Towards Self-Healing Organic Electronics
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CHAPTER 3

Disruption of the Electrical Conductivity of HC PEDOT:PSS by Hypochlorite

The effect of hypochlorite treatment on the layer thickness and conductivity of a state-of-the-art high conducting PEDOT:PSS is investigated as a function of exposure time and hypochlorite concentration. Due to over-oxidation by the hypochlorite the PEDOT:PSS conductivity is decreased by ten orders of magnitude. Comparison of thickness and conductivity as a function of time shows that a residual insulating layer remains on the substrate upon treatment. Going from a low (< 0.01%) to a high (> 0.1%) hypochlorite concentration the interaction between PEDOT:PSS and hypochlorite changes from reaction- to diffusion limited. The decrease in conductivity can be interpreted in terms of the interruption of percolating conductive pathways by the reaction between PEDOT and hypochlorite.

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3.1 Introduction

In section 2.4.2 we described the organic anode PEDOT:PSS and explained that PEDOT:PSS can be over-oxidized with sodium hypochlorite in order to pattern the electrode. The potential for hypochlorite to completely disrupt the conductivity of PEDOT:PSS may open up new possibilities for oxidizing agents within a processing line. If PEDOT:PSS can be deactivated in a controlled situation by hypochlorite, it could be possible to devise a method to locally deactivate the organic electrode in pinholes so that potential short-circuits and defects can be prevented. Hypochlorite could then, hypothetically, be utilized to locally prevent short-circuits as well as be applied to pattern PEDOT:PSS.

Irrespective of the application technology, however, it is necessary to have a fundamental understanding of the mechanisms behind reactive conductivity disruption of PEDOT:PSS as a function of oxidizer concentration and treatment time. At present mechanistic studies concerning systematic variation of treatment conditions are virtually absent in literature. Instead, the focus is primarily on the actual devices on which chemical patterning of PEDOT:PSS layers is applied. Nevertheless, the mechanistic complexity of chemical degradation of PEDOT:PSS is acknowledged, as it is well-known that depending on treatment conditions the chemical changes in the PEDOT:PSS may not only lead to mere disruption of electrical conductivity, but also to loss of material, possibly due to chain scission and disruption of the attractive interaction between PEDOT and PSS. Hence, depending on treatment duration and oxidizer concentration, chemical patterning may either lead to mere deterioration of the conductivity or to complete removal of the PEDOT:PSS in treated areas.

In this chapter the effect of hypochlorite treatment on the layer thickness and conductivity of a novel HC PEDOT:PSS developed for state-of-the art OLED and OPV applications is investigated as a function of exposure time and hypochlorite concentration. A comparison is made between the timescales of loss in thickness and conductivity. It is demonstrated that, going from a low to a high hypochlorite concentration, the time-dependent decrease in conductivity follows a regime transition. The decrease in conductivity is interpreted in terms of the interruption of percolating conductive pathways by the reaction between PEDOT and hypochlorite. By curve-fitting experimental data to a general effective medium (GEM) model values for the percolation threshold and critical conductivity exponent are obtained. The modeling data are then interpreted in terms of morphological aspects of the layer.

3.2 Materials and methods

Dispersions (0.8% solids) of HC PEDOT:PSS either or not containing 1% of an aqueous solution of a polymeric adhesion promoter (the latter indicated below as "HC PEDOT:PSS") were supplied by AGFA Gevaert (Mortsel, Belgium) and were used as received. NaClO$_{aq}$ solution (reagent grade, available chlorine 4.00 – 4.99%) was purchased from Sigma-Aldrich and diluted with de-ionized water to concentrations in the range 0.0025% – 5% by weight. Glass substrates (30 x 30 mm) were cleaned with soap
and de-ionized water, followed by sonication in acetone and 2-isopropanol. The substrates were subsequently dried for 10 minutes at 140 °C in air. The wettability of the substrates was improved by UV-ozone treatment for 20 minutes. Thin layers of \(l = 100 \text{ nm}\) of HC PEDOT:PSS* were spincoated on the glass substrates within 20 minutes of finishing the UV-ozone treatment. The HC PEDOT:PSS* layers were then annealed for 10 minutes at 180 °C. The layers were subsequently allowed to cool down to ambient temperature. Treatment with NaClO\(_{\text{aq}}\) occurred by fully submerging the HC PEDOT:PSS* layers in the NaClO\(_{\text{aq}}\) solutions for durations ranging from zero seconds to 24 hours. The samples were rinsed with de-ionized water for 5 seconds in order to remove excess NaClO from the surface of the layers. The substrates were then spin-dried and vacuum dried \(< 10^{-3} \text{ mbar}\) for one hour. In order to measure in-plane conductivity of the treated HC PEDOT:PSS* layers in a statistically meaningful way, five sets of two gold contacts were evaporated on top of the treated and dried HC PEDOT:PSS* layer, sufficiently remote from the edges of the substrate. The separation between the two contacts in one set was 200 \(\mu\text{m}\). Evaporation was performed at a pressure \(< 10^{-6} \text{ mbar}\). The conductivity of the HC PEDOT:PSS* layers was determined by measuring I-V curves using a Keithley 4200 SCS. The thickness of the layers \(\text{(i.e. averaged over at least five different locations)}\) was measured with a Veeco Dektak 6M stylus profilometer.

### 3.3 Results and discussion

Submerging glass-borne spincoated layers of unmodified HC PEDOT:PSS into NaClO\(_{\text{aq}}\) solutions typically resulted in complete detachment from the substrate, thus prohibiting systematic study of the effect of the treatment itself. Hence, for the investigations reported here a modified grade HC PEDOT:PSS (HC PEDOT:PSS*, see 3.2) containing 1\% of an aqueous solution of a polymeric adhesion promoter was used instead, which exhibited improved adhesion to glass without significantly influencing conductivity.

The thickness of the HC PEDOT:PSS* layers was found to decrease exponentially with exposure time to NaClO\(_{\text{aq}}\) to a final residual value of at least \(\sim 75\%\) of the initial thickness, the decay rate being a function of NaClO concentration. Even after prolonged treatment \(\text{(e.g. 24 hour treatment in }0.01\% \text{ NaClO}_{\text{aq}}\text{)}\) the thickness did not decrease beyond this limiting value. The experimental results, together with empirical fits to mono-exponential functions are shown in Figure 3.1. Interestingly, no (significant) decrease in layer thickness was observed upon treatment with pure water \(\text{(dark blue symbols in Figure 3.1)}\). This observation contradicts the conclusion by DeLongchamp \textit{et al.} \cite{4} that the thickness of a PEDOT:PSS layer decreases considerably by treatment with pure water due to physical dissolution of unbound PSS. It should, however, be noted that their study concerned a different PEDOT:PSS grade than the one used here. In any case, our experiments show that the removal of material from the HC PEDOT:PSS* layers is principally caused by chemical degradation due to reaction with hypochlorite, rather than to mere physical dissolution.

The effect of NaClO concentration on the conductivity of the HC PEDOT:PSS* layer is plotted in Figure 3.2a as a function of exposure time. Similar to the effect on layer thickness, no change in conductivity was observed upon treatment with pure water \(\text{(blue points)}\), which, again deviates from the result reported by DeLongchamp who observed
an increase in the conductivity due to removal of unbound PSS.\[4\] As expected, a pronounced decrease of ten orders of magnitude in conductivity was observed when NaClO is present in solution. At sufficiently long treatment times the conductivity eventually dropped below the sensitivity limit of the measurement equipment. Plotting the thickness and conductivity curves corresponding to treatment with 0.01% NaClO\(_{(aq)} \) in the same graph (Figure 3.2b) shows that the conductivity can be lowered substantially without drastically influencing the layer thickness. Comparison of thickness and conductivity as a function of time also leads to the conclusion that a residual layer consisting of an electrically insulating material remains on the substrate upon treatment of HC PEDOT:PSS\(^* \) with NaClO\(_{(aq)} \).

The (approach to) overlap of the curves obtained for 0.5 and 5% NaClO\(_{(aq)} \) shows that the influence of concentration diminishes at high NaClO content. As the eventual decrease of the conductivity will be controlled by diffusion of NaClO in the (probably swollen) HC PEDOT:PSS\(^* \) layer and subsequent reaction with the PEDOT backbone, we interpret this observation in terms of a transition from a reaction-limited regime at low hypochlorite concentration to a diffusion-limited regime at high concentration. Another important observation is the fact that for NaClO concentrations exceeding 0.05% the conductivity no longer converges to the value at short exposure times, i.e. \( \sim 250 \, \text{S/cm} \). This suggests that in this concentration regime breakdown of the conductivity occurs too fast compared to the experimental handling times and is therefore less well controlled than for lower hypochlorite concentrations. Hence, especially the initial part of the corresponding curves becomes ill defined due to a large error in the plotted treatment time.

A quantitative argument can be given in support of the hypothesis that for low NaClO concentrations (i.e. typically < 0.01%) the decrease in conductivity is reaction-limited. Diffusive mass transport is characterized by the dimensionless Fourier number for mass transport, given by:\[5\]

\[
F_o = \frac{D_{\text{eff}} t}{l^2}
\]  

(3.1)
3.3 Results and discussion

Figure 3.2: a) Conductivity of HC PEDOT:PSS* layers plotted as function of immersion time in NaClO\textsubscript{(aq)} solution for various hypochlorite concentrations: 5 wt\% (light grey), 0.5 wt\% (magenta), 0.05 wt\% (green), 0.01 wt\% (red), 0.005 wt\% (black), 0.0025 wt\% (dark grey), 0 wt\% (blue); the red, black, and dark grey solid lines represent fits to the GEM-reaction model defined by Equations 3.2 and 3.4, the green solid line represents the curve corresponding to [NaClO] = 0.05 wt\%, calculated using input parameters obtained from curve fitting; the thin black lines are guides for the eye; b) Comparison between normalized HC PEDOT:PSS* layer thickness (blue) and conductivity (black) as a function of immersion time in 0.01 wt\% NaClO\textsubscript{(aq)} solution.

Here, $D_{\text{eff}}$ is an effective diffusivity (in the present case that of the hypochlorite anions in the swollen HC PEDOT:PSS* matrix), $t$ is time, and $l$ is a characteristic length scale for the problem under consideration. In our case $l$ represents the initial dry thickness of the HC PEDOT:PSS* layer: $l = 100$ nm. In the reaction-limited regime the concentration profile of the hypochlorite anions in the HC PEDOT:PSS* layer will be (near) steady state, which corresponds to $F_0 \sim 1$. Equation 3.1 then shows that if the curve corresponding to treatment with 5 wt\% NaClO\textsubscript{(aq)} purely reflects the diffusive time scale, one would require $D_{\text{eff}}$ to be of the order $10^{-16} - 10^{-15}$ m$^2$/s to allow for the steady state profile to be installed within tens of seconds, i.e. as indicated by the light blue symbols. Intuitively, this value for $D_{\text{eff}}$ seems rather low, as, for instance, the diffusivity of a small molecule such as water in a glassy polymer is known to be a few orders of magnitude higher (i.e. typically $10^{-13} - 10^{-11}$ m$^2$/s). In other words, $D_{\text{eff}}$ may be higher, especially considering the fact that ingressing water is likely to plasticise the HC PEDOT:PSS* medium.

Irrespective of the exact value of $D_{\text{eff}}$, the important message of this exercise is that in case [NaClO] $\leq 0.01\%$, the timescale for reaching a steady state hypochlorite concentration profile in the HC PEDOT:PSS* layer is significantly smaller than the time scale of the conductivity decay, showing that at low hypochlorite concentration the process becomes reaction-limited. In view of what follows, it is important to realize that in the reaction-limited regime the situation is simplified compared to the transitional region, since diffusion can be ruled out as process parameter. Our study and conclusions on the mechanism of conductivity decrease in HC PEDOT:PSS* due to hypochlorite intrusion will therefore be based on the results obtained for [NaClO]\textsubscript{(aq)} = 0.01, 0.005, and 0.0025%.

It has been shown previously that the bulk (volume-averaged) conductivity of all-

\footnote{Obviously, somewhat higher values for $D_{\text{eff}}$ are obtained if swelling of the HC PEDOT:PSS* is taken into account by choosing an increased value for $l$.}
organic composites based on a conducting filler in a sparsely conducting matrix, such as LC PEDOT:PSS and polyaniline:polystyrene-polybutadiene-polystyrene (PANI:SBS), is well described by General Effective Medium Theory (GEMT). This theory has been derived based on a combination of classical percolation theory and effective medium theory (EMT). In contrast to percolation theory, GEMT is valid for filler fractions in the vicinity, as well as away from the percolation threshold and assumes the conductivity ratio between the conductor and the matrix to be finite. In other words, it assumes the matrix to have a low but non-zero conductivity, which is true for many organic substances generally considered as insulators. GEMT has been presented as a generalized version of Bruggeman’s symmetric and asymmetric models, capable of describing volume-averaged physical properties of composites based on domains with anisotropic grain structures. The GEM equation for electrical conductivity reads:

\[
\frac{(1-\varphi)(\sigma_l^{1/x} - \sigma_m^{1/x})}{\sigma_l^{1/x} + (\frac{1-\varphi}{\varphi_c})\sigma_m^{1/x}} + \frac{\varphi(\sigma_h^{1/x} - \sigma_m^{1/x})}{\sigma_h^{1/x} + (\frac{1-\varphi}{\varphi_c})\sigma_m^{1/x}} = 0 \tag{3.2}
\]

Here, \(\varphi\) and \(\varphi_c\) are the volume fractions of conductive filler and the threshold (critical) volume fraction. \(\sigma_l, \sigma_h\) and \(\sigma_m\) are the conductivities of the matrix (“low”), the pure conductor (“high”), and the composite (i.e. the “effective medium”), respectively.

Stöcker et al. applied the GEM equation to describe the decrease in effective medium conductivity of LC PEDOT:PSS as a function of PEDOT:PSS ratio. Along the same philosophy we propose that the loss in conductivity due to reaction between PEDOT and hypochlorite can also be considered a percolation problem, as during oxidation the volume fraction of conductive material (PEDOT) decreases in time, eventually reaching a threshold around which the conductivity critically drops. This view is supported by the shape of the curves presented in Figure 3.2a. A difference between the present process and the study performed by Stöcker on LC PEDOT:PSS, however, is the accumulation in time of the non-saturated polyol-type reaction product (see Figure 2.7). One could argue that the reason for the (apparent) low conductivity of this reaction product, despite its conjugated electronic structure, might be due not only to loss of doping or even possible chain scission, but also to the occurrence of tautomeric rearrangement, as suggested by Figure 3.3. Clearly, the conjugation in the ketone-type tautomers would be disrupted.

As GEMT describes the conductivity as a function of filler concentration rather than time, we require an additional function which gives the temporal changes in the fraction of conductive material. Two counteracting processes can be identified that influence the volume fraction of conductive material (i.e. PEDOT): i) a decrease in \(\varphi\) is expected due to the reaction between PEDOT and hypochlorite, but ii) an increase in \(\varphi\) is expected if dissolution of non-conducting material from the layer is significant, given the assumption that the pristine PEDOT does not dissolve into the aqueous phase due to its hydrophobicity. Considering the fact that in the reaction-limited concentration regime removal of material from the layer only becomes significant after considerable decrease in conductivity has occurred (see Figure 3.2b), we deem the reaction between PEDOT and hypochlorite to be the dominant process. Hence, without considerably increasing complexity, we summarize the multi-step over-oxidation of PEDOT by formulating an effective rate
3.3 Results and discussion

Figure 3.3: Tautomeric rearrangement of the presumed reaction product of the over-oxidation of PEDOT by hypochlorite.

law, which is to be solved in conjunction with the GEM equation:

\[ \frac{d \varphi}{dt} = -k_{\text{eff}} c^n \varphi \] (3.3)

Here, \( k_{\text{eff}} \) is the effective reaction rate constant, \( c \) is the hypochlorite concentration (here expressed in wt%) in the HC PEDOT:PSS* layer, and \( n \) is an exponent allowing higher order dependence on hypochlorite concentration (i.e. for \( n > 1 \)). The latter is certainly not unlikely, considering the fact that hypochlorite plays a role in several, if not all, steps of the over-oxidation mechanism (Figure 2.7). Integrating Equation 3.3 yields:

\[ \varphi = \varphi_0 e^{-k_{\text{eff}} c^n t} \] (3.4)

, with \( \varphi_0 \) representing the initial fraction of PEDOT in the PSS matrix corrected for the amount of adhesion promoter present in the dry layer. Substituting Equation 3.4 for \( \varphi \) in Equation 3.2 yields the conductivity versus treatment time, and hence a fit function for the experimental data plotted in Figure 3.2.

In the reaction-limited regime \( c \) is considered spatially constant in the HC PEDOT:PSS* layer and assumed equal to the hypochlorite concentration in solution. The remaining parameters, \( \varphi_c, \sigma_l, \sigma_h, x, n, \) and \( k_{\text{eff}} \), were used as free variables in a simultaneous fitting procedure of the data for \([\text{NaClO}]_{\text{aq}} = 0.01\%, 0.005\%, \) and \(0.0025\%\). The number of fitting parameters leaves the curve fitting process not fully unambiguous, as the same fit quality was obtained for different value sets. This was especially the case for the coupling between \( \varphi_c, \sigma_h, \) and \( k_{\text{eff}} \), whereas the remaining variables, i.e. \( \sigma_l, x, \) and \( n \), showed considerably less ambiguity. Hence, constraints of \( \sigma_h < 6 \times 10^5 \text{S/cm} \), i.e. the conductivity of

\(^2\) The PEDOT:PSS ratio in the untreated material is not explicitly given in this work for reasons of confidentiality. It is however comparable to the ratio typically used in most HC PEDOT:PSS systems encountered in the literature.
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<table>
<thead>
<tr>
<th>$\sigma_l$ (S/cm)</th>
<th>$\sigma_h$ (S/cm)</th>
<th>$\varphi_c$</th>
<th>$x$</th>
<th>$n$</th>
<th>$k_{\text{eff}}$ (s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$8.4 \times 10^{-6}$</td>
<td>$8 \times 10^{-8} &lt; \sigma_h &lt; 6 \times 10^{-6}$</td>
<td>0.01 &lt; $\varphi_c$ &lt; 0.1</td>
<td>3.5 ± 0.3</td>
<td>2</td>
<td>$75 &gt; k_{\text{eff}} &gt; 35$</td>
</tr>
</tbody>
</table>

Table 3.1: Values for the parameters of the GEM-reaction model giving the best simultaneous fit of the transient conductivity data of HC PEDOT:PSS* layers immersed in NaClO$_{(\text{aq})}$ with hypochlorite concentrations of 0.01 wt%, 0.005 wt%, and 0.0025 wt%.

bulk silver, and $\sigma_c > 0.01$, i.e. a typical value for the percolation threshold of isotropically distributed conductive filler particles with extreme aspect ratio, were implemented in order to ensure the outcome of the fitting procedure to remain physically reasonable. Best simultaneous fits of all three data series (solid colored lines in Figure 3.2) were obtained for single sets of parameter values. Table 3.1 lists these values in terms of coupled ranges interpolating between the extremes imparted by the mentioned constraints. Besides the fitted curves of the conductivity data corresponding to $[\text{NaClO}]_{(\text{aq})} = 0.01\%$, 0.005%, and 0.0025%, Figure 3.2 also shows the theoretical curve for $[\text{NaClO}]_{(\text{aq})} = 0.05\%$, calculated using the values listed in Table 3.1. Clearly, in this case the simulated result overestimates the degradation rate, further evidencing that the process becomes diffusion-limited at increased hypochlorite concentration. As indicated by Figure 3.2a, the fit to the model presented above is considered applicable for the initial and critical part of the curves, as the measured conductivity does not saturate at the value for $\sigma_l$. Instead, at long treatment times, the conductivity keeps decreasing after initially attempting to indeed curve off towards a saturation value. The straight black lines in Figure 3.2a suggest a second mechanism of conductivity decrease to take over in this regime, following a power law with time for all hypochlorite concentrations. We speculate that the underlying cause for this second process is related to some loss of ionic conductivity due to release of PSS upon elimination of its ion-pairing interaction with PEDOT, once the latter becomes oxidized. The best fit value for $\sigma_l$ is of the same order of magnitude as previously reported values for ionic conductivities of PSS samples containing a residual amount of water. A fraction of water is plausibly also present in the HC PEDOT:PSS* layers, as they do not undergo a thermal drying treatment after submersion in aqueous hypochlorite and rinsing. A single value of $n = 2$ describes the shift in time of the reaction-limited conductivity curves very well, in combination with one single value for $k_{\text{eff}}$. Varying $n$ and $k_{\text{eff}}$ for each data set would seem unreasonable considering the fact that the decrease in conductivity is likely due to the same reaction mechanism, irrespective of hypochlorite concentration.

As a last step we will attempt to relate the fitting results for $\sigma_h$, $\varphi_c$, and $x$ to the nanomorphology of the HC PEDOT:PSS* layers. First of all, the seemingly high value for $\sigma_h$ is dictated by the fact that at the given $\varphi_0$ a sufficiently high $\sigma_h$ is required to make sure that the effective medium value $\sigma_m$ represents the measured conductivity of the untreated layers. Besides this rather abstract description, a more physical interpretation is that $\sigma_h$ represents the intrinsic conductivity of the quasi-metallic, highly doped, probably partially crystalline PEDOT core regions, characterized by a high degree of molecular ordering. We note that our definition of $\sigma_h$ is in that sense different from the approach followed by Stöcker et al., who set $\sigma_h$ equal to the conductivity indicated by the first data point in their concentration series, i.e. corresponding to the sample with the highest PEDOT:PSS ratio (1:1). The difference between their (2.3 S/cm) and our value may therefore
be explained by: i) the fact that according to their definition the conductive remains effectively “diluted” with PSS, and ii) a significantly lower charge carrier mobility due to a higher degree of disorder of the PEDOT oligomers in case of LC PEDOT:PSS.\textsuperscript{13,14}

Another contribution may be expected from the nature of the larger length scale morphology of the PEDOT domains in the PSS matrix. Despite its uncertainty we can safely state that the value for $\varphi_c$ is significantly lower than the percolation threshold of $\varphi_c = 0.29$ of a 3D system of randomly packed spheres.\textsuperscript{15} This suggests a filament-like arrangement of conductive domains, rather than an isotropic globular or “pancake” morphology, as observed for various older types of PEDOT:PSS.\textsuperscript{16} In fact, our value range for $\varphi_c$ is in good agreement with the conclusions of a recently published study combining field-dependent conductivity measurements and TEM analysis of the same type of PEDOT:PSS as studied in this work, though lacking the adhesion promoter.\textsuperscript{17} Indeed, fibrillar structures were observed both in dispersion and in the dry layer, consistent with a quasi-1D variable range hopping behavior of the in-plane conductivity and a percolation threshold of $\varphi_c << 0.125$.

Although some care should be taken in relation to the absence of the adhesion promoter in the PEDOT:PSS formulation used in the study by Kemerink et al.,\textsuperscript{17} we observe that the value we obtain for the critical exponent $x$, i.e. expressing the steepness of the rise in composite conductivity with PEDOT fraction near criticality, agrees strikingly well with their result ($x = 3.5$). What’s more, comparable exponents have been reported for other composites which conductivity relies on the percolation of high aspect ratio filler particles, such as carbon fiber/polymer,\textsuperscript{18} graphite/polymer,\textsuperscript{19} and metal/polymer.\textsuperscript{20} In contrast, the value for $x$ found by Stöcker et al.\textsuperscript{7} for LC PEDOT:PSS ($x = 1.05$) is significantly lower and closer to the “universal” number of $\sim 1.7$, theoretically predicted for ideal (lattice) percolation in three space dimensions.\textsuperscript{21} Considering the above, this is explained by the higher shape isotropy of the globular or “pancake”-like PEDOT domains typically encountered in these more “traditional” types of PEDOT:PSS.\textsuperscript{16}

3.4 Conclusions

This chapter reports on the effect of NaClO\textsubscript{(aq)} treatment on the thickness and conductivity of thin, highly conductive HC PEDOT:PSS layers. The thickness of the layers decayed exponentially with treatment time, to saturate at a residual thickness of at least $\sim 75\%$ of the initial layer thickness. No decrease in layer thickness was observed upon treatment of HC PEDOT:PSS\textsuperscript{*} with pure water, evidencing that the loss of material is principally caused by the reaction between hypochlorite and PEDOT. Using theoretical and experimental arguments, we showed that the decrease in conductivity as a function of treatment time is reaction-limited for hypochlorite concentrations below 0.01\%, but seems to enter a diffusion-dominated regime once the hypochlorite concentration is increased. The decrease in conductivity with treatment time follows a critical behavior followed by a power law at long exposure times. The curves corresponding to the reaction-limited regime were fitted to a general effective medium (GEM) model, integrated with an effective rate law for the over-oxidation of PEDOT. Obtained values for the percolation threshold and critical exponent are in good agreement with recent studies and suggest a filamentary
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rather than an isotropic globular morphology of the conductive PEDOT domains, typically observed for “traditional” low conductive PEDOT:PSS types.

References


REFERENCES


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