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Plenaries

Progress in catalysts for green NH3 synthesis: What we learned from the past decade

Prof. Hideo Hosono
Tokyo Institute of Technology, Japan

Abstract

Research on catalysts for NH_3 synthesis at mild conditions has been much accelerated in that last decade as evidenced by rapidly increasing publication number of the papers. In this talk, Prof. Hosono summarized the features of the various activation methods reported so far, looking chronologically back at progress in heterogeneous catalysts since the use of iron oxide for the Haber–Bosch process, and finally the current technical challenges to be overcome were presented.

Biography

Hideo Hosono is an honorary and institute professor at the Tokyo Institute of Technology and a distinguished fellow and a group leader at National Institute for Materials Science. He received a Ph.D. in Applied Chemistry from Tokyo Metropolitan University in 1982 and became a professor of Tokyo Tech in 1999 via Nagoya Tech, Institute for Molecular Science and Vanderbilt University. He studied point defects in SiO_2 glass and worked on the creation of photosensitive glasses utilizing point defects, photonic glasses by ion implantation, protonic conductive glasses and micro-porous glass-ceramics with phosphate skeleton. After this research, he shifted his main subject to cultivation of electro-active functionality in transparent oxides in 1993. His research focuses on the creation of novel functional materials. The representative achievements so far are material design of transparent oxide semiconductors such as IGZO and their TFT applications for a state-of the art displays such as OLED-TVs, the creation of stable electrides and their application to catalysts for ammonia synthesis, and discovery of high-Tc iron-based superconductors which led to the 2nd research fever since high-Tc cuprates. His current interest is “quantum materials and catalysis”. Prof. Hosono is a recipient of various honors including the Japan Prize, von Hippel Prize (MRS), J. McGroddy Prize (APS), Karl Ferdinand Braun Prize (SID), Eduard Rhein Award (Germany), Imperial Prize (the Japan Academy), and is a Thomson Reuter Citation Laureate and a foreign fellow of the Royal Society.

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Ammonia direct combustion - General features and applications

Prof. Hideaki Kobayashi
Tohoku University, Japan

Abstract

Ammonia, along with hydrogen, is a promising carbon neutral fuel for the energy and industrial sectors. Research and technology development in ammonia combustion for use as a fuel has intensified in the last decade. Ammonia and hydrogen can be regarded as family fuels in terms of no CO_2 emission, but their characteristics of combustion are completely different. Hydrogen has very high reactivity and ignitability and NOx production is due to thermal NOx, whereas ammonia has very low reactivity and ignitability and NOx production is due to fuel NOx. Recent advances of combustion science in terms of combustion chemistry, numerical analysis as well as combustion diagnostics play an important role in meeting these challenges. New knowledge on ammonia combustion has led to various application studies, some of which are approaching social implementation. In particular, the co-firing of ammonia and pulverized coal in thermal power generation and the development of ammonia gas turbines are at this stage. Heat utilizations in various ammonia combustion furnaces for material and chemical industries are also nearing practical application. In this presentation, the progress of applied technology as well as research on ammonia combustion that supports ammonia combustion technology were presented.

Biography

Hideaki Kobayashi is a Research Professor at Tohoku University, Japan. He has been involved in research on fundamental processes of combustion phenomena in extreme environments, such as high-pressure turbulent premixed combustion, supersonic combustion, microgravity combustion and low-oxygen, high-temperature air combustion. He served as the team leader of the ammonia direct combustion research in the national project SIP “Energy Carriers”, which ran for five years from 2014. He is presently involved in projects on basic ammonia combustion, development of ammonia gas turbines and industrial furnaces using ammonia. He completed his master’s degree at Tohoku University in 1983 and became an associate professor at the university in 1992 after obtaining his PhD in 1991. He became a professor at the Institute of Fluid Science, Tohoku University, in 2003. He served as President of the Combustion Society of Japan from 2015 to 2017 and Vice-President of The Combustion Institute from 2016 to 2020. He received The Commendation for Science and Technology by The Minister of Education, Culture, Sports, Science in 2017 and Technology. In 2018 he was honored as a Fellow of The Combustion Institute and in 2022 he was awarded The Bernard Lewis Gold Medal.

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New routes of ammonia synthesis and decomposition

Prof. Ib Chorkendorff
Technical University of Denmark, Denmark

Abstract

Activating molecular nitrogen is an extremely important process as it supplies, in the form of fertilizer, the nitrogen that is a prerequisite for building all amino acids and nucleic acids essential for life. Ammonia is also considered an energy vector for storing energy over longer time. During the plenary, Prof. Chorkendorff motivated the discussion on why an alternative route to the current thermal ammonia synthesis route – the commercial Haber-Bosch process - could be attractive in a decentralized electrified society. This was extended to new routes of promotion of thermal ammonia synthesis (and decomposition) showing how cobalt can also be made very active. The active site has been identified by a combination of cobalt single crystals with and without steps combined with reaction over mass-selected nanoparticles made in situ by a cluster source. The plenary briefly discussed the cracking of ammonia for making it useable for the shipping industry. In the second part of the talk, Prof. Chorkendorff turned to electrochemical ammonia synthesis where his group now has shown how one can make ammonia at ambient conditions. The Li-mediated process was discussed, and it was shown how, over the last 5 years, his group has gone from having a process that did only make very little ammonia to now being capable of obtaining more than 80% Faradaic efficiency and high current densities. The scale-up approach was discussed, making emphasis on how grams of ammonia just as characterization of in situ measurements of the dynamic assembly of the solid electrolyte interface (SEI) layer - known from the Li batteries field – have been formed by controlling the transport processes. Despite excellent recent progress there are still substantial outstanding questions concerning energy efficiency which were also discussed.

Biography

Ib Chorkendorff is Professor in Heterogeneous Catalysis at DTU-Physics. He earned his PhD in 1985 Odense University Denmark, and after a post-doc at University of Pittsburgh, USA, he was employed in 1987 at DTU where he became full professor in 1999. From 2005-2016 he was director of the Danish National Research Foundation Center for Individual Nanoparticle Functionality (CINF) and from 2016 he has been director of The Villum Center for the Science of Sustainable Fuels and Chemicals (V-SUSTAIN). He was elected Fellow of The Academy for Technical Sciences in 2001 and member of the Royal Danish Academy of Sciences and Letters in 2018. He has authored or coauthored more than 400 scientific papers, 23 patents and one textbook "Concepts of Modern Catalysis and Kinetics". He has since 2017 been listed as a Highly Cited Researcher (ISI) (top 1% in the field). Prof. Chorkendorff's research activities focus on finding new catalysts for improving sustainable energy production/conversion and for environmental protection. He is co-founder of three start-up companies RENCAT APS, HPNOW APS and Spectroinlets APS and has received numerous awards, being the latest the Villum Kann Rassmussen Annual Award (2021), which is the most prestigious award in Denmark and in 2022 The Eni Award: Energy Frontiers Prize.

Efficient direct ammonia fuel cells for transport applications

Prof. Shanwen Tao
Warwick University, UK

Abstract

Ammonia emerges as a promising indirect hydrogen storage medium, boasting well-established storage and transportation infrastructure that renders it an accessible fuel source. Direct ammonia fuel cells exhibit a theoretical energy efficiency exceeding 100%, significantly surpassing that of hydrogen fuel cells. With an estimated energy efficiency of approximately 75%, direct ammonia fuel cells outperform ammonia internal combustion engines, rendering them highly suitable for on-board transport applications such as vessels, boats, lorries, buses, drones, planes, and even cars. A diverse array of ammonia fuel cell types, ranging from high-temperature solid oxide fuel cells to low-temperature alkaline membrane fuel cells, has undergone intensive investigation. However, several challenges persist, including material selection, NOx formation, CO_2 tolerance, limited power densities, and long-term stability. Fortunately, Prof. Tao's group has discovered a family of ceramic mixed OH-/H+ ionic conductors ideally suited for use as electrolytes in both near-ambient temperature solid oxide fuel cells (NAT-SOFCs) and near-ambient temperature solid oxide electrolytic cells (NAT-SOECs). This discovery lowers the operating temperature of conventional SOFCs and SOECs from the range of 500-800 °C to below 200°C. These ceramics mixed OH-/H+ ionic conductors exhibit excellent chemical compatibility with CO_2, and their utilization as electrolytes for ammonia-fueled NAT-SOFCs has been successfully demonstrated. This presentation aimed to review the most recent advances in ammonia fuel cells, highlighting the promising prospects of employing direct ammonia fuel cells with high energy efficiency across various applications, particularly in the realm of transportation.

Biography

Shanwen Tao is currently the Warwick-Monash Alliance Professor in Chemical Engineering & Sustainable Processes at the University of Warwick. Prof. Tao is a Fellow of the Royal Society of Chemistry. With about 25 years of experience, he specializes in developing new electronic and ionic conducting materials for batteries and fuel cells. Prof. Tao's research involves new materials, fuel cell systems, and catalysts related to ammonia synthesis and cracking. In terms of materials, his group discovered the first fast OH- ionic conductors in ceramic materials (Nature Communications 2024, patented). Together with Prof. John Irvine, Prof. Tao discovered the first

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efficient redox-stable anode $(La_{0.75}Sr_{0.25})Cr_{0.5}Mn_{0.5}O_{3-\delta}$ for solid oxide fuel cells (Nature Materials 2003). Prof. Tao and Irvine also identified an easily sintered, stable, dense, and conductive proton-conducting material, $BaCe_{0.5}Zr_{0.3}Y_{0.16}Zn_{0.04}O_{3-\delta}$, which exhibited high proton conductivity at intermediate temperatures. In respect of new fuel cell systems, Prof. Tao's group developed the first near-ambient temperature (≤ 200 °C) solid oxide fuel cell (NAT-SOFC) and near-ambient temperature electrolytic cell (NAT-SOEC). Together with Prof. John Irvine, Prof. Tao developed the first reversible solid oxide fuel cell, the first symmetrical solid oxide fuel cell, and the first all-perovskite solid oxide fuel cell. Prof. Tao's group also developed the first urea/urine fuel cells, which have been highlighted by BBC News and New Scientist. Prof. Tao's group invented the first low-temperature ammonia fuel cell based alkaline membrane electrolyte, and the first ammonia fuel cell based on ceramic mixed OH-/H+ ionic conducting electrolyte (NAT-SOFC). Prof. Tao's group reported the first symmetrical ammonia fuel cell. Prof. Tao is very interested in using carbon-free ammonia as a hydrogen carrier to solve the challenges associated with hydrogen storage and transport. His group has developed robust and highly active ammonia synthesis catalysts for the Haber-Bosch process for green ammonia synthesis (patented). They also developed a low-cost Ru-free ammonia cracking catalyst with ammonia conversion nearly 100% at a temperature below 600 °C.

Renewable energy-driven NH3 synthesis and its decomposition

Prof. Junwang Tang
Tsinghua University, China

Abstract

Renewable energy, in particular solar-driven water splitting, is scientifically and industrially of significance as it promises an efficient pathway for green H_2 production, leading to substantial CO_2 emission reduction. Herein green H_2 storage and transportation are equally important to its production, hence the plenary was presented around this research. Prof. Tang's early study on charge dynamics in inorganic semiconductor reveals that the current low solar to fuel conversion efficiency is due to both fast charge recombination and sluggish water oxidation on an inorganic semiconductor, thus his group developed effective material strategies to improve the activities of photocatalysts. Typically, they found that oxygen doping could narrow the bandgap of carbon nitrides and furthermore facilitate charge separation. The material prepared via an oxygen rich organic precursor has a dark colour, resulting into an efficient H_2 production from water by UV and visible, even IR light with a quantum yield of 10%, which is the first example of a polymer photocatalyst working in such long wavelength for H_2 fuel production. The charge dynamics in these polymer photocatalysts were also systematically investigated. Prof. Tang's group next attempted to store green H_2 in NH_3 by photocatalysis as NH_3 can be transported using the current infrastructure. In parallel they also work on H_2 on demand release from NH_3.

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Biography

Prof. Junwang (John) Tang is a Member of the Academy of Europe, a Royal Society Leverhulme Trust Senior Research Fellow, Fellow of the European Academy of Sciences, Fellow of the Royal Society of Chemistry and Fellow of IMMM. He is the Founding Director of Industrial Catalysis Center in the Department of Chemical Engineering and Chair Professor of Materials Chemistry and Catalysis at Tsinghua University, China and a Visiting Professor at University College London, UK. Tang concentrates on Renewable Energy-to-Chemicals by coupling thermo-catalysis (phonons) with photo-catalysis (photons), involving small molecule activation to produce zero-carbon fuels (eg. H_2O to H_2, N_2 to NH_3) and valuable chemicals (CO_2 to alcohols and CH_4 to C_{2+} hydrocarbons) as well as microwave-catalysed plastic recycling, together with the investigation of the underlying charge dynamics and kinetics by state-of-the-art spectroscopies, resulting in >250 papers published in Nature Catalysis, Nature Energy, Nature Materials, Nature Reviews Materials, Nature Sustainability, Chemical Reviews, Chem. Soc. Rev., Materials Today, Nature Commu., JACS, Angew Chemie etc. with ~29,000 citations. Prof. Tang has received many awards, the latest of which is the 2022 IChemE Oil and Gas Global Awards, 2021 IChemE Andrew Medal, 2021 the RSC Corday-Morgan Prize and 2021 Royal Society-Leverhulme Trust Senior Research Fellowship. He also sits on the Editorial Board of 5 international journals, eg. the Editor of Applied Catalysis B and Associate Editor of Chin. Journal of Catalysis etc.

Net ammonia engine: A utopia or still a challenge?

Prof. Christine Rousselle
Université of d'Oléans, France

Abstract

The objective to reach neutral carbon footprint in 2050 accelerates the energy transition. Industries and scientists collaborate to develop zero CO_2 emission solutions for all energy sectors: power, transport, and industry. Thermal engines will remain one efficient and easy way to produce energy as a function of use and the location, for marine applications, trains, planes, trucks, gensets or auxiliary power units. Hydrogen and hydrogen derived fuels, or 'e-fuels', will play an important role to decarbonize fully all these sectors. Ammonia, one of the simplest electro-fuels, is a promising candidate as an energy and hydrogen carrier, but it can also be used directly as a zero-carbon fuel. The combustion properties of ammonia are far from those of conventional fuels and remain not well known at high temperature and pressure engine relevant conditions. During this talk, the state of art of ammonia combustion in internal combustion engines was presented with focus on the remaining challenges.

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Biography

Christine Rousselle is a Professor at the University of Orléans (Laboratoire PRISME). Her main research fields are: fundamental to applied combustion, new combustion modes (lean burn, LTC, RCCI,…), low and zero carbon-vectors (ammonia, alcohols, low-carbon fuels) described by optical diagnostics, and various topics focused on engines. She has held positions at the International Energy Agency (IEA) as representative of France and as chair/co-chair of the IEA Clean and Efficient Combustion Technical collaborative program. She is a member of the Scientific Council of IFP-EN. She is a Fellow of the Combustion Institute (2021), Associate Editor of the proceedings of the Combustion Institute and the Journal of Ammonia Energy. She was chair of the 2nd Symposium on Ammonia Energy, held at the University of Orléans in July 2023. She is an ambassador of the ASME-ICE. She also has chaired the mini-symposium on ammonia sprays in the International Conference of Numerical Combustion (Kyoto, Mai 2024). She is a visiting professor at IFS-Tohoku University.