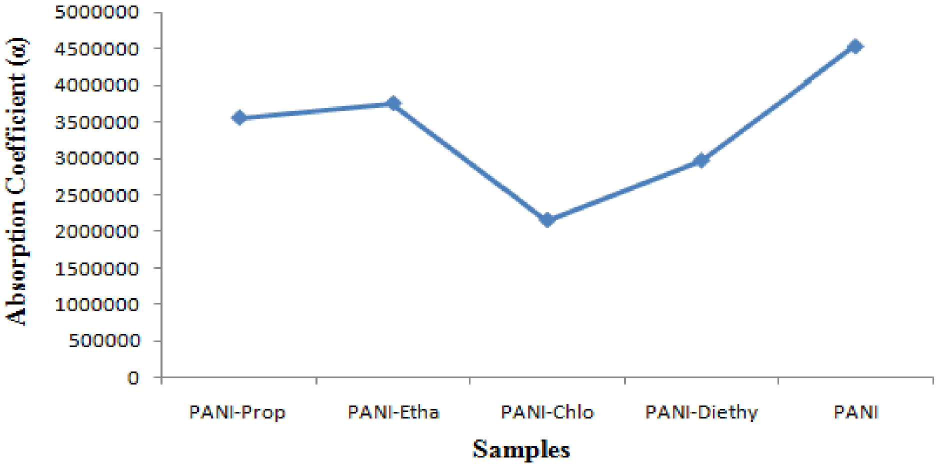

Fig.5: Plot of absorption coefficient against pure PANI and PANI with organic solvents

From Fig.5 it could be observed that the value of the absorption coefficient (α) varied in the range of 2.15×10^6 – 4.54×10^6, with pure PANI showing the highest value of α and with PANI-chloroform showing the lowest value of α. The variation in their value may be related to differences in their nature and the uniformity in the thickness, and has resulted in the lowest transmittance in pure PANI and the highest transmittance in PANI-chloroform. However, it could be generally observed that high absorption by the pure PANI and PANI thin films exposed to the vapour of organic solvents results in the lowest reflection, this is attributed nature of organic materials, especially plants, which absorb more sunlight in their building processes.

3.5 Extinction Coefficient

The extinction coefficient, K, for five samples was calculated from the formula (Alias *et. al.*, 2013) at a wavelength of 550 *nm*;

$$K = \frac{\alpha\lambda}{4\pi} \qquad (3)$$

Where α is the absorption coefficient of the film and λ is the wavelength of light

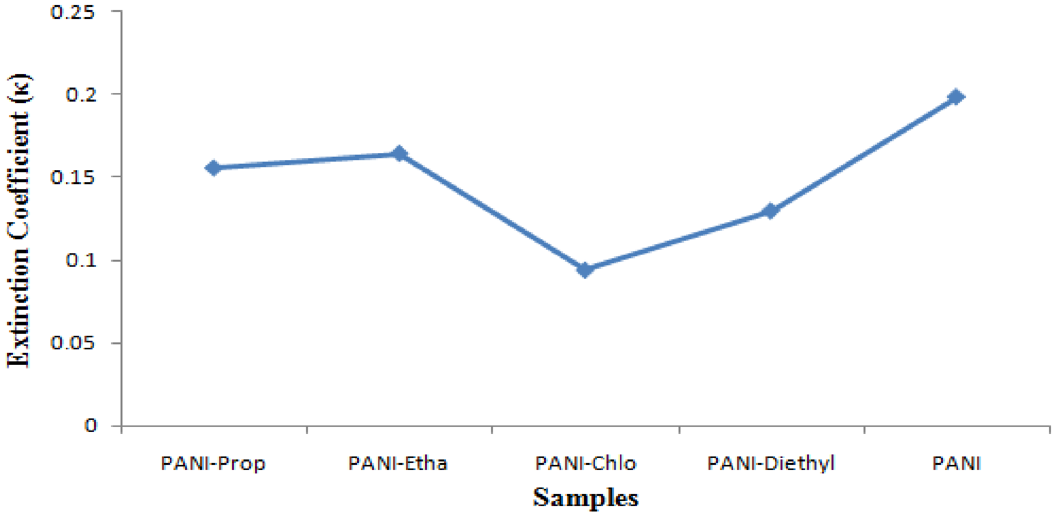

Fig. 6: Plot of extinction coefficient against pure PANI and PANI samples with organic solvents.

From Fig.6, the Extinction coefficient (k) increase in the range of 9.41×10^{-2}-19.87×10^{-2}. The decreases or increases in the values of extinction coefficient may be due to variation in substrate organic solvents and has such result in higher and lower absorption of light at the grain boundary (Amrithesh, 2009). While the high and low value of extinction coefficient K, obtained for the pure polyaniline thin film and PANI-chloroform indicates high absorption and reduced transmittance and as well as low absorption and high transmittance, the variation in extinction coefficient is parallel by the absorbance of HCl-doped PANI thin films.

3.6 Refractive index (n)

The refractive index (n) for five samples was calculated from the formula (Alias *et. al.*, 2013) at a wavelength of 550 *nm;*

$$n(\lambda) = \frac{1+\sqrt{R}}{1-\sqrt{R}} \qquad (4)$$

where R is the reflectance

From Fig 7 it is seen that there is variation in the value of Refractive index (n) with PANI-Propanol, PANI-Chloroform, and PANI having high value of n (1.50) and PANI-Ethanol and PANI-Diethyl ether with low value of n (1.31 and 1.35), and this is in agreement with report of Vosgueritchian *et al.* (2012), that a typical polymer has a refractive index of range 1.30-1.70. The high and low value of n could be attributed to the differences in the polarizability, chain flexibility and molecular geometry of polymers results from the variation in the substrate organic solvents, and has such increase or decrease the surface transparency which result into variation in the values of refractive index (Song and Ning, 2014).

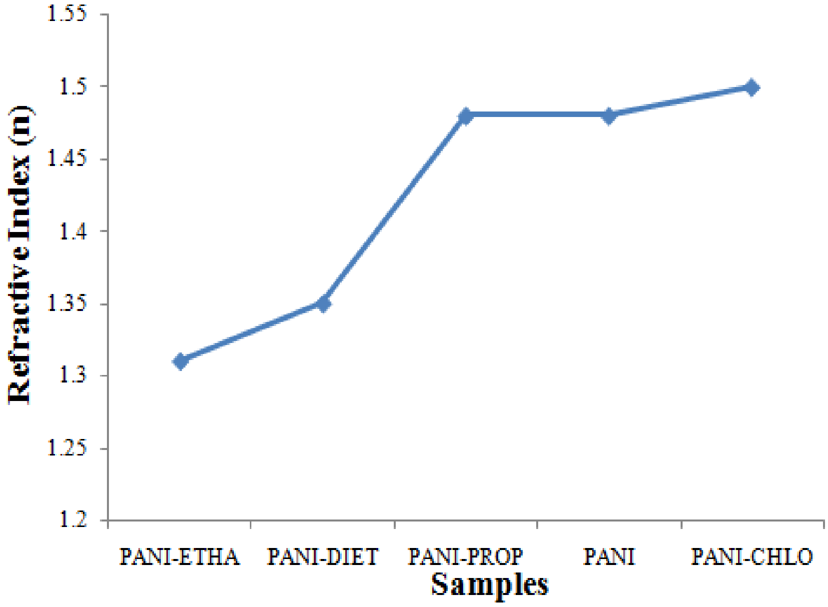

Fig.7: Plot of Refractive index (n) against pure PANI and PANI samples with organic solvents.

4.0 Conclusion

PANI samples doped with HCl$^-$ acids, are synthesized on soda lime glass substrate using *in situ* chemical oxidative polymerization technique with APS as oxidant and post deposition treatment is done with four different organic solvents; propanol (C_3H_7OH), ethanol (C_2H_6OH), chloroform ($CHCL_3$) and diethyl ether ($C_4H_{10}O$) using water bath method. UV-visible studies of the samples are performed with excitation wavelength chosen at 300*nm*.This is because the π-π* transition wavelength of the benzenoid unit, the unit responsible for transmittance in PANI, corresponds to about 330 *nm*. Transmittance is observed at around 571 *nm*. Highest transmittance intensity is recorded for PANI-chloroform, followed by PANI-diethyl ether, PANI-propanol, PANI-ethanol and pure PANI. The high Transmittance intensity of PANI-chloroform could be attributed to more orderly arrangement of benzenoid and quinonoid units. PANI-diethyl ether has the highest electrical conductivity despite the presence of bulky hydrogen in it. The possible reason may be the better crystallinity of PANI ($C_4H_{10}O$), which compensates for the heaviness of the dopant ions.

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Bala Yakubu Alhaji developed the methodology and analyzed the data. Ibrahim Abdullahi carried out experimental procedure for deposition of the polyaniline thin film and contributed to manuscript drafting. Ahmadu U. conceptualized the study and supervised the project. Muhammed Muhammed Ndamitso reviewed the manuscript and ensured technical accuracy.