Photocatalytically Active Titania Aerogels

– Optimization of their Mechanical Stability

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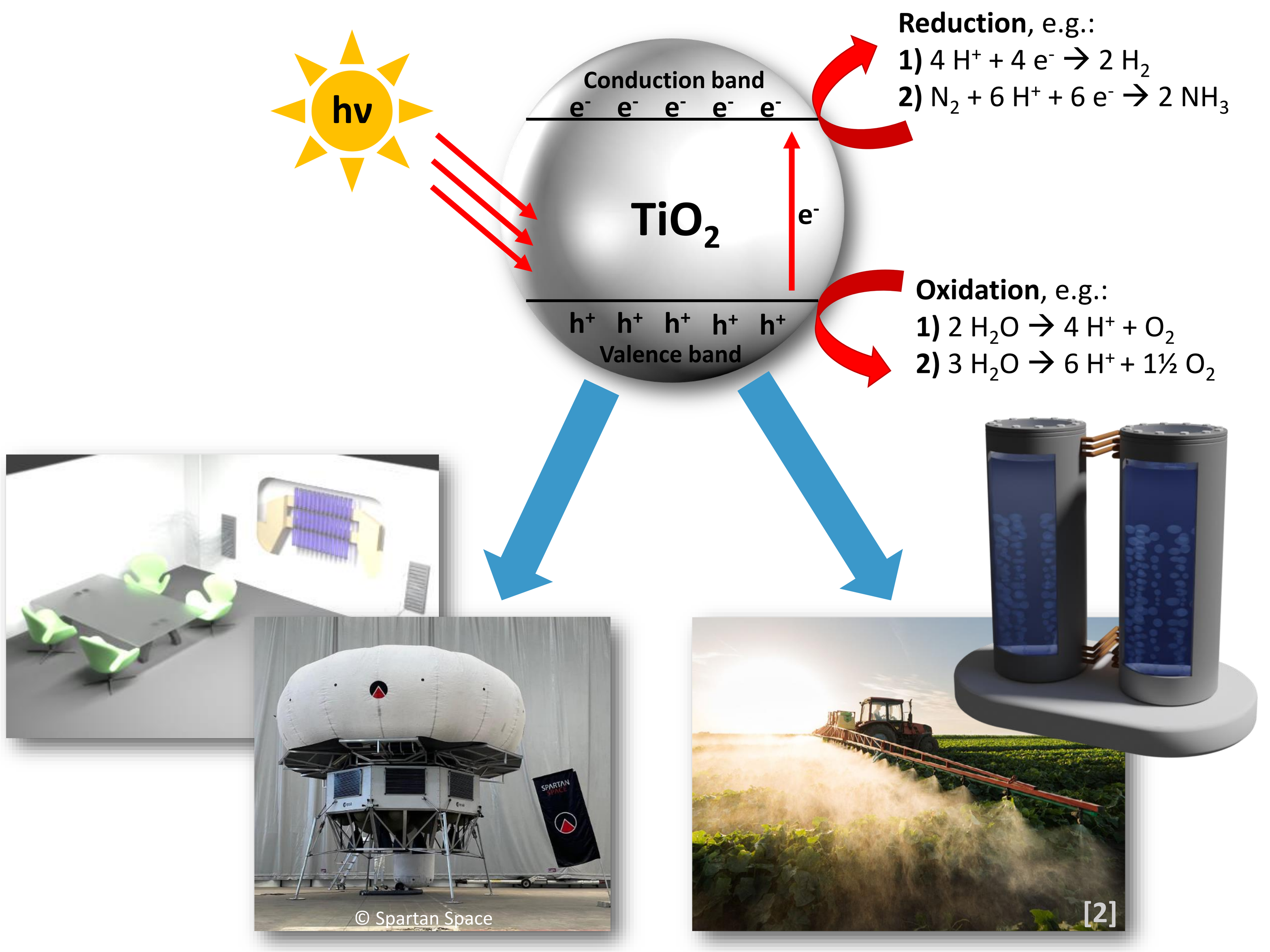


Schematic principle of photocatalysis with TiO_2 and example reactions: 1) Hydrogen production via water hydrolysis, 2) Ammonia synthesis via nitrogen reduction; with examples for possible applications: air purification in a space habitat (left) and decentralized ammonia production for fertilizers (right).

Fertilizers - Without them it would be impossible to feed our ever-growing population. They are mostly produced from ammonia synthesized in the Haber-Bosch-process, which makes up 1-2% of the global energy demand and carbon emissions. Furthermore, ammonia production is a very centralized process, leading to long transportation distances and economical dependencies. Thus sustainable, small-scale applications are needed.[1]

Space - To clear the air in a habitat located on the moon you can't just open a window and typical air purifiers are heavy and take up a lot of space. A perfect solution could be a thin device incorporated in the habitat wall, that also improves the thermal insulation of the outer walls.

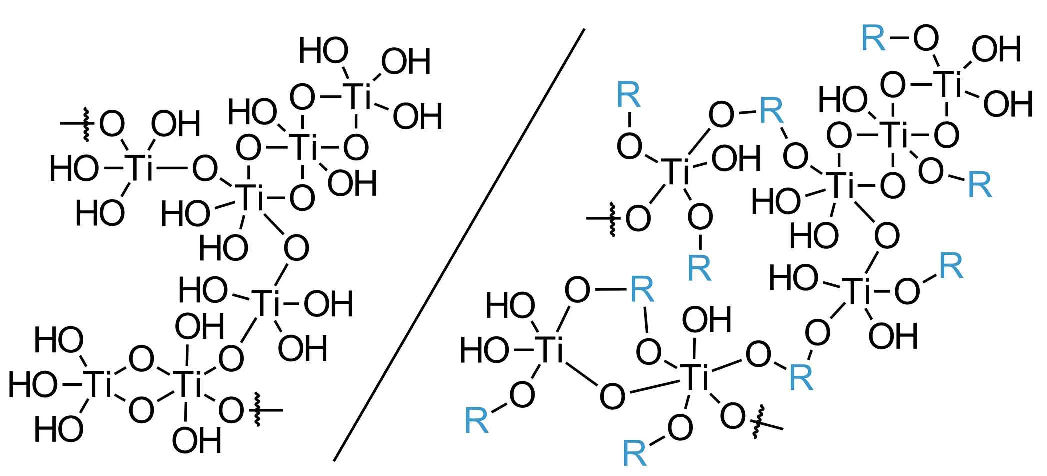
Material Optimization

Crystallinity, specific surface area and pore structure can be tuned by changing the synthesis parameters of the developed simple, acid-catalyzed sol-gel route. This includes type of solvent, acid concentration, water concentration and aging time.[3]

Amorphous TiO_2 with up to 700 $m^2\,g^{-1}$
100% crystalline TiO_2 with up to 300 $m^2\,g^{-1}$
Large fraction of brookite achieved

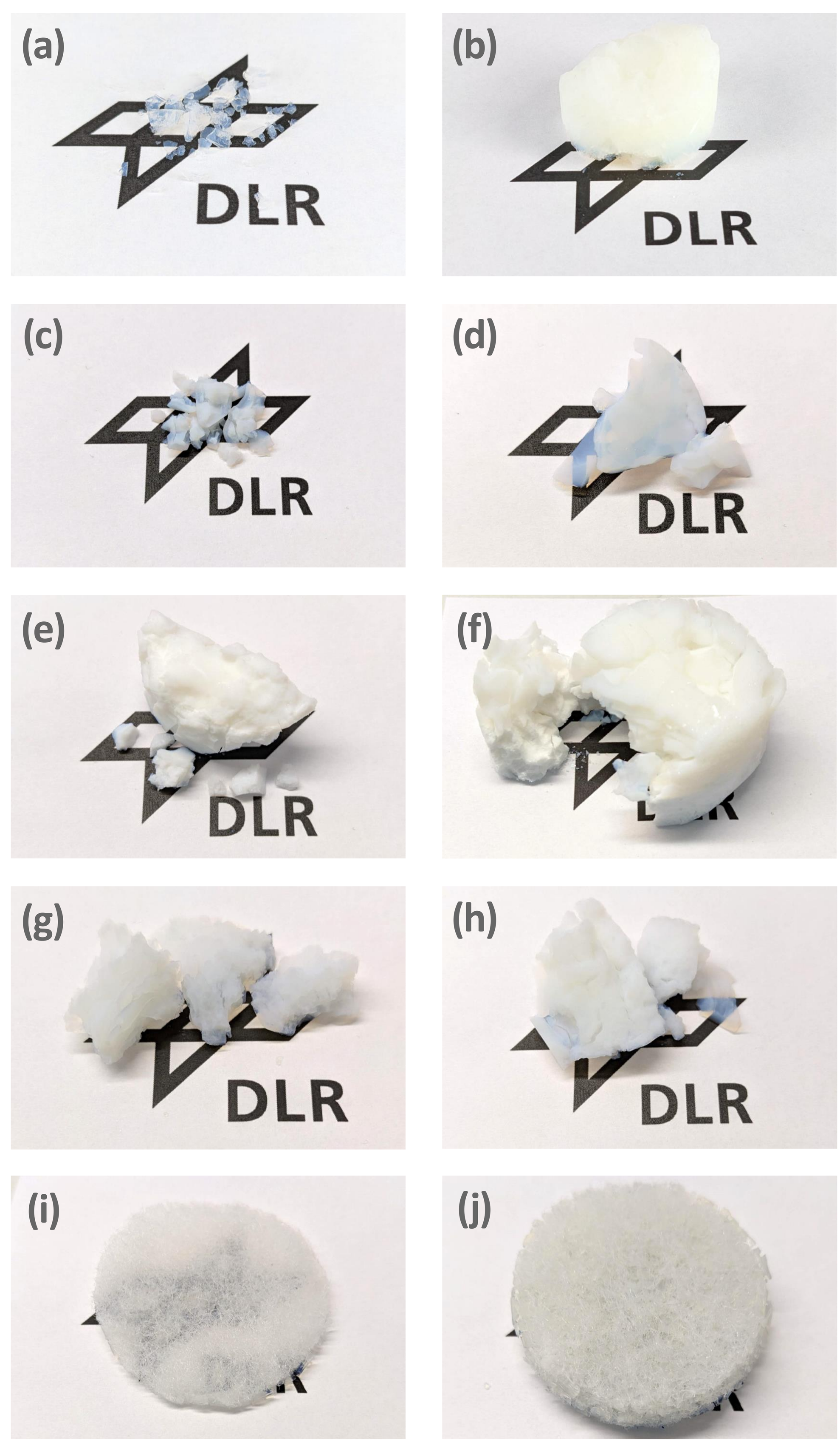
Mechanical stability and dust formation remain a problem for applications. Studies on denaturing agents in ethanol showed that complexing agents can be incorporated into the aerogel network.[4]

→ Can introduced rotational freedom increase mechanical stability?

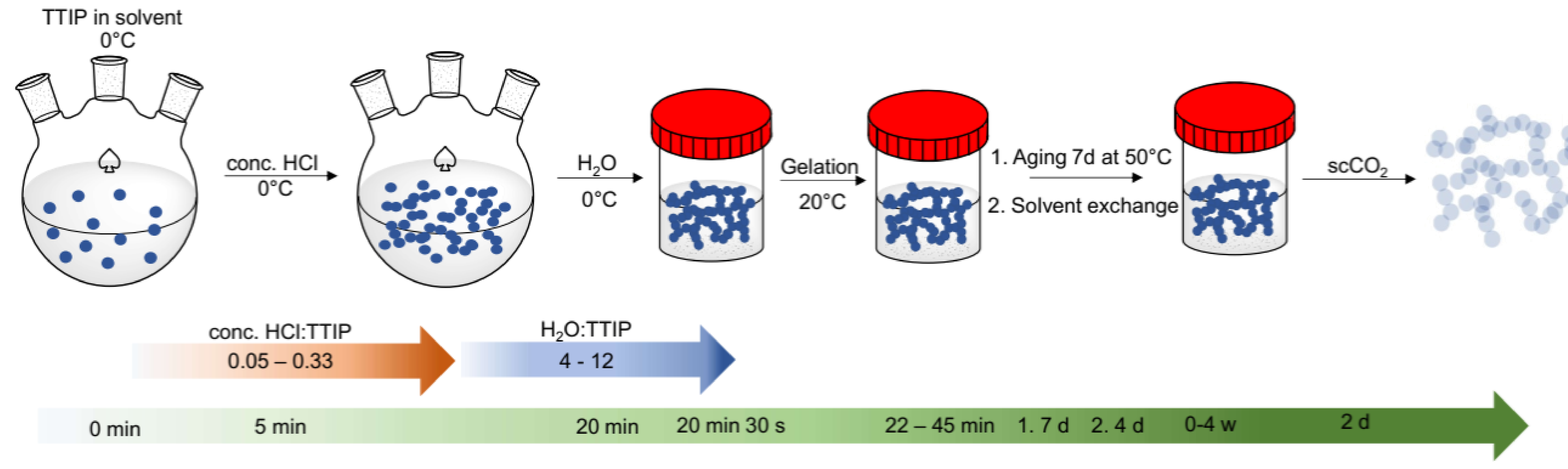


R = $(CH_2)_{2\text{-}6}$, $CH_2CH_2OCH_2CH_2OCH_2CH_2$, poly(oxyethylene)

Morphology of TiO_2 aerogels synthesized with different additives and fibers:



Pictures of TiO_2 aerogels synthesized without additives (a) and with added ethylene glycol (b), 1,3-propanediol (c), 1,4-butanediol (d), 1,5-pentanediol (e), 1,6-hexanediol (f), triethylene glycol (g), polyethylene glycol (h). TiO2 aerogels synthesized without additives, reinforced with 5 mm PET-fleece (i) and with 10 mm PET-fleece (j).



Scheme of the general synthesis procedure for TiO_2 aerogels.

Application

Together with our cooperation partners we have found that TiO_2 aerogels can catalyze nitrogen reduction under UV light radiation in the liquid phase and gas phase, can store electrons for time-shifted photocatalysis,[5] and can degrade VOCs, whilst exhibiting low thermal conductivity. Thus the material could be used for decentralized and sustainable green fuel and fertilizer production, as well as for air cleaning in spaces demanding for light-weight materials and good thermal insulation.

Conclusion and Outlook

Diols are promising spacers for the synthesis of titania-based aerogels with a higher mechanical stability. Also fiber-reinforcement yielded good first results. More linkers, different synthesis and aging conditions, and the scaffolding with TiO_2 fibers will be tested in the future to produce mats, thin films and beads.

Acknowledgement and Literature

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[2] AmmPower, July 13, **2022**. www.iamm.green/ammonia-fertilizers/
[3] A. Rose, "Photocatalytically Active Aerogels – Development and Characterization of (Semi-)Crystalline Titania", University of Cologne, **2023**.
[4] P. Kuschmitz, "Denaturing Agents in the Synthesis of Titanium Dioxide Aerogels & Relaxometry as a Fast Analysis Method for Porous Media", University of Cologne, **2024**.
[5] A. Rose, A. Hofmann, P. Voepel, *et al.*, *ACS Appl. Energy Mater.* **2022**, 5, 14966–14978.

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