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POLYPYRROLE INFUSED COTTON FABRICS: AN ELEGANT SOLUTION FOR GAS SENSING

Chemical Science

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ABSTRACT

Air pollution is a silent killer that has captured many regions of our planet. Nine out of ten human breathe air with pollution levels that surpassing W.H.O. limits. One of the perilous atmospheric pollutants that endanger both the environment and human life is Nitrogen dioxide (NO2). This scenario increases the necessity to have device which can detect the NO2 gas. The paper presents a cotton fabric-based gas sensor using polypyrrole (PPy) as the sensing material. Due to its distinct electrical and chemical characteristics, PPy is considered as a good candidate for gas sensing applications. The In-Situ chemical oxidative polymerization techniques were used to synthesize PPy with Iron (III) Chloride as oxidant.

This study investigates the creation of a cotton fabric-based NO2 gas sensor with a PPy sensing layer, focusing on reducing NO2 risks and supporting the use of PPy as the sensing material. The synthesis procedure and characterization methods like FTIR were used to understand the chemical bonds and chemical makeup of the PPy-coated fabric. Future research should focus on improving sensor performance and exploring applications in environmental monitoring and safety systems.

KEYWORDS

NO_2, PPy, gas sensor, Cotton, Fabric

INTRODUCTION:

In recent years, there has been a rising fascination with creating fabrics that offer unique attributes. Smart conductive textiles have surfaced as an enticing field in the world of smart fabrics, intriguing the attention of researchers, engineers, and designers. These textiles exhibit an extraordinary capacity to engage with their immediate surroundings or the user, unlocking thrilling prospects for use in healthcare, sports, the automotive sector and aviation. The quest for innovation has led to the rapid development of smart materials, paving the way for groundbreaking advancements across various industries. These fabrics are not just passive materials, they are active participants in our daily lives, engaging with the world around us. It's as if your clothing has come to life.

At the heart of this textile revolution lies conductive polymers, which are organic materials with the remarkable ability to conduct electricity. They are like the superheroes of the textile world, combining the electrical characteristics of metals with the mechanical flexibility of plastics. These polymers have become the building blocks of smart fabrics, offering a multitude of benefits, including low weight, cost-effectiveness, adjustability in electrical conductivity, flexibility, biocompatibility, sensing, actuating capabilities, and ease of production. But not all conductive polymers are created equal. Among them, Polypyrrole (PPy) stands out as a star player. PPy, a conductive polymer with exceptional electrical conductivity, ease of production, and environmental resilience, has attracted significant attention from researchers and scientists. It's like the most valuable polymer of the textile world. Researchers are now exploring how to coat cotton fabrics with PPy, as cotton's softness and moisture-absorbing properties make it an ideal substrate. Smart fabrics that not only keep you comfortable but also generate electricity and respond to your needs a true fusion of fashion and function.

The applications for conductive fabrics are mind-bogglingly diverse. They find their place in biomedical materials, flexible supercapacitors, strain sensors, and electromagnetic shielding. Furthermore, they are like the guardians of our well-being, helping to detect and monitor harmful gases like Nitrogen dioxide(NO_2). This gas is a hazardous to both human health and the environment, making it crucial to keep its levels in check.

Researchers are now delving deep into the challenge of detecting extremely low concentrations of nitrogen dioxide, aiming to protect us from its harmful effects. This paper discusses a journey into the creation of conductive fabrics by coating cotton with polypyrrole. It explores how the fabric's properties are affected by the reaction conditions and employs advanced techniques like Fourier Transform Infrared (FTIR) to study its characteristics. Moreover, the article introduces the development of a gas sensor using this smart conductive cotton fabric, shedding light on its sensitivity to NO_2, a vital step in the on-going battle to ensure our safety and the health of our planet.

MATERIALS AND METHODS:

Materials:

The material being used was a pure cotton cloth (Bleached Printed Cotton Cloth) acquired from Bombay Rayon Fashions Ltd., Mumbai. The Pyrrole purchased from Spectrochem (India) Pvt. Ltd. Also, Iron(III) Chloride ($FeCl_3.6H_2O$) purchased from Loba Chemie. Ltd. of AR grade were used. Double distilled water was utilized for the sample preparation process.

Methods:

Synthesis of Polypyrrole based Cotton-Fabric Sample:

To prepare the commercial cotton fabrics for use, they underwent a cleaning and drying process to eliminate any underlying impurities such as starch, oils, and waxes. The fabric samples were then subjected to a chemical oxidative polymerization method using pyrrole as the monomer and $FeCl_3$ as the oxidizing agent in a 1:1 monomer to oxidant ratio. The reaction of polypoyrrole synthesis is shown in Figure 1.

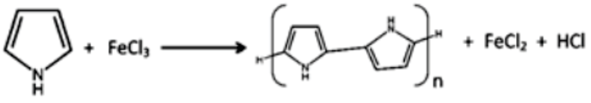

Figure 1: Chemical Reaction of Synthesis of Polypyrrole

Briefly, the process involved adding 10 mL of $FeCl_3.6H_2O$ drop by drop to 1 ml of a 1M aqueous Pyrrole solution. The mixture was continuously stirred using a magnetic stirrer for four hours at 5°C. Once the reaction was complete, a cotton fabric was immersed in the solution and swirled for an additional five hours at a low RPM. The fabric was left in the solution overnight. The following day, it was stirred for 8-10 hours and then removed and dried. The observations were made for the pure cotton sample and the PPy-coated cotton sample.

Characterization:

Measurement Of The Infrared Spectra:

The infrared (IR) spectra were measured using the Attenuated Total Reflectance (ATR) technique on a Fourier transform infrared (FTIR) spectrometer (Bruker ALPHA II FTIR Spectrometer) in the range of 4,000-500 cm^{-1} with Eight scans and a resolution of 2 cm^{-1}.

Dc Electrical Conductivity Measurement:

Under a pressure of 5N, the surface resistance of the samples was evaluated using a four-point probe resistivity instrument with copper electrodes. Two probes were used to measure electrical conductivity. Using the formula, we have determined the sample's electrical conductivity before and after washing with deionized water.

$$\text{Conductivity, } \sigma = \frac{Vt}{lA} = \frac{t}{R \times A}$$

Where, V = voltage applied, t = Thickness of the sample, I = current, R= resistance of the sample, A = Area of the sample.

RESULTS AND DISCUSSIONS:

The polymerization of PPy resulted in the development of black cotton fabrics; ensure that the polymer completely encased the fabric surface. Figure 2 displays the actual picture of the PPy/Cotton fabric sample. FTIR characterization had been carried out to verify the fabric's polymerization.

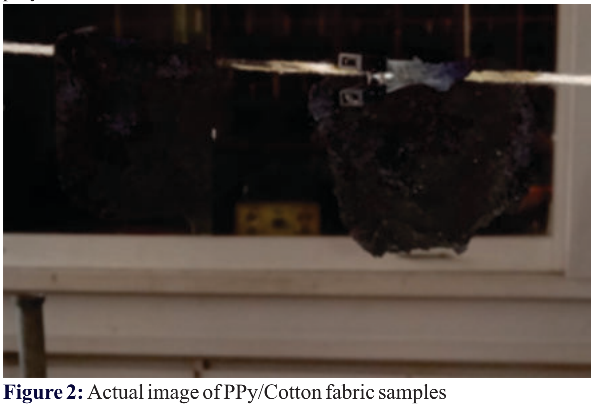

Figure 2: Actual image of PPy/Cotton fabric samples

FTIR analysis:

Figure 3 shows the FTIR curves of unprocessed normal cotton fabric, PPy/cotton fabric sample.

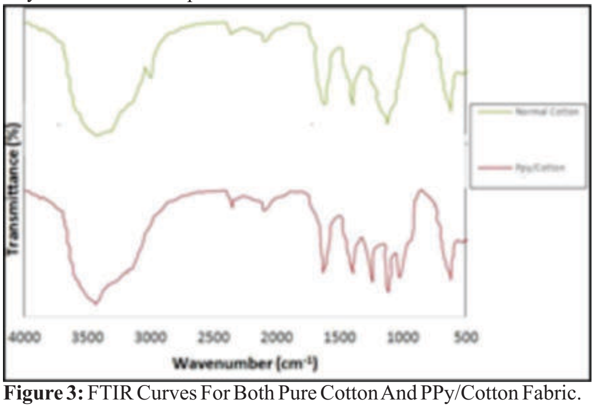

Figure 3: FTIR Curves For Both Pure Cotton And PPy/Cotton Fabric.

The pure cotton FTIR curves show that there is evidence of O-H stretching vibration at peak 3456 cm^{-1}, and C-H stretching vibration at peak 2992 cm^{-1}. After the alcohol has partially oxidized to the carboxyl group, the carbonyl group's stretching vibration peak is located at approximately 1749 cm^{-1}. The untreated cotton's typical infrared absorption peaks simultaneously emerged at 1388 and 1127 cm^{-1}. However, at 2822-1740 cm^{-1}, the peak values of the PPy/cotton composites are higher than those of cotton. The increasing water-based in situ polymerization process is the reason of this. The absorption peaks observe at 1634, 1426, 1267, 1227 and 1188 cm^{-1}. These peaks were distinct because the PPy/cotton sample had been rinsed in deionized water, which cleans the surface of dirt and contaminants.

Electrical Properties:

The amount of polymer was calculated by measuring the surface resistance of cotton specimens as a function of temperature. At all temperatures, the surface resistance of the conductive cotton fabrics with PPy coating was lower than that of the untreated normal cotton fabrics. Normal untreated cotton cloth has an extremely high surface resistance. Figure 4 depicts the temperature with the surface resistance of PPy/Cotton samples. Experimentally, adding PPy to cotton fabric could have an effect on the electrical resistivity of PPy/cotton fabric. It is feasible to improve the electrical conductivity of cotton fabric by this technique.

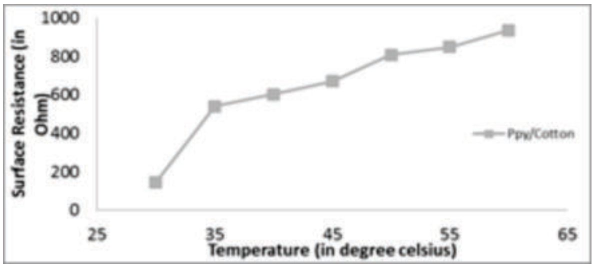

Figure 4: Temperature With The Surface Resistance Of PPy/Cotton Samples

The current-voltage (I-V) characteristics for PPy/Cotton samples with respect to temperature are shown in Figure 5 below. We have calculated electrical conductivity which is 1.45 X 10^{-2} Scm^{-1} for PPy/Cotton fabric which is much higher than the pure cotton sample.

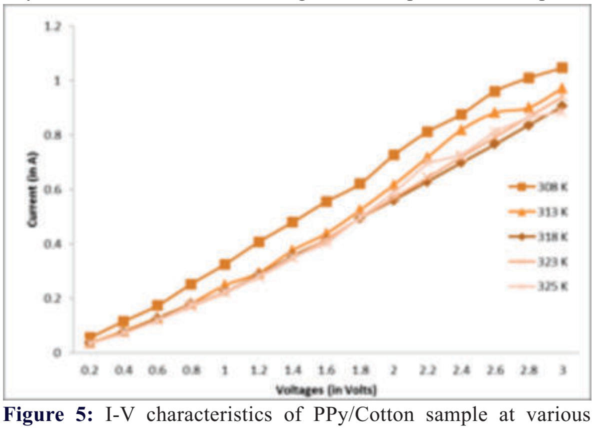

Figure 5: I-V characteristics of PPy/Cotton sample at various temperatures

Fabrication Of Gas Sensor:

Finally, these PPy/Cotton fabrics were used to detect gases. To detect and measure the quantity of gaseous pollutants, sensors are essential. PPy is used in the manufacturing of gas sensor devices in this instance. The gas sensing setup is illustrated in Figure 6.

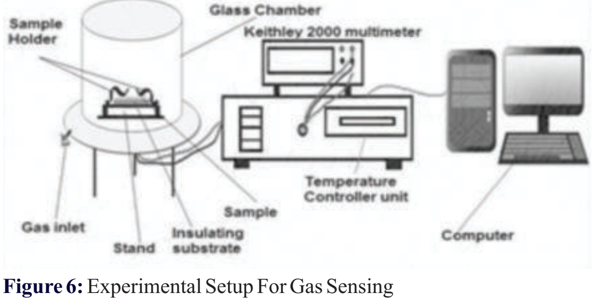

Figure 6: Experimental Setup For Gas Sensing

The temperature-controlled resistance of a piece of conducting fabric was measured over time using a Keithley 2000 Multimeter. NO_2 gas concentrations ranging from 5 ppm to 65 ppm were subjected to the sensor in the test chamber to determine its sensitivity. Figure 7 depicts the sensitivity of composite fabrics for various concentrations after exposure to NO_2 gas.

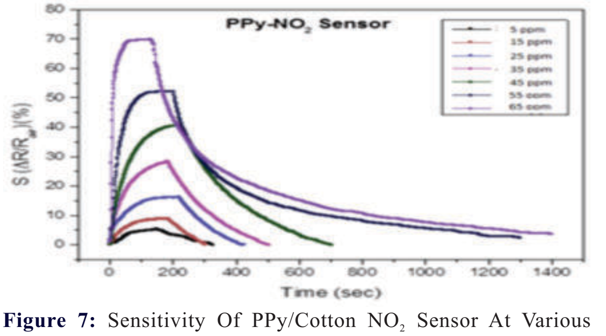

Figure 7: Sensitivity Of PPy/Cotton NO_2 Sensor At Various Concentrations

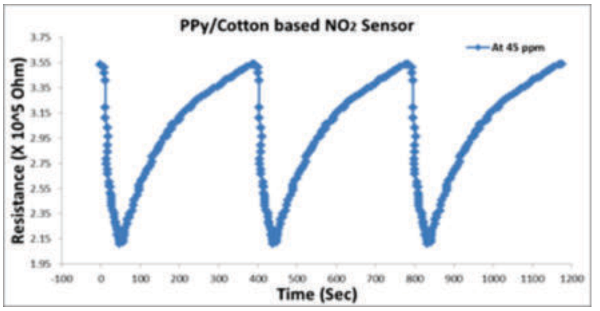

Figure 8: Resistance characteristics of PPy/Cotton based NO_2 gas sensor at 45 ppm concentration

We obtained the repetitive response of PPy/Cotton sensor to 45 ppm of NO_2 gas. For these ppm value, the resistance before and after exposure of NO_2 gas with function of time is recorded in Figure 8.

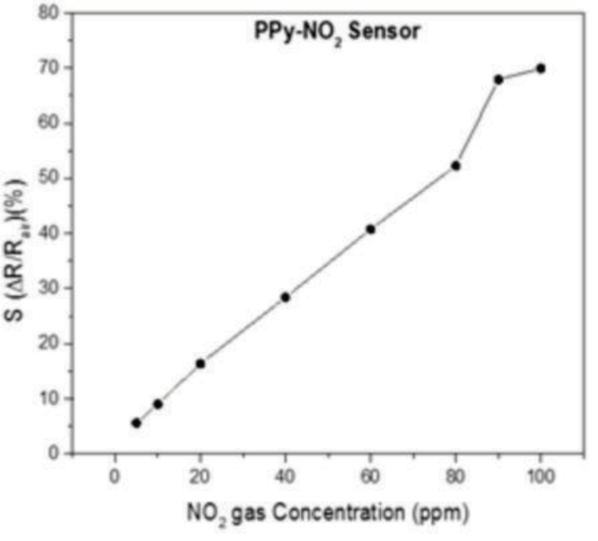

Figure 9: Sensitivity of PPy/Cotton based NO_2 gas sensor

Figure 9 displays the sensitivity of the NO_2 gas sensor at various concentrations. The sensor's sensitivity increased along with the concentration of NO_2 gas. This sensor shows very fascinating results of sensitivity during NO_2 gas exposure, made this sensor very advantageous in detecting hazardous NO_2 gas. In the future research, this sensor might be used to detect other hazardous gases.

CONCLUSION:

In conclusion, our study successfully illustrates the synthesis of PPy-coated cotton fabrics via in situ chemical polymerization technique. FTIR characterizations validated the interactions of $FeCl_3$ and PPy on cotton fabric. Even after washing, the high electrical conductivity found in the PPy coated fabrics emphasizes their enhanced stability. Furthermore, the manufactured PPy-coated fabrics performed admirably as NO_2 gas sensors, with extraordinary responsiveness, rapid recovery, and great repeatability. These discoveries pave the way for the creation of advanced textile-based technologies and emphasize the need for additional study in this promising subject.

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