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Fabrication of new polypyrrole/silicon nitride hybrid materials for potential applications in electrochemical sensors: Synthesis and characterization

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ABSTRACT

In this research, an efficient fabrication process of conducting polypyrrole (PPy)/silicon nitride (Si_3N_4) hybrid materials were developed in order to be employed as transducers in electrochemical sensors used in various environmental and biomedical applications. The fabrication process was assisted by oxidative polymerization of pyrrole (Py) monomer on the surface of $Si/SiO_2/Si_3N_4$ substrate in presence of $FeCl_3$ as oxidant. To improve the adhesion of PPy layer to Si_3N_4 surface, a pyrrole-silane (SPy) was chemically bonded through silanization process onto the Si_3N_4 surface before deposition of PPy layer. After Py polymerization, $Si/SiO_2/Si_3N_4$-(SPy-PPy) substrate was formed. The influence of SPy concentration and temperature of silanization process on chemical composition and surface morphology of the prepared $Si/SiO_2/Si_3N_4$-(SPy-PPy) substrates was studied by FTIR and SEM. In addition, the electrical properties of the prepared substrates were characterized by cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS). It was found that the best silanization reaction conditions to get $Si/SiO_2/Si_3N_4$-(SPy-PPy) substrate with high PPy adhesion and good electrical conductivity were obtained by using SPy at low concentration (4.3 mM) at 90°C. These promising findings open the way for fabrication of new hybrid materials which can be used as transducers in miniaturized sensing devices for various environmental and biomedical applications.

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1. Introduction

Silicon nitride (Si_3N_4) plays an important role in microelectronics, integrated circuits technology, memory and thin film transistors, optoelectronics, optics, and hard surface coating (1, 2). Si_3N_4 offers a number of advantages when compared to other materials, such as the absence of undesirable impurities and the excellent control of the film composition and thickness (3). In addition, Si_3N_4 is considered as a biocompatible material in contact with bone *in-vitro* and it has been suggested as a load-bearing implant material due to its favorable mechanical properties (4). Also, the application of Si_3N_4 thick film for the fabrication and development of novel biosensors have been reported (5, 6). However, only few Si_3N_4-based biosensors have been successfully developed. This is due to the lack of an efficient and direct protocol for the integration of biological elements with Si_3N_4-based substrates and it is still one of its main drawbacks.

Nowadays, there is a great challenge to develop Si_3N_4 based devices. In this regard, the application of conductive polymers (CPs) has opened a new alternative to easily modify the Si_3N_4 substrate and to generate new materials with novel properties. Among all CPs, polypyrrole (PPy) is one of the most successfully employed polymers due to its high electrical conductivity, good environmental stability, biocompatibility, electro activity in neutral environments, and easy synthesis (7). PPy presents good electrical and optical properties for biosensor technology due to its π-electron conjugation along the polymer backbone (8, 9). Therefore, to enhance the conducting properties of Si_3N_4 semiconducting-based materials, recent studies have focused on the use of PPy conducting polymers as tools (transducers) which have the ability for amplification of the response signal arise from biomolecules interactions (e.g. in DNA biosensors, glucose sensing electrodes, amperometric enzyme biosensors, amperometric cholesterol biosensors, etc) (10–13).

Recently, Si_3N_4 and PPy have been used to generate novel Si_3N_4-PPy composites by using different techniques. For example, Si_3N_4 nanoparticles have been coated with PPy by the sonoelectrochemical synthesis of PPy (14). Besides, other techniques including the electrochemical grafting of PPy on porous silicon (Si) was used for gas sensors applications (15). Previously, we have reported PPy microstructures printed on glass and polyethylene terephthalate (PET) substrates for biosensing applications (16).

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