

3-Glycidoxypropyltrimethoxysilan: Description, And Analysis of Works Approaches and Applications

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Abstract:

3-Glycidoxypropyltrimethoxysilan, also known as GPTMS, is a versatile organosilane compound that has gained significant attention in various fields. Its unique chemical structure, consisting of a glycidoxy group and three methoxy groups attached to a propyl chain, enables it to exhibit exceptional reactivity and compatibility with different materials. In the literature, extensive research has been conducted to understand the properties and behavior of GPTMS. Studies have focused on its synthesis methods, All of the GPTMS work is discussed and evaluated in this article. The work done in various areas of GPTMS has also been assessed. We have discovered and discussed all of the applications of GPTMS as well as its physical and chemical properties. In conclusion, here is the complete GPTMS description. We have covered all of the GPTMS applications as well as all of the experimental work done on them, including sol-gel pressure synthesis, hybrid coating sol-gel processes, cellulose-based sensors, etc.

Keywords: GPTMS, Wearable sensor, Epoxy-ring opening, FT-IR kinetics, Sol-gel Coating, Hybrid organic–inorganic materials, epoxy coatings, Hydrolytic Reaction,

Introduction:

Silane Coupling Agents were the first extensively applied coupling compounds, having been in use for almost 40 years [1]. The reactive groups on one end of its structure, such as amino and vinyl, can react with epoxy, phenolic, polyester, and other synthetic resin molecules. Because of these reactive groups, the silane coupling agent and synthetic resin molecules may form strong chemical bonds, which improve adhesion and compatibility.[2,3] The silicon atom at the other end of the silane coupling agent structure may link with various inorganic surfaces such as glass, metal, or ceramic, improving the composite material's overall performance and endurance. 3- Glycidoxypropyltrimethoxysilane can enhance the electrical properties of epoxy resin-based sealants, packaging materials, and printed circuit boards. It may also be used to improve the cohesiveness of water-containing caulking glue and sealants in polyurethane and epoxy resin coatings. When combined with organic toner, it increases the adhesive's solubility, dispersity, and fluidity.[4] 3-glycidoxypropyltrimethoxysilane is used as a cross-linking agent and adhesion enhancer in commercially available silicone sealant compositions.[5] In addition, 3-glycidoxypropyltrimethoxysilane is commonly employed as a surface treatment agent for glass fibers in composite materials, enhancing their mechanical strength and adhesion to resin matrices. Furthermore, it

has been found to be effective in improving the moisture resistance and thermal stability of various polymeric materials, making it a valuable additive in the production of electronic components and insulation materials. The opposite end is made up of alkoxy (methoxy, ethoxy, etc.) or chlorine atoms that are linked with silicon. Hydrolysis in a water solution or moist air can convert these groups to silanol [6]. Furthermore, the generated silanol can react with the surface hydroxyls of glass, minerals, and inorganic fillers. As a result, silane coupling agents are widely utilized in silicate-filled epoxy, phenolic, and polyester resin systems, among others. [7] In addition, it can also be used for FRP production, in order to improve its mechanical strength and resistance to wet environment. The organic groups of the silane coupling agent are selective about the reaction of the synthetic resin. Generally, these organic groups lack sufficient reactivity with synthetic resins such as polyethylene, polypropylene and polystyrene, and thus the coupling effect for them is poor [8,9]. In recent years, new varieties of silane coupling agents with better coupling for polyolefins have been developed, but are limited in cost and other properties and are not yet widely used. 3-Glycidyloxypropyltrimethoxysilane (GPTMS) is a bifunctional organosilane containing three methoxy groups and an epoxy ring on one side. The methoxy groups form a three-dimensional matrix when they bond to glass substrates. With amides, alcohols, fatty acids, and acids, the epoxy group interacts. GPTMS is extremely reactive in water & can serve as a linker between the silica surface & the polymeric matrix [10]. 3-Glycidyloxypropyltrimethoxysilane can enhance the electrical properties of epoxy resin-based sealants, packaging supplies, & printed circuit boards. It may also be used to improve the cohesiveness of water-containing caulking glue and sealants in polyurethane and epoxy resin coatings. When combined with organic toner, it increases the adhesive's solubility, dispersity, and fluidity [11]. 3-glycidyloxypropyltrimethoxysilane is a substance utilized as a cross-linking agent and adhesion enhancer in commercially available silicone sealant compositions. 3-Glycidyloxypropyltrimethoxysilane is mostly employed in coatings as a chemical intermediary and adhesion booster. It is a coupling agent with an epoxy group [11]. It has been used as a caulking glue or sealer of polysulfide and polyurethane, as well as an epoxy resin adhesive. 3-Glycidyloxypropyltrimethoxysilane is a coupling agent that may be founded in polysulfide and polyurethane caulks and sealants, mineral-filled or a glass-reinforced thermosets and thermoplastics, and glass roving size-binders. It is used as an adhesion-promoting component in aqueous systems, for an example, to improve the adherence of acrylic latex sealants [12]. 3-Glycidyloxypropyltrimethoxysilane has the potential to increase the dry and wet strength of cured composites reinforced with glass fiber roving, as well as the wet electrical characteristics of epoxy-based wraps and packaging materials. Remove the need for a separate primer when using polysulfide and urethane sealants. Enhance the adherence of aqueous acrylic sealants as well as urethane and epoxy coatings [12,13,15]

Molecular Structure:

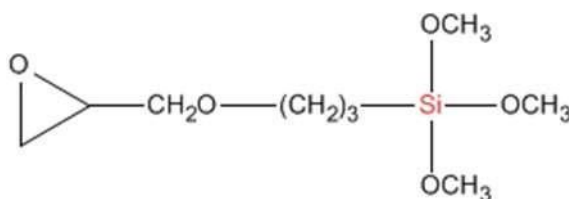


Fig.1 molecular structure: 3-Glycidyloxypropyltrimethoxysilane

3-Glycidyloxypropyltrimethoxysilane an organosilane having three methoxy groups on one side and an

epoxy ring on the other [14]. The methoxy groups bond effectively to glass substrates, forming a three-dimensional matrix. Amides, alcohols, thiols, and acids are all reactive with the epoxy group.[15] 3-Glycidoxypropyltrimethoxysilane is mostly employed in coatings as a chemical intermediary and adhesion booster [17]. It is a coupling agent with an epoxy group. It may be used as a caulking glue or sealer of polysulfide and polyurethane, as well as an epoxy resin adhesive[15,16]

Table 1. Basic description: 3-Glycidoxypropyltrimethoxysilane

Chemical Name:	3-Glycidoxypropyltrimethoxysilane
Synonyms	GLYMO;3-GLYCIDYLOXYPROPYLTRIMETHOXYSILANE Glycidyloxypropyltrimethoxysilane;3-(2,3-EPOXYPROPOXY)PROPYLTRIMETHOXYSILANE;Silane coupling agent KH-560;γ-Glycidoxypropyltrimethoxysilane;GOPTS;A 187;Silane coupler KH-560;(GLYCIDOXYPROPYL)TRIMETHOXYSILANE
CAS No.	2530-83-8
CB Number:	CB2194134
Molecular Formula:	C ₉ H ₂₀ O ₅ Si
Molecular Weight:	236.34
MDL Number:	MFCD00005144
MOL File:	2530-83-8.mol

Table 2. 3-Glycidoxypropyltrimethoxysilane: Physical and Chemical Properties

Melting point	-50°C
Boiling point	120 °C/2 mm Hg(lit.)
Density	1.070 g/mL at 20 °C
vapor pressure	0-12790Pa at 20-25°C
refractive index	n _{20/D} 1.429(lit.)
Flash point	>230 °F
storage temp.	Store below +30°C.
Solubility	Acetonitrile (Slightly), Chloroform
Form	Liquid
Specific Gravity	1.07
Color	Clear
Water Solubility	Miscible with alcohols, ketones and aliphatic or aromatic hydrocarbons. Immiscible with water.
Hydrolytic Sensitivity	7: reacts slowly with moisture/water
Sensitive	Moisture Sensitive
BRN	4308125
Stability	Moisture Sensitive
InChIKey	BPSIOYPQMFLKFR-UHFFFAOYSA-N
LogP	-2.6-0.5 at 20°C
CAS Database Reference	2530-83-8(CAS Database Reference)

FDA UNII	5K9X9X899R
NIST Chemistry Reference	3-Glycidoxypropyltrimethoxysilane(2530-83-8)
EPA Substance Registry System	3-(Trimethoxysilyl)propyl glycidyl ether (2530-83-8)

Table 3. Handling, Storage, Toxicological Information

Physical Properties
Colorless transparent liquid.
Soluble in a variety of organic solvents
Easy to hydrolysis
Able for condensation to form polysiloxanes
Easy to polymerize in the presence of overheating, light and peroxide.
Handling
Normal measures for preventive fire protection.
Storage
Keep container tightly closed in a dry and well-ventilated place. Recommended storage temperature is 2-8 °C.
Fire-fighting measures- Flammable properties
Flash point: - 135 °C (275 °F)-closed cup
Ignition temperature: - 400 °C (752 °F)
Suitable extinguishing media
Toxicological Information
Acute toxicity: LD50 Oral-rat-8,030 mg/kg
LD50 Dermal-rabbit-4,248 mg/kg
Irritation and corrosion: -Eyes-rabbit-Mild eye irritation
<input type="checkbox"/>

Detailed explanation of GPTMS research and experimentation in several manufacturing sectors: - The importance of the sol-gel precursors 3-glycidoxypropyltrimethoxysilane in the creation of wearable sensors for health surveillance:

Textiles constitute a highly appealing material class to use to develop wearable biosensors. Electronic textiles, also known as smart textiles, are materials that can perceive, compute, communicate, and operate due to the convergence of technology and textiles [19]. As more electrical gadgets are attached to clothes, a wearable technology becomes more adaptable, and the user may modify its appearance based on changes in the environment as well as individual preference [20]. This review will describe how to create the sensing component of a wearable sensor using the sol-gel technique with opportune organofunctional trialkoxysilane precursors including 3-glycidoxypropyltrimethoxysilane [21]. The results indicate how the halochromic dyestuffs are totally entrapped in the sol-gel coatings, both physically as well as chemically with the textile fabric. Furthermore, some washing fastness was discovered. Sensor films with dynamic ranges of pH 4.4-6.0 (Methyl Red), pH 6.0-7.0 (Nitrazine Yellow), and pH 4.5-8.3 (Litmus) exhibit high repeatability, reversibility, and quick reaction times

[22,23,24,25].

(3-Glycidoxypropyl) trimethoxysilane-Based Hybrid Organic-inorganic Materials: An Experimental Synthetic Route:

Hybrid organic-inorganic materials have been obtained by co-hydrolysis of (3-glycidoxypropyl) trimethoxysilane (GPTMS) and tetraethyl orthosilicate (TEOS) in acidic conditions. Boron trifluoride diethyl etherate (BF₃OEt₂) has been used to catalyze the epoxide polymerization. Multinuclear magnetic resonance (NMR) in the precursor and infrared spectroscopy with the Fourier transform in the final material were used to investigate the influence of BF₃OEt₂. The addition of a solution of BF₃OEt₂ to a pre reacted sol of GPTMS and TEOS permitted the epoxidizing to open at room temperature without the production of diol units or the precipitation of boric acid in the final product [26]. The pre reaction time of GPTMS with TEOS has been identified as a critical parameter. The catalytic impact of BF₃OEt₂ in sol gel processing of GPTMS-based hybrid organic and inorganic materials, such as zirconium butoxide and 1-methylimidazole, has been evaluated [26,27,28].

A Nonhydrolytic/Hydrolytic Reaction of 3-Glycidoxypropyl-Trimethoxysilane with TiCl₄ Results in a Novel Synthesis of Sol Gel Hybrid Composites

These sol-gel hybrid composites have demonstrated intriguing capabilities for coatings, adhesives, and optical materials. The no sol-gel hydrolytic process enables careful control of the composites' composition and structure, resulting in increased durability and thermal stability. Furthermore, the addition of TiCl₄ infuses titanium into a matrix, increasing the hybrid composite's overall performance [28]. A unique multistep non-hydrolytic/hydrolytic synthesis yielded hybrid organic-inorganic compounds generated from (3-Glycidoxypropyl)-trimethoxysilane (GPTMS). To catalyze the epoxy ring opening in the organically modified alkoxide, titanium (IV) chloride was used instead of titanium alkoxides [29]. The precursor sols were investigated using electrospray ionization (ESI) investigations, gas chromatography paired with mass spectrometry (GC-MS), and multinuclear solution-state magnetic resonance (NMR) methods. Multi-nuclear solid-state magic angle spinning (MAS) NMR, Fourier transform infrared (FT-IR), and matrix-assisted laser desorption/ionization (MALDI) studies were used to characterize the synthesized powdered gels. All of these studies suggest that epoxy ring opening may be accomplished at low temperatures and with short reaction times. Interestingly, many reactions occur concurrently and are implicated in the early polymerization phase, resulting in quick deactivation of catalysts in solution, chlorination of GPTMS organic groups, and titanium dispersion inside precursor sols [30]. Despite a somewhat complicated chemical pathway, this approach may be utilized to generate transparent hybrid organic-inorganic materials with qualities suitable for photonic applications [30,31].

Evaluation of Nanocomposite Materials and Hybrid Coatings Based on 3-Glycidoxypropyl-trimethoxysilane and Bisphenol

Characterization procedures are a typical way for testing nanocomposite materials & hybrid coatings based on 3-glycidoxypropyl-trimethoxysilane and bisphenol. Scanning electron microscopy (SEM) is used to study surface morphology and particle dispersion, FTIR (Fourier transform infrared spectroscopy) is used to analyze chemical bonding, and mechanical testing is used to measure the durability and strength of the material [32]. Thermal methods of analysis such as DSC, or differential scanning calorimetry, are also used. The sol-gel method was used to create organic-inorganic hybrids with

3-glycidoxypropyl-trimethoxysilane (GPTMS) and bisphenol A (BPA) as cross-linking agents. In hybrid coatings, the cross-linking agent is used to prevent brittleness and fracture development. The hybrids' structure was determined using attenuated total reflectance infrared (ATR-IR) spectroscopy. Scanning electron microscopy and Si mapping were used to analyze the morphology of the hybrid coatings [33]. The hybrid systems have a homogeneous network topology, and the inorganic phases are smaller than 100 nm in size. Furthermore, the influence of the BPA/GPTMS molar ratio on cross-linking was explored using ATR-IR, and the corrosion protection capabilities of hybrid coatings were assessed using linear sweep voltammetry (LSV) and the 2000-h salt spray test techniques. The findings of these trials demonstrate that enhancing the cross-linking between the silica network and BPA will prevent fracture development and reduce brittleness [34]. Increasing the amount of BPA in organic-inorganic hybrid coatings or nanocomposites resulted in the production of an effective barrier against water and corrosion initiators like chloride and oxygen. Organic-inorganic hybrids have lately received increased interest in nanomaterial research as a novel class of materials. The sol-gel technique may be used to synthesize these compounds through the synergistic mixing of organic and inorganic polymers [34,35]. These systems combine the benefits of organic polymers such as toughness, flexibility, and simplicity of processing with those of inorganic polymers like strong heat resistance, excellent barrier, mechanical, and optical characteristics. Because the fineness of the generated inorganic particles is often less than 100 nm, these hybrid materials are also known as nanocomposites. They frequently produce optically transparent materials. The sol-gel technique is a well-known method for creating organic-inorganic hybrid materials. It includes the growth of inorganic networks via the production of a colloidal suspension (sol), as the name indicates [36]. This sol phase is converted to a continuous gel phase to produce the network. The precursors used to create these colloids are made up of a metal or metalloid element surrounded by different reactive ligands. Metal alkoxides are the most often used because they react quickly with water. The alkoxy silanes, such as tetramethoxysilane, tetraethoxysilane, and 3-glycidoxypropyl-trimethoxysilane, are the most commonly used metal alkoxides. According to the functional group, the sol-gel process involves three reactions: hydrolysis, alcohol, and water condensation. The microstructure of metal oxide produced by the sol-gel technique is determined by hydrolysis and condensation processes that are typically regulated by solution pH. The hydrolysis stage in the acid-catalyzed process is quicker than the condensation step, resulting in a more stretched and less branching network structure [37]. Condensation is quicker than hydrolysis in the base-catalyzed process, resulting in highly condensed species that can agglomerate into tiny particles. Furthermore, the sol-gel process involves a very complicated reaction involving several factors such as pH, solvent type and quantity, water/alkoxide ratio, concentrations of organic and inorganic reactants, ageing, cross-linking agent/alkoxide ratio, and drying processes. We looked into some of these aspects. GPTMS modified, or mosil, is an organic-inorganic hybrid material that has been claimed to be useful in a variety of applications by various researchers. Metrok et al. investigated GPTMS-TEOS hybrid composites generated from sol-gel. Their findings show that organic content and the water/alkoxide ratio have a significant impact on the corrosion resistance of metal coatings. Their findings revealed that these films failed corrosion resistance tests (i.e., salt spray) due to localized pit development. It is most likely to occur in hydrophilic portions of the films, such as the non-condensed silanol group [37,38]. To address this issue, a thick, continuous, and impermeable layer against corrosion initiators is required. Schmidt et al. discovered that organic-inorganic nanocomposites made from epoxy-functionalized silicones are scratch and abrasion resistant, as well as hard coatings for glass and polymers. They discovered that

epoxide ring opening promotes the wettability of nanocomposites. The use of diol cross-linking improves the scratch resistance, corrosion resistance, and flexibility of organic-inorganic hybrid materials or nanocomposites [39,40]. The sol-gel procedure was used in this work to generate organic-inorganic hybrid materials or nanocomposites, with GPTMS as the precursor, bisphenol A (BPA) as the cross-linking agent, and hydrochloric acid as the acidic catalyst. The effect of the cross-linking agent/alkoxide ratio on the protective qualities of hybrid systems was explored using ATR-IR and corrosion resistance assessment test techniques in this study [38,39,40].

3-glycidoxypropyltrimethoxysilane sol-gel reactions in a strongly basic aqueous solution.

Multinuclear magnetic resonance and light scattering methods were used to investigate the reactions of 3-glycidoxypropyltrimethoxysilane in a very basic aqueous solution [41,42]. According to the findings, the alkoxy groups of 3-glycidoxypropyltrimethoxysilane undergo rapid hydrolysis and condensation in this unusual chemical environment, favouring the development of open hybrid silica cages. Even after 9 days, the silica condensation has reached 90% but has not reached completion [42,43]. The extremely basic circumstances also impede the opening of the epoxies, which completely respond after many days. Several reaction pathways have been seen as a result of the epoxy opening, including the development of polyethylene oxide chains, diols, the termination of the organic chain by methyl ether groups, and the synthesis of dioxane species. Light scattering analysis has revealed that clusters with dimensions less than 20 nm develop after two days of reactions, but their additional development is hampered by the highly basic conditions, which limit full silica condensation and the formation of organic chains [43,44].

3-glycidoxypropyltrimethoxysilane reactivity in connection with the complicated nature of aqueous and plasma gel media:

Organosilanes are flexible reactants that may be used to chemically modify silicas and organic polymers. The goal of this study is to look at the organic-inorganic reactivity of 3-glycidoxypropyltrimethoxysilane in aqueous media with a glutamic-like nucleophile residue and on protein gels. This is accomplished by the use of a mix of computational, spectroscopic, and thermal approaches. There are correlations between the in-silico results obtained using Density Functional Theory and the sol-gel chemistry of 3-glycidoxypropyltrimethoxysilane in water [45]. They explain the dominance of esterification reactions with glutamic-like residues over hydrolysis of this molecule's methoxy groups and epoxy ring. When this organosilane is introduced to blood plasma at quantities more than 75 mM at neutral pH, its esterification contributes to the formation of crosslinked gels. Under acidic circumstances, however, the prehydrolyzed molecule is less reactive towards nucleophiles, and the silanol and diol groups serve as a plasticizer on the gels. This, together with non-extensive condensation in protein media as demonstrated by ^{29}Si NMR spectroscopy, enables the identification of oligomers and silsesquioxanes in these samples [46]. In conclusion, this type of reactivity research helps to overcome the obstacles of rationalizing organosilane chemical reactions and effects in the gelation of proteins from complicated sources.

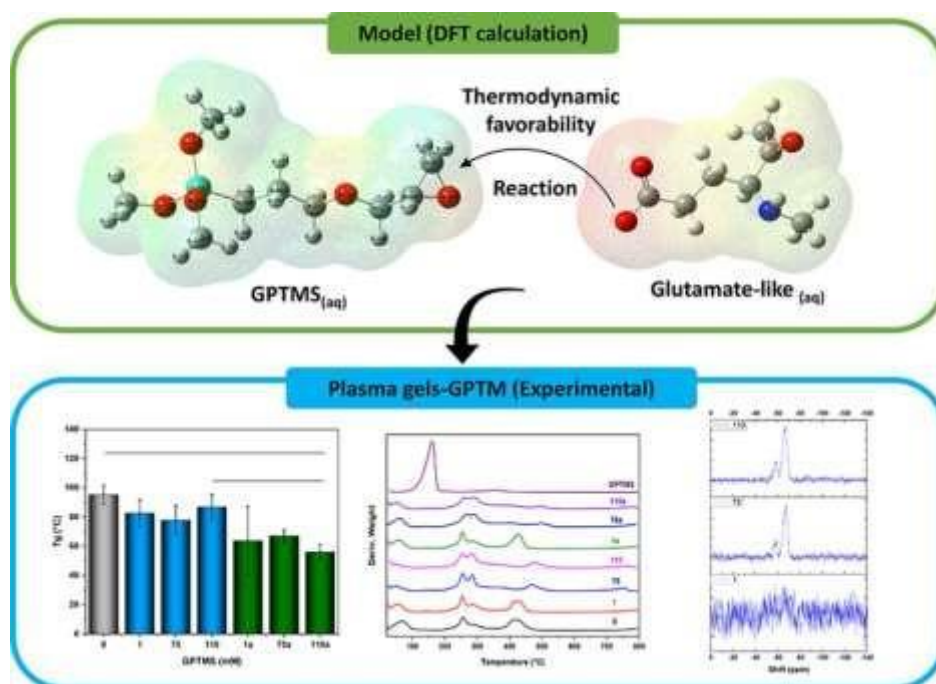


Fig.2: The reactivity of 3-glycidoxypropyltrimethoxysilane depends on the complexity of

aqueous and plasma gel media. (Y. Galeano-Duque, J.C. Poveda-Jaramillo, M. Mesa, Considerations about 3- glycidoxypropyltrimethoxysilane reactivity in function of the complexity of aqueous and plasma gel media, Journal of Molecular Structure, Volume 1284,2023), 3-glycidoxypropyltrimethoxysilane (GPTMS) is a versatile silica metal hydroxide surface functionalizing agent and polymer crosslinker [47]. Its inorganic reactions in water are controlled by the silicon-stable octet structure and the low polarity of Si single bond C and Si single bond O bonds. Its hydrolysis and condensation require hypervalent silicon centers, which is explained by the anomeric Si's negative hyperconjugation and the partial nature of the Si single bond O bond. The strong reactivity of its epoxy ring in organic solvents has been demonstrated for nucleophiles such as azide anions and primary and secondary amines, but not for thiols and alcohols. Propanoic acid at 40 °C has also been shown to form ester linkages in water at pH 6.0-7.5, particularly with organic acid moieties [48]. The nucleophilic addition of propylamine, propanol, and propanthiol in water does not occur, however these nucleophiles can catalyze the inorganic condensation. Controlling reaction conditions, particularly pH and ageing time, and regulating inorganic-organic reactivity GPTMS has been computationally studied using first-principles Density Functional Theory (DFT) techniques to investigate its structure, dimerization, hydrolysis, condensation kinetics, and grafting processes. Natural and synthetic polymers can be functionalized and crosslinked using organosilanes under non-hydrolytic and hydrolytic conditions. Because proteins include carboxylic acid residues, the reaction with GPTMS has been used to create biodegradable and bioactive gelatin crosslinked hydrogels [49]. In order to obtain homogeneous organic-inorganic hybrids, the epoxy interaction with nucleophilic amino acids, silanol condensation, as well as non-covalent connections of silica species with the organic moiety are all involved. GPTMS reactions with gels produced from fibrinogen and plasma proteins have yet to be described. These gels are

appealing for biomedical applications because the presence of organosilanes allows them to modify mechanical and biological behaviour.[50,51] The goal of this research is to investigate GPTMS reactivity in the aqueous phase, which will be beneficial for finding connections with the physicochemical features of gels made from blood plasma proteins. DFT computations, Thermogravimetry (TGA), Modulated Differential Scanning Calorimetry (MDSC), and ^{29}Si Nuclear Magnetic Resonance (^{29}Si NMR) will be used to get the results. The results on water and plasma will demonstrate the implications of medium complexity on GPTMS reaction [52].

Fabrication of a long-lasting hydrophobic cellulose fabric out of water glass & mixed organosilanes

Through the application of the sol-gel process, a durable superhydrophobic cellulose fabric was created from water glass & n-octadecyltriethoxysilane (ODTES) with 3-glycidyloxypropyltrimethoxysilane (GPTMS) as a crosslinker. The findings indicated that the addition of GPTMS might improve the attachment of silica coating from water glass on cellulose fabric. The silanization of hydrolyzed ODTES was examined and optimized at various temperatures and periods. The findings revealed that silanization time was more significant than temperature in generating a long-lasting hydrophobic surface. XPS was used to assess the durability of super hydrophobicity treatment [53]. As a consequence, even after 50 washing cycles, the superhydrophobic cotton treated under ideal conditions retained its hydrophobic qualities. Because of their economic and industrial relevance, superhydrophobic fabrics made from sol-gel coatings have been studied in recent years. Water glass has been utilized as a precursor for silica particles to save costs. It has been demonstrated that a superhydrophobic surface with a high-water contact angle may be created from water glass using the synergy of long carbochain provided by hydrolyzed organosilane [76]. However, the washing durability of such goods' superhydrophobicity has not been determined. Despite the fact that silane coupling agents have been used as heterogeneous grafting chemicals to improve the interaction and adhesion of cellulose fiber and hydrophobic silica layer prepared from tetraalkoxysilicates, there have been few reports on the effect of silane coupling agent on the washing durability of hydrophobicity of cellulose fabrics until now [54]. The silanization of alkylsilanes on a silica substrate is critical in the formation of a packed and ordered monolayer. However, multiple ideal temperatures and timeframes for the silanization process have been recorded. **Silanization is the process of functionalizing the silicon or borosilicate substrates with a silane solution resulting in the formation of a silane monolayer which acts as a coupling agent between the PEG hydrogel and silicon substrate thereby improving the adherence of PEG hydrogel to the silicon substrate** Furthermore, the substrate in silanization has a varied impact on the silanization process [55]. Because of the high hydrophilicity of cellulose fiber, the wetting and assembly processes of alkylsilanes on silica coated cellulose should differ from those described. There is, however, no information on the kinetics of silanization of hydrolyzed organosilanes on silica-coated cellulose fiber [55,56]. The enhancement of washing durability of hydrophobic surfaces was investigated in this article. 3-glycidyloxypropyltrimethoxysilane (GPTMS) was employed as a crosslinker to connect silica coating and cotton fabric for this purpose. The silanization of n-octadecyltriethoxysilane (ODTES) at various temperatures and periods was also examined and optimized [56,57].

Kinetic analysis of 3-glycidoxypropyltrimethoxysilane epoxy ring opening by Lewis acid in the manufacture of a cellulose-based sensor.

In acidic conditions, hybrid halochromic sensor coatings were created by immobilizing Nitrazine Yellow (NY) onto cotton textiles using the epoxy group of 3-glycidoxypropyltrimethoxysilane (GPTMS) silica precursor [57,58]. Boron trifluoride diethyl etherate (BF₃OEt₂) was employed to catalyze the epoxide ring opening at varied percentages (1-10%, w/w GPTMS). An FTIR research was done and kinetic data for the epoxy ring opening process were gathered to optimize the system [81]. A linear relationship was found between the obtained kinetic rates and the BF₃ %. The actual structure of NY, generated from an assault of diazonium salt on the para hydroxyl position, was validated by nuclear magnetic resonance (NMR) analysis in solution, and the ultimate product of the reaction between NY and GPTMS was characterized. Finally, varied concentrations of catalyst were discovered to impact the wash fastness of the coatings as well as the halochromic reactivity of the cellulose-based sensors. [83]

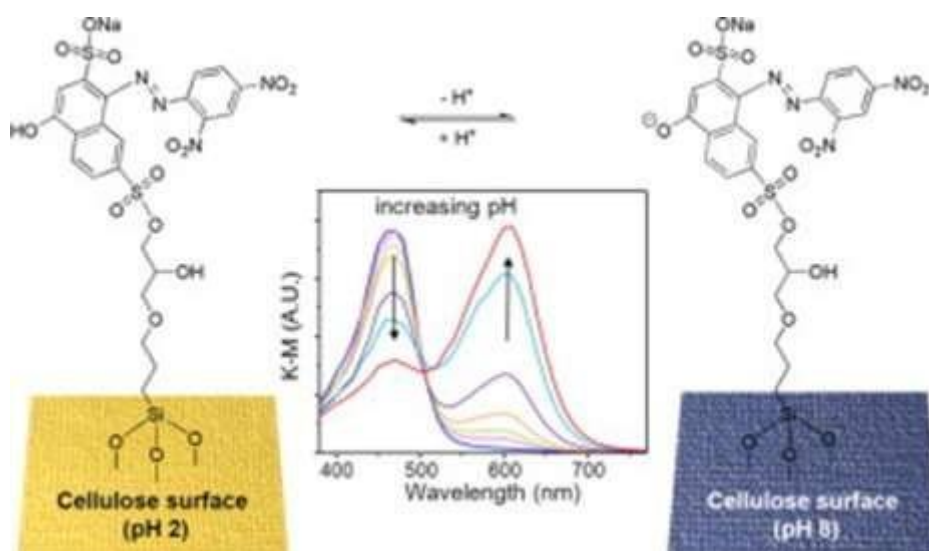


Fig 3: The role of catalyst in the manufacture of a cellulose-based sensor: a kinetic investigation of 3-glycidoxypropyltrimethoxysilane.

Emanuela Guido, Claudio Colleoni, Karen De Clerck, Maria Rosaria Plutino, Giuseppe Rosace, Influence of catalyst in the synthesis of a cellulose-based sensor: Kinetic study of 3-glycidoxypropyltrimethoxysilane epoxy ring opening by Lewis acid, *Sensors and Actuators B: Chemical*, Volume 203, 2014,

3-Glycidoxypropyltrimethoxysilane (GPTMS) Applications

3-Glycidoxypropyltrimethoxysilane improves the electrical properties of epoxy resin-based sealants, packaging materials, and printed circuit boards. It improves adhesive solubility, dispersibility, and fluidity, as well as the cohesiveness of caulking glue and sealant [59]. It is an epoxy-functional silane. Silane coupling agents are widely employed in a variety of industries, including automotive, construction, and electronics [60]. These agents are critical in enhancing adhesion between various materials, such as metals and polymers. Furthermore, silane treatment agents can improve the durability and performance of coatings, adhesives, and sealants by forming a strong molecular link [61]. Silane coupling agents are essential for increasing the adhesion of organic polymers to inorganic substrates.

They operate as a bridge, forming a strong link between the organic matrix and the inorganic fillers, resulting in improved mechanical characteristics and composite material longevity [62,63]. This makes them extremely important in a variety of sectors, including automotive, construction, and electronics. 3-Glycidoxypropyltrimethoxysilane has the potential to increase the dry and wet strength of cured composites reinforced with glass fiber rovings [63,64].

Improve the wet electrical characteristics of epoxy encapsulate and packaging materials. Remove the requirement for a priming in polysulfide and urethane sealants. Enhance the adherence of aqueous acrylic sealants, as well as urethane and epoxy coatings [65]. It is primarily utilized in unsaturated polyester composites to enhance the mechanical, electrical, and light transmission qualities of the composites, particularly in wet environments [65,66]. When used to treat EPDM systems packed with ceramic clay and crosslinked by peroxide in the wire and cable sector, it can increase consumption factor as well as particular inductance capacitance. 3-Glycidoxypropyltrimethoxysilane is a transparent, light straw liquid that is an epoxy-functional silane [67,68].

3-Glycidoxypropyltrimethoxysilane is a coupling agent that may be found in polysulfide and polyurethane caulks and sealants, mineral-filled and glass-reinforced thermosets and thermoplastics, and glass roving size-binders. It is used as an adhesion-promoting component in aqueous systems, for example, to improve the adherence of acrylic latex sealants. Water spray, alcohol-resistant foam, dry chemical, or carbon dioxide can all be used [69]. Firefighters must use special safety equipment. If required, wear self-contained breathing apparatus for firefighting. It may be used as a polysulfide and polyurethane caulking glue or sealer, as well as an epoxy resin adhesive [69,70]. Copolymerized with monomers such as vinyl acetate, acrylic acid, or methacrylic to create polymers that are widely used in coatings, adhesives, and sealants, offering good adherence and durability. Carbon steel pretreatment with 3-(Glycidoxypropyl) trimethoxysilane improves dry and wet adhesion while decreasing cathodic disbondment rate of an epoxy coating (3-Glycidoxypropyl) Trimethoxysilane is utilized in the manufacturing of carbon steel, and its pretreatment improves epoxy coating dry and wet adherence. It's also utilized to make epoxy-functionalized silica nanoparticles, which provide a reactive surface for one-step, high-density protein immobilization [69,70].

It acts as a coupling agent as well as an adhesion promoter. 3-GlycidoxypropylTrimethoxysilane is a transparent, light straw liquid that is an epoxy-functional silane [71,72,73]. 3-Glycidoxypropyltrimethoxysilane is a coupling agent that may be found in polysulfide and polyurethane caulks and sealants, mineral-filled or glass-reinforced thermosets including thermoplastics, and glass roving size-binders [74,75]. It is used as an adhesion-promoting component in aqueous systems, for example, to improve the adherence of acrylic latex sealants. [82] 3-Glycidoxypropyltrimethoxysilane has the potential to increase the dry and wet strength of cured composites supplemented with glass fiber roving [76,82,83]. Improve the wet electrical characteristics of epoxy encapsulate & packaging materials. Remove the requirement for a priming in polysulfide & urethane sealants. Enhance the adherence of aqueous acrylic sealants, as well as urethane & epoxy coatings [76,77,78,79,80].

Sol-gel waterborne inorganic-organic hybrid coatings on magnesium 3-glycidoxypropyltriethoxysilane (GPTMS):

Figure 4 depicts the GPTMS FTIR spectrum. The epoxy ring stretching was responsible for the bands at 1732, 1602, and 1342 cm^{-1} . The Si-O-CH₃ stretching vibration of ethoxy groups directly attached to silicon atom caused the band approximately 1090 cm^{-1} . There were also large peaks at 2846 and 2939

cm⁻¹ due to -CH₂- and -CH₃ - symmetric stretching, as well as another broad peak between 3524 & 3597cm⁻¹ due to OH stretching (from impurity) [84].

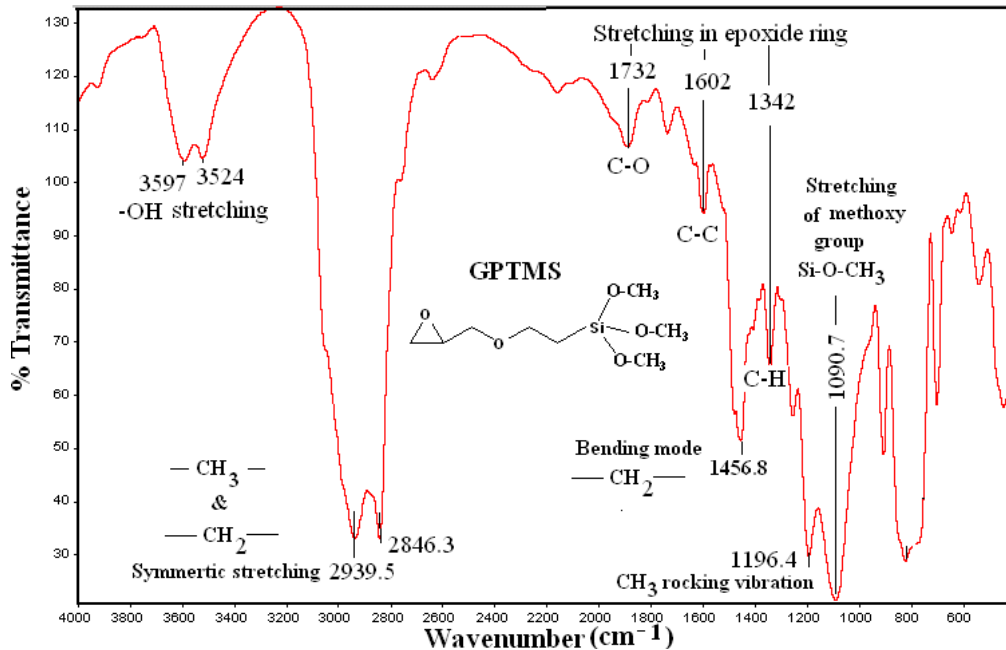


Fig 4. FT-IR spectrum of 3-glycidoxypropyltriethoxysilane (GPTMS)

Jain, Rachna. (2015). Waterborne inorganic-organic hybrid coatings on magnesium by sol-gel route. 10.13140/RG.2.1.3457.1368.

Infrared spectroscopy of 3-Glycidoxypropyltrimethoxysilane (GPTMS) hydrolysis:

The investigation of silanes as well as polymers with particular functionalities is expanding, and the production of products based on silane-based polymers is following suit. Infrared spectroscopy was used to study the hydrolysis of 3-Glycidoxypropyltrimethoxysilane (GPTMS) as a function of hydrolysis time in solutions containing 50% alcoholic solvents. It was demonstrated that the chemical processes including the hydrolysis / condensation of GPTMS, as well as the key kinetic fluctuations during the process, could be analyzed qualitatively and quantitatively. The infrared spectra of the reagents employed in the GPTMS hydrolysis research are shown in Figure 5.[85]

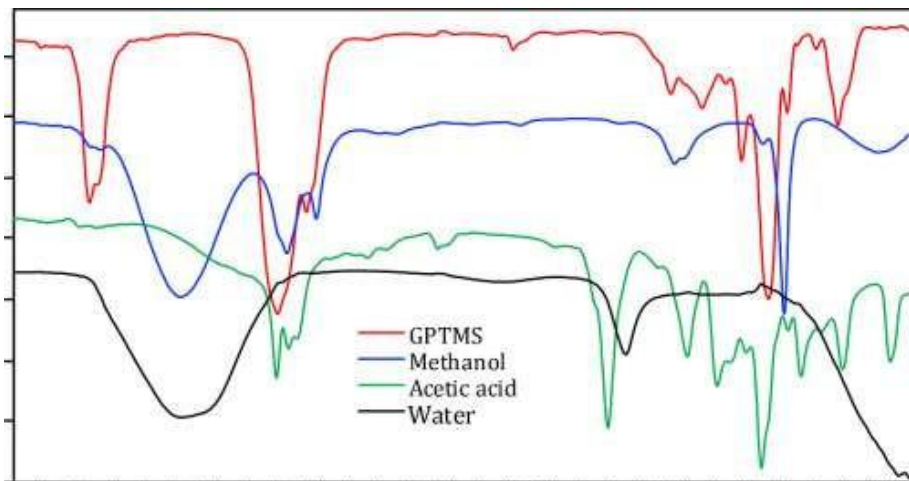


Fig 5. the infrared spectra of reagents used in the GPTMS hydrolysis study (Casagrande,

Cézar & Jochem, Lidiane & Repette, Wellington. (2020). Analysis of the 3-Glycidoxypropyltrimethoxysilane (GPTMS) hydrolysis by infrared spectroscopy. *Matéria* (Rio de Janeiro). 25. 10.1590/s1517-707620200003.1111.)

CANCLUSION:

The objective of this work is to study the GPTMS reactivity in the aqueous phase, being useful for making correlations with the physicochemical properties. Additionally, the article highlights the potential future applications of GPTMS, including its use in biomedical engineering, nanotechnology, and environmental science. Furthermore, it discusses the challenges and limitations faced in utilizing GPTMS in various industries and suggests areas for further research and development to optimize its performance and expand its potential applications. We will delve into the findings and conclusions drawn from the evaluation of GPTMS research across different domains. Additionally, we will explore any potential implications and future directions for further advancements in GPTMS technology.

Reference:

1. FA Ngwabebhoh, A Erdem, and U Yildiz (2016) are authors. The response surface technique was used to optimize the removal of Cu(II) and nitrazine yellow dye in synergy utilizing an eco-friendly chitosan-montmorillonite hydrogel. *Journal of Applied Polymer Science*. U. Korent, M. Turel, and A. Lobnik (2012) Optical chemical sensor design and applications Wang W. edited *Advances in Chemical Sensors*, IntechOpen Limited, UK.
2. Emanuela Guido, Claudio Colleoni, Karen De Clerck, Maria Rosaria Plutino, and Giuseppe Rosace are among the Catalyst effect in the production of a cellulose-based sensor: Lewis acid kinetic analysis of 3-glycidoxypropyltrimethoxysilane epoxy ring opening. *Sensors and Actuators B: Chemical*, 203, 213-222 (2014).
3. A. Lobnik (2012). *Wearable optical chemical sensors. Intelligent fabrics and apparel for ballistic and NBC protection*, edited by Kiekens P and Jayaraman S. Series B of NATO Science for Peace and Security: Physics and Biophysics. Dordrecht: Springer.
4. Stoppa M, Chiolerio A (2014) A critical assessment of wearable electronics and smart textiles. 14:11957-11992 *Sensors*.
5. Diamond, D., Coyle, S., Scarmagnani, S., and Hayes, J. (2008) *Wireless Sensor Networks for Chemo/Biosensing*. *Chemistry Review* 108:652-679.
6. Diamond, D., Lau, K.T., Brady, S., and Cleary, J. (2008). Integration of analytical measures with wireless communications: existing difficulties and future initiatives. *Talanta* 75(6):606-612.
7. Farré M, Kantiani L, Pérez S, et al. (2009) *Sensors and biosensors for EU Directives*. *Anal Chem Trends* 28:170-185.
8. Kotanen, CN, Moussy, FG, Carrara, S, and Guiseppi-Elie, A (2012) *Implantable enzyme amperometry biosensors*. 35:14–26 in *Biosensor Bio electron*.
9. Yang, Y-L, Chuang, M-C, Lou, S-L, and Wang, J. (2010) *Amperometry sensors and biosensors based on thick-film textiles*. *Analyst* number 135:1230. Google Scholar Article.
10. Williamson ED, Savage VL, Lingard B, et al. *A biocompatible microdevice for measuring core body temperature in the early detection of infectious illness*. 9:51-60 in *Biomed Microdevices*. Google Scholar Article.
11. Pinna GD, Maestri R, Mortara A, et al. (2010) *Long-term time-course of nocturnal breathing*

- difficulties in patients with heart failure. 35:361-367, European Respiratory Journal. Google Scholar Article.
12. Massagram W, Hafner N, Chen M, et al. (2010) ASIC digital heart-rate variability parameter monitoring. 4:19-26, IEEE Trans Biomed Circuits Syst. Google Scholar
 13. Wireless capsule endoscopy, NA, 2000. 405:417-419 in Nature. Google Scholar
 14. Ledet EH, D'Lima D, Westerhoff P, and colleagues (2012). Implantable sensor technology: from research to clinical practise. Journal of the American Academy of Orthopaedic Surgeons, 20:383-392. Google Scholar
 15. Massagram W, Hafner N, Chen M, et al. (2010) ASIC digital heart-rate variability parameter monitoring. 4:19-26, IEEE Trans Biomed Circuits Syst. Wireless capsule endoscopy, NA, 2000. 405:417-419 in Nature.
 16. Ledet EH, D'Lima D, Westerhoff P, and colleagues (2012). Implantable sensor technology: from research to clinical practise. Journal of the American Academy of Orthopaedic Surgeons, 20:383-392. Google Scholar
 17. Troster, G. (2005). The Agenda of Wearable Healthcare. Medical informatics yearbook, IMIA. Schattauer, Stuttgart, Germany, pp. 125-138
 18. S. Lam Po Tang and G.K. Stylios (2006) A look at smart technology used in clothes design and engineering. International Journal of Cloth Science and Technology, 18:108-128. Google Scholar Article
 19. Chiang CK, Fincher CR, Park YW, and colleagues (1977) Doped polyacetylene has high electrical conductivity. Physical Review Letters 39:1098-1101. Google Scholar Article
 20. NKE Guimard, JL Sessler, and CE Schmidt Towards a biocompatible and biodegradable copolymer containing electroactive oligothiophene units, 2009. 502-511 in Macromolecules.
 21. F. Carpi and D. De Rossi (2005) Electroactive polymer-based devices for biomedical e-textiles. 295-318 in IEEE Trans Inf Technol Biomed
 22. M. Maccioni, E. Orgiu, P. Cosseddu, and others (2006) Towards the textile transistor: Assembly and characterisation of a cylindrical organic field effect transistor. 89:143515, Appl Phys Lett.
 23. Rosace G, Trovato V, Colleoni C, and colleagues (2017) MWCNTs hybrid coating onto cotton fabric for structural and morphological characterisation as a possible humidity and temperature wearable sensor. Actuators Sensitive B Chem 252:428-439.
 24. Wong YWH, Yuen CWM, Leung MY, and colleagues (2006) Selected nanotechnology uses in textiles. 6:1-8 Autex Res J.
 25. Brinker CJ and Scherrer GW (1990) Sol-gel science is concerned with the physics and chemistry of sol-gel processing. Boston: Academic Press Inc.
 26. Lin, J. (2000). Recent advances and applications of optical and fiber-optic pH sensors. Anal Chem Trends 19:541-552
 27. Tsai P-J, McIntosh J, Pearce P, and colleagues (2002) Anthocyanin and antioxidant capacity in Roselle (*Hibiscus Sabdariffa* L.) extract. Food Research International 35:351-35.
 28. VBV Maciel, CMP Yoshida, and TT Franco (2012) Development of a colorimetric temperature indicator prototype for monitoring food quality. Journal of Food Engineering 111:21-27.
 29. Van der Schueren L. and K. De Clerck (2010) pH-indicator colours are used for pH-sensitive textile fabrics. Journal of Textual Research 80:590-603.
 30. M-H Schmid-Wendtner, HC Korting (2006) The pH of the skin's surface and its effect on barrier

- function. *Skin Pharmacol Physiol*, 19, pp. 296-302.
31. Curto VF, Coyle S, Byrne R, et al. An autonomous wearable microfluidic platform for real-time pH sweat measurement was conceptualised and developed. 175:263-270 in *Sens Actuators B Chem*.
 32. Curto VF, Coyle S, Byrne R, et al. (2012) Concept and development of a self-contained wearable microfluidic device for real-time pH sweat measurement. *Actuators Sensitive B Chem* 175:263- 270.
 33. Patterson MJ, Galloway SD, Nimmo MA (2000) Regional sweat composition variations in normal human men. *Experiment Physiol* 85:869-875.
 34. Morgan, RM, Patterson, MJ, and Nimmo, MA (2004) The acute effects of dehydration on sweat composition in males following extended hot exertion. *Acta* 182:37-43, *Physiol Scand*.
 35. Robinson KL and Lawrence NS (2006) developed a redox-sensitive copolymer as a single-component pH sensor. *Anesthesiology* 78:2450-2455.
 36. D. Wencel, T. Abel, and C. McDonagh (2014) Chemical pH sensors that are optical in nature. *Anesthesiology* 86:15-29.
 37. Seitz WR and Sepaniak MJ (1988) Immobilised indicators and fibre optics are used in chemical sensors. *Crit Rev Anal Chem* 19:135-173. *C R C Crit Rev Anal Chem* 19:135-173.
 38. L. Van der Schueren and K. de Clerck (2012) The use of halochromic textile materials as pH sensors is novel. *Advances in Science and Technology* 80:47-52.
 39. Ismail WNW (2016) A review of sol-gel technology for revolutionary fabric finishing. *Journal of Sol-Gel Science and Technology* 78:698-707
 40. Mahltig B, Haufe H, Böttcher H (2005) Functionalization of textiles by inorganic sol-gel coatings. *J Mater Chem* 15:4385.
 41. Camlibel NO, Arik B (2017) Sol-gel uses in textile finishing processes. Recent applications in sol-gel synthesis, edited by Chandra U. IntechOpen Limited, UK, pp. 253-281
 42. tular D, Simoni B, Tomi B (2017) Stimuli-responsive hydrogels for textile functionalisation: a review. *Tekstilec* 60:76-96
 43. Abidi N, Hequet E, Tarimala S, Dai LL (2007) Cotton fabric surface modification for better UV radiation protection using a sol-gel technique. *J Appl Polym Sci* 104:111-117.
 44. Mahltig B, Textor T (2006) Combination of silica sol and dyes on textiles. *J Sol-Gel Sci Technol* 39:111-118
 45. Mahltig B, Fiedler D, Böttcher H (2004) Antimicrobial sol-gel coatings. *J Sol-Gel Sci Technol* 32:219-222.
 46. Poli R, Colleoni C, Calvimontes A, et al. (2015) An innovative sol-gel approach in neutral hydroalcoholic conditions to achieve antibacterial cotton finishing by zinc precursor. *J Sol-Gel Sci Technol* 74:151-160.
 47. Colleoni C, Guido E, Migani V, Rosace G (2015) Hydrophobic behaviour of non-fluorinated sol- gel based cotton and polyester fabric coatings. *J Ind Text* 44:815-834.
 48. Colleoni C, Guido E, Migani V, Rosace G (2015) Hydrophobic behaviour of cotton and polyester fabric coatings based on non-fluorinated sol-gel. *Journal of Industrial Text* 44:815-834.
 49. Colleoni C, Esposito F, Guido E, and colleagues (2017) Ceramic coatings for water-repellent fabrics. 254:122002, *IOP Conf Ser Mater Sci Eng*.
 50. B. Mahltig and T. Textor (2008) *Textiles and nanosols*. Singapore: World Scientific Publishing Co. Pte. Ltd.
 51. Alongi J, Colleoni C, Malucelli G, Rosace G (2012) Hybrid phosphorus-doped silica structures

- produced from a multistep sol-gel technique for increasing cotton fabric thermal stability and flame retardancy. *Stab Polym Degrad* 97:1334-1344.
52. Vasiljevi J, Hadi S, Jerman I, et al. (2013) Investigation of flame-retardant finishing of cellulose fibres: Organic-inorganic hybrid vs standard organophosphonate. *Stab Polym Degrad* 98:2602-2608.
53. Kappes RS, Urbainczyk T, Artz U, et al. (2016) Amino silane and phenylphosphonic acid flame retardants. *Stab Polym Degrad* 129:168-179.
54. Guido E, Alongi J, Colleoni C, and colleagues (2013) Thermal stability and flame retardancy of polyester textiles sol-gel treated with boehmite nanoparticles. *Stab Polym Degrad* 98:1609-1616.
55. Grancaric AM, Colleoni C, Guido E, et al. (2017) Thermal behaviour and flame retardancy of cotton fabric monoethanolamine-doped sol-gel coatings. *Prog Organ Coat* 103:174-181. DOI: 10.1016/j.porgcoat.2016.10.035 Article Google Scholar
56. Colleoni C, Massafra MR, Rosace G (2012) Photocatalytic capabilities and optical characterisation of cotton fabric covered with noncrystalline TiO₂ modified with poly(ethylene glycol) by sol-gel. 207:79-88 in *Surf Coat Technol*.
57. Bhosale, RR, Shende, RV, and Puszynski, JA (2012) Thermochemical water splitting in a packed bed reactor for H₂ synthesis utilising sol-gel produced Mn-ferrite. *International Journal of Hydrogen Energy* 37:2924-2934.
58. Yin Y, Wang C (2012) Organic-inorganic hybrid silica film coated for increasing capsicum oil resistance on natural compounds using the sol-gel technique. *Journal of Sol-Gel Science and Technology* 64:743-749.
59. Schmidt H, Jonschker G, Goedicke S, Mennig M (2000) The sol-gel technique as a fundamental technology for nanoparticle-dispersed inorganic-organic composites, *Google Scholar* 56. 19:39-51 in *J Sol-Gel Sci Technol*.
60. Schmidt, H. (1985), A new form of non-crystalline solid derived from inorganic and organic ingredients. *Journal of Non-Crystalline Solids*, 73:681-691.
61. Sanchez C, Rozes L, Ribot F, and colleagues (2010) "Chimie douce": a land of possibilities for the creation of functional inorganic and hybrid organic-inorganic nanomaterials. 13:3–39 in *Comptes Rendus Chim*.
62. Wolfbeis OS (2008) Article Google Scholar Chemical sensors and biosensors based on fibre optics. *Anal Chem*. 1980; 80:4269-4283.
63. Jerzy J. Chruciel, Elbieta Leniak, 69. Functional silanes, polysiloxanes, silsesquioxanes, silica, and silicates are used to modify epoxy resins. *Progress in Polymer Science*, 41, pp. 67-121, 2015.
64. Davide Carboni, Alessandra Pinna, Heinz Amenitsch, Maria F. Casula, Danilo Loche, Luca Malfatti, and Plinio Innocenzi are among the 70 members. The instance of 3-glycidoxypropyltrimethoxysilane in achieving order in mesostructured thin films, from pore organisation to crystalline walls. *Physical Chemistry Chemical Physics*, 17 (16), pp. 10679-10686, 2015.
65. Emanuela Guido, Claudio Colleoni, Karen De Clerck, Maria Rosaria Plutino, and Giuseppe Rosace are among the Catalyst effect in the production of a cellulose-based sensor: Lewis acid kinetic analysis of 3-glycidoxypropyltrimethoxysilane epoxy ring opening. *Sensors and Actuators B: Chemical*, 203, 213-222 (2014).
66. Francisco del Monte and Maria L. Ferrer. Nile Red Fluorescent Nanoparticles Embedded in Hybrid

- SolGel Glasses Emit More Light. *The Journal of Physical Chemistry B*, 109 (1), pp. 80-86, 2005.
67. Plinio Innocenzi, Giovanna Brusatin, Silvia Licoccia, Maria Luisa Di Vona, Florence Babonneau, and Bruno Alonso are among the Controlling the Thermal Polymerization Process of Hybrid OrganicInorganic Films Made from 3-Methacryloxypropyltrimethoxysilane and 3-Aminopropyltriethoxysilane. *Chemistry of Materials*, 15 (25) (2003),
68. Plinio Innocenzi, Enrico Miorin, and Giovanna Brusatin, Alessandro Abboto, Luca Beverina, and Giorgio A. Pagani, Mauro Casalboni and Felice Sarcinelli, and Roberto Pizzoferrato. Zwitterionic PushPull Chromophores in Hybrid OrganicInorganic Matrix. *Chemistry of Materials*, 14 (9), 3758-3766, 2002.
69. Composite mixtures based on nanoporous SiO₂-matrices and TiO₂ nanoparticles 34. 2020 *Functional Materials*.
70. Nadia Embarek, Nabahat Sahli, 35. A Novel Green Poly (3-Glycidoxypropyltrimethoxysilane) Synthesis Method Catalysed by Treated Bentonite. 2020, *Bulletin of Chemical Reaction Engineering and Catalysis*, pp. 290-303.
71. F.X. Perrin, F. Ziarelli, and A. Dupuis are among the 36. Corrosion resistance and chemical structure of hybrid sol-gel coatings with interconnected inorganic-organic network. *Organic Coatings Progress* 2020, 141, 105532.
72. Sasan Rezaei, Ali M. Zolali, Amirjalal Jalali, and Chul B. Park are among the 37. A novel macromolecular polyether-based precursor is used to create a nanostructured, super-insulative, and flexible hybrid silica aerogel. 2020, *Journal of Colloid and Interface Science*, 561, pp. 890-901.
73. Hee Seon Lee, Jeong Min Park, Kyu Hong Hwang, and Hyung Mi Lim are the 46th and 47th members of the cast. Surface Functionalization of Zirconia Nanocrystals with a Silane Coupling Agent and their Dispersion Behaviour in O-Phenylphenoxyethyl Acrylate. 922, 20-25, *Materials Science Forum* 2018.
74. C. Rodriguez, O. Ahumada, V. Cebrián, V. Torres Costa, and M. Manso Silván are among the 47. Visible light triggered epoxy capping and selective plasma etching were used to create biofunctional porous silicon micropatterns. 2018 *Vacuum*, 150, pp. 232-238.
75. M. Martinez-Ibaez, I. Aldalur, F.J. Romero-Gavilán, J. Suay, I. Goi, and M. Gurruchaga are among the 48. Immobilisation techniques and dissolving characteristics of nanostructured siloxane-gelatin coatings. *Journal of Non-Crystalline Solids*, vol. 481, pp. 368-374, 2018.
76. Rita B. Figueira and Carlos J. R. Silva are both 50. The use of the Sol-Gel method to create organic-inorganic hybrid coatings to reduce corrosion in metallic substrates. 2017, 355-412.
77. Xianling Meng, Xia Jiang, and Peijun Ji are among the 51. A strong adhesive block polymer covering for big molecular weight protein antifouling. *Chinese Journal of Chemical Engineering*, 25 (12), pp. 1831-1837, 2017.
78. Xiaobang Liu, Wei Li, Xuefei Li, Ying Wang, Zhengnan Mao, Shukun Shen, Jian Gang Chen, and Daodao Hu are among the 52 participants. The influence of sol maturation on the production of luminous ormosils. *Journal of Applied Polymer Science*, 134 (39): 44849, 2017.
79. Nadia Embarek, Nabahat Sahli, and others. Using an Eco-Catalyst (Treated Montmorillonite) for the Green Synthesis of Functionalized Poly(3-Glycidoxypropyl-Trimethoxysilane). 2023, *Chemistry & Chemical Technology*, 17 (1), pp. 60-69.
80. Y. Galeano-Duque, J.C. Poveda-Jaramillo, M. Mesa, Considerations about 3-glycidoxypropyltrimethoxysilane reactivity in function of the complexity of aqueous and plasma gel

media, Journal of Molecular Structure, Volume 1284,2023

81. Rina Wu, Yanan Li, Jiahui Shi, and Qiuyu Wang are among the cast members. ATRP and "click" chemistry are used to functionalize cellulose and create hydrophobic filter paper for oil/water separation. *Cellulose* 2021, 28 (14), pp. 9413-9424.
82. Agustin Forchetti Casarino, Santiago Andrés Bortolato, Diana Alejandra Estenoz, and Marisa Elisabet Spontón are among the cast members. Controlling the sol-gel and curing procedures to tune the morphology of siloxane bondbased polybenzoxazines. *Polymer Engineering & Science*, 61(6), 1611-1623, 2021.
83. Emanuela Guido, Claudio Colleoni, Karen De Clerck, Maria Rosaria Plutino, Giuseppe Rosace, Influence of catalyst in the synthesis of a cellulose-based sensor: Kinetic study of 3-glycidoxypropyltrimethoxysilane epoxy ring opening by Lewis acid, *Sensors and Actuators B: Chemical*, Volume 203,2014,
84. Tao Zhou, Jin Zhang, Jianguo Zhao, Wenshan Qu, Xinyu Li, Shijie Li, Baoyan Xing, and Yongchun Fu are among the 104. aqueous epoxy curing agent based on grafted graphene oxide for strengthening corrosion protection of aqueous epoxy coating. *Surface and Coatings Technology*, 412, 127043, 2021.
85. Jain, Rachna. (2015). Waterborne inorganic-organic hybrid coatings on magnesium by sol-gel route. 10.13140/RG.2.1.3457.1368.
86. Casagrande, César & Jochem, Lidiane & Repette, Wellington. (2020). Analysis of the 3-Glycidoxypropyltrimethoxysilane (GPTMS) hydrolysis by infrared spectroscopy. *Matéria* (Rio de Janeiro). 25. 10.1590/s1517-707620200003.1111.)