Nanostructured Photocatalytic Materials Enable Capturing Solar Energy and Simultaneously Powering Water Purification

-An interview of Associate Prof Darren Delai SUN, Nanyang Technological University, Singapore-

Abstract: A Singapore research group led by Associate Prof Darren Delai SUN in Nanyang Technological University (NTU) in Singapore has developed world leading research capability in TiO_2-based nanostructures for clean water and energy (hydrogen and solar energy) production. They have the expertise in synthesizing special shapes, composition and pre-designed nanostructures using electronspinning, hydrothermal, anodization or doping method. Their flexible TiO_2 nanofiber/tube/wire membrane has not only successfully been applied in the water treatment system for the concurrent filtration and photocatalytic oxidation functions, but also used as electrodes for dye sensitized solar cells (DSSCs) to achieve low-cost, flexible and printable thin film solar cells. Dr. Sun and his colleagues designed a dye sensitized TiO_2 nanostructures based system for producing clean water and electric energy simultaneously by taking advantage of both the photocatalytic and photovoltaic properties of their proprietary TiO_2-based nanostructures. This smart design has great commercial potential in realizing the water purification at almost zero cost.

Both Water and Energy are indispensable for our lives, however, the demand for drinking water and energy has been increasing dramatically with the explosive population growth and ongoing rapid industrialization in the past decades. Water treatment and clean energy technologies attract intensive attention from both academia and industry. A Singapore research group led by Dr Darren Delai SUN, associate professor of School of Civil and Environmental Engineering, Nanyang Technological University (NTU) has developed innovative materials and technologies in the area of TiO_2-based nanostructures for clean water and energy (hydrogen and solar energy) production applications. In mid July 2010, NanoGlobe team had the privilege to interview Dr SUN and learned about the R&D activities and achievements of his research group.

Dr Sun completed his PhD in Chemical Engineering at the University of New South Wales, Australia in 1992 and currently holds the associate professor position in NTU. He is also a Chair for International Water Associate (IWA) Specialist Group on Chemical Industries and Editor for Water Science and Technology. He is the author or co-author of more than 100 scientific publications in the peer-reviewed journals such as *Small, Nano Letters, Advanced Functional Materials, Environmental Science and Technology* and so on. He is also a co-editor of 2 books and co-author of a chapter in 3 books. Dr SUN and his group won the Prestigious Engineering Achievement Award 2008 from Institute of Engineering Singapore and the Nanyang Award 2009 for Innovation & Research. As a chemist, he has always devoted in the fundamental research for physical and chemical properties of TiO_2, ZnO, SnO_2 and other nano oxides especially for membrane material applications. At the same time, his engineering background enables him to focus on materials application of water and wastewater treatment, water reclamation and heavy metals stabilization. TiO_2 nanomaterials have promising applications in both areas of photovoltaics and photocatalysis, such as TiO_2 nanocrystalline electrode for dye sensitized solar cells (DSSC) and TiO2 nanomaterials photocatalytic water splitting. Instead of using dopants to modify the TiO_2 properties, Dr. SUN and his colleagues control the TiO_2 material properties by controlled synthesis of different nanostructures. For example, they use the electrospinning technique to make fibers about 100 nm wide consisting of two thinner threads fused together. One of these two threads is made of TiO_2 and the other of SnO_2 which enhances the photocatalytic activity of TiO_2. The twin fiber also has larger surface area on which photocatalytic reaction can occur more efficiently than other composite structures. In addition, they also succeeded in growing ZnO nanocrystals directly onto the surface of porous TiO_2 nanotube arrays for increasing the quantum efficiency and recyclability of the TiO_2 photocatalysts.

In order to realize the production of clean water with almost zero cost, Dr SUN and his colleagues solved the problems - sludge, nitrogen, membrane fouling and energy – step by step. At first, they successfully eliminate sludge and nitrogen by adding the prolonged sludge retention time aerobic membrane bioreactor (MBR) into the wastewater treatment system. However, the cost reduction for water purification is still limited by a membrane fouling problem which is caused by deposition of the foulants on membrane surface such as nature organic matters (NOMs) and bacteria etc., since the consequence of membrane fouling is the reduction of permeate production or need of high driving force to maintain a required rate of permeate production. TiO_2 nanomaterials are the most popular photocatalysts which can effectively oxide the organic pollutants in the wastewater. Dr SUN's group developed the nonwoven TiO_2 nanofiber/tube/wire micro and ultrafiltration membrane (see Figure 1) using their proprietary process in the electronspinning or alkaline hydrothermal technology. This robust and free standing TiO_2 nanofiber membrane has the concurrent filtration and photocatalytic oxidization functions in the presence of UV or visible light irradiation. This design has the following advantages: a high surface area of nanofiber structures allow enhanced adsorption rate of various trace organics and bacteria, while the full surface exposure to UV or visible lights accelerates photocatalytic oxidation and effectively overcome the membrane fouling problem. Not only filtration efficiency is enhanced, but the lifetime span of filtration membrane is also prolonged. As a result, the cost of water treatment can be dramatically reduced by integrating this membrane into the water treatment system. In addition, its unique flexible property enables this self-generation membrane to be formed into various membrane modules for larger commercial application, e.g. roll to roll production.

Not only taking advantage of the photocatalytic property of TiO_2 nanofiber membrane for wastewater reclamation applications, Dr Sun's group has been also investigating the photovoltaic property of their membranes for the application in DSSCs. Using their flexible TiO_2 nanofiber/tube/wire membrane as the electrode, the low-cost flexible DSSCs with conversion efficiency of about 5% can be fabricated . Combining the photocatalytic and photovoltaic properties of TiO_2 nanofiber/tube/wire membrane, Dr Sun's group designed a dye sensitized TiO_2 nanostructure-based sandwich structure to smartly realize the concurrent production of clean water and electricity. Furthermore, a nano composited low pressure RO membrane with multifunctional properties for the concurrent desalination and production of electricity has been recently developed. "Our dream is to produce drinking water with almost zero cost, and we believe this dream is coming true," concluded Dr Sun.

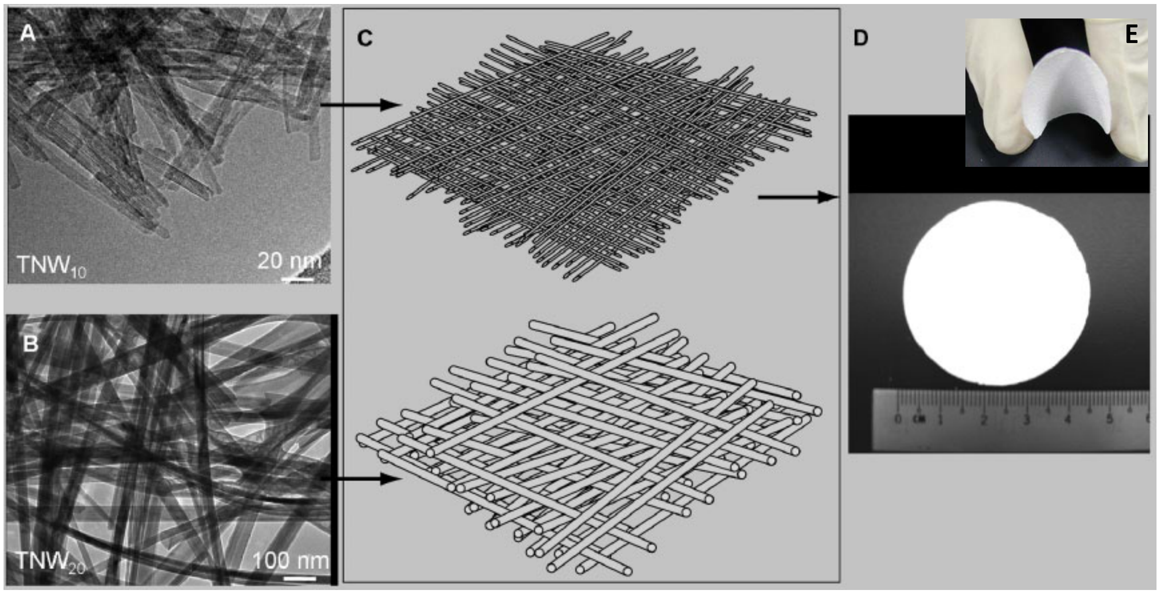

Figure 1. A) TEM image of the TiO_2 nanowires (TNW_{10}, diameter is around 10 nm); B) TEM image of TNW_{20} (diameter is around 20 nm); C) Schematic profiles of the nonwoven TNW ultrafiltration (UF) membrane. D) Digital photo of the TNW UF membrane (diameter is up to 45 cm); E) unique flexible property of the TiO_2 nanofiber/tube/wire membrane without substrate. [1, 2]

Reference:

1. Zhang X.W.; T. Zhang; J.W. Ng and D. D. Sun (2009) "High-Performance Multifunctional TiO_2 Nanowire Ultrafiltration Membrane With Hierarchical Layer Structure for Water Treatment" ***Advanced Functional Materials***, 19, 3731-3736.
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