Design and Research of Electromagnetic Monitoring and Visualization Intelligent Flexible Devices

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Abstract: Based on the principle of electrochromism, this paper studies its application in the monitoring of electromagnetic field strength changes in the environment, aiming to provide a theoretical basis for smart wearable textiles. In this paper, the conductive path between the electromagnetic wave detector and the electrochromic device is built to provide the required color-changing voltage conditions for the polyaniline electrochromic device. The polyaniline is synthesized by microemulsion polymerization using a scanning electron microscope and an X-ray diffractometer. Electrochemical workstation and infrared spectrometer systematically analyze the morphology, crystallization, chemical structure and electrochemical properties of polyaniline film; fabricate polyaniline electrochromic device with "sandwich" structure, and test its optical with visible light photometer. The performance, combined with the electromagnetic wave detection device, has developed an electromagnetic monitoring visual intelligent flexible device that can be packaged on the fabric. The results show that the prepared polyaniline electrochromic material has good discoloration performance, and the electromagnetic monitoring and visualization intelligent flexible device encapsulated in the fabric can respond to the color change according to different electromagnetic fields in the environment.

1. Introduction

Electrochromic materials are materials that undergo reversible color changes under applied voltage conditions [1]. As one of the most typical electrochromic materials, polyaniline (PANI) not only has the advantages of good environmental stability, low cost, good optical effect, fast color conversion, etc., and the cycle reversibility is also good [2]. Its structure is shown in Figure 1 [3].

![Polyaniline molecular structure](image)

It has been found that the color and conductivity of polyaniline are different when the degree of redox (y value) is different, as shown in Table 1 [4].

| y value | Commodity Description         | Colors     | Conductivity          |
|---------|------------------------------|------------|-----------------------|
| 1.0     | Colorless emeraldine Light yellow | Insulator |                       |

Table 1 Different y values correspond to different PANI, color and conductivity

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However, pure electrochromic materials are not practical, and electrochromic devices (ECDs) must be fabricated according to certain structures and principles [5]. Based on the detection function of electromagnetic wave detector and the discoloration function of electrochromic device, this paper develops an intelligent and visualized electromagnetic wave monitoring device using polyaniline electrochromic device which can display different colors according to different electromagnetic field intensity, so as to provide a certain theoretical basis for the diversification of the function of radiation protection suits.

2. Preparation and Characterization of Polyaniline Films

Polyaniline emulsion was prepared by microemulsion polymerization, and polyaniline film was prepared. The microstructure, crystallinity, chemical structure and morphology of the film were analyzed by scanning electron microscopy (SEM), X-ray diffraction (XRD), infrared spectrometer and electrochemical workstation. Electrochemical performance, ready for the material of the electrochromic layer of the subsequent electrochromic device.

2.1. Preparation of polyaniline emulsion

2.1.1 Raw materials and instruments. The main materials for the synthesis of polyaniline by microemulsion polymerization are Ammonium persulfate (APS), 4-Dodecylbenzenesulfonic acid (DBSA), Polyvinyl alcohol (PVA) and Aniline (An). DBSA acts as an emulsifier and dopant and provides an acidic reaction environment; APS is an oxidant, which initiates polymerization of aniline monomer; PVA is a film-forming agent that does not participate in the polymerization of aniline, and its role is to improve the film forming ability of polyaniline. The main instruments are Digital display type overhead (RW 20 digital), Electronic balance (LE104E/02), Glue machine (KW-4A), Vacuum drying oven (DZF-6050), Electric thermostatic water bath (HWS24), Ultrasonic cleaner (KQ-700B) and Cryogenic coolant circulation pump (DLSB-5L/40).

2.1.2 Preparation methods and processes. 1.97 g of PVA was dissolved at 90-95 °C, and cooled to room temperature; an appropriate amount of APS was weighed and dissolved in 10 mL of deionized water, and sealed for use. Weigh 2.38 g DBSA and 0.8 g AN. Turn on the low temperature coolant circulating pump, adjust the temperature to 0 ~ 3 °C, transfer the three-necked flask into the pump, add the prepared PVA and DBSA, and stir at a speed of about 1700 rpm. After stirring evenly, the stirring speed was increased to about 2000 rpm, and AN was added. Finally, the APS solution was slowly added dropwise to the emulsion at a rate of 1 drop/second, and the mixture was continuously stirred at a high speed for 2.5 to 3.5 hours to obtain a dark green polyaniline emulsion. During the synthesis process, the emulsion will show different colors due to the different degrees of oxidation, as shown in Figure 2.
2.2. Preparation of polyaniline film
Fix the ITO substrate on the suction cup of the homogenizer (KW-4A type), set the rotation speed to 600rpm, titrate the polyaniline emulsion in 15 seconds, rotate it slowly, and rotate it at 5000 rpm for 1-2 seconds. The emulsion is evenly spread. Then, the prepared composite film was placed in an oven and baked at room temperature for 4 hours before being ready for use.

2.3. Performance and analysis of polyaniline film

2.3.1 Microtopography. The surface morphology of polyaniline film was characterized by JEOL JSM-840 scanning electron microscope. Figure 3 is an SEM image of a polyaniline film at different magnifications. It can be seen that the particle size of PANI particles is in the micron range, and the diameter and distribution are uniform. It is also observed that the PANI/PVA composite film has a flat appearance and no agglomeration. PANI particles can form a polyaniline conductive mesh and are suitable for use in electrochromic devices [7].

2.3.2 Crystallization properties. The degree of crystallization of polyaniline was observed and analyzed by an X-ray diffractometer. Figure 4 shows the X-ray diffraction intensity curves of the PANI/PVA composite film. The intensity of the diffraction peak indicates the degree of crystallization of polyaniline and the degree of crystal ordering, and also affects the conductivity and electrochemical properties of PANI. The main structure peak of PANI is shown near 2θ=20°, and the greater the intensity of the diffraction peak here, the better the electrochemical performance and conductivity of doped polyaniline [7]. The results show that the doped PANI has better molecular chain order and electrical conductivity.
2.3.3 Chemical structure. Infrared spectroscopy is used to study and analyze molecular structure and chemical composition. Figure 5 shows the FTIR infrared spectrum of the polyaniline composite film. The peak of PANI is similar to the range described in reference [8]. The infrared transmission curve of PVA is also related to the infrared curve in reference [9]. In agreement, it was confirmed that during the in-situ polymerization, the aniline monomer was polymerized to form polyaniline, and no chemical bond formed between PANI and PVA was found.

2.3.4 Electrochemical performance. The electrochemical performance of polyaniline was tested using the CHI660E A16742 Electrochemical Workstation. As can be seen from the cyclic voltammetry curve of Figure 6, in the cyclic scan of -0.5 V and +1.5 V, two oxidation peaks and two reduction peaks appeared. The peak position of the curve is close to the peak range of the CV curve of PANI in Reference [7], indicating that polyaniline can reversibly oxidize and restore the reaction between different oxidized states.

As can be seen from Figure 7, the degree of oxidation-reduction of polyaniline also changes with voltage. The voltage is in the range of -0.5 to 1.5 V, and the film exhibits a yellow-green-green-blue change. Due to the color limitation of polyaniline itself, green can’t completely fade, so that polyaniline shows yellow-green when applied with negative pressure [10].

(a) yellow-green  (b) green  (c) blue

Figure 6. Cyclic voltammetry of polyaniline film

Figure 7. Electrochromic performance test chart of polyaniline
3. Electromagnetic monitoring and visualization of intelligent flexible device preparation and packaging

The polyaniline ECD is prepared by sandwich structure to characterize the optical properties of the ECD; the electrochromic device and the electromagnetic wave detector are connected, and the test device can intelligently monitor the electromagnetic wave with color change; the appearance of the modified electromagnetic wave detector is modified by the fabric and the ECD is configured. The electromagnetic monitoring and visualization intelligent flexible device is obtained, which is packaged on the fabric, and the fabric is intelligently visualized to monitor the effect of electromagnetic radiation.

3.1. Preparation of electrochromic devices

3.1.1 Structural design of electrochromic devices. Self-synthesized polyaniline as electrochromic layer and ion storage layer of ECD, preparing polymethyl methacrylate (PMMA) gel electrolyte as ion conductor layer, ITO conductive film as transparent electrode layer, selecting typical five-layer structure ECD. The structural design is shown in Figure 8. Since the polyaniline material has a dual effect, the ECD is actually simplified to four layers: a transparent electrode layer + an electrochromic layer + an ion conductive layer + a transparent electrode layer.

![Figure 8. Structural design of electrochromic device](image)

![Figure 9. Visible light spectrum of the electrochromic device](image)

The main experimental materials for preparing polyaniline electrochromic devices are Polyaniline (PANI), PMMA based gel electrolyte and ITO conductive film. The main experimental instruments are KW-4A Glue machine, DZF-6050 Vacuum drying oven and KQ-700B Ultrasonic cleaner.

3.1.2 Preparation of PMMA gel. A certain amount of lithium perchlorate was added to 0.7865 mL of propylene carbonate (PC), and ultrasonically mixed uniformly to obtain an electrolyte salt solution; 0.20045 g of PMMA was weighed, 3 mL of absolute ethanol was added, and ultrasonic suspension was also obtained to obtain a suspension; mixed electrolyte salt solution The polymer suspension was ultrasonically dispersed and stirred with a glass rod; the white suspension became a colorless transparent solution and stirred with a thermostatic magnetic stirrer for 1 h.

3.1.3 Preparation process of electrochromic device. (1) Cut an ITO film of appropriate size, perform sonication with ethanol and deionized water for 5-10 minutes, and then blow dry with nitrogen.

(2) The polyaniline film was uniformly spin-coated on the conductive surface of the ITO film by a KW-4A type homogenizer and dried.

(3) An appropriate amount of PMMA gel was titrated on another ITO film, and two ITO films were pressed, air bubbles were extruded, and sealed with a tape.

3.2. Optical performance and analysis of electrochromic devices

Visible (vis) absorption spectra were recorded using a X-rite SP60 type spectrophotometer. It can be seen from Figure 9 that during the voltage rise, the absorption peak corresponding to the potential of -0.5
to 1.5V moves from the short wave to the long wave direction, and the film gradually changes from yellow to green and finally to blue. When the voltage is -0.5V, PANI is pale yellow; at 0.5V, PANI is green in the semi-oxidized doping state; at 1.5V, the semi-oxidative dedoping PANI shows blue \[11\].

3.3. Electrochromic device monitoring electromagnetic wave performance test and analysis

Three pairs of polyaniline electrochromic devices were prepared and connected to the voltage output of the modified electromagnetic wave detector. As shown in Figure 10(a), when the electromagnetic field strength is within the safe range, the ECD appears green; (b) the electromagnetic field strength corresponding to the warning level, the electromagnetic detector applies the voltage, the ECD changes to yellow-green; (c) the ECD becomes Blue, the electromagnetic wave intensity is at a dangerous level. The color change and color change interval described above are consistent with the modification ideas in the second chapter of this paper, indicating that the combination of ECD and detector is successful.

Figure 10 Electrochromic device monitors the discoloration of electromagnetic fields

4. Conclusion

The subject combines polyaniline ECD with an electromagnetic wave detector and encapsulates it in a fabric, and attempts to study the function of visualizing electromagnetic monitoring of fabrics. The conclusions of the lesson are summarized as follows:

(1) The polyaniline emulsion was prepared by microemulsion polymerization. The SEM, XRD, FTIR and CV curves of the polyaniline film were analyzed. The results show that the prepared polyaniline has good properties and is suitable as an electrochromic material.

(2) The polyaniline ECD was prepared by “sandwich” structure, combined with the modified electromagnetic wave detector and packaged in the fabric. The test showed that the device can intelligently monitor the electromagnetic radiation changes in the environment.

(3) Using three polyaniline ECDs instead of the LED tri-color lamp of the detector, three voltage output terminals are connected to the detector to complete the conductive path between the detector and the electrochromic device.

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