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Simple Electronic Circuit for Measuring Electrical Conductivity of Conducting Polymer Traducers

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Abstract:

The proposed measurement technique for electrical conductivity is a handy device to measure the unknown resistance of a sensor whose resistance changes according to environmental changes. Polypyrrole (PPy) was synthesized by the chemical oxidative method. The electrical conductivity was altered by using various dopants. Thin films of these preparations were cast on the inter digitated electrodes or by socking it with cotton material and spandex material to study the detection of the electrical signal produced by polymer transducers. The resistance changes according to environment changes, which amplified to desire value so that it can come in measurable range.

Keywords: *Polypyrrole, doping, transducers, electrodes, electronic circuit*

1. Introduction:

In the last few years, intrinsic conducting polymers having conjugated double bonds attracted much attention as advanced smart materials. Polypyrrole (Ppy) is the most popular and promising among all other polymers for commercial uses due to its stability factor ease in synthesis, and excellent conductivity. Ppy can often be used as a multipurpose transducer for many applications like gas sensors [1, 2], actuators [3], super capacitors [4, 5], mobile batteries, Field effect transistors, and functional membranes, etc. [6, 7]. They are useful as electro-mechanical devices. Just like most of the conductive polymers Polypyrrole also behaves like p-type semiconductors. And its conductivity can be changed using doping / dedoping. A large number of sensing applications are designed by exploring these characteristics of conducting polymers.

Conducting electro active polymers (CEPs) such as polypyrrole (Ppy), Polyaniline and Polythiophene constitute a class of polymeric materials that are inherently able to conduct charge through their conjugated polymeric structure. Ppy, in particular, has a significant role to play, as it is easily prepared in several formats viz films, powders, or composites. It has a comparatively high conductivity with significant stability in its conducting state. Polypyrrole, in the form of films, has been used for sensors for the detection of various gases and volatile organic compounds [8-11].

A. Sensors:

The most common types of sensors used are conductivity sensors (Metal Oxide Semiconductor and Conducting Polymer types); Metal Oxide Semiconductor Field Effect Transistors (MOSFET), optical sensors, and piezoelectric sensors.

Metal oxide semiconductor (MOS) sensors have been used extensively in (electronic) gas sensing instruments and are readily available commercially [13]. Typical offerings include oxides of tin, zinc, titanium, tungsten, and iridium, doped with a noble metal catalyst such as platinum or palladium [12]. The metal oxide semiconductor is deposited between two electrodes and over a heating element (see Figure 1) that operates at temperatures from 200^0C - 400^0C. The mechanism most responsible for gas reactions with MOS in the air at elevated temperatures is the change in the concentration of the adsorbed oxygen at the sensor surface [13]. As the number of charge carriers decreases, the conductivity of the sensor decreases, and the change in the semiconductor resistance can be measured during this reaction. The oxide, the doping material, and the operating temperature allow controlling sensor selectivity as per the sensitivity.

The drawbacks of MOS sensors are because of the high operating temperature, power consumption is a particular concern in applications.

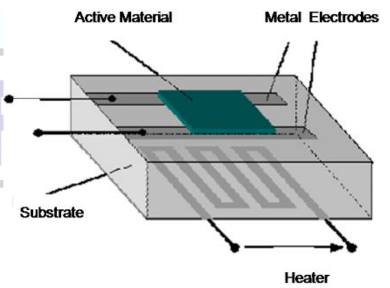


Figure 1: MOS sensor

B. Conducting Polymers:

Simple conducting polymer sensors are made up of two electrodes with a conductive polymer coating between them. As shown in Figure 2, the active material is a conducting polymer from such families that include Polypyrrole, Polythiophenes, indoles, or furans. Changes in the conductivity of these materials occur as they are exposed to the various types of chemicals that interact with the polymer backbone [12]. The interaction of gas with the sensor surface affects the transfer of electrons along the polymer chain. It is this reaction that changes the sensor conductivity. Fabrication of these sensors involves forming two electrodes separated by a gap of 1 to 2 mm. The conducting polymer is then deposited or pasted between the two electrodes [12]. The response time of the sensor is inversely proportional to the polymer's thickness. Because conducting polymer sensors operate at ambient temperatures, they do not need heaters.

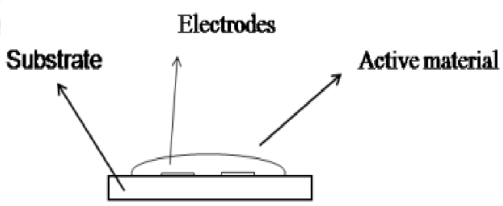


Figure 2: Conducting polymer sensors

In the present paper, we report the preparation of gas sensors by conducting polymer like polypyrrole, attempts were made to improve the conductivity and response to gases by using dopants such as $LiClO_4$, p-TS, NSA. The Printed Circuit Board (PCB) with two electrodes separated by a gap of 10 to 20 micrometers is prepared. The conducting polymer was then pasted between the two electrodes by making a slurry of it in a distilled water. An electronic circuit was designed and prepared. The response of these materials, when exposed to environmental changes is being reported for a regular interval of time.

II Experimental methods and preparations:

Highly pure Pyrrole was distilled before use. All other chemicals were of reagent grade. All solutions were prepared using distilled water. All reactions were conducted at a temperature of 5^0C [14]. The solution of the oxidizing agent, $FeCl_3$, was prepared using distilled water and was used in the proper ratio of monomer: oxidant [15]. Polypyrrole with dopants was also prepared in the standard way to check the changes in characterization of it.

The Polypyrrole was prepared chemically by the simple titration type method. 1 M Pyrrole solution was prepared in distilled water and mixed with oxidizing agents in the desired ratio slowly. The solution is kept stirring for several minutes. Then the reaction was continuing for few more hours. This preparation was kept steady so that Ppy powder settled down. The Polypyrrole powder was filtered and washed many times to make it impurities-free. The precipitate was dried for 2 days at room temperature to obtained pure Polypyrrole.

Printed circuit boards (PCB) were used to measure one of the applications of polymer transducer, the gas response. The electrodes, separated by 1mm. from each side, were prepared (Figure 3) and the slurry of Polypyrrole powder prepared with distilled water was spread over it uniformly and dried at room temperature. The Ammonia gas was passed with Nitrogen gas as a carrier through the chamber in which the PCB was fitted firmly. The current was recorded, at a constant voltage, for every 30 seconds.

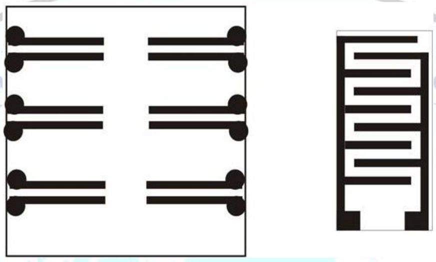


Figure 3: Printed circuit board (PCB) for gas detection

A. CIRCUIT ANALYSIS:

(a)**Concept**: The concept used here to measure the unknown resistance is to pass a small constant known amount of current through that resistance and measure the voltage produced across it. The voltage measured divided bypassed current gives the values of resistance. Precise the amount of current flowing, precise the resistance can be measured. So the Precision Current Source is created as follows

Components used:

OP07- Op Amp

BC547C- NPN transistor

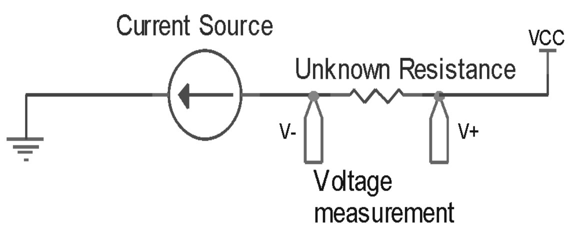
7815, 7805 and /or 7915- Voltage Regulator

Precision Resistor Known value resistor

Power Supply ± 15 V dc

CIRCUIT DESCRIPTION:

Figure 5: Block Diagram: Resistance measurement using constant current source



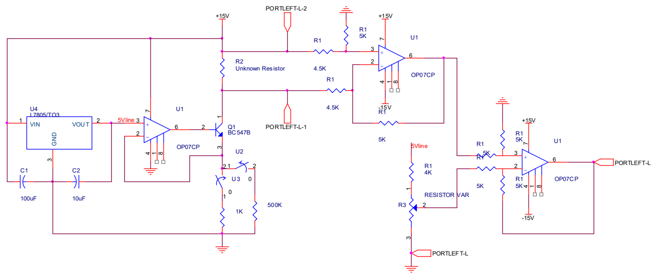


Figure 6: Resistance measurement circuit for sensor using constant current source

(b) **Working:** As shown in Figure 5, a constant 15 Volt supply is generated with the help of voltage regulator 7805. Op-Amp has given a supply of 15V at +Vss and 0(GND) at –Vdd pin. At +ve input pin of OP07, a constant 5V supply is given with the help of 7805. Other connections to BC547 and unknown resistors are as shown in the figure. Due to the very low offset voltage of OP07 Op-Amp the voltage at its –ve input is also 5V which is given to one end of Precision Resistor of known value- R. So current flowing through this resistance is I = (5/R). This current comes as emitter current IE from the transistor. As IE is almost equal to the IC current flowing through the unknown resistance is also the same. Thus by measuring the voltage across unknown resistance and dividing it with the known value of current we find resistance.

R (unknown) = V (measured)/ Current known

(c) **Error is reduced by:**

Using Op. Amp. of very low offset, this ensures that voltage at –ve input of op-amp remains almost same as that at +ve input i.e. 5V.

Using transistor of very high gain, since IE = IC + IB current Ic is less than IE by amount IB. Thus by very high gain means IB << IC so the current passing through unknown resistance IC is almost equal to current we are taking for granted- IE.

By using a precision resistor the current flowing matches the calculated IE to large extent.

(d) Resistance measurement Range:

The value of the precision resistor is selected according to the range of amount of resistance needed to be measured. To measure the high value of unknown resistance the precision resistance is set higher.

The target range required for us was:

100 to 1000 Ω & 100 to 1000 K Ω

To achieve this with maximum accuracy for a smaller range of 100 to 1000 Ω the precision resistor is set at exactly 1000 Ω, so that Current flowing I = 5/1000 i.e. I= 5mA

Now when voltage measured across unknown resistance comes out to be 'V' it is divided by I to get R i.e.

R (unknown) = V (measured) / 5mA

The accuracy achieved in this range of resistance is 0.1%

For a higher range of 100 to 1000 K Ω

The precision resistance was set at 1000KΩ so that current flowing is

I = 5/106 = 5μA

To measure resistance the same procedure is carried out

1) Resistance Sensor board circuit shows only one sensor. Repeat the circuit seven times from 5 V lines for 8 sensors.

2) PORT LEFT-L (pin 6 of U1) lines are to be connected in input 1 to 8 in the data acquisition board

3) Ground of all eight R3 pots are to be connected to the ANAGND point.

III. Results and discussions:

All the Polypyrrole samples were studied using our circuit for the detection of ammonia gas. A typical plot of Resistance vs. Time for polypyrrole prepared using FeCl3 as oxidant and various dopants exposed to ammonia gas is given in Figure 9. All samples were studied for 3 cycles to check their reproducibility and absorption and desorption process. It may be seen from the Figure. 6(a, b, c, d, e) that the R vs Time plot for 2nd and 3rd cycles somewhat differ from the first cycle. This may be because desorption maybe not be completed within the given time.

The Sensitivity factor is calculated using the equation

$$S = \frac{Rg - Ro}{Ro}$$

Where Rg and Ro are resistances with gas and without gas (in the air) respectively [16, 17]. The values calculated during the present investigation for sensors fabricated using differently doped polypyrrole and for different gases are given in Table 1.

The response of different materials towards gas was seen to be different. When pure Ppy and Ppy doped with LiClO4 were exposed to gas like ammonia, The current was increased means there are decreases in resistivity. It was noted during these investigations that when Ppy doped with p-TS and NSA were used, a decrease in current i.e. increase in resistivity was observed when exposed to ammonia gas. The electrical conductivity of these two samples is more than that of pure Ppy.

Table – 1: Sensitivity for Ammonia of Ppy prepared with different dopants

Sample	Sensitivity for Ammonia
Pure Polypyrrole	0.84
Polypyrrole with $LiClO_4$	0.86
Polypyrrole with p- TS	0.55
Polypyrrole with NSA	1.66

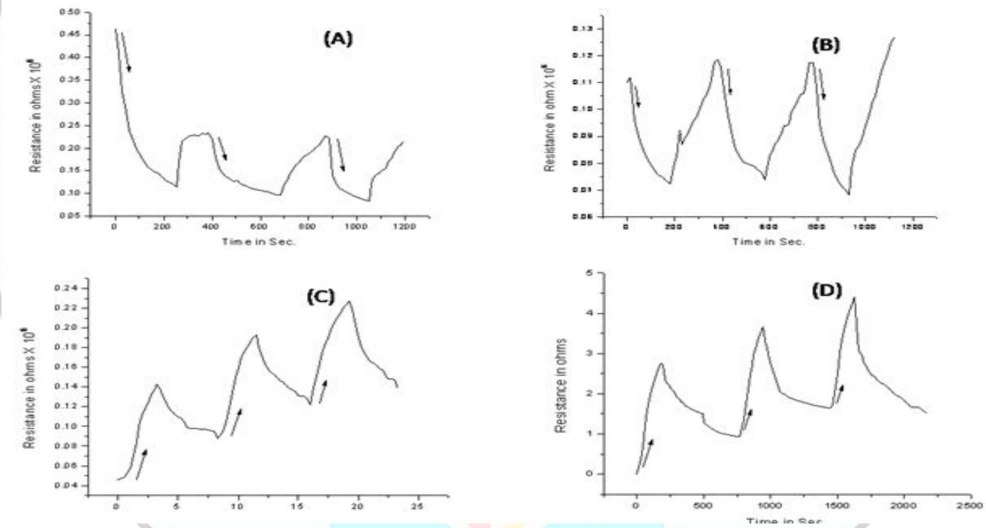


Figure 9: Resistance graph of PPy prepared with (A) $FeCl_3$ and (B) $LiClO_4$, (C) p-TS and (D)NSA as dopants

IV. Conclusions:

Polypyrrole was synthesized in the pure form and doped with various dopants. These materials were used as gas sensors for the detection of ammonia as one of the transducers. The electrical conductivity was tested by the electronic circuit. It was found that Circuit works quite well and very sensitive to measure very small changes in conductivity efficiently and the signal produced can be easily interfaced with a computer which can be analyzed for further study. As ammonia gas is giving different responses to different sensors prepared with various dopants this can be considered as the signature of this gas and can be used as the fingerprint of this gas for various studies.

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