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Chemical functionalization of carbon/polymer bipolar plate materials via oxygen plasma activation and subsequent silanization

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ABSTRACT

A simple coating routine in order to tune the wettability of carbon/polymer bipolar plate materials is presented. Standard carbon/polypropylene composite materials as used for commercial bipolar plates for polymer-electrolyte-membrane fuel cell application are chemically modified via oxygen plasma activation and subsequent silanization using distinct precursor molecules including perfluorodecyltrichlorosilane and aminopropyltrimethoxysilane. For characterization of the samples contact angle measurements, infrared and Auger electron spectroscopy and scanning electron and atomic force microscopy are employed. Spectroscopic data provides direct evidence for successful functionalization of the substrates. Microscopic data reveals the inherent roughness of the micro-/nanostructured substrate surfaces. Depending on the particular silane precursor, the coating procedure yields hydrophilic and hydrophobic surfaces with static water contact angles ranging from 55° to 160°. The wettability of these substrates remains unchanged upon storage in clean air over a period of one year and more. Prospects of the coating procedure targeting the optimization of the water management in fuel cell applications are discussed.

1. Introduction

In recent years, polymer-electrolyte-membrane (PEM) fuel cells have gained tremendous attention as a future power source both in automotive vehicles and in stationary applications [1,2]. Current efforts target further improvement of such devices in terms of efficiency, long-term stability and overall cost-reduction. Among other issues, the water management remains a challenging problem because of the impact on the performance and durability of the device. Two main sources are responsible for the formation of liquid water in the fuel cell during operation: the continuous water production by oxygen reduction at the cathode and water condensation from humidified reactant gas feeds. The presence of liquid water eventually blocks oxygen transport through the gas-diffusion electrode and results in flooding of the active catalyst side and intermittent power losses. In particular, water in the gas flow channels and/or the gas diffusion layer can result in inhomogeneous and discontinuous distribution of reactants over the active catalyst area. This affects the cell performance and leads to variations of the cell-to-cell performance within a stack [3]. A promising approach in order to tackle this problem considers the modification of the wettability of the bipolar plates, respectively the gas flow fields. In this work we present a simple coating routine to modify the wettability of carbon/polymer bipolar plates via chemical functionalization with silane precursor molecules.

Silanization routines are widely used in order to functionalize a variety of materials including silicon wafers, glass and polymers and tailor their wettability [4]. Because of covalent cross-linking of the molecular entities to each other and to the substrate surface via strong siloxane bonds these coatings exhibit exceptionally high thermal, chemical and mechanical stability (Fig. 1). In particular thermal decomposition takes place at temperatures above 200 °C [5,6]. This makes these coatings particularly attractive when targeting technical applications such as those addressed here. We note that the typical operation temperature in low temperature PEM fuel cells is about 80 °C [7]. Depending on the detailed coating procedure and the substrate material thick disordered films or more ordered monomolecular layers are formed. Ultimately, films with thicknesses of 1–2 nm are obtained [8]. The ultrathin nature of such films leaves the surface topography unchanged. Hence, such coatings provide unique opportunities in order to tailor the surface of rough substrates exhibiting micro- and nanostructured topographies [9,10]. In addition, little impact on the electrical conductivity is expected. All these issues are considered favorable when targeting the functionalization of bipolar plates. In this contribution we focus on the impact of silane-based coating on the wettability of such materials.

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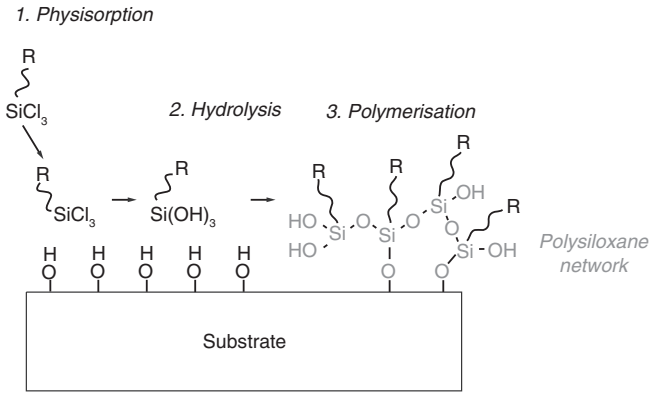

Fig. 1. Silanization reaction scheme.

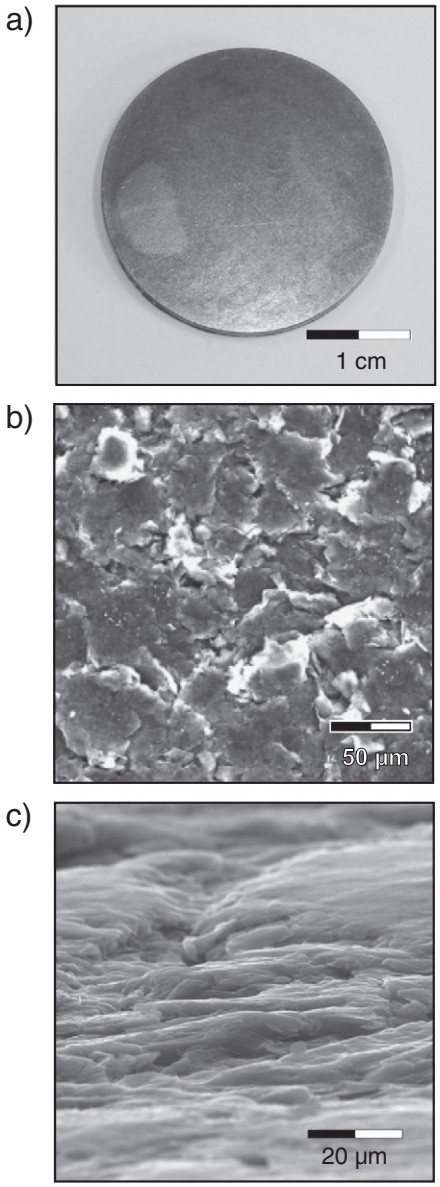

Fig. 2. a) Sample of bipolar plate materials produced by the ZBT Duisburg, b) and c) SEM-images (top view and view from a tilted perspective) of the surface structure.

2. Material and methods

Circular samples of composite bipolar plate materials as used for the fabrication of commercial bipolar plates are fabricated via compounding the base materials via an extruder and injection molding [7] (Fig. 2). The samples exhibit a diameter of 3 cm and a thickness of 2 mm and consist of close to 80% graphite and about 20% of polypropylene. In addition, little amounts of carbon black, typically less than 1%, are added. The density of the samples is about 1.75 g cm^{-3}. In order to improve the electrical conductivity at the surface of the bipolar plates surface treatment via a milling process is carried out. This procedure removes a thin polypropylene layer on the top of the plates. In order to ensure the applicability of the coating procedures in future work addressing

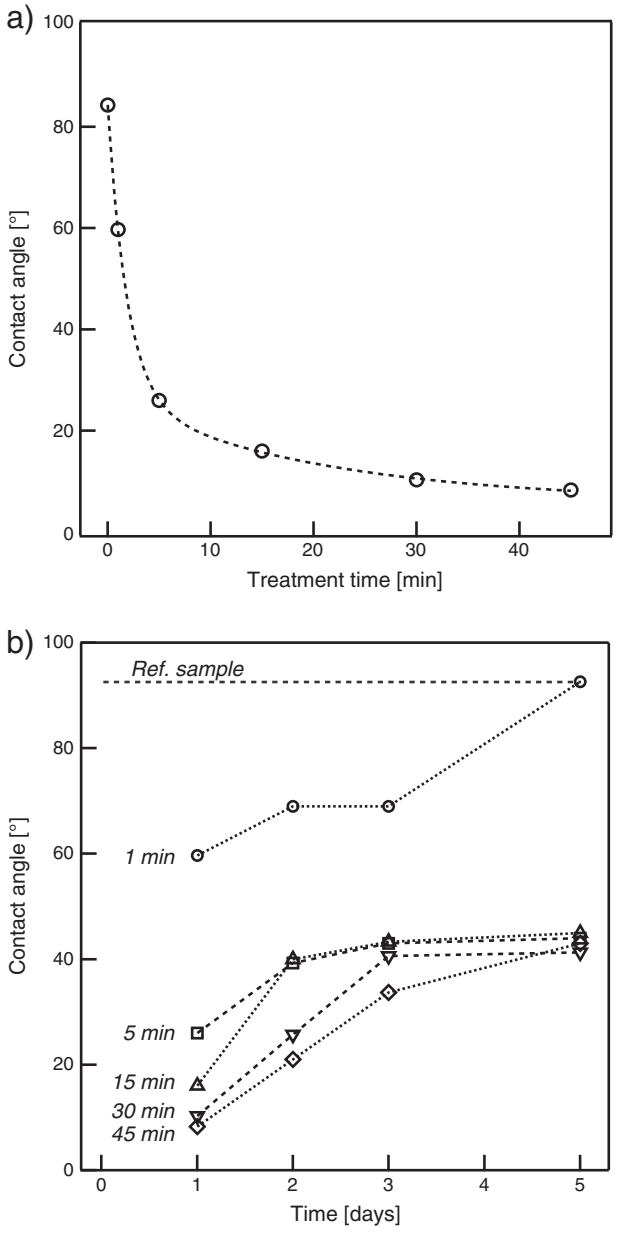

Fig. 3. a) Plasma processing of carbon/polypropylene samples at a microwave power of 90 W and an oxygen pressure of 0.5 mbar. The graph shows a decreasing static water contact angle with increasing oxygen plasma treatment time. b) Aging of plasma-treated samples in ambient air. The graph shows an increasing static water contact angle with increasing storage time in air at ambient conditions for samples which have been processed at different oxygen plasma treatment times. For reference, the dashed horizontal line at the top in Fig. 3b shows the value of the static water contact angle on native samples.