Nanowire Gas Sensors for a Range of Analytes of Industrial interest

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1.0 ABSTRACT

In this research work, conductive polymers/DNA (CP-DNA) composite nanowires were chemically synthesized using a simple and low cost fabrication method by employing DNA as a template on which to carry out the polymerization. Their chemical (FTIR, UV-vis and XPS), morphological (AFM and TEM) and (electronic conductivity (two-terminal I-V characterization measurement) and volatile organic vapor sensing test were carried-out investigated.

2.0 INTRODUCTION

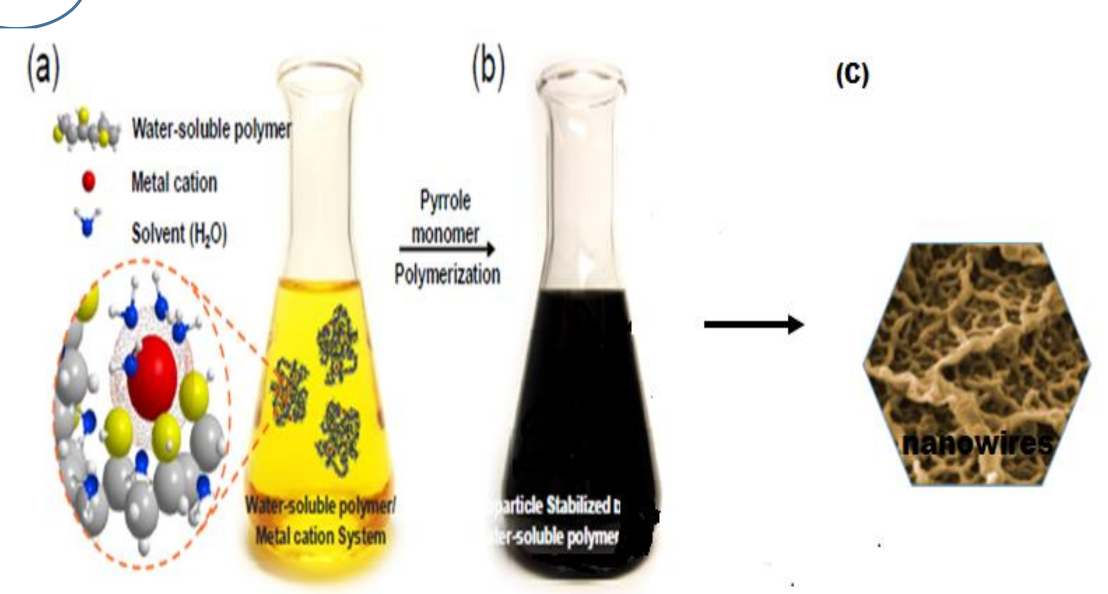
Gas sensor networks have a wide variety of applications in environmental and safety monitoring that can be very useful to businesses and the general public. However, gas sensor technologies are still developing and have yet to reach their full potential in capabilities and usage [1].

Scientific and technological communities globally have great interest on materials that can form well-defined materials on the nanometer scale.

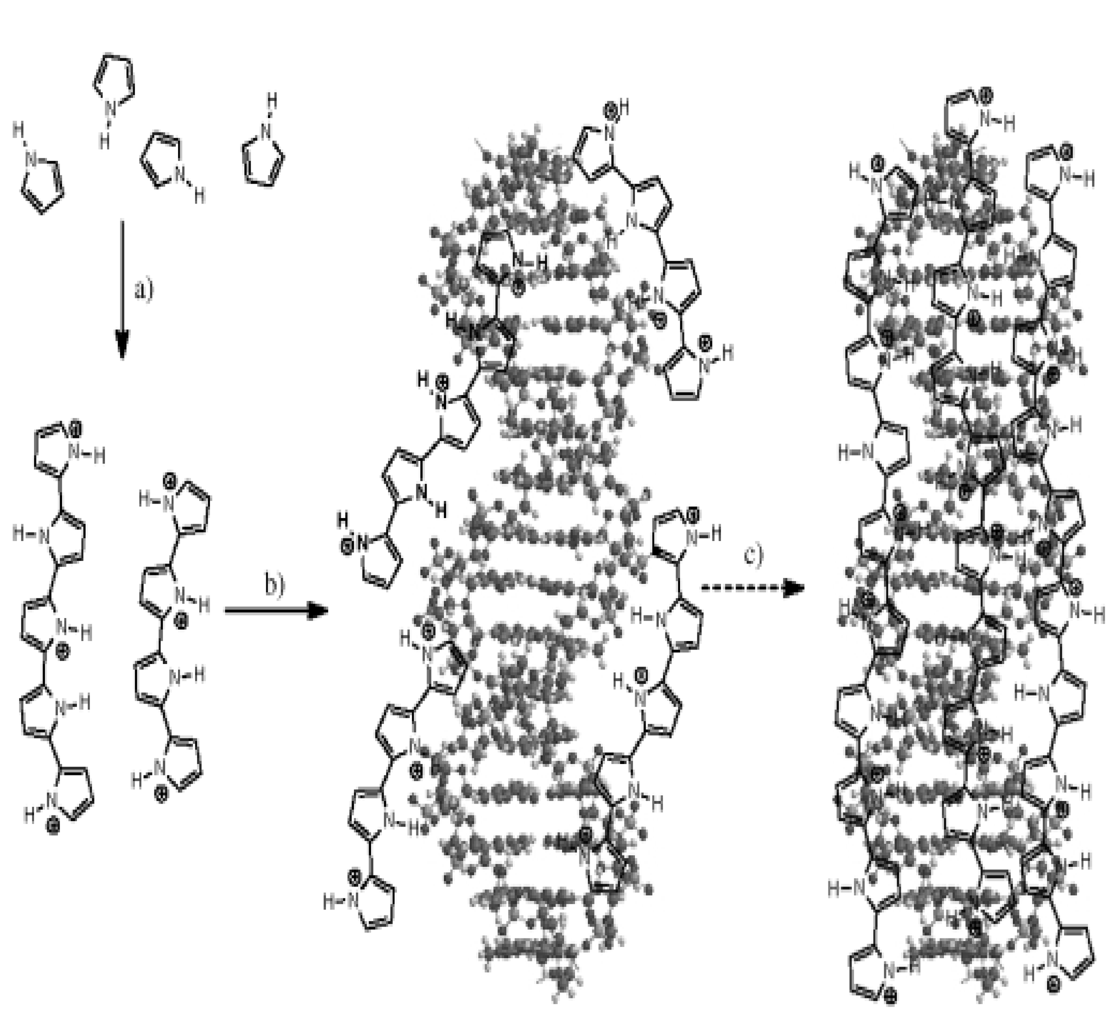
Conducting polymers (CPs) are unique materials because they exhibit electronic, magnetic and optical properties of metals and semiconductors while retaining the attractive mechanical properties and processing advantages of polymers [2].

Oxidative polymerization in DNA-containing solutions resulted in thin, homogeneous and uniform nanowires because the cationic oligomers are strongly attracted to the anionic sugar-phosphate backbone of DNA molecules. [3]

3.0 Polymerization of CP in DNA containing solutions



4.0 Proposed mechanism of self-assembly of DNA/CP nanowires



5.0 CHEMICAL CHARACTERIZATION

5.1 XPS Studies

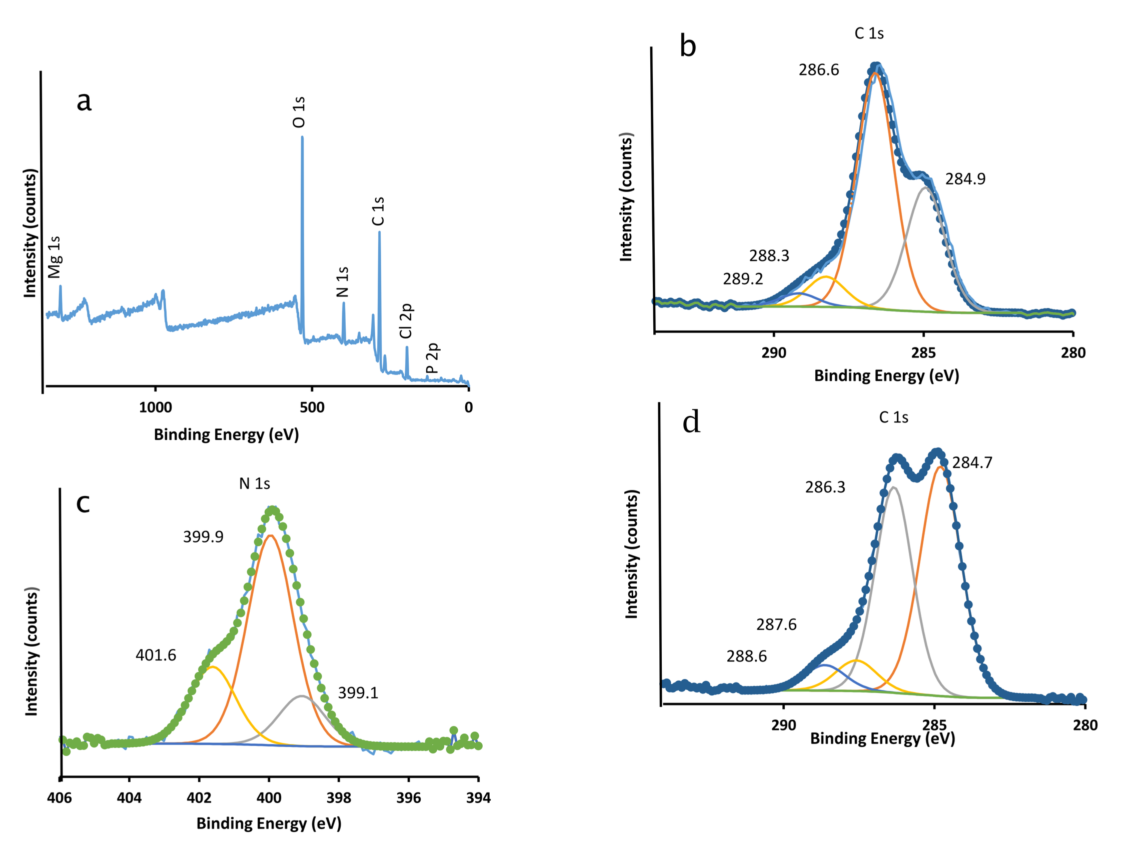


Figure 1. Core level XPS spectra of CP/DNA: (a) survey scan, (b and d) C1s spectra and (c) N1s spectrum

5.2 FTIR Studies

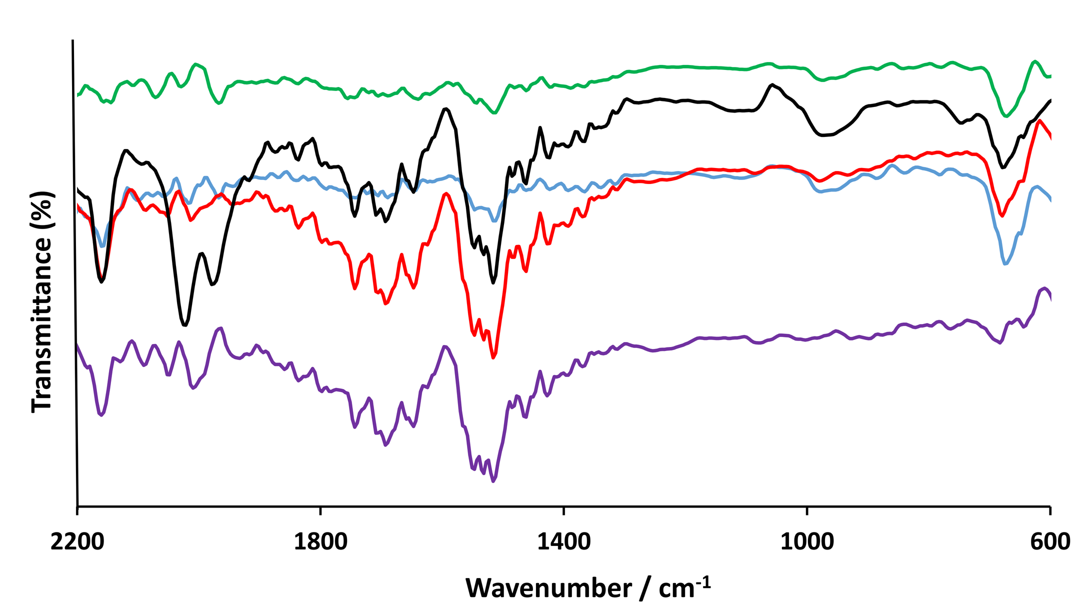


Figure 2. FTIR Transmission spectra of PIn/DNA vs. controls Spectra of indole (black), Polyindole (PIn; blue), λ-DNA (DNA; red), PIn/DNA nanowires (green) and the difference spectrum (PIn/DNA – DNA; purple, 120 scans co-added and averaged, 16 cm^{-1} resolutions. Samples solution (5µL) were deposited on a clean p-Si (100) chip (1 cm x 1cm) and dried in air for 1 hour prior to analysis. A clean p-Si (100) chip served as the background. The spectra are offset for clarity.

Table 1: Selected bands in DNA and CP/DNA FTIR Transmission spectra and their assignments

Wavenumber in DNA (cm^{-1})	Wavenumber in PIn/DNA (cm^{-1})	Peak Shift (cm^{-1})	Assignment
984	972	-12	N-H deformation/stretching of aromatic C-N bonds
1084	1091	+7	C-O deoxyribose stretch/ PO2- symmetric stretch
1516	1520	+4	In plane vibrations of cytosine and guanine
1647	1651	+7	C═N guanine and adenine C7═N stretches

5.3 UV-vis Studies

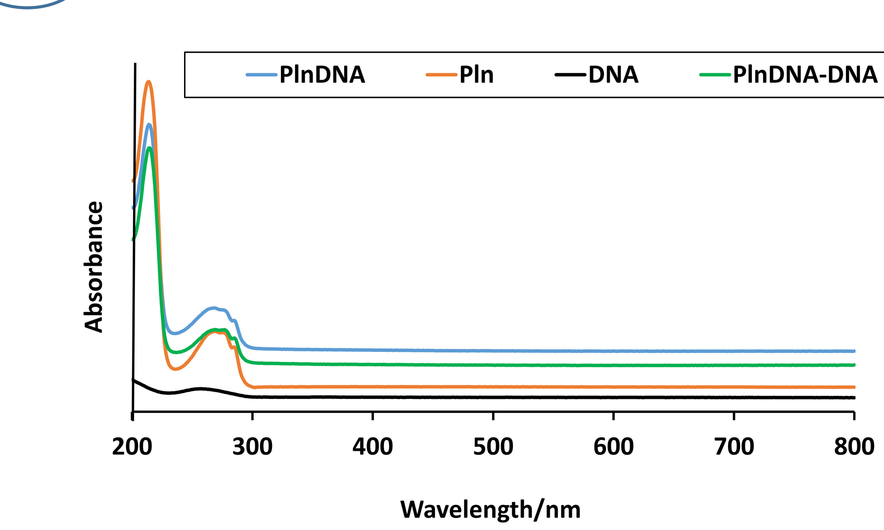


Figure 3. UV-Vis absorption spectra at different stages of the synthesis: absorption spectra of λ-DNA (black); aqueous PIn solution (purple); PInDNA solution (blue) and PInDNA –DNA (green)

6.0 MORPHOLOGICAL CHARACTERIZATION

6.1 AFM Studies

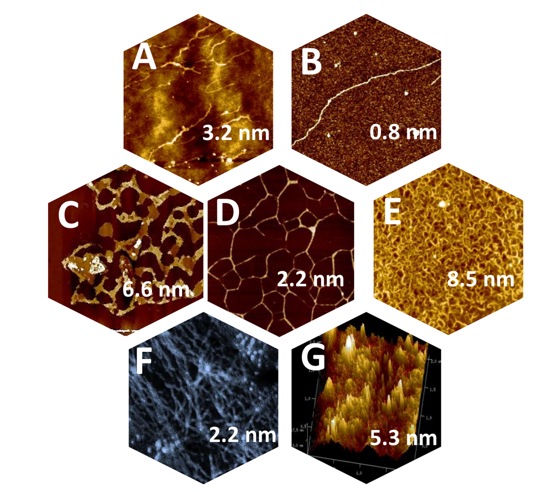


Figure 4. Tapping mode AFM images of CP/DNA nanowires showing single (B) and clusters with smooth, regular morphologies

6.2 TEM Studies

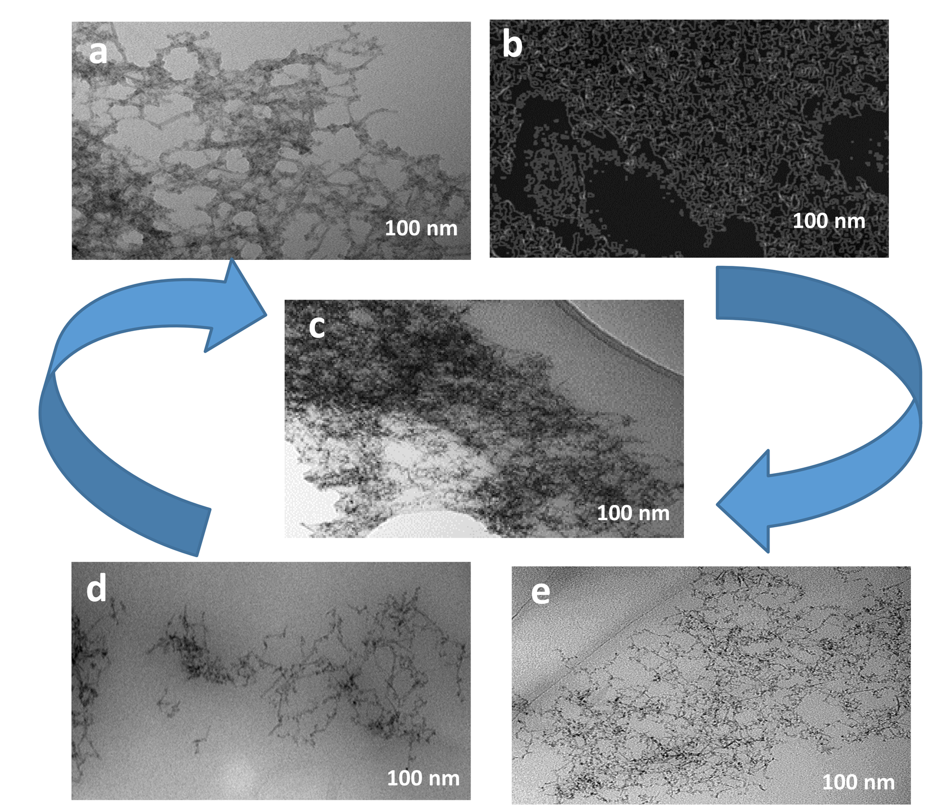


Figure 5. TEM images of CP/DNA nanowires after more than 24 h reduction time, showing large scale networks structures and enlargement of the nanowires

7.0 ELECTRICAL MEASUREMENT

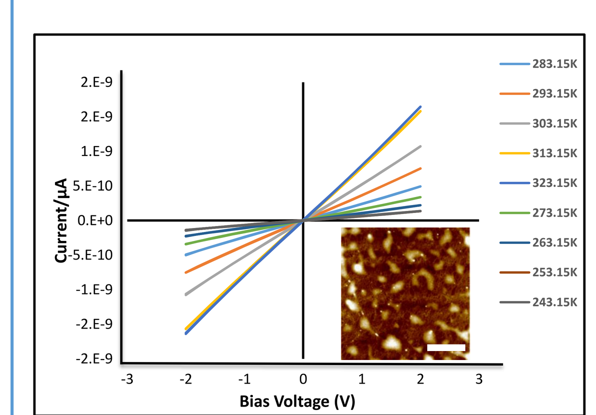


Figure 6. Current-voltage (I-V) curves of a two-point contact PIm/DNA nanowire at a temperature range from 243.15 K to 283.15 K (Inset: An AFM height image of the network, the data scale is 5.2 nm, scale bar = 500 nm)

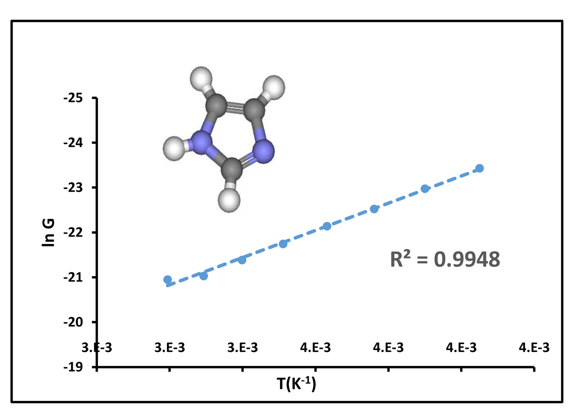


Figure 7. Arrhenius plot for the Conductance of a PIm/DNA nanowire

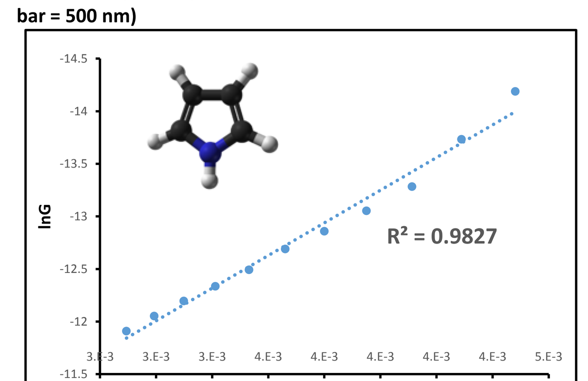


Figure 8. Arrhenius plot for the Conductance of a Ppy/DNA nanowire

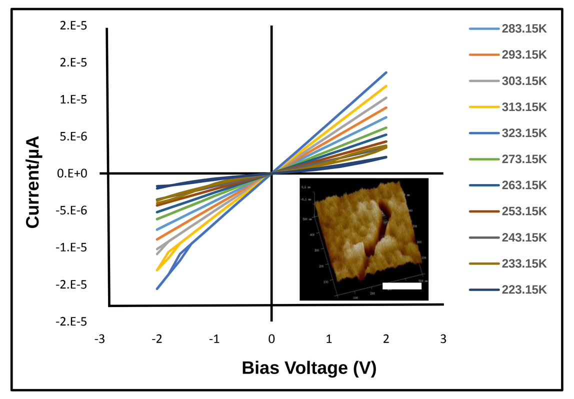
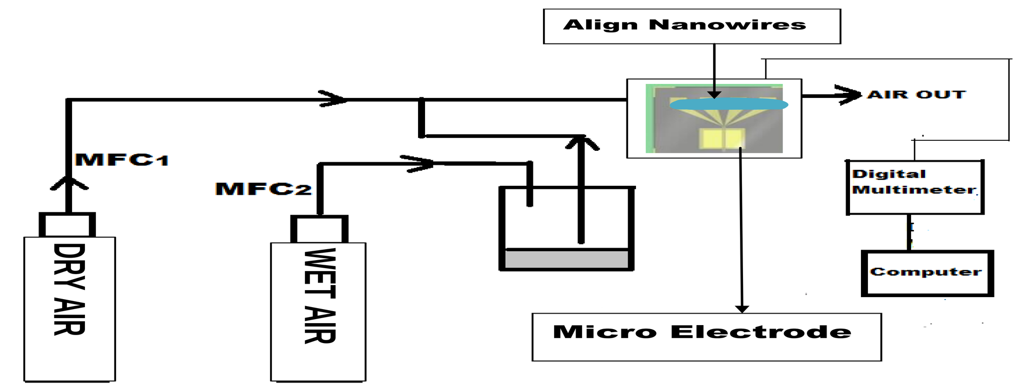


Figure 9. Current-voltage (I-V) curves of a two-point contact Ppy/DNA nanowire at a temperature range from 223.15 K to 283.15 K (Inset: An AFM height 3D image of the network, the data scale is 0.8 nm, scale bar = 500 nm)

8.0 Gas Sensing Test



Schematic diagram of the laboratory fume cupboard gas sensing set up

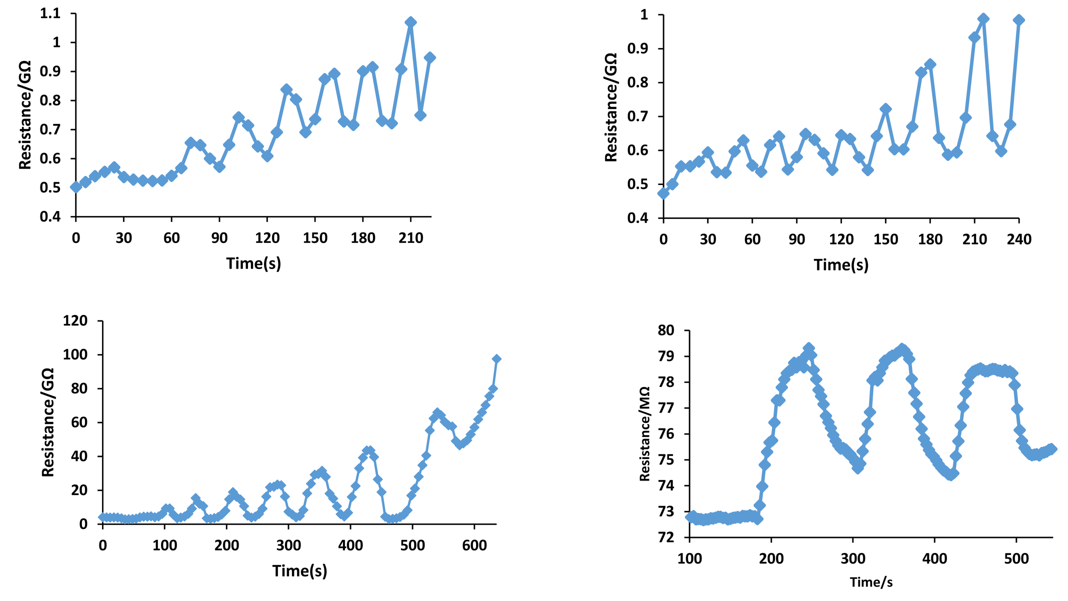


Figure 10. Qualitative response characteristic at room temperature of PpyDNA sensor to pulses of 0.1% Propanol in air

9.0 CONCLUSIONS

- The FTIR and UV-vis spectra of the product material provided evidence of the formation of a supramolecular hybrid polymer containing λ -DNA and conductive Polymers.
- AFM and TEM images before and after templating show a smooth and uniform morphology along their length. An increase of the average height from 1 nm to 20 nm after templating with FeCl3 was also observed
- XPS survey spectra of CP/DNA samples revealed the presence of the elements C and N in addition to Cl, O and P (which indicated the presence of DNA).
- No signature of the presence of iron was observed in the survey spectra which confirm that the FeCl3 was used only to drive the polymerisation without any oxidative damage to DNA.
- The current–voltage (I–V) data obtained shows that the nanowires are electrically conductive.
- Repeatability in response characteristics at room temperature of CP/DNA sensor to pulses of different volatile organic vapours in air, reveals the possibility of the nanowires to be good sensor materials.

10 FUTURE WORK

- Sensitivity studies with different analyte saturated vapours
- Understanding the conduction mechanism
- organic vapour combination that will works best
- Sensing test at variable temperature

11 REFERENCES

[1] Al-Hinai M. et al. Mater. Chem. A, 2016, 3, 11991

[2] Tingting Y. et al. J. Mater. Chem. A, 2015, 3, 11991

[3] R. Hassanien et al. Nanotechnology, 2012, 23

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