



A new method for the synthesis of 3-hydrazinopropyl trimethoxysilane

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Abstract. A new method for the synthesis of 3-hydrazinopropyl trimethoxysilane is proposed. The method is relatively simple and is based on hydrosilylation like the synthesis of analogous aminosilanes. For drying allylhydrazine hydrate a new efficient silyl hydride base method is proposed. The product, a new hydrazino-ormosil (organically modified silicate), can be applied in chemical modification of SiO₂ surfaces, thus offering an alternative to aminosilane modification, which is widely applied in several surface coating technologies.

Key words: hydrazinosilanes, surface silanization, hydrosilylation, allyl hydrazine, dehydration of allyl hydrazine hydrate.

INTRODUCTION

Silicon alkoxides, also known as ormosils (organically modified silicates), are a group of the most common reagents for covalent treatment of SiO₂ surfaces. Aminosilanes, especially 3-aminopropyl triethoxysilane (APTES), are the most frequently used compounds in biosensorics for tethering biological species to solid substrates [1–4]. Other applications include treatment of membranes [5] or adsorbents for the adsorption of heavy metal ions [6,7] and design of novel chiral stationary phases for chromatography [8]. Aminosilanes are synthesized catalytically (different Rh-complexes and Speier's catalyst [9]) by hydrosilylation of an appropriate aminoalkene with compatible alkoxy silane [10–12].

To our knowledge the usage of chemically close analogues of aminosilanes – hydrazinosilanes – for surface silanization has not been reported. However, hydrazinosilanes may have advantages over aminosilanes, as hydrazines can be used in a broader pH range. For example, by aldehyde linking a hydrazone is formed from a hydrazine group [13], which is hydrolytically more stable than imine obtained from an amino group. Another advantage may rise from a greater

chemical versatility of hydrazines, as they can have a larger number of chemical substitutions than amines.

Recently we proposed a pioneering method for the synthesis of a hydrazino analogue of APTES – 3-hydrazinopropyl trimethoxysilane (HPTMS) [14]. The method is relatively simple and is based on hydrosilylation like the synthesis of aminosilanes. Allyl hydrazine reacts with trimethoxysilane in the presence of PtO₂, which is a novel and efficient catalyst for hydrosilylation of aminoalkenes [15]. The major challenge of the synthesis lies in preventing the hydrolysis of trimethoxysilane, which may seriously decrease the yield and purity of the product. In the current paper we present our recent progress in the development of the synthesis route of HPTMS. Also, an efficient way for the drying and in situ use of the primary reagent allyl hydrazine is proposed.

RESULTS AND DISCUSSION

For the synthesis of HPTMS it is necessary to use anhydrous allyl hydrazine as a parent substance to prevent hydrolysis of trimethoxysilane. However, this is complicated because hydrazines like amines form strong hydrates due to their basicity [16]. A well-known example here is hydrazine hydrate (64 wt.% of

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hydrazine [17]). Hydrazines can also form azeotropes with water; for example, hydrazine at the mixture composition 71.5 wt.% of hydrazine [18] and monomethyl hydrazine at 35 wt.% [17]. In the literature no specific studies on hydrates and azeotropes of allyl hydrazine can be found, yet the data for its boiling point indicate some inconsistency that may be caused by either of these cases. Namely, two substantially different temperatures have been reported (at normal pressure): 122–124 °C [19] and 102–112 °C [20]. This deviation can be caused by the formation of an azeotrope or a very stable hydrate.

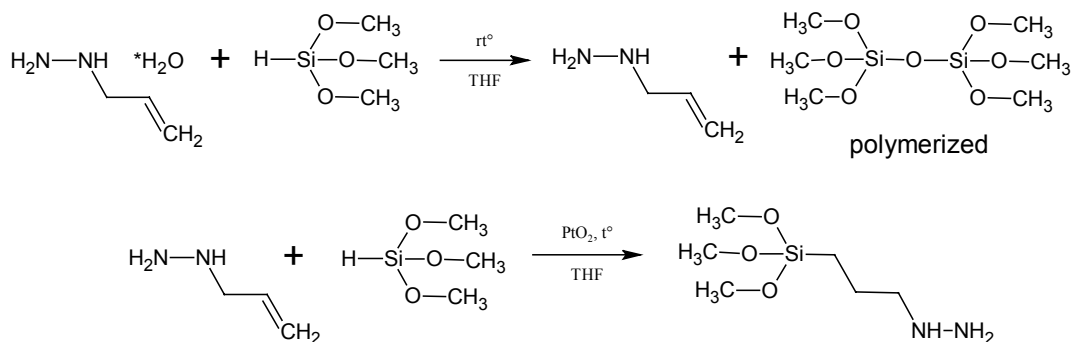
Thus, obtaining anhydrous allyl hydrazine from its hydrate is not a trivial task, but neither is its direct synthesis. Traditional methods for the synthesis of allyl hydrazine make use of hydrazine hydrate as a parent substance [19,20]. As a result of its reaction with allyl halides allyl hydrazine hydrate is formed. An alternative method uses the orthogonal protective group strategy [21], but in case the reagents are in contact with water in subsequent steps of the synthesis, the formation of the hydrate cannot be precluded. Lack of proper methods for obtaining anhydrous allyl hydrazine is supposedly the major reason why the compound is commercially available only in the form of hydrates. The synthesis of allyl hydrazine is discussed in greater detail in our previous study [22].

The dehydration of hydrazine hydrate, in contrast, is well known. In the current work an analogous approach was attempted for the preparation of anhydrous allyl hydrazine from its hydrate. There are two methods for removing water: by applying drying agents or by azeotropic distillation with aniline as an entrainer. Technical problems emerge when applying the distillation approach, as both liquid and vapour hydrazine are quite explosive. The drying-agent approach was performed using KOH [23], CaH₂ [17], BaO [24], and molecular sieves [25]. The effectiveness of a drying agent was assessed by qualitative reaction with trimethoxysilane or by recording a ¹H-NMR spectrum. The hydrolysis of trimethoxysilane is a suitable means for this purpose, as this reaction must be avoided when

synthesizing HPTMS from trimethoxysilane and allyl hydrazine hydrate. Trimethoxysilane reacts very violently with water, leading to the formation of different polysiloxanes (e.g. hexamethoxydisiloxane). The reaction can be readily screened by the formation of H₂. As a result of the series of drying experiments it was confirmed that allyl hydrazine formed an extremely stable hydrate, which could not be decomposed with the traditional drying agents.

Next, we hypothesized that trimethylsilane might be hydrolysable by the hydrate water in allyl hydrazine hydrate similarly to trimethoxysilane. This reaction would pose an important advantage as compared to the hydrolysis of trimethoxysilane, as it only yields hexamethyldisiloxane, in contrast to different polysiloxanes, which cannot be removed from the mixture due to their very high boiling points. Hexamethyldisiloxane has the boiling point at 101 °C, meaning that it can be easily removed from the reaction mixture by distillation. However, trimethyl silane did not react with allyl hydrazine hydrate at any mixture compositions. Its lower reactivity compared to trimethoxysilane could be explained by different influences of alkyl and alkoxy groups on the polarity and stability of the Si–H bond. Due to the electronegativity of oxygen the electron density of the Si–H bond in trimethoxysilane is localized on silicon, thus loosening hydrogen and making the alkoxy compound more reactive. The hydrolysis of trimethylsilane was reported earlier, but at considerably higher temperatures [26]. In our case the high temperatures could not be applied due to the disproportionation of allyl hydrazine by heating [22].

However, quite surprisingly it was found that allyl hydrazine hydrate could be reacted with trimethoxysilane to produce HPTMS (instead of polysiloxanes) in the case of dilution and great excess of silane. Here the polymerization of the latter appeared to be effectively suppressed. Trimethoxysilane acts like a drying agent, generating free allyl hydrazine, which then immediately reacts with the remaining trimethoxysilane to form HPTMS in the presence of PtO₂ catalyst and heating (Scheme 1). To suppress the polymerization of the



Scheme 1. Synthesis of 3-hydrazinopropyl trimethoxysilane.

hydrolysis products the reaction mixture was diluted in tetrahydrofuran (THF). The formation of HPTMS was confirmed by spectral data (NMR, IR, MS). Unlike in the case of stoichiometric parent mixture, which only produced traces of HPTMS [14], the yield was now considerably improved; however, excess trimethoxysilane and some polysiloxanes remained in the mixture. The experiment starting from 0.05 mol of allylhydrazine hydrate gave 21.84 g of crude liquid product. The purification of HPTMS will be the main focus of our future research.

CONCLUSIONS

A simple and efficient method for the synthesis of 3-hydrazinopropyl trimethoxysilane was developed by just mixing allyl hydrazine hydrate and trimethoxysilane in the presence of PtO₂ catalyst and heating. Also, it was shown that allyl hydrazine hydrate is very stable and cannot be dehydrated by conventional drying agents, such as KOH, BaO, CaH₂, and molecular sieves.

EXPERIMENTAL SECTION

General

The ¹H-NMR and ¹³C-NMR spectra were recorded at ambient temperature on a Bruker Avance II 200 spectrometer, using CDCl₃ as the solvent and TMS as the internal standard. The ¹H-NMR spectra were measured at 200 MHz and the ¹³C-NMR spectra at 50 MHz. The IR spectra were obtained on a Perkin-Elmer Spectrum BXII FT-IR instrument, where the samples were in the form of a film on a KBr pellet. GC-MS analysis was performed using a Varian Saturn 3000 instrument (column 30 m × 0.25 mm with liquid phase DB-5) under the following conditions: the column temperature 120 °C and the inlet temperature 200 °C. GC analyses were performed using a HP 5890A gas chromatograph with a FID detector and an Elite PE-5 column (30 m × 0.25 mm) under the following conditions: the column temperature 120 °C, the inlet temperature 200 °C, the detector temperature 200 °C. HRMS spectra were measured on a Thermo Electron LTQ Orbitrap ESI spectrometer. All reagents were of commercial quality and were purified according to general procedures.

Treatment of allyl hydrazine hydrate with common drying agents

For the dehydration of allyl hydrazine hydrate drying agents were applied according to their effectiveness in the following order: KOH, BaO, CaH₂, and molecular sieves.

KOH was added to allyl hydrazine hydrate up to saturation. Organic and aqueous phases were separated. Next, BaO was added to allyl hydrazine and the formed suspension was stirred for one hour and filtrated. The content of water in allyl hydrazine was determined qualitatively by the reaction with trimethoxysilane. In contact with allyl hydrazine trimethoxysilane hydrolysed, indicating that traces of water were still present in allyl hydrazine.

Next, allyl hydrazine was treated with CaH₂. The mixture was stirred and heated at 50 °C for one hour. The content of water in allyl hydrazine was again determined with trimethoxysilane.

Molecular sieves were added to allyl hydrazine, which was previously treated with KOH, BaO, and CaH₂, and the mixture was stirred at ambient temperature for 3 days. The recorded ¹H-NMR spectra indicated that after treatment with molecular sieves the content of water in allyl hydrazine was equal with that of allyl hydrazine hydrate.

¹H-NMR: δ = 3.18 (s, 1H, NH), 3.41 (d, 2H, J = 5.8 Hz, N-CH₂), 5.19–5.27 (m, 2H, CH₂), 5.72–5.92 (m, 1H, CH).

Treatment of allyl hydrazine hydrate with trimethylsilane

Trimethylsilane was prepared according to the procedure in the literature [27] from trimethylchlorosilane by reduction with LiAlH₄. Formation of the product was determined with GC.

For the hydrolysis about 4 g of trimethylsilane was transferred into 5 mL of allyl hydrazine hydrate at room temperature in argon flow. Alternatively, trimethylsilane was cooled and added with syringe to allyl hydrazine in liquid state. The mixture was stirred at ambient temperature and the course of the reaction was monitored by recording NMR spectra. No hydrolysis of trimethylsilane was observed.

Synthesis of HPTMS

Five mL (0.05 mol) of allyl hydrazine monohydrate was dissolved in 30 mL of THF and a catalytic amount (~1 mg) of PtO₂ was added to the solution. The mixture was stirred in the argon atmosphere at room temperature, and 20 mL (0.15 mol, 3 equiv.) of trimethoxysilane was added dropwise. After the addition of trimethoxysilane the mixture was stirred for 30 min at room temperature and then heated for 93 hours under reflux. After heating THF was removed from the mixture by distillation, PtO₂ precipitated. The reaction gave 21.84 g of crude liquid product.

¹³C NMR: δ = 6.80 (Si-C), 21.1 (C-CH₂-C), 50.5–51.2 (Si-O-C), 68.0 (C-N).

$^1\text{H NMR}$: δ = 0.63–0.71 (m, 1H, Si–CH₂), 1.50–1.69 (m, 2H, C–CH₂–C), 2.73–2.81 (m, 2H, CH₂–N), 3.57–3.59 (m, 9H, O–CH₃), 3.74 (m, 2H, NH₂).

IR: 2946 cm⁻¹, 2844 cm⁻¹ (CH₂, CH₃), 1457 cm⁻¹ (NH def), 1192 cm⁻¹, 1060 cm⁻¹ (Si–O), 826 cm⁻¹ (Si–C).

GC–MS: NH₂–NH–(CH₂)₃–Si–(OCH₃)₃ [MH⁺]: 195.

HRMS (C₆H₁₈O₃N₂Si): M(calc) = 195,11595; M(det) = 195,11575.

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Uus meetod 3-hüdrasinopropüültrimetoksüsilaani sünteesiks

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On välja töötatud uus sünteesimeetod 3-hüdrasinopropüültrimetoksüsilaani (HPTMS) valmistamiseks. HPTMS on uudne hüdrasinofunktsionaalne pindade silüülimisreagent. Antud ühendil on mitmeid hüdrasinorühmast tulenevaid eeliseid, võrreldes analoogilise ja palju rakendust leidnud 3-aminopropüültrimetoksüsilaaniga (APTES). Näiteks aldehüüdlinkimise korral moodustub molekulide sidumisel HPTMS-iga modifitseeritud pinnale hüdrasiinist hüdrasoon. Tekkinud struktuurid on stabiilsemad ja seetõttu kasutatavad laiemas pH vahemikus, kui sidumisel üle aminorühma saadavad imiinid. Lisaks sellele jääb hüdrasinorühma korral pärast immobiliseerimist alles üks vaba NH-rühm, mille abil saab elektrondonoorsete või -aktseptoorsete asendusrühmade ja steerika kaudu mõjutada struktuuri reaktsioonivõimet.

HPTMS-i sünteesistrateegia valikul lähtuti sarnasusest APTES-iga, mida nagu teisi aminiokoksüsilaane on sünteesitud vastava amiini hüdroksilüülimisel sobivate alkoksüsilaanidega. Käesolevas artiklis on kirjeldatud HPTMS-i sünteesimeetodit, mis põhineb allüülhüdrasiini katalüütilisel hüdroksilüülimisel trimetoksüsilaaniga. Probleemid selle sünteesimeetodi juures on tingitud nõudest kasutada veevaba allüülhüdrasiini, et vältida trimetoksüsilaani hüdrolyüsumist. Trimetoksüsilaani hüdrolyüsi tulemusena saadakse soovitud produkti asemel mitmesugustest polüsiloksaanidest koosnev sade.

Hüdrasiinid nagu amiinidki moodustavad aluselisuse tõttu üsna püsivaid hüdraate. Antud uurimuse raames võrreldi erinevaid kuivatusmeetodeid allüülhüdrasiinhüdraadist veevaba allüülhüdrasiini saamiseks. Leiti, et allüülhüdrasiin moodustab veega väga püsiva hüdraadi, mille lõhkumiseks ei piisa töötlemisest traditsiooniliste kuivatavate reagentidega, näiteks NaOH, CaH₂, BaO ja molekulaarsõelad.

Probleemi lahendusena töötati välja HPTMS-i sünteesimeetod, kus lähteainena kasutatakse siiski allüülhüdrasiinhüdraati, kuid kõrvalreaktsioonina kulgeva trimetoksüsilaani hüdrolyüsi mõju sünteesi lõpptulemusele on allasurutud. Allüülhüdrasiinhüdraadile lisatakse toatemperatuuril liias trimetoksüsilaani, osa trimetoksüsilaanist hüdrolyüsub allüülhüdrasiini hüdraatvee toimel. Selle tulemusena genereeritakse segusse veevaba allüülhüdrasiin, mis kuumutamisel reageerib katalüsaatori (PtO₂) mõjul allesjäänud trimetoksüsilaaniga ja moodustub HPTMS. Saadud ühendi struktuur tõestati, kasutades erinevaid nüüdisaegseid analüüsimeetodeid, nagu FTIR, NMR, GC-MS ja HRMS.

Kokkuvõtteks võib öelda, et väljatöötatud meetod HPTMS-i sünteesiks on lihtne ja efektiivne. Uurimistöö edasine eesmärk on ühendi praktiline rakendamine erinevate SiO₂ pindade modifitseerimiseks.