Electrochemical deposition of silicon from organic electrolytes

Electrochemical reduction of silicon from SiCl₄ in 1-butyl-1-methylpyrrolidinium bis(trifluoromethylsulfonyl)imide [BMP][TFSI] and in propylene carbonate (PC) with SiCl₄ as a precursor is performed at room temperature. The process is studied by means of Linear Sweep Voltammetry and chronoamperometry. The results exhibit considerable differences during the silicon deposition for copper and nickel. Scanning Electron Microscopy (SEM) of the layers shows a rough surface morphology. The composition of Si deposit is confirmed by Energy Dispersive X-ray analysis (EDX). Furthermore, the deposition of silicon onto TiO₂ nanotubes is discussed. In conclusion, a method of recycling the used ionic liquid by a simple extraction procedure is presented.

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Electrochemical reduction of silicon from SiCl$_4$ in 1-butyl-1-methyl-pyrrolidinium bis(trifluoromethylsulfonyl)imide [BMP][TFSI] and in propylene carbonate (PC) with SiCl$_4$ as a precursor is performed at room temperature. The process is studied by means of Linear Sweep Voltammetry and chronoamperometry. The results exhibit considerable differences during the silicon deposition for copper and nickel. Scanning Electron Microscopy (SEM) of the layers shows a rough surface morphology. The composition of Si deposit is confirmed by Energy Dispersive X-ray analysis (EDX). Furthermore, the deposition of silicon onto TiO$_2$ nanotubes is discussed. In conclusion, a method of recycling the used ionic liquid by a simple extraction procedure is presented.

1 Introduction

Silicon (Si) is widely used in many industrial applications, including microelectronics, photovoltaics and more recently for electrochemical energy storage. However, due to the expansion of the technical applications, where Si is implemented more versatile deposition technologies are required. Up to date, the most of the available Si technologies need high vacuum or high temperatures [1, 2]. Electrodeposition is a less complex and low-cost alternative to deposit Si layers [3]. The big advantage of electrochemistry is the possibility to adjust the properties of the layers by varying the deposition parameters, e.g. electrolyte composition and electrochemical potential. However, electrodeposition must be carried out in non-aqueous solvents due to the high reactivity of silicon precursors with water and the very low reduction potential [4]. Initial attempts for silicon electrodeposition were made in propylene carbonate (PC) [5] and tetrahydrofuran [6] based electrolytes. Many other researchers reported the successful reduction of silicon from acetonitrile [7-9], tetrahydrofuran [8, 10], propylene carbonate [11-18], high-temperature molten salts (HTMS) [19, 20] or ionic liquids (IL) [1-3, 21-26]. However, the main drawback of the volatile organic media is their flammability, so that safety precautions must be taken when using them as electrolytes. HTMS are also problematic as electrolytes, because they are highly reactive and energy consuming. In addition, electrodeposition from propylene carbonate or acetonitrile results in silicon deposits with a considerable amount of carbon and oxygen impurities because of solvent decomposition during the reduction process [11]. Besides that, ILs gained a high interest because of their large potential window of stability [1, 24]. These room-temperature molten salts have a low toxicity, low vapor pressure and are not flammable. Nevertheless, electrodeposition from ILs is also found to be accompanied with incorporation
of solvent and decomposition products into the silicon layers [24, 27, 28]. El Abedin and coworkers showed the possibility of silicon thin film deposition from these solvents [1]. In 2013 the same group analyzed the influence of various anions of the ILs to the deposit properties at different temperatures [29]. Vlaic et al. [24] and Komadina and coworkers [27] used electrochemical quartz crystal microbalance (EQCM) and X-ray photoelectron spectroscopy (XPS) to show that during the deposition process also chemical side reactions take place. This could be an explanation for the detection of decomposition products of the IL in the deposits. Recently, a more detailed insight to the processes on the electrode-electrolyte interface on the molecular level was given by Tsuyuki et al [30]. With X-ray reflectivity measurements and density functional calculations they found that during the reduction a polymer-like structure of \( \text{Si}_x \text{Cl}_y \) components is formed at the electrode surface. A variety of different deposition parameters were investigated by Thomas and coworkers [31]. It turned out that mainly the overpotential and the temperature have a decisive impact on the silicon deposition.

In the past twenty years, silicon also gained a lot of interest as anode material for Lithium-Ion batteries (LIB) [32, 33]. The capacity of the commonly used anode – graphite is limited to 372 mAh/g and therefore it must be substituted by another material to enhance the energy storage of LIBs [34]. Besides tin [32, 33, 35] and lithium [36-37], silicon is a promising candidate because of its high theoretical capacity of 4.2 Ahg\(^{-1}\) for \( \text{Li}_{22} \text{Si}_5 \) [13] and low operation voltage similar to the graphite anode [12]. However, the lithiation of this material involves high volume expansions (more than 300 %) resulting in a rapid capacity fade [14]. Approaches to overcome this problem are Si nanomaterials, nanocomposites and nanostructuring of the electrodes [38, 39]. Titanium dioxide nanotubes offer both space for the volume expansion of silicon during the lithiation and a high surface, which leads to a better lithium diffusion [7, 40]. Coated with silicon they are therefore a promising candidate for anodes in LIBs, especially for micro battery applications. Various electrolyte systems for the preparation of TiO\(_2\)-nanotubes are already investigated [41-43]. Promising results were received by using glycerol or ethylene glycol as a solvent and HF or NH\(_4\)F as fluoride source [39, 41, 44]. First successes on their application in LIBs are reported by Ivanov et al. [45] and Brumbarov and coworkers [44], who sputtered silicon onto the nanotubes, with the aim to enhance the cycling stability. Nanostructured copper electrodes are a good alternative to TiO\(_2\) due to the fact that copper has a higher electrical conductivity than TiO\(_2\). In addition, it is already used as a stable current collector in lithium-ion-batteries and the production of copper foam is easy and low cost.

Another problem is the high first cycle irreversible capacity loss when silicon is used in LIBs [37, 46-51]. Rehnlund et al. recently showed a lithium-ion trapping mechanism in silicon materials, which is responsible for this phenomenon [35]. A way to circumvent the problem of lithium trapping could be using pre-lithiated anode materials [50]. Recycling of the used electrolytes, especially ILs, is an important issue due to their high prices. It is well known, that when heated, the ILs partially decompose displaying a change in color [52]. Since already small amounts of impurities impair the physical and chemical properties and ILs are expensive, efficient cleaning techniques have to be developed [53]. Various methods are used to enhance the purity of these solvents like distillation [52, 54], extraction [54], zone melting [52] or membrane-based methods [54]. All of these procedures offer advantages and disadvantages.
Moreover, it is strongly dependent on the properties of the IL, e.g. if they are water-miscible or not, and the expected impurities whose cleaning process is most suitable for the electrolyte recycling [54].

Besides the results on the electrodeposition of silicon and the influence of different substrates and electrolytes to the thin films, an easy way to apply a reference electrode for different organic solvents is presented in this article. In addition, the results on the investigation of nanostructured substrates and, finally, an attempt to recycle the used Ionic Liquid will be shown.

2 Experimental

2.1 Chemicals and materials

Highly pure propylene carbonate and silicon tetrachloride were supplied by Alfa Aesar. 0.1 M tetrabutylammonium chloride (Sigma Aldrich, grade of purification ≥ 97 %) served as supporting electrolyte salt. The mixture of PC and tetrabutylammonium chloride (TBACl) was dried with a molecular sieve (pore diameter 0.3 nm, CarlRoth, Germany) for two days before adding the silicon precursor. The ionic liquid 1-butyl-1-methylpyrrolidinium bis(trifluoromethylsulfonyl) imide [BMP][TFSI] (99 %) was chosen because of its broad potential window and received from IoLiTec (Heilbronn, Germany) [1, 24]. It was dried at 120 °C under vacuum for 48 h until a value of 15 ppm was reached. The moisture in the solvents for the electrochemical experiments was controlled by Karl-Fischer titration with a Metrohm 831 KF Coulometer.

The chemicals for the anodization process (glycerol (99 %), NH₄F (98 %)) of titanium foils (96 %, 0.25 mm (GoodFellow)) were purchased from Alfa Aesar.

2.2 Reference electrode

An in lab made Ag/AgCl electrode with organic electrolytes, based on an idea of Saheb et al. [55], served as reference electrode. A silver wire was oxidized with a saturated FeCl₃ solution for 3 minutes, rinsed with water and dried under vacuum. It was immersed in a 6.4 cm long glass capillary, containing a solution of 0.1 M TBACl in [BMP][TFSI] or PC and closed with a glass frit (Vycor® glass, pore diameter 10 nm). The electrodes were calibrated against ferrocene/ferrocenium (fc/fc⁺) redox couple in the corresponding solvent (2.5 mM fc in [BMP][TFSI] or PC + 0.1 M TBACl).

2.3 Electrodeposition of silicon

All experiments were carried out in an argon filled glovebox (M Braun UNIlab LMF auto) maintaining water and oxygen levels below 0.1 ppm. A homemade PTFE cell was used for the electrochemical measurements. The working electrode (Cu or Ni) is clamped via a viton o-ring to the cell providing a geometric area of 0.33 cm². A platinum plate (A = 2 cm²) served as counter electrode and was heated to red glow prior to silicon electrodeposition. All potentials are measured against the above mentioned reference electrodes. Copper and nickel were polished with a silicon carbide grinding paper (granularity of 4000), rinsed with ethanol and dried for 1 hour under argon. The electrolytes were prepared by solving 0.5 M SiCl₄ in [BMP][TFSI] or PC and stirred for at least 12 hours. All electrochemical measurements were accomplished with a multi-channel potentiostat/galvanostat (VMP3 Bio-Logic Scientific Instruments).

After the deposition the samples were thoroughly rinsed with PC to remove residual electrolyte.
2.4 Anodization of Titanium

Before the formation of TiO$_2$ nanotubes the titanium foils were polished with SiC grinding paper (granularity of 4000) and sonicated for 5 minutes in ethanol and acetone, respectively. The anodization process was carried out in a two electrode electrochemical cell with a Pt mesh as counter electrode (40 V for 75 min). The electrolyte consisted of 0.5 wt% NH$_4$F and 2.0 wt% H$_2$O in glycerol. More details about the anodization of Ti can be found in [41].

Electrochemical reduction was performed in H$_2$SO$_4$, K$_2$SO$_4$ and KOH (E = -1.5 V vs. Ag/AgCl) with a concentration of 0.5 M for 1 minute, respectively.

2.5 Surface analysis

The surface morphology of all samples was investigated using an ultrahigh resolution scanning electron microscope (FE-SEM, Hitachi S-4800) with EDX analysis.

2.6 Recycling of [BMP][TFSI]

Recycling of the IL was carried out similarly to the purification steps after the synthesis of [BMP][TFSI] [56]. The spent electrolyte was stirred for 3 hours with the double amount of distilled water (Millipore-Milli-Q system, resistivity 18.2 MΩ) to remove remaining SiCl$_4$. After a filtration step to eliminate solid particles (SiO$_2$), water and IL were separated by an extraction funnel and collected in extra bottles. The IL was washed 6 times with H$_2$O (ratio 1:4). Subsequently, traces of the ionic liquid in the washing water were extracted with dichloromethane (H$_2$O : CH$_2$Cl$_2$ = 4:1) and mixed with the remaining IL to decrease the viscosity for the next step. To remove organic impurities the solution of [BMP][TFSI] and dichloromethane was cleaned three times by using a glass column with a frit (G4) filled with granular charcoal. After microfiltration (pore diameter 0.2 µm) CH$_2$Cl$_2$ was removed with the rotary evaporator. [BMP][TFSI] was dried for 48 h under vacuum at 120 °C. The measurement of the electrochemical stability window was carried out in inert atmosphere using a platinum working and counter electrode (geometric area 0.018 cm$^2$ or 2 cm$^2$).

3 Results and discussion

3.1 Reference electrodes

Nearly in all investigations of silicon electrodeposition Pt was used as a quasi-reference electrode. However, as commonly known, these electrodes do not ensure a stable potential as it can be seen in the potential variation of the silicon reduction from -2.0 V [24] to ca. -2.4 V [29]. Furthermore, often the potential of the Pt electrode shifts during the experiments [4]. For better comparison of the results and especially for kinetic measurements a reference electrode with a better stability is required.

Therefore, an Ag/AgCl electrode with organic electrolyte (Fig. 1a) is applied in the experiments. We found that the potential of this electrode changes with its geometry. Hence, a calibration against an internal standard is necessary. A well-known and widely investigated redox couple is ferrocene/ferrocenium. In most organic solvents, including ILs and PC, it shows a good reversibility, although the peak to peak separation is larger than the ideal 59 mV for a one electron, reversible process [55, 57-61] at 298 K. This is assumed to be due to the uncompensated resistance [61]. Thus, all voltammetric measurements were performed using the internal IR-compensation of the potentiostat.
The calculation of the reference-potentials were made using Equation 1:

\[ E = E_{pa} - \frac{\Delta E_p}{2} \]  \hspace{1cm} \text{<1>}

where \( E \) is the calculated reference-potential of the electrode, \( E_{pa} \) is the peak potential of oxidation process and \( \Delta E_p \) is the peak-to-peak separation [61]. The calculated values are 503 +/- 2 mV for the IL based reference and 714 +/- 5 mV for the PC based one.

From the cyclic voltammograms in Figure 1b it can be seen, that the IL based electrode is stable up to five months. After that time the vycor glass frit was clogged, but could be recovered by cleaning with \( \text{H}_2\text{O}_2 \). The differences in the currents are due to the various immersion depths of the used Pt wire for the calibration.

In contrast, the potential of the PC based reference shifted within 5 weeks about 25 mV to more positive values (Fig. 1c) and therefore it was replaced every third week.

3.2 Electrodeposition of silicon

It is known that silicon deposition from \( \text{SiCl}_4 \) in organic media is irreversible [6, 15, 29]. In order to investigate the reduction process and determine the potential for silicon deposition, LSVs were performed. In [BMP][TFSI] there are three reduction peaks at -0.6 V, -1.15 V and -1.6 V observable for the copper substrate (Fig. 2, black line). The latter one varies between -1.6 V and -1.7 V depending on the pretreatment of the substrate and corresponds to the bulk reduction of silicon, which is in agreement with the literature [29]. The first and second peaks are attributed to an adsorption of the IL, an underpotential deposition/ alloy formation [29] or a partial reduction of \( \text{Si}^{4+} \) to \( \text{Si}^{2+} \).

Density functional theory (DFT) calculations of
Tsuyuki et al. indicate that a partial reduction of the precursor takes place by forming first a $\text{Si}_2\text{Cl}_6$ dimer and with further reduction a polymer-like structure in front of the electrode surface [30]. They used, however, an ammonium-based IL for their experiments. Nonetheless, a similar process is imaginable for [BMP][TFSI]. This would mean, that the first two peaks could be adsorption and or partial reduction of the silicon chloride with following polymer formation. At potentials more negative than -2.0 V decomposition of the electrolyte occurs.

For the nickel substrate (Fig. 2, red line) a different voltammetric shape is observable. There are 2 current peaks (-0.4 V and -1.7 V) and two shoulders (-0.9 V and -1.35 V) present on the voltammogram. The first one (-0.4 V) could be an adsorption of the IL. Maybe a partial reduction of silicon on nickel takes place, too, but with a different mechanism than on Cu. At -1.7 V bulk deposition of silicon takes place. To the best of our knowledge there is no literature based on silicon deposition on nickel from IL to compare the results.

In contrast, in PC (Fig. 3) there is only one reduction wave at -1.1 V for both substrates. Below -1.5 V the electrolyte decomposes. Nevertheless, potentiostatic experiments at -1.1 V lead to no visible layers, indicating that the silicon reduction occurs at more negative potentials. Indeed, the LSVs exhibit a small shoulder at -1.75 V (black curve) for copper and a peak at -1.9 V for nickel. Due to the decomposition of electrolyte, potentiostatic deposition was performed at -1.5 V. However, only a very thin layer was visible on nickel and further deposition experiments were made by applying a more cathodic potential. Similar results are obtained by other researchers [13-15].

The impact of the different substrates and electrolytes on the silicon deposition can be analyzed by comparing the current-time transients (Fig. 4). In table 1 the parameters of the potentiostatic experiments are summarized. First of all, it should be mentioned that the absolute current for the same substrate, electrolyte and applied potential is not the same due to different active surface areas coming from the pretreatment. Hence, the data presented in Figure 4 just
show a trend of the current behavior. Independent from the electrolyte type, the copper substrates (Fig 4a, b) always exhibit the highest currents. The higher current in PC compared to the IL could be explained by a decreased viscosity of this electrolyte. Nevertheless, the current of the nickel substrate in PC (Fig. 4d) is even lower than in the IL. An explanation for this could be the decomposition of the electrolyte which hinders the diffusion of SiCl$_4$ molecules to the electrode surface resulting in a very thin layer. Similar assumptions are made by Nishimura and coworkers [15]. In contrast, there are several current waves visible for nickel in the IL based solution (Fig. 4c). Decomposition of the electrolyte could be an explanation for this behavior.

Since the active surface area for the nanostructured substrate is much higher than the geometric one, it is hard to compare the current densities with copper or nickel. The TiO$_2$ nanotubes show a very low current, not only because of a lower precursor concentration, but also due to the lower conductivity of this material. The current should be the lowest of all substrates, if the exact surface area is known and used for the calculation of the current density.

3.2.1 Surface analysis of silicon thin films

The morphological characterization of the silicon deposits was made by SEM. The layers obtained from the IL are dense and have only a few cracks (Fig. 2a, c). At higher magnifications (Fig. 2b, d) the materials exhibit a globular surface morphology. On copper there are spherical units with diameters between 50 – 400 nm observable. Similar morphologies are reported by other researchers [24, 29]. On the other hand, there is a superimposed structure with globular units perceptible on Ni. These structures enable the inclusion of electrolyte into the layer. EDX-analysis of the deposits showed the presence of C, O, N, F, S and Cl, which originates from trapped electrolyte or its decomposition products. The stability of the [TFSI]$^-$ ion during the deposition was analysed by Vlaic et al [24]. Oxygen, however, originates from air exposure during the sample transport to the SEM, too.

**Fig. 4:** Chronoamperograms of copper and nickel in [BMP] [TFSI] and propylene carbonate and of TiO$_2$ nanotubes in [BMP][TFSI]. The concentration of the precursor is 0.5 M, respectively, except for the TiO$_2$ nanotubes (0.1 M). The applied potentials are -1.7 V (a), -1.5 V (b), -1.7 V (c), -1.9 V (d), and -1.9 V (e)

| Tab. 1: Parameters for the electrodeposition of silicon |
|---------------------------------|----------------|----------------|----------------|----------------|
| substrate | Cu | Ni | Cu | Ni | TiO$_2$ |
| electrolyte | [BMP][TFSI] | [BMP][TFSI] | PC | PC | [BMP][TFSI] |
| c (SiCl$_4$) | 0.5 M | 0.5 M | 0.5 M | 0.5 M | 0.1 M |
| potential | -1.7 V | -1.7 V | -1.5 V | -1.9 V | -1.9 V |
| color of deposit | orange - brown | yellowish - green | orange - brown | yellowish - green | black |
In contrary, the silicon layer on copper obtained from PC shows a superimposed and very rough structure with voids (Fig. 3a). This is in accordance with the works of Momma and coworkers and Epur et al., who observed a rough structure with cracks and uneven thickness [11, 13]. The thin film on nickel is also rough, but without any cracks. The size of the particles varies between 100 and 700 nm. Similar results are found by Nishimura and Fukunaka [15]. However, they used galvanostatic methods and much higher potentials (-3.6 V vs. Pt-QRE). Beside silicon, carbon, oxygen and a minor amount of chlorine are present in these deposits.

The exact composition of the silicon layers is currently investigated by X-ray photoelectron spectroscopy (XPS).

### 3.3 Nanostructured substrates

#### 3.3.1 Titaniumdioxide nanotubes

The nanostructured electrodes, especially TiO$_2$ nanotubes, could buffer the high volume expansion of silicon during lithiation. However, titanium dioxide has a very low electrical conductivity, which could be a problem for silicon electrodeposition. Therefore, we tried to increase the conductivity by electrochemical reduction of the nanotubes. We observed that in acidic or alkaline electrolytes the nanotubes (NTs) are destroyed during the reduction process (Fig. 5a). This phenomenon occurs even in neutral solutions for reaction times over 1 minute.

The reduced NTs were used as templates for silicon deposition. Figure 5b shows that the coating is mainly on the surface leading to the assumption that the tubes are too close to each other (15-50 nm from SEM analysis) for the IL based electrolyte to reach the bottom of the substrate. Recently, Nemaga et al. discovered an electrolyte with hydrofluoric acid, which provides homogeneous tubes with high distances (100 – 200 nm) [62]. Due to the hazard potential of HF, it would be advantageous to use HF-free electrolytes with regard to large-scale production of this substrate. This is the subject of ongoing research.

#### 3.4 Recycling of electrolytes

Removing the remaining precursor and purging the electrolyte from decomposition products is relatively straight forward. To verify the cleaning, it is possible to do spectroscopic measurements and to check the electrochemical stability window (Fig. 6).

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![Fig. 5: SEM micrographs of the titanium foils anodized in glycerol with 2 wt% H$_2$O and 0.5 wt% NH$_4$F at 40 V - 75 min. Electrochemically reduced TiO$_2$-NTs in KOH electrolyte (a) and silicon coated NTs (b)](image)
As can be clearly seen, there is no cathodic peak observable for the recycled IL, whereas this is not the case for the fresh solution. However, the oxidation current increases at lower anodic voltages, which is probably due to residual small amount of decomposition products in the IL. Moreover, it has a slightly yellow color, which can originate from these compounds [52]. Indeed, it is known that changes in color could result from impurities which are below the detection limit of NMR spectroscopy [63]. However, since the color affects spectroscopic measurements with light absorption or emission, it is not possible to verify the purity of the IL with these methods [64]. Therefore, a method for decolorizing the solutions based on the work of Earle and coworkers will be used to verify the purity of the recycled electrolytes in addition to electrochemical techniques also with optical spectroscopic methods [64]. In summary, from the absence of any additional peaks, especially in the cathodic region of the voltammetric data for the recycled IL, it can be anticipated that the IL contains no more electroactive species, which would adversely affect further use as an electrolyte for silicon deposition. Hence the used cleaning procedure is an appropriate method for recycling of used electrolytes.

4 Conclusion

The electrochemical deposition of silicon from two different electrolytes has been investigated. The different substrates showed a similar behavior in the LSVs in PC. The bulk deposition at the nickel substrates occurred at more negative potentials. The chronoamperograms showed higher currents for the copper substrates. However, despite the lower viscosity of the PC based solution, the current for nickel is lower than for the IL electrolyte. This could be attributed to the decomposition of the electrolyte. SEM analysis displays rough silicon deposits. The layers obtained in IL are dense with small cracks and consist of small spherical units. EDX confirms the presence of trapped electrolyte or its decomposition products. The deposition of silicon from PC results in a superimposed structure with voids and holes. A high contamination with carbon and oxygen is confirmed by EDX analysis, especially due to the electrolyte decomposition during the deposition. An Ag/AgCl reference electrode for organic electrolytes provided a stable potential for the experiments over weeks (PC) and up to five months (IL). The electrochemical deposition of silicon onto TiO\(_2\) nanotubes was not possible because of the small tube distances. SEM analyses pointed out that long reduction times and highly acidic or alkaline media destroy the nanotubes. Purging of the used electrolyte by a simple extraction method is easy and fast to recycle the expensive solution. Although there was a change in color to slightly yellow, electrochemical measurements confirmed a thorough cleanup.

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References


[33] Obrovac, M. N., Chevrier, V. L. (2014). Alloy negative electrodes for Li-ion batteries. Chemical reviews, 114(23), 11444-11502


[38] Manthiram, A. (2017). An outlook on lithium ion battery technology. ACS central science, 3(10), 1063-1069


[43] Ng, S. W., Yam, F. K., Beh, K. P., Hassan, Z. (2014). Titanium dioxide nanotubes in chloride based electrolyte: an alternative to fluoride based electrolyte. Sains Malaysiana, 43(6), 947-951


[49] Li, C., Liu, C., Wang, W., Mutlu, Z., Bell, J., Ahmed, K., Ye, R., Ozkan, M., Ozkan, C. S. (2017). Silicon derived from glass bottles as anode materials for lithium ion full cell batteries. Scientific Reports, 7(1), 917


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