This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

Nanostructured zirconium titanate fibers prepared by particulate sol-gel and cellulose templating techniques

P. Rouhani [a], E. Salahinejad [b,c], R. Kaul [d], D. Vashaee [a], L. Tayebi [b,e,*]

[a] Helmerich Advanced Technology Research Center, School of Electrical and Computer Engineering, Oklahoma State University, OK 74106, USA

[b] Helmerich Advanced Technology Research Center, School of Material Science and Engineering, Oklahoma State University, OK 74106, USA

[c] Department of Materials Science and Engineering, School of Engineering, Shiraz University, Zand Blvd., 7134851154, Shiraz, Iran

[d] Department of Biochemistry & Microbiology, Center for Health Sciences, Oklahoma State University, OK 74107, USA

[e] School of Chemical Engineering, Oklahoma State University, Stillwater, OK 74078, USA

* Corresponding author: Tel.: +1 918 594 8634.

E-mail address: lobat.tayebi@okstate.edu (L. Tayebi)

Abstract

In this paper, a method for cost-effective production of nanostructured zirconium titanate ($ZrTiO_4$) fibers is introduced. In this method, $ZrTiO_4$ fibers were synthesized by a sol-gel technique using cellulose fibers as the template. The resultant structures were studied by transmission electron microscopy, X-ray diffraction, scanning electron microscopy, and Brunauer–Emmett–Teller (BET) analyses. The photocatalytic activity of the fiber was compared to that of $ZrTiO_4$ powders prepared by the same sol-gel method, in dark and under UVA and UVC radiations. According to the results, after calcination accompanied by the template removal, the $ZrTiO_4$ fiber consists of uniformly-deposited, crystalline nanoparticles. This nanostructured fiber exhibited a higher surface area and a higher porosity compared with the $ZrTiO_4$ powders, resulting in considerably higher photocatalytic characteristics, as

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

confirmed by the experiment. The large surface area and the enhanced photocatalytic activity of the $ZrTiO_4$ fibers also offer applications in sensors and bioactive films.

Keywords: Ceramics; Nanostructured materials; Sol-gel processes; Catalysis

1. Introduction

Zirconium titanate ($ZrTiO_4$) is used in a wide range of applications, including as high-dielectric materials [1-3], high-temperature pigments [4], humidity sensors [5], and bifunctional catalysts, albeit the latter in features of the TiO_2-ZrO_2 binary system [5-9]. It is well-known that in applications like catalysts, sensors, and bioactive films, having a high surface area, purity, and homogeneity is essential, while considering a low-cost and environmental friendly method is acknowledged.

$ZrTiO_4$ can be prepared by different methods like a time-consuming, solid-state reaction between ZrO_2 and TiO_2 at high temperatures [8-14]. Also, high-energy milling of ZrO_2 and TiO_2 is another method that can yield into amorphous powders in a lower temperature, but this method is still energetically costly, as well as has the disadvantage of introducing impurities of milling balls [9,10]. The sol-gel method is an outstanding method to produce homogeneous and amorphous $ZrTiO_4$ powders which can crystallize at low temperatures, compared to the other methods. Ceramics synthesized by sol–gel processes are also very pure and their microstructure is comparatively easy to tailor [15-18]. The sol-gel synthesis of $ZrTiO_4$ can be conducted by hydrolysis and condensation reactions of inorganic salts [3,9-11] or alkoxides [2,12-14].

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

Photocatalytic materials have attracted a considerable interest and have emerged as an important destructive technology leading to the total mineralization of most organic pollutants, including organic dyes for wastewater treatments [19]. There are a few studies on the photocatalytic property of $ZrTiO_4$ which indicates a lower activity of $ZrTiO_4$ in comparison to TiO_2 and ZrO_2 [20]. To improve the photocatalytic characteristic of materials which is directly related to surface area, there are different approaches. Considerable efforts have been devoted to the design and synthesis of one-dimensional nanomaterials, such as nanorods, nanowires, nanotubes, and nanofibers, due to their unique properties in fabricating electronic and optoelectronic devices, biosensors, and high surface area electrodes in electrochemistry [20-26].

Fiber composites can be produced by interfacial polymerization and electro spinning [26-29]. Template synthesis has also been adopted to prepare one-dimensional materials, using different templates such as nano-channel glasses and polymeric membranes, and anodized aluminum substrates [30]. However, their synthesis usually consists of a complicated process. As an alternative, a conformal replication of the morphologies of natural fibrous materials has been used in this study, which offers a low-cost, simple, and environmentally safe method for the formation of sophisticated nanostructures [31-33]. There are reports that described the use of natural templates to grow nanostructures of ceramics and ceramic-based composites [34-36]. Cellulose is the most abundant natural polymer, and in the form of cotton consists of fibers of a few micrometer diameters, with a surface area of about 1 m^2/g. It is low cost and economically favored for practical applications [37,38].

In this work, a facile approach to the deposition of $ZrTiO_4$ nanoparticles onto cellulose fibers is originally considered. Self-standing nanostructured $ZrTiO_4$ was fabricated by the

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

heat removal of the cellulose template, followed by sintering. The morphology of the fibers consists of chains of $ZrTiO_4$ connected to each other, which makes $ZrTiO_4$ hybrid, and could be practical to increase surface area and adsorption compared to $ZrTiO_4$ powders when used as a photocatalytic surface. During this investigation, cellulose fibers were used as templates to make porous fibers of $ZrTiO_4$. The photocatalytic behavior of $ZrTiO_4$ fibers was studied and compared to $ZrTiO_4$ powders by analyzing the photodegradation of methylene blue under exposure to UV A and UV C. Methylene blue (MB) is a heterocyclic aromatic dye which is one of the most prominent dyes used as a probe molecule to investigate the heterogeneous photocatalytic behavior [38-40].

2. Materials and Method

18.2 mmol of $ZrCl_4$ (Alfa Aesar, 99.5%) was added to 400 ml deionized water and stirred for 30 min. 18.2 mmol of $TiCl_4$ (Alfa Aesar, 99.99%) was then added to the solution dropwise while stirring. 1 g of natural cellulose fibers was put in the prepared solution having a pH value of 1. The pH value of the solution was increased by adding NaOH (2M) dropwise while stirring to reach pH = 4 at room temperature. The fibers were then removed from the solution and were rinsed with deionized water to remove remaining species. The obtained fibers were dried at room temperature and were calcined in air at 600 °C for 1 h, which removes the cellulose template and produces the final $ZrTiO_4$ fibers. Fig. 1 shows a schematic of the synthesis method, where particles have a negative charge and absorb to the cellulose having a positive charge. Some $ZrTiO_4$ powders were produced by the same sol-gel and calcination procedures for microstructural characterization.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

A transmission electron microscope (TEM, JEOL JEM-2100) operating at an acceleration voltage of 200 kV was used to evaluate the powder particle size and morphology. To do so, a small amount of the powder was dispersed in ethanol, ultrasonicated for 15 min, and then dropped on a carbon grid. The X-ray diffraction (XRD) pattern of the calcined powders was recorded by a Bruker. AXS Inco. diffractometer using Cu Kα radiation (λ =1.54056 Å). The surface morphology of the $ZrTiO_4$ fibers was investigated using a scanning electron microscope (SEM, Hitachi S-4800). Also, the specific surface area of the fibers and powders was measured by the Brunauer–Emmett–Teller (BET) analysis from the N_2 isotherms collected with a Belsorp mini II BEL system on the degassed samples.

To measure the photocatalytic efficiency, methylene blue degradation tests under ultraviolet (UV) light were performed. To do so, 1 mg of the photocatalyst powder was dispersed in 10 ml MB solution of 5 μM concentration. The suspension was placed in a dark chamber under stirring for 1 h for the adsorption of dye molecules on the powders, and then irradiated using a UV lamp (4 W, UVA, UVC low pressure Hg lamp). The decrease of the MB absorption peak upon irradiation time was measured using a UV-Vis spectrophotometer, NanoDrop 2000, Thermo Science. The same procedure was also run for the $ZrTiO_4$ fibers.

3. Results and discussion

Fig. 2a presents the TEM micrograph of the powder calcined at 600 °C. As can be seen, the powder particles have an average size of 50 nm with a relatively wide size range of 20 nm to 100 nm. Furthermore, the crystallinity of this powder led to Debye-Scherrer diffraction spots in the selected area diffraction (SAD) pattern, as represented in the insert of Fig. 2a.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

The XRD pattern of the xerogel (before calcination) and the powder calcined at 600 °C is indicated in Fig. 2b. The broad halo pattern of the xerogel suggests a typical amorphous structure. Nonetheless, the presence of $ZrTiO_4$ reflections for the calcined powder is indicative of the occurrence of structural ordering and crystallization, as confirmed in the TEM studies (Fig. 2a). The XRD reflections were also confirmed by the ICSD reference code of 00-034-0415 for zirconium titanate with the orthorhombic α-PbO_2 type structure. The direct crystallization of $ZrTiO_4$, rather than TiO_2 and ZrO_2, at the low temperature is due to the high level of homogeneity of the xerogel [41].

Fig. 3a depicts the SEM micrograph of the coated cellulose fibers (before calcination), showing a uniform deposition of nanoparticles on the surface. It was found that the uniformity of the coatings depends on growth conditions, especially pH. Note that the conditions detailed in the experimental section are optimized ones for achieving a uniform coating. Also, the thickness of the $ZrTiO_4$ film can be controlled by changing the deposition time. After calcination, the organic parts are removed and pure $ZrTiO_4$ fibers remain. So, a relatively thick wall of $ZrTiO_4$ is required to prevent the collapse of the hollow structure due to shrinkage of the tube during calcination. As shown in Fig. 3b, a sound $ZrTiO_4$ fiber was prepared by the template, sol-gel, and calcination procedures used. The appearance of particles on the fiber surface after calcination is due to particle coarsening, as reported already [41-43]. Indeed, as a result of sintering, the nanoparticles grow and start appearing on the surface due to a mass transfer caused by transformation from a glass state to a crystalline one. In other words, initially a strained continuous layer is formed on the fiber and then the strain is released by the formation of three-dimensional islands on that layer (Stranski–Krastanov growth model) [42-43].

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

The BET surface area of the $ZrTiO_4$ powders was measured to be 29.71 m^2/g with a total pore volume of 0.0084 cm^3/g , while that of the $ZrTiO_4$ fibers was 72.43 m^2/g with a total pore volume of 0.257 cm^3/g. Such a result indicates that the surface area of the $ZrTiO_4$ fibers increases about 2.5 times in the hybrid structure. Both the $ZrTiO_4$ powder and fibers have solid mesoporous structures, but the total pore volume of the $ZrTiO_4$ fibers was almost 30 times greater than that of the $ZrTiO_4$ powders, which yields into a material with a higher porosity level. It is anticipated that the higher surface area and higher porosity level of the $ZrTiO_4$ fibers make them more active than the $ZrTiO_4$ powders.

The photocatalytic activity of the $ZrTiO_4$ fibers was studied by the degradation of the MB dye as a model pollutant. Fig. 4a presents the results of MB removal using the $ZrTiO_4$ fibers and powders. Prior to UV irradiation, the samples were placed in dark for 60 minutes to evaluate the MB adsorption power of the $ZrTiO_4$ fibers and powders. As shown in Fig. 4a, about 7 % MB was adsorbed on the $ZrTiO_4$ powders, while this amount is up to 30 % on the $ZrTiO_4$ fibers under the dark condition. This shows that the $ZrTiO_4$ fibers improve the adsorption of the MB molecules. As shown above, the surface area of the $ZrTiO_4$ fibers is higher than that of the pure $ZrTiO_4$ powders, which facilitates the additional adsorption of dye molecules. Since absorptivity increased about 23 % for the $ZrTiO_4$ fibers, one can conclude that the fibers provide more adsorption sites compared to the $ZrTiO_4$ powders. Also, Fig. 4b shows the photocatalytic degradation of MB under UVA illumination for the $ZrTiO_4$ fibers and powders. The effect of initial dark adsorption has been eliminated. It can be observed that the photocatalytic decomposition of MB over the $ZrTiO_4$ fibers is more than that of the powders.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

Fig. 4c indicates the results of photodegradation of MB by the $ZrTiO_4$ powders and fibers under UVA irradiation. As can be seen, the $ZrTiO_4$ fibers are able to remove almost 95% MB after 130 minute, while the $ZrTiO_4$ powders remove 35% MB after the same duration. The MB concentration does not change after 80 minutes of UVA irradiation for the $ZrTiO_4$ powders, which might be related to the powders covered by MB molecules and the low energy of UVA to irritate. To investigate the effect of UVC irradiation on MB decomposition, the same test was run with UVC lamp. For the fiber sample, about 95% MB is decomposed after 50 minutes of irradiation of UVC, while this duration is 280 minutes for the $ZrTiO_4$ powders. It is noticeable that the UVC irradiation is powerful enough to active the photocatalytic effect of the $ZrTiO_4$ powders in comparison to the UVA irradiation.

In summary, the higher rate of the photocatalytic removal of MB by the $ZrTiO_4$ fibers as compared to the powders can be explained by the adsorption of intermediates on the large surface area. The decomposition rate considerably decreased in the case of the powder sample, due to the screening effect of the powders being denser than the fibers.

4. Conclusions

In this work, a $ZrTiO_4$ fiber was synthesized by a low cost, environmentally friendly method of sol-gel and by using cellulose fibers as the template. By removing the template during heat treatment, $ZrTiO_4$ particles were sintered to each other and made a hybrid structure with a high surface area of 72.43 m^2/g. Such a hybrid structure showed an enhancement in the surface adsorbent and photocatalytic effect in comparison to the $ZrTiO_4$ powders. The increase in the photodegradation rate for the $ZrTiO_4$ fiber was attributed to its

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

higher surface area which resulted in introducing more photocatalytic active sites to dye molecules.

Acknowledgments

This work was partially supported by AFOSR under Grant no. FA9550-10-1-0010 and the National Science Foundation (NSF) under Grant no. 0933763. We also acknowledge Dr. Shohreh Rouhani for her technical helps.

References

[1] Y. Park, Y. Kim, Influence of cooling rate on the physical properties of tin modified zirconium titanate, J. Mater. Sci. Lett. 15 (1996) 853-855.

[2] G. Wolfram, H.E. Gobel, Existence range, structural and dielectric properties of $Zr_xTi_ySn_zO_4$ ceramics (x+y+z=2), Mater. Res. Bull. 16 (1981) 1455-1463.

[3] A. Bianco, M. Viticoli, G. Gusmano, M. Paci, G. Padeletti, P. Scardi, Zirconium tin titanate thin films via aqueous polymeric precursor route, Mater. Sci. Eng. C 15 (2001) 211-213.

[4] F. Hund, Mixed-phase pigments with $ZrTiO_4$. Z. Anorg. Allg. Chem. 525 (1985) 221-229.

[5] I.C. Cosentino, E.N.S. Muccillo, R. Muccillo, Development of zirconia-titania porous ceramics for humidity sensors. Sens. Actuator B 96 (2003) 677-683.

[6] J. Fung, I. Wang, Dehydrocyclization of C6-C8 n-paraffins to aromatics over TiO_2-ZrO_2 catalysts, J. Catal. 130 (1991) 577-587.

[7] M.C. Barrera, M. Viniegra, J. Escobar, M. Vrinat, J.A. de los Reyes, F. Murrieta, Highly active MoS_2 on wide-pore ZrO_2-TiO_2 mixed oxides, Catal. Today 98 (2004) 131-139.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

[8] A.E. McHale, R.S. Roth, Low-temperature phase-relationships in the system ZrO_2-TiO_2, J Am. Ceram. Soc. 69 (1986) 827-832.

[9] M. Stubicar, V. Bermanec, N. Stubicar, D. Kudrnovski, D. Krumes, Microstructure evolution of an equimolar powder mixture of ZrO_2-TiO_2 during high-energy ball-milling and post-annealing, J. Alloy. Compd. 316 (2001) 316-320.

[10] A. Gajovic, I. Djerdj, K. Furic, R. Schlogl, D.S. Su, Preparation of nanostructured $ZrTiO_4$ by solid state reaction in equimolar mixture of TiO_2 and ZrO_2, Cryst. Res. Technol. 41 (2006) 1076-1081.

[11] F.H. Brown, P. Duwez, The zirconia-titania system, J. Am. Ceram. Soc. 37 (1954) 129-132.

[12] L.W. Coughanour, R.S. Roth, V.A. Deprosse, Phase equilibrium relations in the systems lime-titania and zirconia-titania, J. Res. Nat. Bur. Stand. 52 (1954) 37-41.

[13] R.W. Lynch, B. Morosin, Thermal-expansion, compressibility, and polymorphism in hafnium and zirconium titanates, J.Am. Ceram. Soc. 55 (1972) 409-413.

[14] C.L. Wang, H.Y. Lee, F. Azough, R. Freer, The microstructure and microwave dielectric properties of zirconium titanate ceramics in the solid solution system $ZrTiO_4$-$Zr_5Ti_7O_{24}$, J. Mater. Sci. 32 (1997) 1693-1701.

[15] A.K. Bhattacharya, K.K. Mallick, A. Hartridge, J.L. Woodhead, Sol gel preparation, structure and thermal stability of crystalline zirconium titanate microspheres, J. Mater. Sci. 31 (1996) 267-271.

[16] J.A. Navio, F.J. Marchena, M. Macias, P.J. Sanchezsoto, P. Pichat, Formation of zirconium titanate powder from a sol-gel prepared reactive precursor, J. Mater. Sci. 27 (1992) 2463-2467.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

[17] E.L. Sham, M.A.G. Aranda, E.M. Farfan-Torres, J.C. Gottifredi, M. Martinez-Lara, S. Bruque, Zirconium titanate from sol-gel synthesis: Thermal decomposition and quantitative phase analysis, J. Solid State Chem. 139 (1998) 225-232.

[18] S.N. Koc, Zirconium titanate synthesis by diethanol amine based sol-gel route, J. Sol-Gel Sci. Technol. 38 (2006) 277-281.

[19] A. Fujishima, T.N. Rao/ Interfacial photochemistry: Fundamentals and applications/ Pure Appl. Chem. 70 (1998) 2177-2187.

[20] J.A. Navio, G. Colón, J.M. Herrmann, Photoconductive and photocatalytic properties of ZrTiO4. Comparison with the parent oxides TiO_2 and ZrO_2, J. Photochem. Photobiol. A 108 (1997) 179-185.

[21] S.I. Roohani-Esfahani, Z. Lu, H. Zreiqat, Novel, simple and reproducible method for preparation of composite hierarchal porous structure scaffolds, Mater. Lett. 65 (2011) 2578-2581.

[22] L. Zhao, S. Mei, P. Chu, Y. Zhang, Z. Wu, The influence of hierarchical hybrid micro/nano-textured titanium surface with titania nanotubes on osteoblast functions, Biomaterials 31 (2010) 5072-5154.

[23] V. Vimonses, B. Jin, C. Chow, C. Saint, An adsorption-photocatalysis hybrid process using multi-functional-nanoporous materials for wastewater reclamation, Water Res. 44 (2010) 5385-5482.

[24] F. Siviero, N. Coppedè, A.M. Taurino, T. Toccoli, P. Siciliano, S. Iannotta, Hybrid titania–zincphthalocyanine nanostructured multilayers with novel gas sensing properties, Sens. Actuators B 130 (2008) 405-410.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

[25] S. Yadav, S. Madeshwaran, J. Cho, Synthesis of a hybrid assembly composed of titanium dioxide nanoparticles and thin multi-walled carbon nanotubes using "click chemistry", J. Colloid Interface.Sci. 358 (2011) 471-477.

[26] Y. Zunxian, D. Guodong, G. Zaiping, Y. Xuebin, C. Zhixin, G. Tailiang, TiO_2(B)@anatase hybrid nanowires with highly reversible electrochemical performance, Electrochemistry Communications 13 (2011) 46-49.

[27] R.S. Rastogi, K. Pourrezaei, Deposition, characterization, thermo-chemical compatibility and failure analysis of multi-layer coated silicon-carbide fiber-reinforced metal-matrix composites, J. Mater. Process. Technol. 43 (1994) 89-107

[28] X. Kongliang, Z. Yanli, Y. Yanhong/ Preparation and characterization of cellulose hybrids grafted with the polyhedral oligomeric silsesquioxanes (POSS), Carbohydr. Polym. 77 (2009) 858-862.

[29] H.J. Jeon, J.S. Kim, T.G. Kim, J.H. Kim, W.R. Yu, J.H. Youk, Preparation of poly(epsilon-caprolactone)-based polyurethane nanofibers containing silver nanoparticles, Appl. Surf. Sci. 254 (20080 5886-5890.

[30] S. Berchmans, R.G. Nirmal, G. Prabaharan, S. Madhu, V. Yegnaraman, Templated synthesis of silver nanowires based on the layer-by-layer assembly of silver with dithiodipropionic acid molecules as spacers, J. Colloid Interface. Sci. 303 (2006) 604-610.

[31] X.S. Li, G.E. Fryxell, C.M. Wang, J. Young/ Templating mesoporous hierarchies in silica thin films using the thermal degradation of cellulose nitrate/ Microporous Mesoporous Mat. 99 (2007) 308-318.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

[32] M. Kemell, V. Pore, M. Ritala, M. Leskela, M. Linden, Atomic layer deposition in nanometer-level replication of cellulosic substances and preparation of photocatalytic TiO_2/cellulose composites, J. Am. Chem. Soc. 127 (2005) 14178-1419.

[33] Y. Shin, G.J. Exarhos, Template synthesis of porous titania using cellulose nanocrystals, Mater. Lett. 61 (2007) 2594-2597.

[34] H. Ghanem, M. Kormann, H. Gerhard, N. Popovska, Processing of biomorphic porous TiO_2 ceramics by chemical vapor infiltration and reaction (CVI-R) technique, J. Eur. Ceram. Soc. 27 (2007) 3433-3438.

[35] M.K. Aminian, N. Taghavinia, A. Iraji-zad, S.M. Mahdavi, M. Chavoshi, S. Ahmadian, Highly porous TiO_2 nanotibres with a fractal structure, Nanotechnology 17 (2006) 520-525.

[36] N. Sharifi, F. Tajabadi, N. Taghavinia, Nanostructured silver fibers: Facile synthesis based on natural cellulose and application to graphite composite electrode for oxygen reduction, Int. J. Hydrogen Energy 35 (2010) 3258-3262.

[37] L. Shooshtari, M. Rahman, F. Tajabadi, N. Taghavinia, TiO_2 fibers enhance film integrity and photovoltaic performance for electrophoretically deposited dye solar cell photoanodes, ACS Appl. Mater. Interfaces 3 (2011) 638-679.

[38] Y. Ohko, Y. Utsumi, C. Niwa, T. Tatsuma, K. Kobayakawa, Y. Satoh, Self-sterilizing and self-cleaning of silicone catheters coated with TiO_2 photocatalyst thin films: A preclinical work, J. Biomed. Mater. Res. 58 (2001) 97-101.

[39] A. Matsuda, T. Matoda, Y. Kotani, T. Kogure, M. Tatsumisago, T. Minami, Evaluation of photocatalytic activity of transparent anatase nanocrystals-dispersed silica films prepared by the sol-gel process with hot water treatment, J. Sol-Gel Sci. Technol. 26 (2003) 517-521.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

[40] A. Matsuda, T. Matoda, T. Kogure, K. Tadanaga, T. Minami, M. Tatsumisago, Formation of anatase nanocrystals-precipitated silica coatings on plastic substrates by the sol-gel process with hot water treatment, J. Sol-Gel Sci. Technol. 27 (2003) 61-69.

[41] E. Salahinejad, M.J. Hadianfard, D.D. Macdonald, I. Karimi, D. Vashaee, L. Tayebi, Aqueous sol–gel synthesis of zirconium titanate ($ZrTiO_4$) nanoparticles using chloride precursors, Ceram. Int. 38 (2012) 6145-6149.

[42] E. Salahinejad, M.J. Hadianfard, D.D. Macdonald, M. Mozafari, D. Vashaee, L. Tayebi, Zirconium titanate thin film prepared by an aqueous particulate sol–gel spin coating process using carboxymethyl cellulose as dispersant, Mater. Lett. 88 (2012) 5-8.

[43] E. Salahinejad, M.J. Hadianfard, D.D. Macdonald, M. Mozafari, D. Vashaee, L. Tayebi, Multilayer zirconium titanate thin films prepared by a sol–gel deposition method, Ceram. Int. 39 (2013) 1271-1276.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

Figures

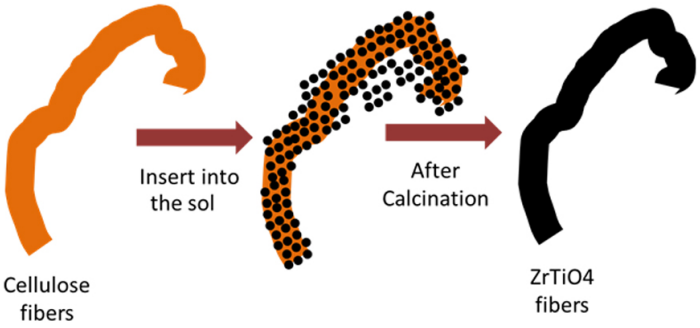

Fig. 1. Schematic illustration of the synthesis method of the fibers.

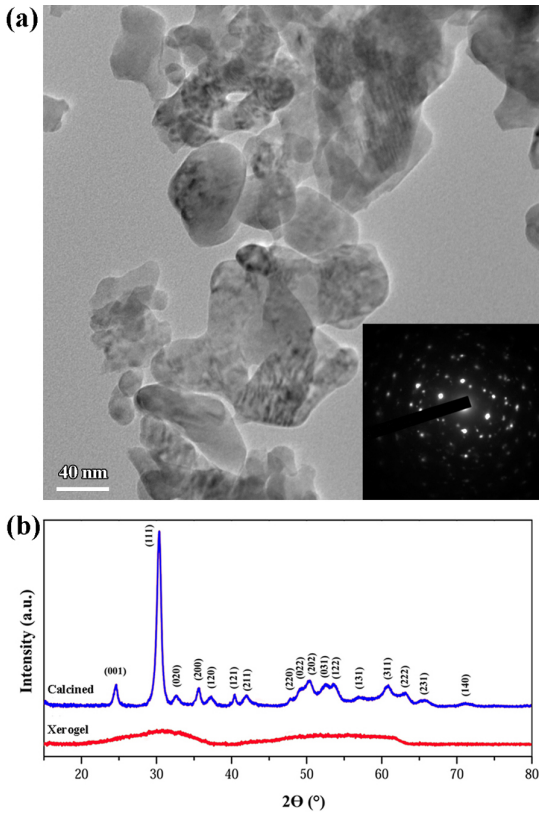

Fig. 2. (a) TEM micrograph and SAD pattern of the powder calcined at 600 °C and (b) XRD pattern of the xerogel and the powder calcined at 600 °C.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

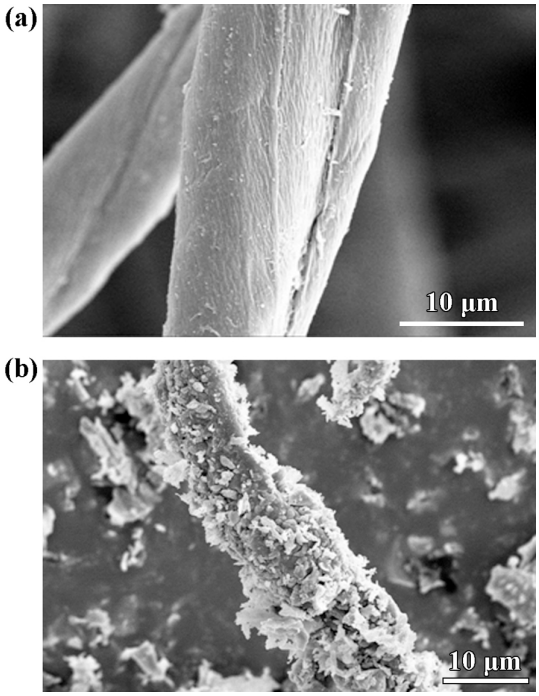

Fig. 3. SEM micrograph of the fiber (a) before calcination and (b) after calcination.

This is the accepted manuscript (postprint) of the following article:
P. Rouhani, E. Salahinejad, R. Kaul, D. Vashaee, L. Tayebi, *Nanostructured zirconium titanate fibers prepared by particulate sol–gel and cellulose templating techniques*, Journal of alloys and compounds, 568 (2013) 102-105.
https://doi.org/10.1016/j.jallcom.2013.03.142

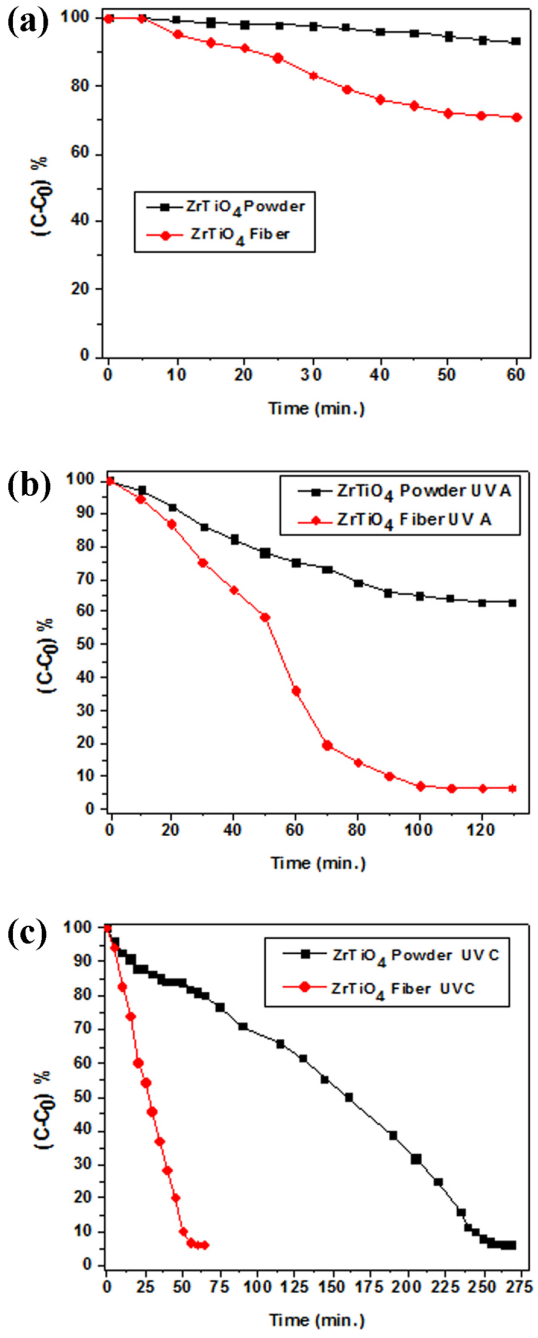

Fig. 4. (a) Adsorption graph in the dark condition, (b) photodegradation graph in the UVA condition, and (c) photodegradation graph in the UVC condition.