INER-F1337 **INER-F1337**

出國報告（出國類別：開會）

赴美國參加「第 43 屆國際先進陶瓷與複合材料會議及展覽會」出國報告

服務機關：　　核能研究所
姓名職稱：　　劉建國　工程師
派赴國家/地區：美國
出國期間：　　108 年 1 月 25 日~108 年 2 月 3 日
報告日期：　　108 年 4 月 22 日

摘 要

核能研究所核子燃料及材料組劉建國工程師奉派於 108 年 1 月 25 日至 2 月 3 日，赴美國佛羅里達州代托納比奇市(Daytona Beach, FL)，參加「第 43 屆國際先進陶瓷與複合材料會議及展覽會(The 43rd International Conference and Exposition on Advanced Ceramics and Composites, ICACC'19)」暨「第 16 屆國際固態氧化物電池材料、科學與技術研討會(16th International Symposium on Solid Oxide Cells (SOC): Materials, Science and Technology, 16th IS-SOC-MST)」。劉員受邀於本屆會議以"Solid Oxide Cells Technology Development at Taiwan Institute of Nuclear Energy Research"為題進行邀請演講，發表核能研究所於固態氧化物電池(Solid oxide cells, SOCs)領域研發成果。

核能研究所自 2003 年起投入固態氧化物燃料電池(Solid oxide fuel cell, SOFC)研發，成果顯著並受到國際肯定，2013 年起接受大會邀請擔任國際固態氧化物燃料電池材料、科學與技術研討會之籌組單位及籌組委員。本屆大會計有 17 項研討會及 4 項重點會議，於 1 月 27 日至 2 月 1 日分場次同時進行，計有來自 42 國的 1,000 餘位與會者，發表超過 1,000 篇論文，參展廠商則超過 30 家。其中第 3 分項(S3)研討會：「第 16 屆國際固態氧化物電池材料、科學與技術研討會」，為國際發表固態氧化物燃料電池(SOFC)與固態氧化物電解電池(SOEC)最新研究進展之最重要討論平台與學術會議之一，探討主題包括：電解質/氧離子/質子與混合型導體及傳導機制、電極材料與微結構工程、陶瓷與金屬連接板、封裝技術、電池新穎製程與設計、材料及組件之機械與熱機特性、表面與界面反應、電極效能劣化及系統組件相關模擬、高溫電解電池、系統設計與實證示範等，相關議題與本所研發範疇有密切關聯性。

核能研究所長期致力於 SOFC/SOEC 研發且成效良好，相關研發成果論文發表於本屆會議計 3 篇，包括 1 篇邀請演講及 2 篇海報論文。核能研究所長期參與本項國際會議的籌組與學術活動，於國內外已建立良好之聲譽及連結關係，藉由參與本屆國際會議，對於維繫及強化與國際著名研究機構之人脈關係，以及彰顯本所於先進陶瓷及 SOFC/SOEC 領域之研發成果，並尋求可能之技術推廣及強化國際合作關係與提昇本所之研發量能，均有相當大的效益。此外，本屆研討會中揭示了 3D 列印技術應用於 SOC 製造進一步擴展了元件設計之尺度、QC 技術及軟硬體的發展亦將補全商品化生產的缺失拼圖，而 PCFC(Proton Ceramic Fuel Cell)將是繼 SOFC/SOEC 後吸引投入之研究趨勢。

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一、目的

「國際先進陶瓷及複合材料會議及展覽會」(International Conference and Exposition on Advanced Ceramics and Composites, ICACC)由美國陶瓷學會(The American Ceramic Society, ACerS)所主辦，固定於每年 1 月下旬，在美國佛羅里達州代托納比奇市(Daytona Beach, Florida)舉行，為陶瓷及複合材料領域之最重要國際學術會議之一。本屆會議計有 17 項研討會及 4 項重點會議，於 1 月 27 日至 2 月 1 日計 6 日同時進行，其中第 3 分項研討會：「第 16 屆國際固態氧化物電池材料、科學與技術研討會(16th International Symposium on Solid Oxide Cells (SOC): Materials, Science and Technology, 16th IS-SOC-MST)」，為研究及發表 SOC 領域最新研究進展之最重要國際會議之一。

核能研究所於 SOFC/SOEC 之研發成效顯著並受到國際肯定，自 2013 年起大會持續邀請本所擔任該會議之籌組單位之一，並由本所 SOFC 計畫主持人李瑞益博士擔任籌組委員(附錄一)。本屆會議除了來自世界各地於陶瓷及燃料電池領域頂尖之學者專家，齊聚一堂討論及發表最新的研究成果之外，其中 SOFC/SOEC 材料、組件與系統開發等議題與本所執行「固態氧化物燃料電池技術發展與聯網整合應用」計畫相關技術有密切關聯性。藉由參加本屆國際會議，將研發成果與國際專家學者進行交流，蒐集國際先進陶瓷及燃料電池技術研發趨勢，汲取最新及第一手之技術研發經驗，以期掌握國際間最新之相關研發現況及發展趨勢；此外，持續保持與強化與國際學者專家之人脈關係，並尋求可能之技術推廣及強化國際合作關係與提昇本所之研發量能，亦有利於本所研發技術與國際接軌及技術產業化之拓展。

核能研究所 SOFC/SOEC 相關研究成果投稿本屆研討會論文計 3 篇，其中燃材組劉建國工程師主撰論文“Solid Oxide Cells Technology Development at Taiwan Institute of Nuclear Energy Research”獲接受並進行邀請演講(附錄二)。此外，包括燃材組郭弘毅助理工程師主撰“Performance Evaluation for Solid Oxide Fuel Cell by Addition of Tetragonal Zirconia Polycrystal in Anode Substrate”及物理組楊昇府副工程師主撰“Performance and Thermal Properties of Ni/Mo Alloy-supported Solid Oxide Fuel Cell”論文，亦均獲得接受(劉員為共同作者)並排定於會議進行海報論文發表。

二、過程

核能研究所核子燃料及材料組劉建國工程師奉派於 108 年 1 月 25 日至 2 月 3 日，赴美國佛羅里達州代托納比奇市(Daytona Beach, FL)，參加「第 43 屆國際先進陶瓷與複合材料會議及展覽會(The 43rd International Conference and Exposition on Advanced Ceramics and Composites, ICACC’19)」暨「第 16 屆國際固態氧化物電池材料、科學與技術研討會(16th International Symposium on Solid Oxide Cells (SOC): Materials, Science and Technology, 16th IS-SOC-MST)」。首屆國際先進陶瓷與複合材料會議及展覽會自 1977 年起舉辦，2007 年起每年之年會則固定於一月下旬在代托納比奇市進行，今年已為第 43 屆。代托納比奇市位於佛羅里達州東岸，緊鄰大西洋，隸屬沃盧西亞郡(Volusia County)，距離奧蘭多約 2 小時車程，地理位置如圖 1。

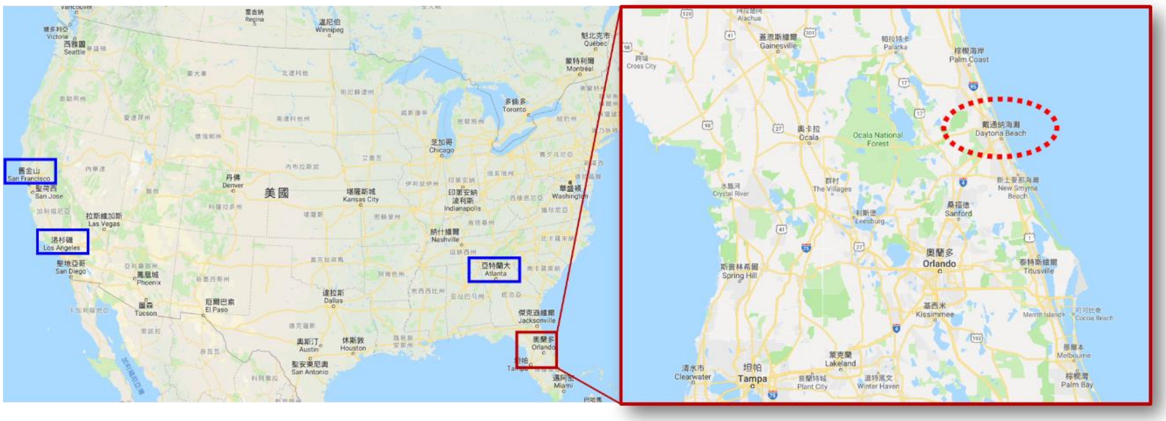


圖 1 大會地點地理位置：美國佛羅里達州代托納比奇市。(Source: Google map)

（一）去程：

01/25(五)搭乘中華航空(CI8)，由桃園機場直飛洛杉磯機場，轉乘美國達美航空(DL2592)飛亞特蘭大機場，再轉機(DL1983)於 01/26(六)飛抵代托納比奇市。

（二）參加會議：

劉員於 2019 年 1 月 27 日至 2 月 1 日全程參加由美國陶瓷學會舉辦之第 43 屆國際先進陶瓷與複合材料會議及展覽會(ICACC’19)，會場位於佛羅里達州代托納比奇市之 Hilton Daytona Beach Resort/Ocean Walk Village (如圖 2)，海報論文發表及廠商展覽會場則在會場對面之 Ocean Center (如圖 3)進行。

(左)圖 2 會議地點(Hilton Daytona Beach Resort/Ocean Walk Village)。
(右)圖 3 海報論文發表及廠商展覽會場(Ocean Center)。

本屆會議計有 17 個不同陶瓷應用領域之研討會(Symposium)，包括：

Symposium 1: Mechanical Behavior and Performance of Ceramics & Composites

Symposium 2: Advanced Ceramic Coatings for Structural, Environmental, and Functional Applications

Symposium 3: 16th International Symposium on Solid Oxide Cells (SOC): Materials, Science and Technology

Symposium 4: Armor Ceramics - Challenges and New Developments

Symposium 5: Next Generation Bioceramics and Biocomposites

Symposium 6: Advanced Materials and Technologies for Direct Thermal Energy Conversion and Rechargeable Energy Storage

Symposium 7: 12th International Symposium on Functional Nanomaterials and Thin Films for Sustainable Energy Harvesting, Environmental and Health Applications

Symposium 8: 13th International Symposium on Advanced Processing and Manufacturing Technologies for Structural and Multifunctional Materials and Systems (APMT13)

Symposium 9: Porous Ceramics: Novel Developments and Applications

Symposium 10: Ceramics Modeling, Genome and Informatics

Symposium 11: Advanced Materials and Innovative Processing Ideas for Production Root Technologies

Symposium 12: Advanced MAX/MXENE Phases and UHTC Materials for Extreme and High Temperature Environment

Symposium 13: Development and Applications of Advanced Ceramics and Composites for Nuclear Fission and Fusion Energy Systems

Symposium 14: Crystalline Materials for Electrical, Optical and Medical Applications

Symposium 15: 3rd International Symposium on Additive Manufacturing and 3D Printing Technologies

Symposium 16: Geopolymers, Inorganic Polymers and Sustainable Materials

Symposium 17: Advanced Ceramic Materials and Processing for Photonics and Energy

以及 4 個重點會議(Focused Session)，包括：

Focused Session 1: Bio-inspired Processing of Advanced Materials

Focused Session 2: Image Based Characterization and Modelling of Ceramics by Non-Destructive Examination Techniques

Focused Session 3: Chemically Processing of Functional Materials: Understanding the Conversion of Molecular Structures to Solid-state Compounds

Focused Session 4: Green Technologies, and Joining of Ceramics

此外，本屆大會亦合併舉行 40th Anniversary Richard M. Fulrath Award Symposium on "Frontiers of Ceramics for Sustainable Society"、8th Global Young Investigator Forum 與 Special Focused Session on Diversity, Entrepreneurship, and Commercialization 等。

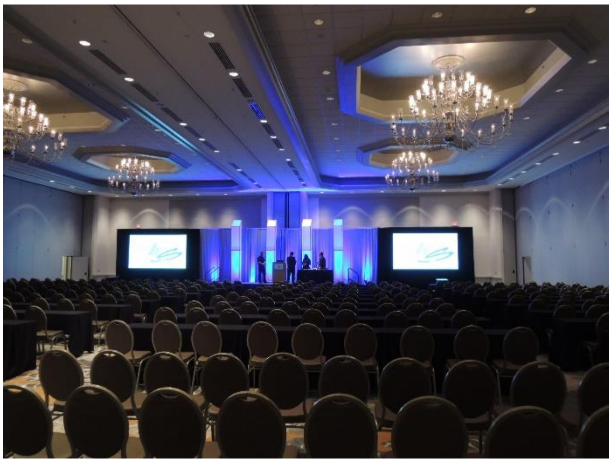
劉員參加本屆會議並受邀於 Symposium 3: 16th IS-SOC-MST 進行邀請演講，另核能研究所燃材組郭弘毅先生等人、物理組楊昇府博士等人投稿海報論文各 1 篇並獲接受，劉員亦為共同作者，故一併攜往會場進行張貼發表。報告人(或主撰作者)及發表論文題目分別為：

1. 劉建國："Solid Oxide Cells Technology Development at Taiwan Institute of Nuclear Energy Research"；
2. 郭弘毅："Performance Evaluation for Solid Oxide Fuel Cell by Addition of Tetragonal Zirconia Polycrystal in Anode Substrate"；
3. 楊昇府："Performance and Thermal Properties of Ni/Mo Alloy-supported Solid

Oxide Fuel Cell”。

本屆會議議程包括註冊、開幕式及專題演講、第 42 屆最佳口頭、海報論文及各獎項頒獎、邀請演講、口頭及海報論文發表、廠商產品展覽、短期課程、玻璃杯擲落競賽等。以下簡要敘述參加本屆會議之各日議程情形：(大會網站 https://ceramics.org/icacc2019)

1 月 27 日：該日為會議註冊報到日，下午進行報到、領取資料，晚間參加大會辦理之歡迎會，如圖 4。



(左)圖 4 註冊報到及歡迎會場。　　　　(右)圖 5 大會開幕式會場。(攝於開幕前)

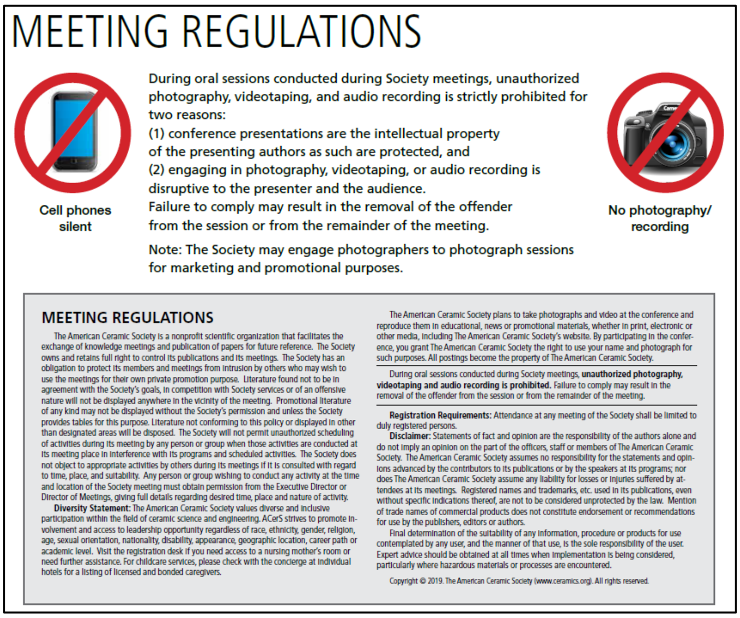


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圖 6 大會規則。(轉錄自大會議程集)

1 月 28 日：08:30 開始進行大會開幕式(如圖 5)及宣布注意事項(如圖 6)。首先由大會主席 Dr. Manabu Fukushima 主持上屆會議(ICACC’18)之最佳論文及最佳海報論文獎頒獎，其中最佳論文獎作者及題目依序為：

1st M. J. Presby, N. Kedir, L. J. Sanchez, C. Gong, D. C. Faucett, and S. R. Choi, “Erosion Behavior in a Gas Turbine Grade Oxide/Oxide Ceramic Matrix Composite”

2nd M. Trini, S. De Angelis, P. S. Jørgensen, A. Hauch, M. Chen, and P. V. Hendriksen, “Phase Field Modelling of Microstructural Changes in Ni/YSZ Solid Oxide Electrolysis Cell Electrodes”

3rd S. Yamaguchi, K. Katagiri, T. Ehiro, T. Ozaki, and A. Kakitsuji, “Evaluation of Power Generation from Biomass Using Solid Oxide Fuel Cell (SOFC) and Downdraft Gasifiers”

最佳海報論文獎則依序為：

1st J. Jiang, S. Falco, N. Petrinic, and R. I. Todd, “Reliable Measurement of Fracture Toughness of Armour Ceramics at the Microstructural Scale”

1st M. Porter, A. D’Angio, J. Binner, M. Cinibulk, B. G. Banos, and A. Aktas, “Optimisation of SiCp/SiCf Preforms Prior to Matrix Formation Using Microwave Enhance Chemical Vapour Infiltration”

2nd S. Agarwal, Y. Zhao, S. J. Zinkle, and W. J. Weber, “Raman Spectroscopy Experiments to Characterize Radiation Induced Defects in SiC/SiC Composites”

3rd S. T. Nguyen, H. Iwasawa, H. Suematsu, L. He, T. Suzuki, K. Niihara, and T. Nakayama, “Crack-Healing Ability and Strength Recovery of Ytterbium Disilicate Ceramic Reinforced with Silicon Carbide Nanofillers”

而後由本屆大會議程主席 Dr. Surojit Gupta 報告議程總覽，他提及本屆大會計有 17 個研討會(Symposium)以及 4 個重點會議(Focused session)同時進行。依大會資料統計，本屆會議計有超過 1,000 篇論文摘要投稿、超過 30 家廠商參展，以及分別來自 42 個國家，約 1,000 人之與會專家學者，其中 60%以上為來自美國本土之外。另外，本屆會議進行期間，因逢美國政府部分部門因預算未通過而暫時性關閉，以及簽證申請延遲之因素影響，甚至是會議第一天代托納比奇市當地

劇烈天氣變化，導致部份論文及報告人未能到場發表。然而，仍然不減對於本屆會議之盛大及討論之熱烈。開幕式隨後頒發 2019 Global Star Award，得獎者分別為 Sungwook Mhin (Korea), Valerie Pralong (France), Joaquin Ramirez-Rico (Spain), Satoshi Tanaka (Japan), Naoaki Yabuuchi (Japan)等 5 人。本屆會議並頒發第 6 屆之 Global Young Investigator Award，得獎人為 Dr. Wei Ji (China)，(因簽證因素未能出席受獎)。此外，本屆大會議程主席並預告第 44 屆國際先進陶瓷與複合材料會議及展覽會(ICACC’20)將於 2020 年 1 月 26 至 31 日在同一地點舉行。隨後進行開幕式之 4 場次專題演講：

首場由 2019 James I. Mueller Award 得主 Dr. Dileep Singh 講演“Renewable Energy: Role of Ceramics and Composites”。他指出使用可再生能源發電，包括太陽能，風力和地熱，由於經常遭遇極端的環境和操作條件，故需要開發先進的材料及系統組件。相對於金屬而言，工程陶瓷及其複合材料具有高溫機械性能、耐腐蝕性及抗潛變性等，作為材料選擇更有機會實現或滿足面對材料技術的需求與挑戰。Dr. Singh 舉太陽熱能儲存(Solar thermal energy storage)的實例，概述陶瓷材料應用於高溫熱能儲存複合系統之挑戰，例如應用相變化材料(Phase change materials, PCMs)做為太陽熱能之儲存介質，需滿足操作溫度大於 700 °C、熱傳導係數大於 20 W/m·K、效率大於 95%及儲能密度需達 300 kWh/m^3。前述遭遇的挑戰，包括極端條件、高溫、新材料、能源傳輸替代方案、規模擴大及新製程等，也形成了工程陶瓷及其複合材料的研發機會。此外，Dr. Singh 亦強調須要進行技術經濟分析以證明先進陶瓷材料於可再生能源系統之可應用性。

其次為 2019 Bridge Building Award 得主 Dr. Jerzy Lis 講述“Processing of Complex Ceramic Materials by Rapid High-energy Techniques”，內容為講者的經驗以及與 AGH 科技大學研究團隊以快速高能技術(Rapid high-energy techniques)應用於合成陶瓷材料。Dr. Lis 舉出兩種 RHET 方法，包括燃燒合成法(Combustion Synthesis)，亦稱為自蔓延高溫合成法(Self-propagating High-temperature Synthesis, SHS)，以及雷射快速製造法(Laser Rapid Manufacturing, LRM)。此類技術可以高能量源在陶瓷材料局部位置進行燒結或熔融，並達到合成材料的目的，與傳統大範圍加熱條件的製程方法相較，前述技術更有節省能源的功效，而且以 RHET 技

術合成之新材料可衍生出新的特性。Dr. Lis 以 Si-C-N，Ti-Si-C-N、Ti-Al-C-N 及 Al-O-N 等不同陶瓷系統及其應用進一步演繹證明，RHET 技術對陶瓷加工製程及材料工程將帶來重大貢獻及未來性。

其餘兩場次專題演講分別由 Dr. Shunpei Yamazaki 及 Dr. Michael J. Cima 講述“Crystalline Oxide Semiconductor (IGZO Ceramics)-based Devices for Artificial Intelligence (AI) and Internet of Things (IoTs)”及“Drug, Device, or Diagnostic? Engineering in a New World of Medicine”。 Dr. Yamazaki 指出目前人工智慧(AI)及物聯網(IoT)技術正在逐步推進，預計在不久的未來，人工智慧和物聯網將遍及整個人類社會；然而，相對應地，必須開發消耗功率更低及運算速率更快的微處理晶片。講者於 2009 年發現了 c 軸對齊結晶銦鎵鋅氧化物(CAAC-IGZO)，CAAC-IGZO 是一種陶瓷材料，此一新穎的晶體結構物可做為 AI 晶片之氧化物半導體材料，應用於電腦圖形處理單元(GPU)、中央處理單元(CPU)、動態隨機存取記憶體(DRAM)等。使用這種新陶瓷材料較傳統使用 Si 半導體製造之晶片，大幅地降低了 AI 晶片的功率消耗。Dr. Cima 於最後場次專題演講提及醫療技術正在迅速發展中，便攜式通信設備和其他手持設備電子產品的需求影響著我們對於未來醫療工具的期待。未來的先進醫療技術不一定需要很大很昂貴的系統，而小型的和一次性的醫療或檢(監)測儀器裝置可能更符合需要。

該日下午開始各分項研討會之口頭論文發表議程，劉員於下午正式開始之 Symposium 3: 16th International Symposium on Solid Oxide Cells (SOC): Materials, Science and Technology 議程發表邀請演講。本屆 S3 研討會共計發表口頭報告論文 52 篇(其中 18 篇邀請演講)及海報論文 11 篇(以上不包含 4 篇撤稿)。論文內涵主要可區分為研究近況之更新與研究議題之討論，發表者大致可區分為學校、產業者、研究機構和國家實驗室，其中以學校之研究發表篇數計 28 篇占大多數，包括學校和國家實驗室的論文主要皆為材料、分析、學理和機制的探討，而產業者則在於驗證設施、測試數據、研究量能的展現和 SOC 領域前景介紹。本屆 IS-SOC-MST 研討會論文來自台灣之論文計 3 篇，均為核能研究所所貢獻。本屆研討會除了邀請演講為 30 分鐘之外，其餘之口頭論文發表時間均為 20 分鐘，口頭論文及海報論文發表會場分如圖 7、8。

(左)圖 7 S3 議程口頭論文發表會場。　(右)圖 8 海報論文發表及廠商展覽會場。

下午之議程主題為“Progress in SOFC and SOEC Technology”及“SOC Stacks and their Integration in the Systems”，計有 6 篇口頭論文發表，重點略錄如後：

美國能源部(Department of Energy, DOE)之 P. Bruke 於本屆會議中報告 US DOE Office of Fossil Energy’s Solid Oxide Fuel Cell Program，提及推動 SOFC 計畫之近程目標為 100 kW 至 1 MW，遠程目標則為 10 MW 至 50 MW，其中包括電池片、電池堆之製造和品質控制為挑戰重點。目前研發進展於電池片及小型電池堆(≤5 kW)之劣化率已可達 0.2~0.5%/kh，而 10 kW 級電池堆之劣化率則約為 2%/kh。目前分別有 LG Fuel Cell 之 200 kW 及 FuelCell Energy 之 50 kW 系統進行概念驗證(Proof-of-concept)系統測試，其效率已可提昇至大於 55%。SOFC 計畫 2018 年之指標及現況為：系統成本(for 100 kW~1 MW)>USD12,000/kW、劣化率(degradation)1~1.5%/kh、耐久性(durability)<2,000 hours、示範驗證規模 50 kW~200 kW；而 2020 年設定的目標則為：系統成本 USD6,000/kW、劣化率 0.5~1%/kh、耐久性 5,000 hours、示範驗證規模 200 kW~1 MW；長程目標至 2030 年，系統成本 USD900/kW、劣化率<0.2%/kh、耐久性 5 years、示範驗證規模 10 MW~50 MW。此外，日本東京瓦斯公司 Y. Kawabata 報告 Recent Achievements and Challenges of SOFC Power Generation Systems，指出於日本九州大學示範運轉之商業型 SOFC-MGT(Micro Gas Turbine)混成式 200 kW 發電系統，已運轉超過 20,000 小時，劣化率 0.7%，效率可達 53.6%(LHV)。德國 Sunfire 公司之 C. Walter

報告 Status of Stack and system development at Sunfire，指出 Sunfire 開發之 SOFC 電池堆容量由 0.7 kW~20 kW，其中 1 kW 電堆為 30 片裝，其劣化率以面積比電阻(Area Specific Resistance, ASR)為指標，其舊型電池堆設計之初始 ASR 為 900 $m\Omega \cdot cm^2$，劣化率為 30 $m\Omega \cdot cm^2/kh$；而新型電池堆之初始 ASR 已降低至 650 $m\Omega \cdot cm^2$，劣化率為 19 $m\Omega \cdot cm^2/kh$。

1 月 29 日：議程主題為“Novel Processing”、“Sealants and Mechanical and Thermomechanical Aspects of Manufacturing”及“Electrolytes”、“Stack / Cell Performance and Durability”，計有 14 篇口頭論文發表，重點摘錄如：義大利陶瓷科技研究所(ISTEC)之 A. Sanson 報告 Supported Films for SOFC Applications，指出製作 SOFC 電池片時，溶劑之添加為影響效能之關鍵因素之一，如使用不適當之溶劑，當球磨時電極粉末之離子會被溶劑濾出，造成粉末之組成改變。渠等開發水基及生質物基之溶劑，並展示所用作網印之漿料使用 50 vol% PG(1,2-Propylene Glycol)/50 vol% H_2O 為溶劑，可得最佳效果。本屆會議報告並提及由歐盟補助之 Cell3Ditor 計畫，其目的為開發 3D 列印技術並應用於 SOFC 電池堆之工業化生產。報告中並舉實例說明藉由 3D 列印技術概念，積層方式製作 SOFC 電池堆不再只有管式和平板式等單純式樣，不過亦指出目前仍以概念式小試樣的製作及特性研究，以及缺乏適合的可列印之功能性氧化物材料為目前遭遇議題。此外，美國康乃迪克大學之 B. Hu 報告 Barium Zirconate Based Electrolyte Densification Using Reactive Sintering Aids，指出鋯酸鋇具有高質子傳導率，可應用為質子傳輸型 SOFC 之固態電解質。然而鋯酸鋇需要非常高的燒結溫度才能達到緻密化。渠等研究使用反應性和奈米尺寸的燒結助劑有效降低鋯酸鋇基質子電解質(BZCY-Yb)的燒結溫度至 1523~1723 K，報告中展現 BZCY-Yb 電解質於氧氣氛中及 1623 K 燒結，其總電導率> 0.01 S/cm^2 (at 973 K，3%H_2O/air 測試條件)。此外，電池堆之耐久性評估往往耗時甚久，如何進行加速測試亦為重要之研究課題。德國 IKTS 的報告指出，SOFC 電池堆的預期壽命為 40,000~80,000 小時，不可能所有的組件都進行如此長的時間測試。故須找出可能加速電池堆劣化之特定的操作參數，渠等對數個 MK35 系列 10 片裝電堆進行 20,000 小時測試，分析指出可能加速劣化之操作參數為更高的溫度、電流密度和空氣濕度。是日傍晚

(17:00~20:00)進行海報論文發表，劉員至 Ocean Center 分別協助同仁郭弘毅先生與楊昇府博士張貼海報論文“Performance Evaluation for Solid Oxide Fuel Cell by Addition of Tetragonal Zirconia Polycrystal in Anode Substrate”及“Performance and Thermal Properties of Ni/Mo Alloy-supported Solid Oxide Fuel Cell”發表，如圖 9、10。

(左)圖 9 協助同仁海報論文發表。

(右)圖 10 協助同仁海報論文發表。

1 月 30 日：議程主題為“Air Electrode Performance and Durability”、“Fuel Electrode Performance and Durability”及“Interconnects and Coatings”及“HT Electrolysis”，計有 17 篇口頭論文發表，重點摘錄如：Y. Sadia 於其報告 Electrochemical Impedance Spectroscopy of $(La_{1-x}Sr_x)Ni_{0.9}Mn_{0.1}O_{4+\delta}$ 中指出，摻鍶(Sr)的氧化物常應用為 SOFC 之陰極材料，而 Sr 於高溫時的表面偏析是造成陰極催化效能劣化的主要原因之一。渠等研究 Sr 和 Mn 摻雜對於 La_2NiO_4 (LNO)陰極材料效能的影響，發現 Sr 和 Mn 摻雜的效果互相衝突，摻雜較多 Sr 可提昇陰極活性，造成電導度顯著的提昇；然而更多 Sr 可能偏析，進而改變材料組成。SOC 電池堆因常使用含鉻金屬連接板，高溫時鉻揮發造成陰極毒化是導致電池堆效能劣化之主因。S. Molin 於其 Development of Protective Coatings for the Hydrogen and Oxygen Side of SOFC/SOEC Interconnects 報告中提醒，對於金屬連接板的保護膜材料選用，在低氧分壓側(燃料極側)，保護膜層基於活性元素考量，可選用 Ce 或 Y；而對於高氧分壓側(空氣極側)，除了使用類陰極材料(LSM)及錳鈷氧化物(MCO)之外，渠等

亦致力研發無毒的保護層材料(例如替代 Co)。此外，義大利都靈理工大學 F. Smeacetto 持續報告渠等使用電泳沈積法研究 Cu, Fe 混摻於錳鈷尖晶石氧化物($Mn_{1.5}Co_{1.5}O_4$)，做為 Crofer22APU 及 AISI441 不銹鋼連接板保護膜之抗氧化及電性效能，結果顯示於 750 °C~800 °C 經 3,500 小時測試後，Cu, Fe 混摻錳鈷尖晶石氧化物鍍膜均能改善 Crofer22APU 及 AISI441 於高溫長時後之電性，然而渠等先前研究亦指出，降低操作溫度對於高溫長時電性之維持較鍍膜更為有效。本日傍晚(17:00~19:30)進行第二場次海報論文發表，劉員至海報論文會場觀摩，以及參觀廠商展覽(廠商名錄摘錄自大會議程集如附錄三)。

1 月 31 日：議程主題為“Air Electrode Performance”、“Air Electrode: Powders, Fabrication, Contacting”及“Proton Conducting Fuel Cells I”及“Proton Conducting Fuel Cells II”，計有 16 篇口頭論文發表，重點摘錄如：SOFC 陰極材料除了容易因 Cr 沈積還原為 Cr_2O_3 而造成毒化之外，另一個原因則是陰極組成與空氣中成分反應，造成成分偏析或組成改變。美國阿岡國家實驗室之 Y. Xu 於 Performance Degradation by Room Temperature Ageing of (La,Sr)(Co,Fe)O_3 Cathodes in Solid Oxide Fuel Cells 報告中指出，渠等將以 $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$ (LSCF)陰極材料之電池片放置於室溫及加濕的 CO_2 氣氛下 5 天，並以電化學阻抗量測及傅立葉紅外光譜分析陰極，結果顯示氣氛的影響亦為加速電池片老化的原因之一，實驗發現電池片電性劣化與 Sr 及 CO_2 反應形成 $SrCO_3$ 的量與粒徑有關。此外，陰極接觸層材料(Cathode Contact Materials, CCM)為 SOFC 電池堆組重要的介面層材料之一，開發穩定、耐久及高電導之 CCM 亦為本所目前進行的研究課題之一。美國太平洋西北國家實驗室之 Y. Chou 報告渠等 Thermal and Electrical Properties of LSCo-Mullite Composite Contact Material for Solid Oxide Fuel Cells 之研究進展，由於鈣鈦礦型鑭鍶鈷氧化物(LSCo)具有高電導率，故為 SOFC 陰極材料之優選。然由於其高熱膨脹係數(~18 ppm/°C)而與 YSZ 電解質(~10 ppm/°C)不匹配，造成熱循環之穩定性差。Y. Chou 等人之研究利用於 LSCo 中混摻 40 vol%莫來石結構之 $3Al_2O_3$-$2SiO_2$ 或 $2Al_2O_3/SiO_2$ 已降低熱膨脹係數至~12 ppm/°C，然而莫來石的添加亦造成電導率下降，渠等後續仍進一步研究此一材料與金屬連接板之接合強度。質子傳輸型燃料電池為本屆研討會發表主題之一，也被認為是繼 SOFC/SOEC 之

後，競相投入之研發領域。美國西維吉尼亞大學 W. Li 報告 Highly Performing Triple-Conductive $Pr_2NiO_{4+\delta}$ Anode for Proton-conducting Steam Solid Oxide Electrolysis Cell，指出適合的陽極材料是發展中溫型質子傳輸型固態氧化物燃料電池的關鍵課題之一，渠等研究使用 $Pr_2NiO_{4+\delta}$(PNO)作為電解電池的燃料電極，證實 PNO 與電解質 Ba(ZrCeY)$O_{3-\delta}$ (BZCY)的良好相容性。實驗結果顯示 PNO 對於電解水的良好催化活性，其水分解活性於 550 °C 及 700 °C 時，分別為 0.52 $\Omega\cdot cm^2$ 及 0.057 $\Omega\cdot cm^2$。渠等亦進行電解電池效能測試，電解電池組構為 Ni-BZCY | BZCY | PNO-BZCY，於 700 °C、電流密度 977 mA / cm^2 時，電解電壓為 1.3 V 及效率約達 95%。本屆 IS-SOC-MST 研討會議程於是日結束。

2 月 1 日：劉員上午持續聽講重點會議 FS2: Image based Characterization and Modelling of Ceramics by Non-destructive Examination Techniques 議程之 X-ray tomography 應用於陶瓷結構損傷測定之相關論文報告。本屆大會於是日中午結束。

（三）回程：

本屆會議於美東時間 2 月 1 日中午結束，劉員於當日下午返程，於代托納比奇國際機場搭乘達美航空(DL1973)飛至亞特蘭大機場，再轉機(DL792)至舊金山機場，而後搭乘中華航空(CI3)直飛於 02/03(日)返抵台灣桃園國際機場。

三、心得

（一） 核能研究所長期於 SOFC/SOEC 之研發成效顯著並受到國際肯定，自 2013 年起受邀擔任為國際固態氧化物燃料電池材料、科學與技術研討會之籌辦單位及籌組委員，長期參與本項國際會議的籌組與學術活動，歷屆均派同仁參與會議並發表論文，於國內外已建立良好之聲譽及連結關係。本屆本所參與會議投稿論文計 3 篇，包括 1 篇邀請演講及 2 篇海報論文，均獲大會接受並進行發表。藉由參與本屆會議過程，除了瞭解國際上在先進陶瓷與複合材料領域的最新發展，亦汲取了如本屆研討會中揭示的 3D 列印技術應用於 SOC 製造進一步擴展了元件設計之尺度、QC 技術及軟硬體的發展亦將補全商品化生產的缺失拼圖、SOEC 不只陰陽極材料影響劣化，電解質通電時結構及組成變化亦是肇因、金屬連接板燃料極側之氧化及鍍膜亦須注意，以及 PCFC(Proton Ceramic Fuel Cell)的研發將是繼 SOFC/SOEC 之後吸引投入之趨勢與方向等。

（二） 本文作者劉員本次赴美國佛羅里達州代托納比奇市參加 ICACC2019 會議並順利完成邀請演講報告。本屆大會包括 17 項研討會及 4 項重點會議，共計收到超過 1,000 篇論文摘要投稿，以及 30 家以上廠商參展，吸引來自 42 個國家超過 1,000 人參與。雖然本項會議由美國陶瓷學會固定每年舉辦，但由於研討內容及論文審核嚴謹，至今已舉辦 43 屆，會議之興盛仍歷久不衰。相信藉由參與本屆會議與發表論文，對於促進國際學術交流、維繫及強化與國際著名研究機構之人脈關係，以及彰顯本所於先進陶瓷及 SOFC/SOEC 領域之研發成果，並尋求可能之技術推廣及強化國際合作關係，以及提升所內研發 SOC 技術水準與對於研究計畫的持續進行，均能產生正向效益。

（三） 第 16 屆國際固態氧化物電池材料、科學與技術研討會，實際發表口頭報告論文 55 篇(其中 18 篇邀請報告)及海報論文 11 篇，其中來自台灣之作者發表 3 篇論文，均為本所所貢獻。相較於第 10 屆發表 83 篇論文(台灣作者貢獻 2 篇)，第 11 屆發表 75 篇論文(台灣作者貢獻 11 篇)，第 12 屆發表 68 篇論文(台灣作者貢獻 4 篇)，第 13 屆發表 73 篇論文(台灣作者貢獻 7 篇)，第 14 屆發表 81 篇論文(台灣作者貢獻 4 篇)，至第 15 屆驟降至 57 篇論文發表(台灣作者貢獻 4 篇)；以及本屆 SOC 研討會論文數量 66 篇(台灣作者貢獻 3 篇)略有回升，如圖 11。

本屆會議進行期間，因逢美國政府部分部門因預算未通過而暫時性關閉，以及簽證申請延遲之因素影響，甚至是會議第一天代托納比奇市當地劇烈天氣變化，均導致部份論文及報告人未能到場發表。然而，相較於其他分項研討會，IS-SOC-MST 研討會之抽回篇數(計 4 篇)已算相當少，且聽講人數也多能維持及堅持到會議終場。分析本項研討會之發表者大致可區分為學校、產業者、研究機構和國家實驗室，其中以學校之研究發表篇數計 28 篇占大多數，包括學校和國家實驗室的論文主要皆為材料、分析、學理和機制的探討，而產業者則在於驗證設施、測試數據、研究量能的展現和 SOC 領域前景介紹。本所的報告內容則介於學校和國家實驗室與產業者之間。參加會議期間，經由簡報報告及討論交流瞭解國際研發單位對於 SOC 投入現況，例如美國能源部(DOE)對於 SOFC 研發持續投入且目標分工明確，哪些由學研單位做，哪些由產業進行，定義非常清楚。例如一些國家實驗室拿 DOE 的經費從事的領域仍偏向基礎研究，而對於本所能做到 3~5 kW SOFC 系統均表示相當不容易，因為需要大投資。

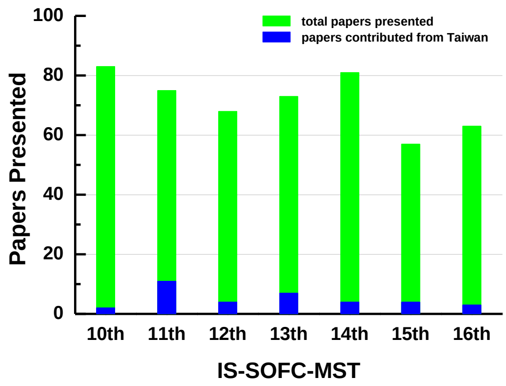


圖 11 歷屆國際固態氧化物燃料電池材料、科學與技術研討會(IS-SOFC-MST)論文發表篇數。

（四） 目前國際研發並將 SOFC/SOEC 相關技術統稱為固態氧化物電池(Solid oxide cells, SOCs)技術，其中部分產品已進入實地驗證或是早期區域市場之商品化銷售。以鄰近之韓國、日本為例，2017 年南韓 SK E&C 公司與 Bloom Energy 建立策略結盟，成功地合作競標南韓某電力公司之 8.35 MW 的 Bloom Energy

Server 裝設，且預計於 2018 年稍晚開始商業運轉。該項目採用高度創新的“電力塔”設計，被認為是世界上能源密度最高的發電廠，每 787 平方英尺可產生 1 MW 電力。2010 年初宣布推出可使用天然氣或生質氣之 SOFC 發電系統之 Bloom Energy 公司，迄今已完成裝設總計逾 200 MW 之發電系統。日本京瓷(kyocera)公司於 1985 年開始開發 SOFC 相關應用之專有陶瓷技術。2011 年，該公司開始大規模生產世界領先的家用型“ENE-FARM type-S” 700 W SOFC 電池堆。2016 年四月，又推出更高效、更小巧的電池堆，做為新的 3 kW SOFC 系統的基礎。2017 年七月，推出首套可應用於商辦機構之 3 kW SOFC 熱電聯產(Combined heat and power, CHP)發電系統。該系統使用京瓷公司專利技術，可提供 52%的發電效率，包括廢熱回收之總體能源效率為 90%，如圖 12。

Rated Output of Power Generation (AC)	3kW
Rated Power Generation Efficiency	52.0% (LHV, default)
Rated Overall Efficiency	90% (LHV, default)
Dimensions	1,150 W × 675 D × 1,690 H (mm)
Weight	375 kg
Gas type	City gas (13A)

圖 12 日本京瓷(Kyocera)公司之 3 kW SOFC 發電機組外觀與規格。

(Reference: http://global.kyocera.com/news/2017/0702_bnfo.html)

日本京瓷公司並指出 SOFC 可做為分散式發電的一種電力源，對於減少與輸電相關之能量損失提供了巨大潛力。除了高效率的產電之外，來自發電過程的廢熱可有效地用於加熱水或其它應用。此外，SOFC 發電系統較其他的內燃機或燃氣渦輪機發電系統具有顯著的降低 CO_2 排放。日本經濟產業省(METI)支持工業用 SOFC 系統的研發，目標是在 2017 年實現其商業可用性，METI 並將至 2020 年之住宅用燃料電池目標設定在 140 萬台，至 2030 年之目標則設定為 530 萬台，以作為達成氫能社會願景的一部分。另外，日本特殊陶業股份有限公司(NGK SPARK PLUG Co., Ltd.)於 2017 年八月宣布，已將其所開發中之平板式

SOFC 電池堆，擴大使用於需要高功率之商業與工業用的發電系統。該公司提供最新開發之 SOFC 電池堆並裝置於日立造船株式會社(Hitachi Zosen)之 20 kW SOFC 發電系統，並已於今年六月下旬於大阪產業技術綜合研究所(ORIST)和泉中心開始進行連續 4,000 小時之示範驗證測試，如圖 13。

Rated Output of Power Generation (AC)	20kW
Rated Power Generation Efficiency	>50%
Rated Heat Recovery Efficiency	>40%
Dimensions	2.2 W × 4.2 D × 2.8 H (m)
Gas type	City gas (13A)

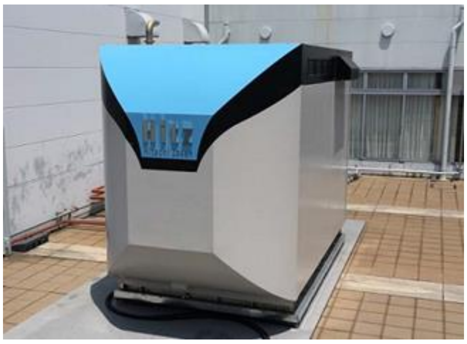


圖 13 日立造船株式會社 20 kW SOFC 發電機組與規格。
(Reference: https://www.ngkntk.co.jp/english/news/detail/001449.html)

（五） 丹麥技術大學之 M. Trini 等人發表於上屆會議之“Phase Field Modelling of Microstructural Changes in Ni/YSZ Solid Oxide Electrolysis Cell Electrodes”論文獲得最佳論文獎第二名。由於固態氧化物電池(SOC)可以操作在產電之 SOFC 及電解之 SOEC 模式，其中陽極(或燃料電極)所含鎳於高溫操作時產生粗化是影響電池效能下降的主因之一，相關議題也是阻礙電池片商業化的原因。渠等研究利用聚焦離子束掃描電子顯微鏡斷層掃描(FIB-SEM Tomography)和相場(Phase field, PF)模擬技術，用於研究鎳/氧化釔安定化氧化鋯(Ni/YSZ)之 SOC 燃料電極的微觀結構演變。渠等使用經測試 9,000 小時後之 25 片裝電池堆中之單一電池片，經 FIB-SEM 斷層攝影重建並與未經測試之參考電池片比較，計算結果顯示參考電池片燃料電極之三相邊界(Triple phase boundary, TPB)長度為 1.85 $\mu m/\mu m^3$，而經長期測試後電池片之 TPB 長度則減小至約 1.01 $\mu m/\mu m^3$，如圖 14。渠等亦對參考電池片之尺寸及微結構進行相場模擬，計算及量化其粒度分佈(Particle size distribution, PSD)、TPB 長度和表面積，結果亦顯示其燃料電極之 TPB 長度隨操作時間減小之趨勢，相關數值結果有利於研究鎳粗化的影響及其動力學分析。

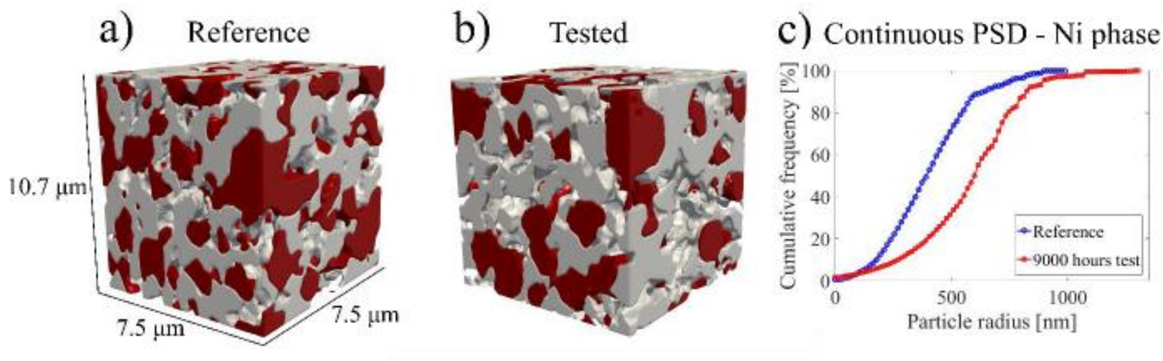


圖 14 電池片燃料電極(Ni/YSZ)測試前後之 3D 重建微結構(a), (b)，及(c)其粒度分布改變。(Reference: M. Trini *et al.*, *Proceedings of the 42nd International Conference on Advanced Ceramics and Composites, Ceramic Engineering and Science Proceedings*, **39(2)**, 165-176 (2018))

（六） 日本大阪產業技術研究所之 S. Yamaguchi 等人於上屆會議發表之"Evaluation of Power Generation from Biomass using Solid Oxide Fuel Cell (SOFC) and Downdraft Gasifiers"論文獲得最佳論文第三名。渠等為了開發可使用生質物作為可再生能源之包含下抽式氣化爐(Downdraft gasifier)及 SOFC 組成之高效率發電系統，分析了自熱、外熱下抽式氣化爐(如圖 15)及 SOFC 的動力學及熱力學。自熱式氣化爐內之化學反應分析結果顯示，在氧化區域幾乎所有生質物均可轉化為 C1 氣體(CO，CO_2 及 CH_4)，而在還原區域所產生的氣體組成則變得平衡，氣化效率達到 87%。渠等使用 Pt/Al_2O_3 觸媒測試外熱式氣化爐，結果顯示活化能可藉由量測生質物氣化為 C1 氣體之轉化率加以計算，而不須經由量測其熱重變化。使用由空氣和蒸汽供應 Pt 催化劑轉化生質物之氣化活化能介於 11 至 36 kJ/mol 之間，而涉及焦油分解和重整的反應過程為氣化速率決定步驟，且在蒸汽氣化中，水在催化劑表面上的吸附和脫氫的活化損失很大。於高於 750 °C 時，氣化之氣體組成於所有實驗條件下均接近平衡狀態；此外，一系列的外熱式氣化爐與 SOFC 的研究，亦表明相較於使用氫氣，以轉化之氣體所能提供的最大功率輸出可以控制在 40-75%。

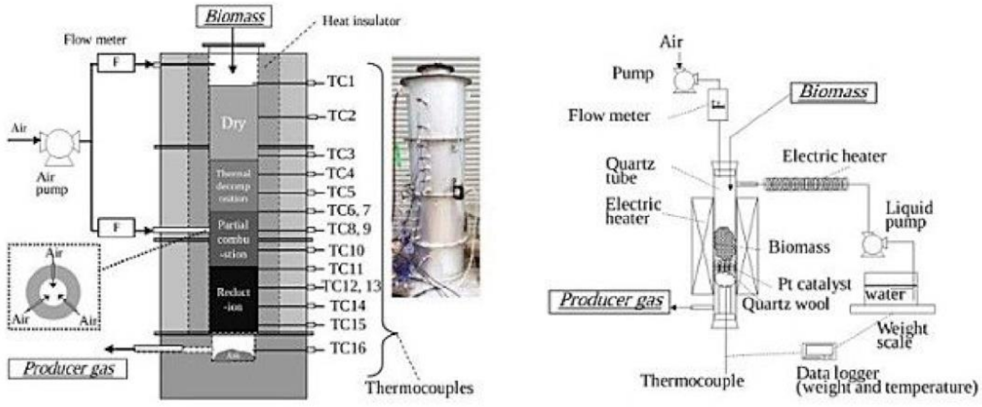


圖 15 自熱式氣化爐(左圖)及外熱式氣化爐(右圖)系統架構圖。(Reference: S. Yamaguchi *et al*., *Proceedings of the 42nd International Conference on Advanced Ceramics and Composites, Ceramic Engineering and Science Proceedings*, **39(3)**, 243-257 (2018))

（七） 劉員去年參加 ICACC2018 會議，返國報告曾討論日本長岡科技大學之 S. T. Nguyen 等人發表的“Crack-Healing Ability and Strength Recovery of Ytterbium Disilicate Ceramic Reinforced with Silicon Carbide Nanofillers”論文，該篇論文於本屆受頒最佳海報論文獎第三名。此篇論文探討 $Yb_2Si_2O_7$-Yb_2SiO_5-SiC 陶瓷複合材料自癒合的效應，渠等研究噴射引擎渦輪葉片之 SiC 強化陶瓷鍍層，於富碳氫氣氛的燃燒環境中易使 SiO_2 揮發造成 SiC 衰減，而造成鍍層失效。而渠等研究發現若使用 $Yb_2Si_2O_7$-Yb_2SiO_5-SiC 陶瓷複合材料作為 SiC 強化陶瓷鍍層的保護鍍層，當產生裂縫時，陶瓷複合材料內部之 SiC 與環境中之 O_2 先反應形成 SiO_2，而後 SiO_2 與 Yb_2SiO_5 進一步反應形成 $Yb_2Si_2O_7$，達到自癒合效果，如圖 16，進而達成降低渦輪葉片維護成本及增長使用壽命的功效。渠等進一步之研究亦發現，SiC 混摻於 $Yb_2Si_2O_7$-Yb_2SiO_5 陶瓷複合材料中，以奈米微粒形式較以奈米纖維或奈米鬚晶之形式更為有效，完整論文並已發表於 Journal of the European Ceramic Society。

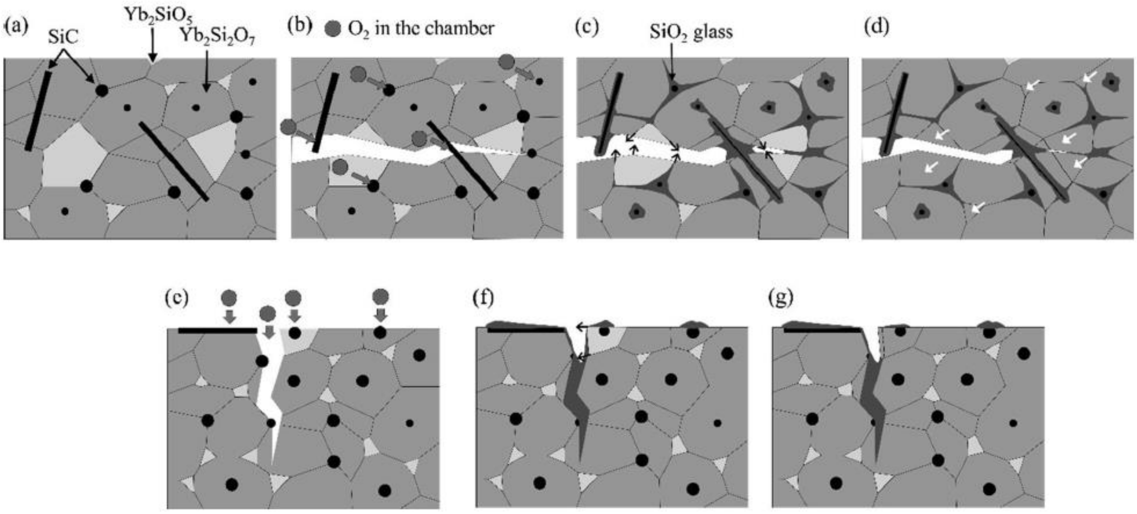


圖 16 $Yb_2Si_2O_7$-Yb_2SiO_5-SiC 陶瓷複合材料自癒合機制示意圖。(Reference: S. T. Nguyen *et al*., *J. Eur. Ceram. Soc.*, in press (2019); https://doi.org/10.1016/j.jeurceramsoc.2019.03.040)

（八） SOC 產品於商業化的進展中，不可避免將面臨量產及品質管理技術之需求。本屆會議有多篇論文發表與電池片和電堆的品質控制(Quality control, QC)相關，包括實測與失效模擬。美國能源部(Department of Energy, DOE)之 P. Bruke 於本屆會議中報告 US DOE Office of Fossil Energy's Solid Oxide Fuel Cell Program，提及推動 SOFC 計畫的近程目標為 100 kW 至 1 MW，遠程目標則為 10 MW 至 50 MW，其中包括電池片、電池堆，以及其製造和品質控制為挑戰重點。美國國家能源科技實驗室(National Energy Technology Laboratory, NETL)於 2017 年之簡報提及 DOE 的 SOFC 計畫即定義電池片(Cell)和電池堆(Stack)的 QC 為重點項目之一(如圖 17)。此外，美國 HaikuTech 公司於本屆會議報告"Artificial Intelligence for Automatic Optical Inspection of Multilayered Solid Oxide Membranes"，發表由其公司所開發之 SOFC 電池片缺陷檢驗機台，藉由結合人工智慧、類神經學習網路及光學檢驗，並由使用者建立對照資料庫，定義缺陷如 hole, pinhole, fiber, crack, bump, impurity 等形式，經人工智慧學習後，辨識速度快且準確，且於此領域實務上已有商規儀器，該機台可檢驗最大尺寸 20×20 cm^2、可檢驗出 10 μm 尺度(影像 pixel 尺寸 3.5 μm)缺陷及辨識種類，時間小於

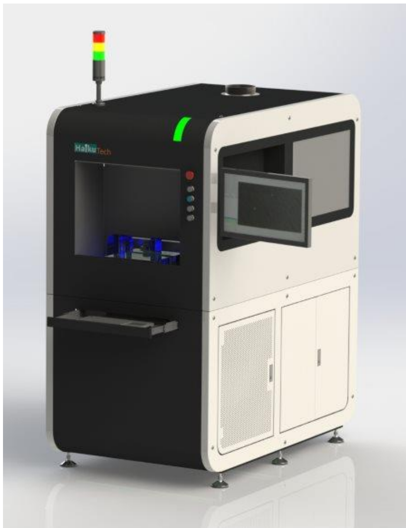
10 秒，如圖 18。

SOFC Reliability Challenges

Fossil Energy | National Energy Technology Laboratory

Technology	Topic	Issue
Cells	Manufacturing/QC	• Manufacturing reliability/quality control issues. • Non- destructive tests • Cell –to-cell variability
	Chemical Instability	• Long-term microstructural/chemical changes in cell • Phase separation
Stacks	Manufacturing/QC	• Dimensional tolerances
	Contacts	• Electrode-Interconnect contact variability and degradation
	Seals	• Seal failure • Corrosion of brazes/welds • Delta T effects
Systems	Electrode Contamination	• Cathode poisoning (e.g., Cr)
	Anode Redox	• Anode redox expansion/contraction
	Commissioning	• BOP components • Thermal management

圖 17 SOFC 電池片及電池堆之製造與品質控制為重點項目。(Reference: R. Conrad, Presentation, Ohio Fuel Cell Symposium (2017))



Specifications µNET Inspector1.6

Field of scanned view:	150 mm by 150 mm 200 mm by 200 mm
Cameras:	2x 8000 pixel line scan cameras
Image collection speed:	<8 s
Image size:	max 2 GPixel
Pixel size:	3,5 or 4,9 µm
Min. defect size	10 µm
Defect detection speed:	appr. 10 s
GUI:	touch panel and HMI screen with keyboard/touchpad
AI tensor performance:	>90 TFlops
Software:	HiQtensor 1.6
Safety:	CE
Electrical:	3 x 400 Vac with N, 50/60 Hz
Fuse; Power	32A; 8 kW
UPS:	30 minutes for server and AI
Air:	200 NL/min, 6 MPa
Dimensions:	W 74 cm, D 102 cm, H 178 cm
Weight:	350 kg

圖 18 Haiku Tech 公司開發之 SOFC 電池片缺陷檢驗機台及其規格。(Reference: www.haikutech.com)

（九） SOFC 封裝技術為製程關鍵議題，高溫封裝材料除了常用之玻璃陶瓷或雲母之外，金屬合金材料及硬焊封接亦是高溫燃料電池領域廣為研究之課題。美國密西根州立大學之 Q. Zhou 於本屆會議發表渠等研究銀基硬焊合金應用於 SOFC

高溫封接之研究論文“New Silver-Based Alloys for Solid Oxide Cell Brazing and Circuit Patterning”。一般以焊接溫度 450 °C 作為硬焊與軟焊之區別，焊接溫度高於 450 °C 稱為硬焊(或銅焊)，反之則為軟焊。傳統的 Ag-CuO 反應空氣銅焊合金(Reactive air brazes, RABs)因使用 Cu 添加以利 Ag 於焊接溫度潤濕，然而易造成孔隙缺陷。渠等介紹 Ag-Ge 及 Ag-Ni 兩種銀基硬焊系統，可於 800~1000 °C 的焊接溫度達成不銹鋼與 CeO_2 或是 YSZ 之封接。此外，渠等研究亦表明於雙重氣氛條件下之快速熱循環及 750 °C 500 小時等溫試驗中，Ag-Ni 硬焊系統較傳統的 Ag-4CuO 表現更少的劣化，透過於陶瓷基板預塗佈圖案化多孔 Ni 層，可進一步促進 Ag 潤濕，使其達成可於不同陶瓷基板粘附良好及緻密的銀厚膜，比較說明如圖 19。

Pore Type	Reactive Air Brazing	Ag-Ni Brazing
Type I (wetting) Pore Formation	• θ ≈ 40° (for Ag-4CuO) occasionally leads to pores during manufacturing [9,10] • Organics in the braze paste can also lead to pores during manufacturing [47]	• θ < 30° leading to a fully infiltrated porous Ni network that puts the Ag in intimate contact with the YSZ [29–31] • Since no organics are used during brazing (these are removed by heating the nickel paste in Ar to obtain the porous nickel network) binder burnout cannot cause pores during brazing
Type II (interfacial) Pore Formation	• With the reduction of CuO along the braze/YSZ and braze/SS interface, micro-pores form during SOFC operation near the H_2 side of the joint [24,25].	• Even after 500 h of oxidation no oxides are present at the SS-braze interface on the anode side of the joint (the oxides forming from the reaction layer are within ductile silver, and only form on the air side of the joint), hence they cannot be reduced by anode gases to produce pores.
Type III (H_2+O_2) Pore Formation	• H_2 and O_2 diffuse through Ag and form water pockets (Type III pores) that mechanically compromise the braze joint after ~10,000 h of SOFC operation [23].	• Since Type II pores form much faster than Type III pores [25,27] and thereby provide a short-circuit path for H_2 invasion into the center of the braze, the elimination of Type II pores should increase joint reliability by delaying the onset of Type III pores.

圖 19 傳統反應空氣銅焊與 Ag-porous Ni 銅焊形成缺陷比較說明。(Reference: Q. Zhou *et. al.*, *Acta Mater.*, **148**, 156-162 (2018))

（十） 高含鉻不銹鋼因具有較優異之高溫抗氧化特性，故廣泛被使用於平板式固態氧化燃料電池堆組之金屬連接板。然而，不銹鋼中的鉻於高溫與水氣反應易形成氣態之氫氧化鉻($CrO_2(OH)_2$)或鉻酸(CrO_3)而揮發，當其沈積於 SOFC 陰極之三相點時，則被還原成穩定之氧化鉻(Cr_2O_3)，佔據了陰極催化反應的活性位置，因而造成陰極毒化使得電池效能衰退。除了採用較低鉻含量不銹鋼或於金屬連接板表面鍍覆保護層之外，另外一種反向思考的方案則為，在其可能的鉻傳導路徑上設置鉻捕獲劑(Cr-getter)。美國太平洋西北國家實驗室之 Dr. Y. Chou 於本屆會議發表研究論文“Investigation of $La_{1-x}Sr_xCo_{0.2}Fe_{0.8}O_3$ as Cr Gettering

Materials: Effect of La/Sr Ratio on Reaction and Validation in Stack Fixture Test"。Dr. Chou 先前與康乃狄克大學的研究團隊，共同開發了 Sr-Ni 氧化物做為 Cr 捕獲劑，獲得不錯的應用可行性。而本次報告內容則是選用 $La_{1-x}Sr_xCo_{0.2}Fe_{0.8}O_3$ 做為鉻捕獲劑，其原因為 Sr 易偏析出晶體結構而與 Cr 反應形成 $SrCrO_4$。渠等研究將不同 La/Sr 莫耳比例(8/2, 6/4, 4/6 及 2/8)之$(La,Sr)Co_{0.2}Fe_{0.8}O_3$與 Cr_2O_3 混合後，分別於 800, 900 及 1000 °C 持溫 500 小時，再以 XRD 量測分析反應後試樣的結晶相。研究結果顯示，在 800 °C~1000 °C 之測試範圍，Sr 與 Cr 反應形成 $SrCrO_4$ 非常快速(30 分鐘以內)，較高 La/Sr 比例之$(La,Sr)Co_{0.2}Fe_{0.8}O_3$具有較低的反應活性，然而較低 La/Sr 比例之$(La,Sr)Co_{0.2}Fe_{0.8}O_3$則可反應形成最多的鉻化物，如圖 20。此外，亦以未鍍膜之 SS441 為連接板及 LSM 為陰極之 SOFC 組裝成之電池堆，進行實際操作於 800 °C、1000 小時及潮濕空氣之鉻捕獲試驗，以觀察測試後電池片 LSM 陰極及鉻捕獲劑$(La,Sr)Co_{0.2}Fe_{0.8}O_3$之組成及微觀結構，評估鉻捕獲劑吸 Cr 之能力。

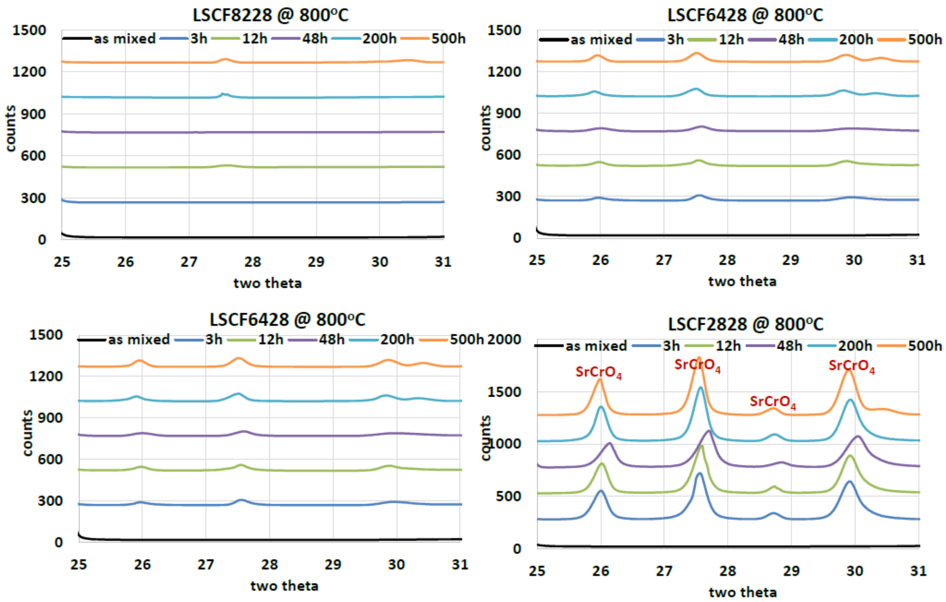


圖 20 不同 La/Sr 比例之$(La,Sr)Co_{0.2}Fe_{0.8}O_3$與 Cr_2O_3 混合於 800 °C 持溫 500 小時，試樣之 XRD 衍射圖。(Reference: Y. S. Chou *et al.*, Presentation, The 19th Annual Solid Oxide Fuel Cell (SOFC) Project Review Meeting (2018))

（十一）義大利帕多瓦大學之 E. Bernardo 在本屆大會重點會議 Focused Session 4: Green

Technologies, and Joining of Ceramics 議程發表論文“Novel Processing of SOFC Glass-ceramic Sealants Based on the Sintering of Glass Powders Mixed with a Reactive Silicone Binder”。講者指出玻璃漿料使用之黏結劑因為在燒結過程不完全分解、黏結力差，或是形成氣體逸散之因素，形成缺陷而對最終成品造成影響。本篇論文主要探討利用矽化物做為黏結劑，以利玻璃粉末之燒結，本研究所使用之 CaO-MgO-Al_2O_3-SiO_2 玻璃系統(V9)已應用於 SOFC 之高溫封裝劑，如圖 21。由於採取矽化物樹酯做為黏結劑，故玻璃系統中 SiO_2 之質量比例減少量可達 15%，摻和之矽化物樹酯與玻璃粉末於燒結過程參與陶瓷化之反應，從而減少缺陷產生，此一新觀念方法亦已成功地應用於玻璃/陶瓷接合件之製作。

	V9	Silica-defective glasses	
		V9’	V9”
Chemical composition (wt%)			
SiO_2	50.4	46.3	48.5
Al_2O_3	8.3	9.0	8.6
CaO	9.3	10.1	9.6
MgO	13	14.1	13.5
Na_2O	10.3	11.1	10.7
ZrO_2	2.9	3.1	3.0
B_2O_3	5.8	6.3	6.0
Characteristic temperatures (°C)			
Glass transition (T_g)	637	605	618
Dilatometric softening point	640	616	627
Littleton point	762	735	747
Reference	[4]	[21]	[21]

圖 21 CaO-MgO-Al_2O_3-SiO_2 玻璃系統(V9)組成及特徵溫度參照圖。(Reference: H. Elsayed *et al*., *J. Eur. Ceram. Soc.*, **38(12)**, 4245-4251 (2018))

四、建議事項

參加第 43 屆國際先進陶瓷與複合材料會議及展覽會暨第 16 屆國際固態氧化物電池材料、科學與技術研討會，無論於參與國際會議汲取新知，或論文發表彰顯研發成效，或與國際一流專家學者討論互動瞭解國際研究趨勢之層面，均感獲益良多。幾點淺見建議如下：

（一）國際先進陶瓷與複合材料會議及展覽會由美國陶瓷學會固定每年舉辦乙次，為國際陶瓷及複合材料領域之最重要學術會議之一。參與會議及論文發表，對於促進國際學術交流、展現研發成果，以及提升技術水準與啟發研究創新，均有正面之效益。下一屆會議將於 2020 年 1 月 26 至 31 日進行，建議於計畫規劃及預算許可之條件，持續派員參加會議以展現研發成果、維繫國際人脈，並提昇台灣之能見度。

（二）本所長期投入 SOC 技術開發，電池單元、電池堆，以及封裝、觸媒材料均已有技轉國內廠商實績。建議除持續精進技術之外，對於 3D 列印技術應用於 SOC 製造，以及品質控制技術及軟硬體的發展亦值得關注。此外，繼 SOFC/SOEC 之後，PCFC(Proton Ceramic Fuel Cell)將是下一步研發趨勢，亦值得投入資源開發。

SYMPOSIUM 3: 16th International Symposium on Solid Oxide Cells (SOC): Materials, Science and Technology

Solid oxide cells (SOCs) offer great potential for clean and efficient power generation from a wide variety of fuels ranging from hydrocarbons to renewables and for highly efficient conversion of electricity to hydrogen or synthesis gas via electrolysis. Durable electrochemical energy conversion in SOC is only possible by proper material choice and processing, cells stacking technology and stack module design. Application of SOC in scalable systems for power, heat, hydrogen and synthetic gas generation needs consideration of stack operating window, operating environment, contaminants sources / level and customer specifications to realize competitive solutions.

This symposium provides an excellent platform for academia and industry to present and to discuss novel solutions for materials, components design, mechanical robustness, durability, system layouts and exchange their experience in application of SOCs in different areas. The goal of the symposium is not only exchange of the latest results by experienced and young scientists, but also extensive discussion of unsolved problems and on development directions.

PROPOSED SESSION TOPICS

- Electrolytes: Oxygen ion, proton and mixed conductors; conduction mechanisms
- Electrode materials and microstructural engineering: Electrode processes, defect chemistry, characterization, accelerated testing and lifetime prediction
- Ceramic and metallic interconnects: Materials development and properties, coatings, accelerated testing and lifetime prediction
- Sealing technology: Material development and characterization, designs and approaches, interactions with sealed materials
- Novel processing and design for cells, stacks, reformers, burners and other system components
- Mechanical and thermomechanical properties of materials and components up to high temperatures
- Surface and interfacial reactions: Electrochemical transport and electrode poisoning, catalytic degradation, carbon fouling
- Simulation: Electrode performance and degradation, distribution of temperature, current density and mechanical stresses in cells and stacks, system layout, stationary and dynamic system operation, etc.
- High temperature electrolysis: Steam, steam and CO2, chemical process engineering utilizing SOEC
- System design and demonstration

SYMPOSIUM ORGANIZERS

- Mihails Kusnezoff, Fraunhofer IKTS, Germany

- Narottam P. Bansal, NASA Glenn Research Center, USA
- Tatsumi Ishihara, Kyushu University, Japan
- Federico Smeacetto, Politecnico di Torino, Italy
- Jeffry W. Stevenson, Pacific Northwest National Laboratory, USA
- Ayhan Sarikaya, Saint-Gobain, USA
- Ruey-Yi Lee, Institute of Nuclear Energy Research, Taiwan
- Vincenzo Esposito, DTU Energy Conversion, Denmark
- Scott A. Barnett, Northwestern University, USA
- Nguyen Q. Minh, University of California San Diego, USA
- Prabhakar Singh, University of Connecticut, USA

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附錄二

View Abstract

CONTROL ID: 3048813

CURRENT SYMPOSIUM: SYMPOSIUM 3: 16th International Symposium on Solid Oxide Cells (SOC): Materials, Science and Technology

CURRENT SESSION: System design and demonstration

PRESENTATION TYPE: Invited (by Invitation Only)

TITLE: Solid Oxide Cells Technology Development at Taiwan Institute of Nuclear Energy Research

AUTHORS (LAST NAME, FIRST NAME): Liu, Chien-Kuo[1]; Lee, Ruey-yi[1]; Cheng, Yung-Neng[1]; Hong, Wen-Tang[1]; Wu, Szu-Han[1]; Lin, Tai-Nan[1]; Chang, Chun-Liang[2]; Hsu, Ning-Yih[3]

INSTITUTIONS (ALL): 1. Nuclear Fuels and Materials Division, Institute of Nuclear Energy Research, Taoyuan City, Taiwan.

2. Physics Division, Institute of Nuclear Energy Research, Taoyuan City, Taiwan.

3. Chemistry Division, Institute of Nuclear Energy Research, Taoyuan City, Taiwan.

ABSTRACT BODY:

Abstract Body: Taiwan Institute of Nuclear Energy Research (INER) has committed to developing solid oxide fuel cell (SOFC) technologies and applications over the past decade. We have made remarkable progress in manufacturing of membrane electrode assembly (MEA), assembling of stack, and integrating of power system. For instance, to date, we have established the fabrication processes separately for making a full size (10×10 cm^2) of planar type of anode-supported cell (ASC) and metal-supported cell (MSC) to reach a power density over 500 mW/cm^2 and degradation rate less than 1%/kh. Moreover, INER's SOFC technologies, including MEA, stack, reforming catalysts, and power system have been technical transferred to the domestic industry companies. It is worth mentioning that the SOFC industry chain in Taiwan is budding and there are many state-run and private companies investing in SOFC technologies. Furthermore, solid oxide electrolysis cell (SOEC) is the reverse operation of SOFC and can produce hydrogen by feeding water and electricity. Therefore, a SOC combined SOFC and SOEC will potentially become one of the most promising new energy conversion and storage devices in the future. In this paper, we showed the state of the art of SOEC technology developments and accomplishments at INER such as high efficiency, stable configuration, and spalling-proof cathode of our home-made cells.

KEYWORDS: Solid Oxide Cells, MEA, Energy conversion, Energy storage.

Presenter Acknowledgment: I have read and acknowledge the above paragraph

PROFESSIONAL/ACADEMIC STATUS:

Chien-Kuo Liu : Professional

Ruey-yi Lee : Professional

Yung-Neng Cheng : Professional

Wen-Tang Hong : Professional

Szu-Han Wu : Professional

Tai-Nan Lin : Professional

Chun-Liang Chang : Professional

Ning-Yih Hsu : Professional

劉建國 Chien-Kuo Liu

寄件者:	43rd International Conference and Exposition on Advanced Ceramics and Composites <onbehalfof@abstractcentral.com>
寄件日期:	2018年9月14日星期五 下午 11:41
收件者:	劉建國 Chien-Kuo Liu
主旨:	ICACC 2019 Abstract Status

Friday, 14-Sep-2018
Abstract ID #: 3048813

Dear Chien-Kuo Liu,

We are pleased to inform you of the acceptance of your abstract entitled "Solid Oxide Cells Technology Development at Taiwan Institute of Nuclear Energy Research", for Invited (by Invitation Only) presentation at the 43rd International Conference and Exposition on Advanced Ceramics and Composites (ICACC 2019). Please inform any co-authors.

The conference dates: January 27- February 1, 2019 at the Hilton Daytona Beach Resort and Ocean Center in Daytona Beach, Florida, USA.

Details of your presentation (including final presentation type, paper number, date, time and location) in 'SYMPOSIUM 3: 16th International Symposium on Solid Oxide Cells (SOC): Materials, Science and Technology System design and demonstration', will be communicated in a separate email at a later date. Abstracts will be published online after the program schedule is final.

Meeting information including hotel links and registration is found at http://ceramics.org/icacc2019.

A personalized letter of invitation is available for you at View visa letters. You can view all emails and invitations at this link.

The government website http://travel.state.gov has official guidelines to obtain entry to the U.S. Processing of a visa application can take many weeks. We advise you print the visa letter provided to begin the process as early as possible to ensure your ability to travel to the conference.

Sincerely,
Marilyn Stoltz
The American Ceramic Society

The American Ceramic Society
www.ceramics.org

17 September 2018

Dr. Chien-Kuo Liu
Institute of Nuclear Energy Research
Nuclear Fuels and Materials Division
No. 1000, Wenhua Rd., Jiaan Village, Longtan District,
Taoyuan City, 32546
Taiwan

Dear Dr. Liu,

We are pleased to invite you to present your topic entitled ***Solid Oxide Cells Technology Development at Taiwan Institute of Nuclear Energy Research***, abstract **#3048813**, accepted for Invited (by Invitation Only) presentation at the 43rd International Conference & Exposition on Advanced Ceramics and Composites. The conference dates: January 27 – February 1, 2019 at the Hilton Daytona Beach Resort & Ocean Center in Daytona Beach, Florida.

Please inform any co-authors of the acceptance of this abstract. The specific details of the day, time and location of your presentation will be communicated by email.

The Society will provide a laptop computer, LCD projector, screen, laser pointer and microphone in each technical session room. If your presentation is prepared on a Macintosh computer, please plan to bring your own computer for your presentation. Check in with your session chair 15 minutes before the start of your session. One day prior to your talk, please bring your presentation on a USB memory stick or CD-ROM to the Speaker Ready Room (Dolphin Room) to be uploaded to the laptop that will be used in your session. If you cannot upload your presentation one day early, please arrive early at your session room on the day of your session to upload it. Presentations may not be loaded while the session is in progress.

All attendees must register for the meeting and pay the appropriate registration fee. Registration and hotel information for the conference is available at http://www.ceramics.org/daytona2019. We encourage you to reserve your hotel room early to take advantage of the special conference rates, available only until January 4, 2019. You must mention that you are participating in The American Ceramic Society conference to qualify for the special conference rate.

If it is necessary for you to obtain a travel visa to attend the conference, you may use this letter as an invitation. Please refer to the U.S. government website http://travel.state.gov for official guidelines to obtain a B-1 nonimmigrant travel visa for entry into the U.S. Early application is suggested to allow for the required processing. Information on obtaining a travel visa also appears on the meeting webpage. Individuals from Visa Waiver Countries must have registered with the U.S. Department of Homeland Security's Electronic System for Travel Authorization (ESTA) program.

Thank you for your interest in participating in the 43rd International Conference & Exposition on Advanced Ceramics and Composites. We look forward to seeing you in Daytona Beach!

Sincerely,

Marilyn Stoltz

Marilyn Stoltz
Associate Manager, Meetings
Direct Dial: 614-794-5868
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ICACC EXPO PREVIEW

Exhibit dates:

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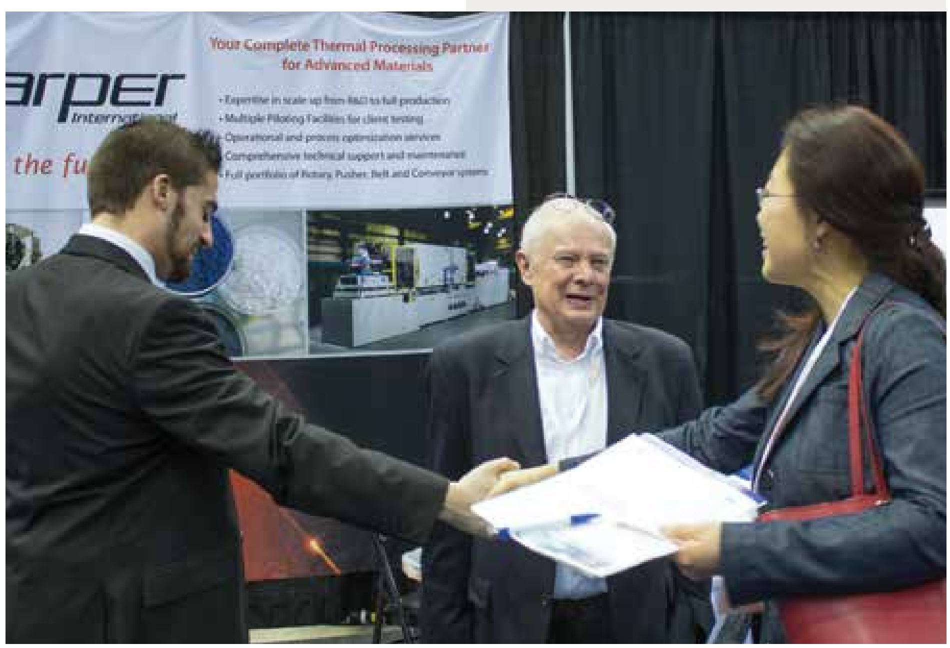

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Haiku Tech
Booth No. 215

Haiku Tech offers tape casting (coating) equipment; as well as stackers, isostatic laminators, furnaces, and materials for the development and manufacturing of Multilayer Ceramic products, including Substrates, Solid Oxide Fuel Cells, etc. We also offer prototyping and consulting services to develop tape casting formulations for standard or customized ceramic powders.

mdemoya@haikutech.com
https://www.haikutech.com

Harper International
Booth No. 309

Harper International is a global leader in the design of complete thermal processing solutions and technical services for the production of advanced materials, including custom designed rotary, pusher and belt conveyor furnaces. Our experience spans a range of engineering ceramics, including designing for the production of silicon nitride, tungsten carbide, boron nitride and aluminas. Harper kilns are widely used to calcine powders and sinter components such as thermistors, varistors and monolithic and multi-layer capacitors. Our focus is enabling our customers with furnace technologies that incorporate improved flexibility, operating efficiencies, and equipment control to help scale up production rates successfully.

info@harperintl.com
http://www.harperintl.com/

H.C. Starck Surface Technology and Ceramic Powders GmbH / Höganäs AB
Booth No. 305

Höganäs is the world's leading manufacturer of metal powder. Our acquisition of H.C. Starck's Surface Technology and Ceramic Powders (STC) division complements our product portfolio and enables us to offer a comprehensive choice of high quality powder solutions enhancing the potential for your industry applications. We are a renowned producer of non-oxide ceramic powders.

susan.vogel@hoganas.com
https://www.hoganas.com

Keyence Corporation of America
Booth No. 301

KEYENCE's microscope and surface management systems ensure that our customers can meet increasing quality standards. High resolution imaging, ISO-certified roughness, and 2D/3D measurement is coupled with easy-to-use interfaces for an elevated inspection experience. KEYENCE offers a range of services: free on-site demos/sample testing, training, and after sale support.

tech@keyence.com
www.keyence.com/products/microscope/index.jsp

Lithoz America LLC
Booth No. 103

Lithoz is the system provider for additive manufacturing (3-D-printing) of high-performance ceramics. As a technology provider, Lithoz covers the whole process chain—from development of the machine to the materials and up to the application. Lithoz developed LCM technology, a slurry-based additive manufacturing technology based on photopolymerization. LCM has very high resolution and very good reproducibility and allows production of finely delicate structures and details directly from CAD data.

sallan@lithoz-america.com | lithoz.com

Microtrac
Booth No. 314

The S3500 line of particle size analyzers, providing the broadest size range with compact design from .02 to 3000 microns. Features rapid wet to dry conversion, advanced Flex software, small footprint, Turbotrac dry powder feeder. The Nanotrac Dynamic Light Scatter units for nanometer sizing and zeta potential. Surface Area, Imaging systems – both wet and and dry and New Blue Laser diffraction Technology "Bluewave" next generation is here.

jay.schild@microtrac.com

Netzsch Instruments
Booth No. 300

NETZSCH Instruments offers highly sensitive, versatile, and reliable thermal analysis instrumentation for R&D, quality control, process safety, and failure analysis. Our instruments and methods allow for material characterization and the study of properties including Cp, enthalpy, weight change, Young's modulus, conductivity, diffusivity, and evolved gas analysis.

nib_sales@netzsch.com
https://www.netzsch-thermal-analysis.com/us/

Nordson SONOSCAN
Booth No. 302

Nordson SONOSCAN manufactures and develops Acoustic Microscope (AM) systems to nondestructively inspect and analyze materials. Our leading edge C-SAM systems provide unmatched accuracy for the inspection of products for hidden internal defects such as poor bonding, delaminations, cracks and voids. We also offer analytical testing lab services throughout the world

info@nordsonsonoscan.com
http://www.nordsonsonoscan.com

Oxy-Gon Industries, Inc.
Booth No. 214

Oxy-Gon offers a wide range of furnaces for, Ceramic Firing, Annealing, Brazing, Hot Pressing and more. Oxy-Gon furnaces have temperatures up to 2800°C (5000°F) and controlled atmospheres, rough to ultra-high vacuum, inert gas, nitrogen, hydrogen or reducing gas. Oxy-Gon is "Degrees Ahead in Quality" since 1988.

sales@oxy-gon.com | https://oxy-gon.com

Praxair Surface Technologies, Inc.
Booth No. 219

Over more than 30 years, Praxair Surface Technologies has established itself as a world leading supplier of multi-metallic component oxide powder and sintered materials to further advancement in the material science field via its Specialty Ceramics division. Specializing in materials for Solid Oxide Fuel Cells and Environmental and Thermal Barrier Coatings.

Ron_Ekdahl@praxair.com
http://www.praxair.com/specialtyceramics

R. D. Webb Company Inc.
Booth No. 208

Manufacturer of inexpensive benchtop vacuum furnaces for active metal brazing and sintering to 2,200°C.

rdwebb@alum.mit.edu | rdwebb.com

SPEX Sample Prep
Booth No. 316

SPEX SamplePrep manufactures ball-mills, Fluxers and Pellet Presses that prepare samples for XRF and ICP analysis. Our fully automated Katanax electric fluxers prepare fused beads for XRF or solutions for ICP. Fusion is the ideal sample preparation technique for ceramic samples. Our high-energy ball mills and cryogenic grinders are able to pulverize the toughest materials.

learnmore@spex.com
https://www.spexsampleprep.com/

ICACC EXPO PREVIEW

Exhibit dates:

Tuesday, January 29, 2019: | 5 – 8 p.m. | Wednesday, January 30, 2019 | 5 – 7:30 p.m.

Springer Nature
Booth No. 107
Springer Nature is one of the world's leading global research, educational and professional publishers, created in May 2015 through the combination of Nature Publishing Group, Palgrave Macmillan, Macmillan Education and Springer Science+Business Media.
anita.lekhwani@springer.com
http://www.springer.com/

TAV VACUUM FURNACES SPA
Booth No. 313
TAV VACUUM FURNACES SPA designs and manufactures customized vacuum furnaces for a wide range of industries and R&D laboratories. Typical applications are heat treatment, advanced ceramics, brazing, sintering, diffusion bonding, additive manufacturing, aluminizing, UHV, TAV vacuum furnaces for advanced ceramics are mainly used in automotive, aviation, medical industry, etc.
info@tav-vacuumfurnaces.com
https://www.tav-vacuumfurnaces.com

Tethon 3D
Booth No. 218
Tethon 3D is the leading manufacturer of ceramic materials for additive manufacturing. Platform agnostic UV-curable resins are available for SLA or DLP 3D printers, including porcelain, glass-ceramic, ceramic for metal investment casting molds, iron, and other composite materials. Tethonite ceramic powders and companion binder are offered for binder jetting 3D printers.
info@tethon3d.com | http://www.tethon3d.com

TevTech LLC
Booth No. 206
TevTech provides custom designed vacuum furnaces and components for CVD, CVI, Sintering, Annealing and Purification systems. From laboratory to Production furnaces, with metal or graphite hot zones, high vacuum to atmospheric pressure, temperatures to 3,000C and exceptional automated control systems for improved product quality. Worldwide commissioning, training and services.
sales@tevtechllc.com | www.tevtechllc.com

Thermal Technology LLC
Booth No. 319
Thermal Technology has been providing solutions for advanced thermal processing since 1946. As a pioneer in the hot-zone, LED, vacuum furnace, and SPS industries, we have served the lighting, renewable energy, electronics, aerospace, communications, health care, and research and development industries utilizing metals, ceramics, glass, nanopowders, crystals, and emerging materials. We carry a wide variety of vacuum furnaces, press systems (HP and SPS), hot zone parts, OEM parts and much more..
bob.aalund@thermaltechnology.com
www.thermaltechnology.com

Thermcraft, Inc.
Booth No. 303
Thermcraft is an international leading manufacturer of furnaces and ovens for temperatures up to 1800°C (3272°F). We offer a full range of products from laboratory benchtop sizes up to full size industrial production systems. With over 45 years of thermal processing experience, we can help you to find the furnace or oven solution that best fits your needs.
info@thermcraftinc.com
http://www.thermcraftinc.com

Wiley
Booth No. 216
Wiley is a content-driven, customer-focused provider of industry knowledge services for research professionals, instructors and students. As publishing partner of The American Ceramic Society, Wiley ensures that all ACerS journals and books contain the most impactful and up-to-date content in all aspects of the field and are made available in both print and digital format.
cs-journals@wiley.com | http://www.wiley.com/

ZEISS Microscopy
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Improve your understanding of material properties. Whether you aim for a fundamental understanding of materials science or want to improve the composition of materials that drive innovation in consumer & industrial products & processes, ZEISS systems are designed to provide you information beyond images. Get to results fast with comprehensive workflow solutions for multi-modal, multi-scale microscopy and analysis from 2D to 3D to 4D.
microscopy@zeiss.com
http://zeiss.com/advanced-materials

ZIRCAR Ceramics, Inc.
Booth No. 202
ZIRCAR Ceramics, Inc. is a producer of ceramic fiber based low-mass high temperature thermal and electrical insulation products. Compositions for use at temperatures as high as 1825C. Includes rigid boards and cylinders, flexible blankets, papers, textiles, coatings and adhesives - with a special emphasis on precision custom CNC machined components. Legendary Heritage in High Performance Materials and Customer Service.
sales@zircarceramics.com
https://www.zircarceramics.com