INER-F0955

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出國報告（出國類別：其他）

赴英國參加第十四屆國際固態氧化物燃料電池研討會與參訪英國倫敦帝國大學出國報告

服務機關：核能研究所
姓名職稱：楊昇府　副工程師
派赴國家：英國
出國期間：104 年 7 月 25 日~104 年 8 月 5 日
報告日期：104 年 9 月 4 日

摘要

本文為核能研究所物理組楊昇府博士奉派於 2015 年 7 月 25 日起至 2015 年 8 月 5 日期間，赴英國蘇格蘭格拉斯哥(Glasgow)參加美國電化學學會(The Electrochemical Society, ECS)主辦之第十四屆國際固態氧化物燃料電池研討會(The Fourteenth International Symposium on Solid Oxide Fuel Cells, SOFC-XIV) 暨電化學能量轉換和儲存研討會(ECS Conference on Electrochemical Energy Conversion & Storage)，進行論文"Ni-Mo Porous Alloy Fabricated As Supporting Component for Metal-Supported Solid Oxide Fuel Cell and Cell Performance"口頭發表，並參訪於固態氧化物燃料電池研究發展領域、關鍵性技術、研發設備、專業人力等具有相當高水準的英國倫敦帝國大學(Imperial College London, UK)，促進技術與學術交流。

藉由參加第 14 屆 SOFC 國際研討會發表論文與參訪英國倫敦帝國大學，可促進技術與學術交流，掌握關鍵技術，並了解國際趨勢，進而建立合作管道及對象，有助於計畫之執行，並對我國推廣 SOFC 產業及其相關領域研發有很大的助益。透過專家討論交流會議，可拓展研究深度與提升國際同業審查應對能力，並提升本所固態氧化物燃料電池相關技術能力。未來應持續規劃與派員參加該國際會議，真實呈現國內的研發成果、研究近況、拓展國際人脈關係，加速計畫之進展。經由口頭發表論文，充實本職學能，參與會議期間向與會專家學者請益，本所 SOFC 能源領域議題備受重視及肯定。會議結束後，對於可能互訪或合作之事宜，仍需持續關注。本所研發的金屬支撐型固態氧化物燃料電池具有領先的優勢，未來可投入更多人力與經費，持續掌握領先優勢，積極研發朝實用化的角度去發展。英國出國公差參訪倫敦帝國大學，為雙方首次彼此互動和交流，建議未來可以本次所建立的合作管道為基礎，進行互訪、合作或派員交流實習，促進技術與學術交流。國際各先進國家(如美國、歐盟和日本)於 SOFC 區域和國家各層級間研究單位、工業和政府部門橫向及縱向聯繫整合、能源政策、經費投入程度的相關作為，值得國內各界的參考與借鏡。

目次

一、目的

美國電化學學會(The Electrochemical Society, ECS)主辦之第十四屆國際固態氧化物燃料電池研討會(The Fourteenth International Symposium on Solid Oxide Fuel Cells, (SOFC-XIV))於 2015 年 7 月 26 日~2015 年 7 月 31 日在英國蘇格蘭(Scotland)格拉斯哥(Glasgow)舉行，內容涵蓋 SOFC 電池片(Cells)、電池堆(Stacks)和電池系統(Systems)之設計、效能、與耐久性探討；陽極材料(Anodes)、電解質材料(Electrolytes)、陰極材料(Cathode)製程和效能；連接板與鍍保護膜(Interconnects and Interconnect Coatings)、模擬(Modeling)、相容性燃料運轉(Fuels and Fuel Compatibility)、固態氧化物電解電池(Solid Oxide Electrolysis and reversible Cells)等議題。此國際會議於 26 年前(1989)於美國佛羅里達州(Florida)好萊塢(Hollywood)舉辦第一屆，後續於歐洲、北美、日本等三個地區輪流，每兩年舉辦一次，已成為國際 SOFC 領域最重要的資訊交流平台之一。為有效掌握國際間固態氧化物燃料電池之發展趨勢，並拓展與國際間 SOFC 主要發展機構成員之關係，楊昇府博士獲指派參加該項會議(邀請函如附錄一)並參訪英國倫敦帝國大學(邀請函如附錄二)。藉由參與本次會議與參訪倫敦帝國大學，展現本所於 SOFC 領域的研發成果，並且加強本所與國際間之資訊交流與人脈關係拓展，有益於後續國內 SOFC 研發策略方向擬訂及研發工作的推展。主要目的如下所述：

1. 赴英國蘇格蘭參加美國電化學學會主辦之第十四屆國際固態氧化物燃料電池研討會，並口頭發表金屬支撐型固態氧化物燃料電池之研發成果論文(摘要與全文接受通知如附錄三和四)，與燃料電池一流人才進行技術探討，於此國際資訊交流之重要平台，收集廣泛且深入的技術資訊。
2. 參訪於固態氧化物燃料電池研究發展領域、關鍵性技術、研發設備、專業人力等具有相當高的水準，世界知名一流的英國倫敦帝國大學，進行簡報(題目：Metal-Supported Solid Oxide Fuel Cell at INER)與交流，強化國際之合作關係，進而瞭解國外研發現況、市場及未來發展方向。

二、過程

(一) 概要說明

第十四屆國際固態氧化物燃料電池研討會於2015年7月26日~2015年7月31日在英國蘇格蘭(如圖1)格拉斯哥(如圖2)舉行。格拉斯哥是英國蘇格蘭最大城市與最大商港，也是英國第三大城市，位於蘇格蘭西部的克萊德河河口。本屆會議主席為美國西北太平洋國家實驗室Dr. Subhash C. Singhal及京都大學Professor Koichi Eguchi，總計共有24場學術研討會，來自世界各地45個國家六百餘專業人士參加，420篇論文投稿，口頭發表268篇，海報發表152篇。倫敦帝國大學是一所位於英國倫敦的公立研究型大學(如圖3)，於1907年由皇家科學院(Royal College of Science)、大英帝國研究院(The Imperial Institute)、皇家礦業學院(Royal school of mines)和倫敦城市與行會學院(City and Guilds of London Institute)合併組成。楊員於2015年8月3日參訪倫敦帝國大學材料工程學系Professor Stephen J. Skinner和Professor John Kilner研究團隊，進行金屬支撐固態氧化物燃料電池發展現況簡報，簡報結束後於Professor Skinner引導下參觀全系實驗室，了解該單位固態氧化物燃料電池研究發展領域、關鍵性技術和研發設備，與專業人力交流，促進雙方與合作。

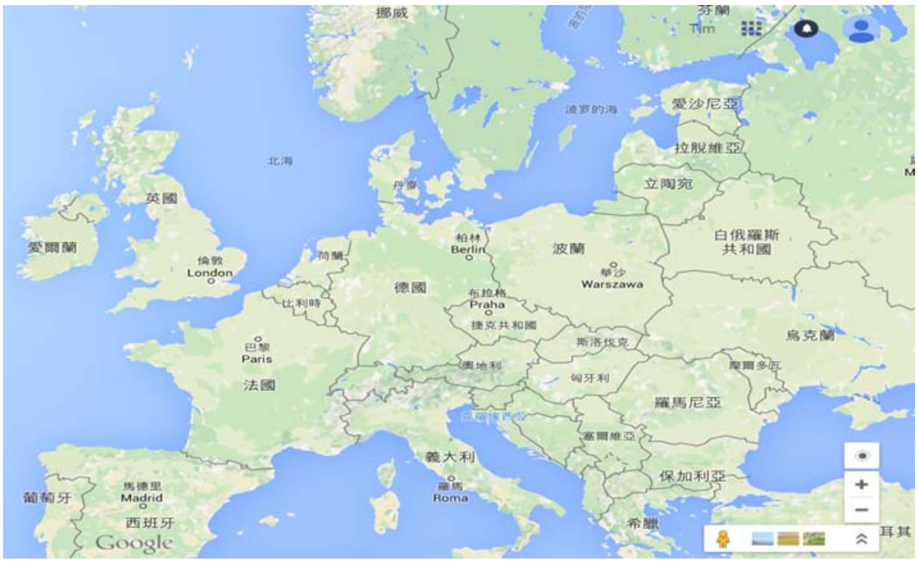


圖 1 英國於歐洲相對地理位置

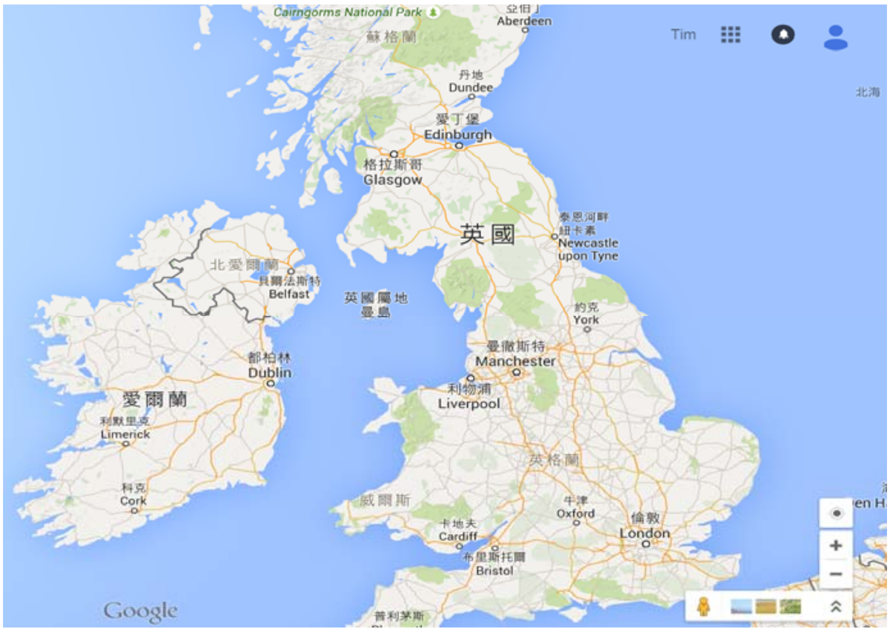


圖 2 英國蘇格蘭格拉斯哥市

圖 3 英國倫敦帝國大學

(二) 行程說明

1. 去程

去程搭乘長榮航空公司由桃園機場出發，中途於泰國曼谷蘇凡納布機場(Suvarnabhumi Airport)停留1小時後，再飛抵英國倫敦希斯洛機場(London Heathrow Airport)，航行時間16小時30分鐘。抵達倫敦後，由倫敦Euston車站搭乘維珍鐵路(Virgin Trains)，至格拉斯哥中央火車站(Glasgow Central station)，再前往本屆會議舉辦場地蘇格蘭會展會議中心(Scottish Exhibition and Conference Centre, SECC)。

A. 7月25日(星期六)

09:00由台灣桃園國際機場搭乘長榮航空BR-067班機(如圖4)起飛前往英國倫敦，於13:00抵達泰國曼谷蘇凡納布機場停留1小時，更換新一批機組人員後，於14:00原班機起飛前往英國倫敦。

B. 7月25日(星期六)

於倫敦時間晚上19:45抵達希斯洛機場，辦理完成出關手續後，轉搭地鐵前往住宿地點，辦理住宿等相關事宜，本日主要行程為飛行航程與住宿確認。

C. 7月26日(星期日)

09:00搭乘地鐵前往倫敦Euston車站，10:30搭乘維珍鐵路(如圖5)前往蘇格蘭格拉斯哥市，並於15:01抵達格拉斯哥中央火車站，轉搭市區公車前往住宿地點，辦理住宿等相關事宜。

圖 4 台灣桃園國際機場搭乘長榮航空班機前往英國倫敦


圖 4 搭乘維珍鐵路前往蘇格蘭格拉斯哥市

2. 參加會議

美國電化學學會主辦之第十四屆國際固態氧化物燃料電池研討會於2015年7月26日~2015年7月31日，在英國蘇格蘭格拉斯哥市蘇格蘭會展會議中心(圖5)舉行。內容涵蓋SOFC電池片、電池堆和電池系統之設計、效能、與耐久性探討；陽極材料、電解質材料、陰極材料製程和效能；連接板與鍍保護膜、模擬、相容性燃料運轉、固態氧化物電解電池等議題。會議過程中，與國際學者及專家進行多方之交流，俾利於SOFC 之技術發展與國際接軌，及SOFC產業聚落之形成，為國內創造一新興能源產業。會議之主要議程安排、口頭簡報之議程和海報展示之議程如附錄五。詳細之大會議程表可參考第十四屆國際固態氧化物燃料電池研討會會議網站：http://www.electrochem.org/meetings/satellite/glasgow/。本所於本屆會議總計發表口頭論文1篇、海報論文1篇，分別為：

I. 口頭論文發表(摘要如附錄六)

楊昇府等人之論文題目：Ni-Mo Porous Alloy Fabricated As Supporting Component for Metal-Supported Solid Oxide Fuel Cell and Cell Performance。

II. 海報論文發表(摘要如附錄七)

林泰男等人之論文題目：Fabrication of $SmBa_{0.5}Sr_{0.5}Co_2O_{5+\delta}$ Cathode Material and Its Application for Sr- and Mg-Doped $LaGaO_3$ Electrolyte-Supported Solid Oxide Fuel Cell。

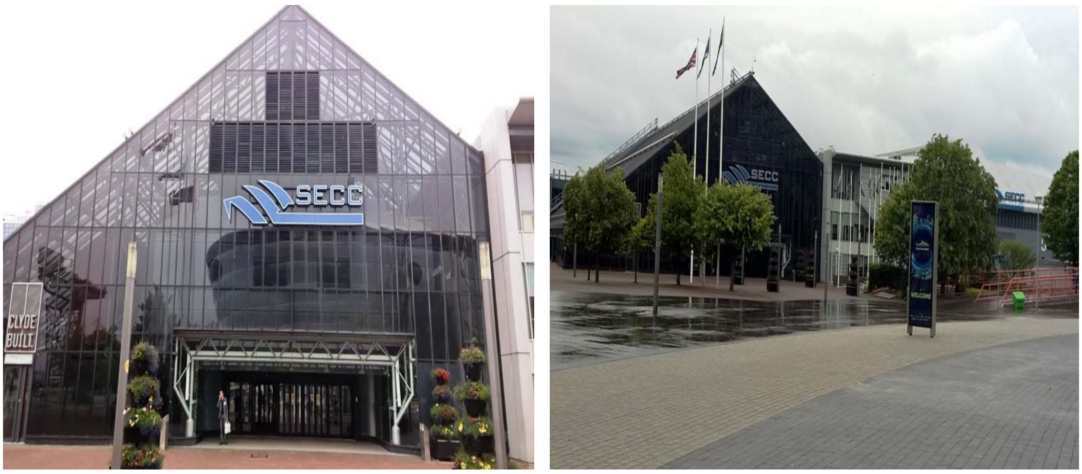


圖 5 蘇格蘭會展會議中心

A. 7月27日(星期一)

本日為會議註冊日，楊員於是日進行報到、資料領取及熟悉會場附近環境，並且完成大會報到註冊，如圖6和圖7所示。本屆會議主席由美國太平洋西北國家實驗室(Pacific Northwest National Laboratory, PNNL) Dr. Subhash C. Singhal以及日本京都大學(Kyoto University) Professor Koichi Eguchi共同擔任，此外24場學術研討會於蘇格蘭會展會議中心三個大型會議室舉行(Boisdale, Lomond Auditorium, Alsh)，各分組議程邀請兩位協同主席，主持與引導會議進行。

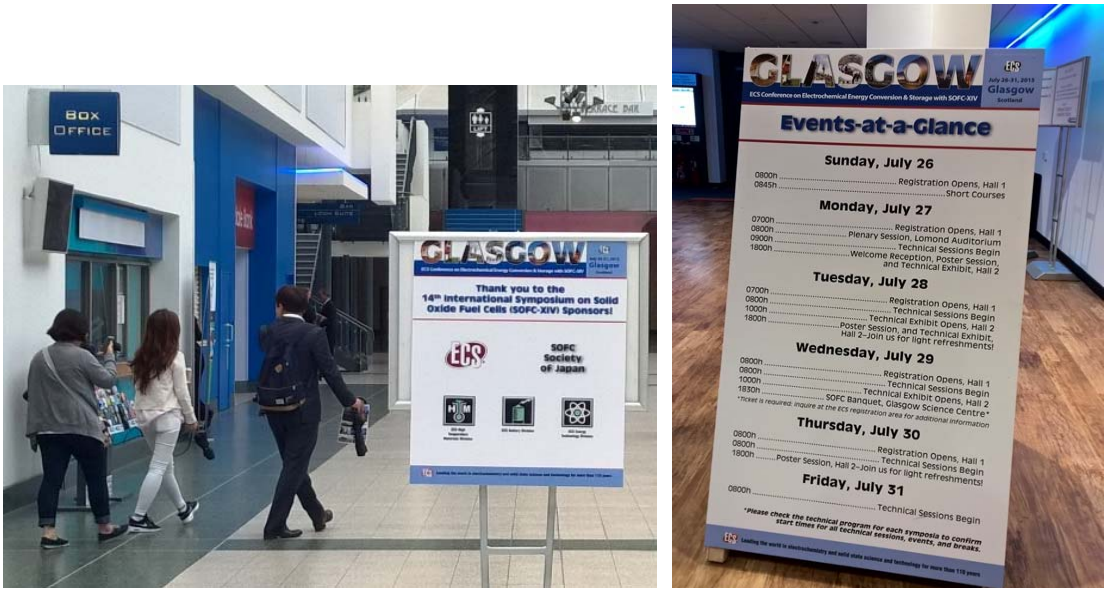


圖 6 本屆會議舉辦地點

圖 7 報到註冊

7月27日上午08:00 正式進行大會議程，首先由大會主席Dr. Singhal進行簡短引言，報告國際SOFC最新之技術進展，隨即進入時程為1小時的ECS Plenary Session (圖8)，由英國倫敦帝國大學地球科學與工程學系Professor Nigel Brandon主

講電化學於能源領域的應用，敘述電化學科技包括燃料電池、鋰離子電池、液流電池、超級電容等，於實現安全和永續的能源系統所扮演的腳色和價值。

圖 7 ECS Plenary Session

ECS Plenary Session結束後進行四場Plenary Lecture，分別由歐盟燃料電池暨氫氣聯合企業(Fuel Cells and Hydrogen Joint Undertaking, FCH-JU) Dr. Atanasiu報告SOFC在燃料電池暨氫氣聯合企業的計畫中的研究與發展現況、日本新能源產業綜合開發機構(New Energy and Industrial Technology Development Organization, NEDO) Dr. Kadowaki 闡述日本國家級SOFC計畫的近況、美國能源部國家能源技術實驗室(United States Department of Energy National Energy Technology Laboratory) Dr. White 敘述美國能源部的石化能源SOFC計畫的成果、發展情形與規劃藍圖、博思艾倫漢密爾頓控股公司(Booz Allen Hamilton)及美國能源高等研究計劃署(Advanced Research Projects Agency-Energy, ARPA-E) Dr. Litzelman解說中溫燃料電池(Intermediate Temperature Fuel Cells; range between 200℃~500℃)希望和挑戰。下午開始進行各議題的研討，包括Cathodes (1)、Cells and Stacks (1)、System (1)

7月27日晚上18:00~20:00為第一場海報論文發表(Poster Session 1)，主題包括SOFC System、Cathodes、Interconnects和SOECs，楊員協助林泰男等人發表之海報論文Fabrication of $SmBa_{0.5}Sr_{0.5}Co_2O_{5+\delta}$ Cathode Material and Its Application for Sr- and

Mg-Doped LaGaO₃ Electrolyte-Supported Solid Oxide Fuel Cell，如圖8所示，現場記錄相關問題詢問和回答，並帶回相關資訊供該團隊參考。過程中與九州大學Professor Tatsumi Ishihara進行討論與交流，傳達李瑞益副組長與林泰男博士問候之意。

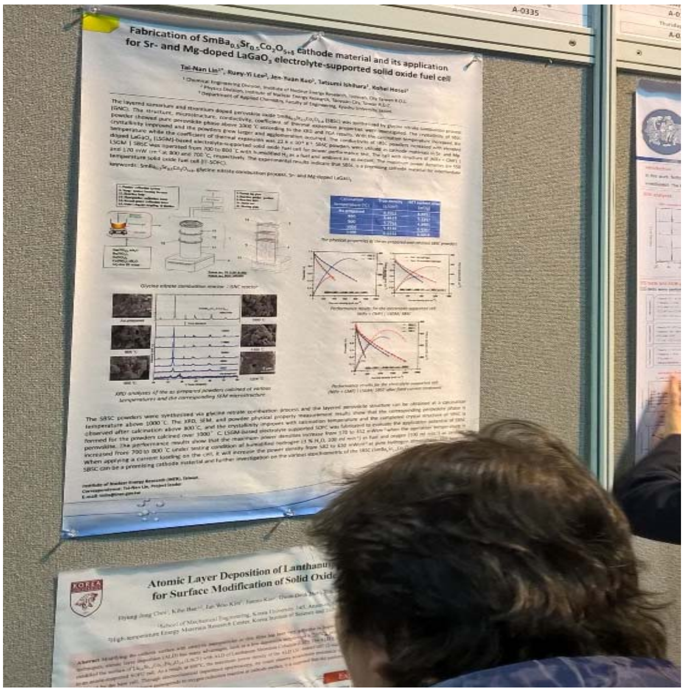
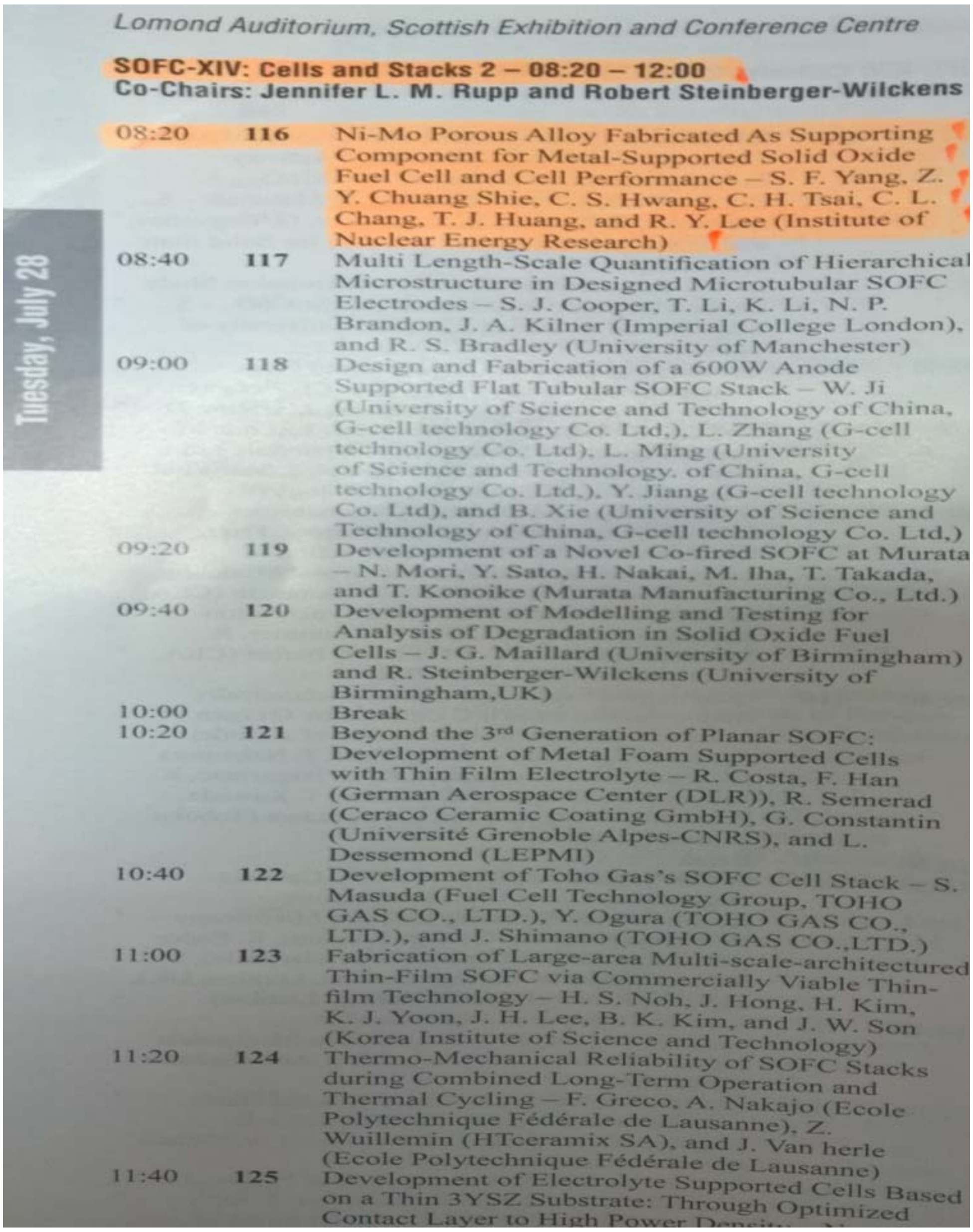


圖 8 林泰男等人發表之海報論文

B. 7月28日(星期二)

今天是研討會舉行的第二天，早上08:20開始，議程包括Cathodes (2和3)、Cells and Stacks (2和3)、System (2)、Interconnects and Interconnect Coatings。楊員今日早上08:20 Cells and Stacks (2)議程(圖9)，於Lomond Auditorium (圖10~圖12)口頭發表論文" Ni-Mo Porous Alloy Fabricated As Supporting Component for Metal-Supported Solid Oxide Fuel Cell and Cell Performance "，報告鎳鉬多孔金屬合金支撐基板compression molding 研製包括起始物料噴霧造粒增加流動性與塑性，作為多孔金屬基板的加壓成型前驅原料、compression molding 最佳成型操作條件建立及適宜煅燒溫度探討，加壓成型後的生胚試體，煅燒溫度區間為1000℃~1250℃，可獲得完整多孔金屬合金基板，再藉由大氣電漿噴塗技術將功能層包括陽極、電解質

和陰極被覆於合金基板上，做成SOFC電池片，測試與呈現電池片性能。展現本所於金屬支撐型固態氧化物燃料電池片之技術進展，簡報內容(如附錄八所示)受到與會成員關注，與會成員熱烈提問，於休息時間與其他專家學者有熱烈討論。晚上18:00~20:00為第二場海報論文發表(Poster Session 2)，主題包括SOFC Fuels、Anodes和Modeling。



Lomond Auditorium, Scottish Exhibition and Conference Centre

SOFC-XIV: Cells and Stacks 2 – 08:20 – 12:00
Co-Chairs: Jennifer L. M. Rupp and Robert Steinberger-Wilckens

Tuesday, July 28

08:20	116	Ni-Mo Porous Alloy Fabricated As Supporting Component for Metal-Supported Solid Oxide Fuel Cell and Cell Performance – S. F. Yang, Z. Y. Chuang Shie, C. S. Hwang, C. H. Tsai, C. L. Chang, T. J. Huang, and R. Y. Lee (Institute of Nuclear Energy Research)
08:40	117	Multi Length-Scale Quantification of Hierarchical Microstructure in Designed Microtubular SOFC Electrodes – S. J. Cooper, T. Li, K. Li, N. P. Brandon, J. A. Kilner (Imperial College London), and R. S. Bradley (University of Manchester)
09:00	118	Design and Fabrication of a 600W Anode Supported Flat Tubular SOFC Stack – W. Ji (University of Science and Technology of China, G-cell technology Co. Ltd.), L. Zhang (G-cell technology Co. Ltd), L. Ming (University of Science and Technology. of China, G-cell technology Co. Ltd.), Y. Jiang (G-cell technology Co. Ltd), and B. Xie (University of Science and Technology of China, G-cell technology Co. Ltd.)
09:20	119	Development of a Novel Co-fired SOFC at Murata – N. Mori, Y. Sato, H. Nakai, M. Iha, T. Takada, and T. Konoike (Murata Manufacturing Co., Ltd.)
09:40	120	Development of Modelling and Testing for Analysis of Degradation in Solid Oxide Fuel Cells – J. G. Maillard (University of Birmingham) and R. Steinberger-Wilckens (University of Birmingham,UK)
10:00		Break
10:20	121	Beyond the 3rd Generation of Planar SOFC: Development of Metal Foam Supported Cells with Thin Film Electrolyte – R. Costa, F. Han (German Aerospace Center (DLR)), R. Semerad (Ceraco Ceramic Coating GmbH), G. Constantin (Université Grenoble Alpes-CNRS), and L. Dessemond (LEPMI)
10:40	122	Development of Toho Gas's SOFC Cell Stack – S. Masuda (Fuel Cell Technology Group, TOHO GAS CO., LTD.), Y. Ogura (TOHO GAS CO., LTD.), and J. Shimano (TOHO GAS CO.,LTD.)
11:00	123	Fabrication of Large-area Multi-scale-architectured Thin-Film SOFC via Commercially Viable Thin-film Technology – H. S. Noh, J. Hong, H. Kim, K. J. Yoon, J. H. Lee, B. K. Kim, and J. W. Son (Korea Institute of Science and Technology)
11:20	124	Thermo-Mechanical Reliability of SOFC Stacks during Combined Long-Term Operation and Thermal Cycling – F. Greco, A. Nakajo (Ecole Polytechnique Fédérale de Lausanne), Z. Wuillemin (HTceramix SA), and J. Van herle (Ecole Polytechnique Fédérale de Lausanne)
11:40	125	Development of Electrolyte Supported Cells Based on a Thin 3YSZ Substrate: Through Optimized Contact Layer to High Power Densit…

圖 9 楊員於Cells and Stacks (2)口頭發表論文議程

圖 10 於Lomond Auditorium口頭發表論文(1)

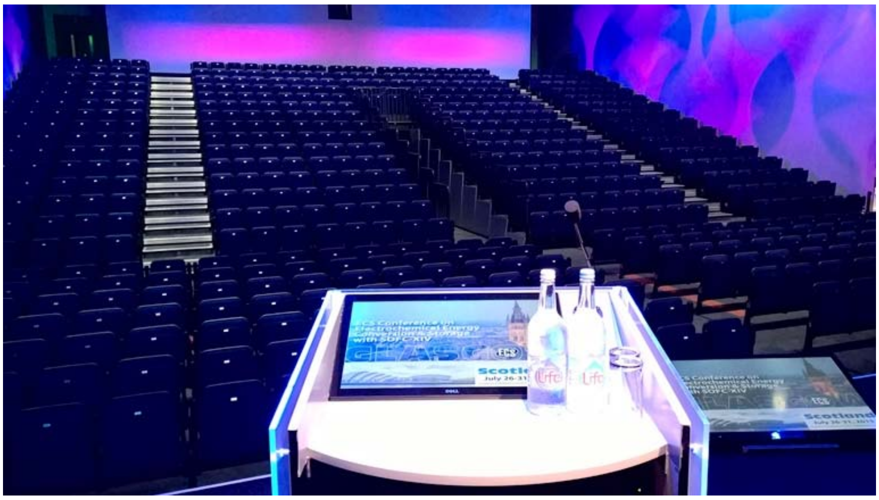


圖 11 於Lomond Auditorium口頭發表論文(2)

圖 12 Cells and Stacks (2)議程兩位協同主席

7月29日(星期三)

會議進行第三天，口頭論文發表議程包括Anodes (1)、Cells and Stacks (4)、Modeling (1)，是日議程楊員全程聽講，並於休息時間與加州大學聖地牙哥分校能源研究中心Dr. Nguyen Minh進行討論與交流(圖 13)，傳達核能研究所與李瑞益副組長問候之意。本屆會議之廠商參展於今日結束，共有23家廠商參與展覽，分別為Alvatek LTD.、Blue Scientific LTD.、CAP CO., LTD、Ceramic Powder Technology AS、DOWA HD Europe GmbH、ec-lab/Bio-Logic、EL-CELL GmbH、ESL ElectroScience、The Expanded Metal Company、Fiaxell Sàrl、Flexitallic、Forschungszentrum Jülich、Fuel Cell Materials、FuelCon AG、Gamry Instruments、Kyoto University、Metrohm AutoLab UK、Noritake/DJK Europe、Pine Research Instrumentation、Praxair Surface Technologies, Inc.、STFC, ESRN & Energy SUPERSTORE、WMG Centre HVM Catapult和ZAHNER-elektrik。

圖 13 楊昇府博士與加州大學聖地牙哥分校能源研究中心Dr. Minh合影

7月30日(星期四)

今日白天議程包括Anodes (2和3)、Cells and Stacks (5和6)、Modeling (2)、Solid Oxide Electrolysis / Reversible Cells (1)，是日議程楊員全程聽講。晚上18:00~20:00為第三場海報論文發表(Poster Session 3)，主題包括SOFC Fuels、Anodes和Modeling。發表本屆會議之海報論文發表議程於今日結束。

7月31日(星期五)

今日為本屆會議最後一天，議程包括Cells and Stacks (7和8)、Fuels and Fuel Compatibility、Solid Oxide Electrolysis / Reversible Cells (2和3)、Electrolytes，是日議程楊員全程聽講，並於休息時間與會議主席美國西北太平洋國家實驗室Dr. Subhash C. Singhal進行討論與交流(圖 14)，傳達核能研究所與李瑞益副組長問候之意。最後Closing Session會議主席Dr. Singhal宣佈兩年後，2017第十五屆國際固態氧化物燃料電池研討會(The Fifteenth International Symposium on Solid Oxide Fuel Cells, SOFC-XV)將於美國佛羅里達州好萊塢Diplomat Resort & Spa舉行，如圖15所示，歡迎大家再次共享盛舉，與燃料電池一流人才進行技術探討，並於此國際資訊交流之重要平台，收集廣泛且深入的技術資訊。

圖 14 楊昇府博士和會議主席PNNL Dr. Singhal、國際學者合影

圖 15 2017第十五屆國際固態氧化物燃料電池研討會訊息

3.　參觀訪問英國倫敦帝國大學

8月1日(星期六)

10:00搭市區公車前往格拉斯哥中央火車站，11:40搭乘維珍鐵路(如圖16)前往倫敦Euston車站，準備參觀訪問英國倫敦帝國大學，途中因交通號誌故障與事故，原搭乘火車於Preston停靠約一個半小時，最後列車長告知火車須返回格拉斯哥中央火車站，原車所有乘客須改搭下一班或下下一班火車前往倫敦Euston車站，而且所有人幾乎站至目的地(約2小時)，因此插曲下午18:00才抵達倫敦，楊員前往倫敦途中已與飯店通電話，告知此一變故，會較晚抵達飯店，之後轉達搭乘地鐵前往住宿地點，辦理住宿等相關事宜。

圖16　格拉斯哥中央火車站

8月2日(星期日)

本日行程主要上午為準備前往倫敦帝國大學材料系簡報資料，下午15:00前往倫敦帝國大學熟悉附近環境與交通方式(圖17~圖19)，避免隔天因天候或交通因素導致遲到等情形發生，使得參觀訪問能順利完成。

圖17　倫敦帝國大學附近環境(1)

圖18 倫敦帝國大學附近環境(2)

圖20 倫敦帝國大學材料系系館

8月3日(星期一)

早上08:30由住宿地點出發，搭乘地鐵前往英國倫敦帝國大學材料學系，拜訪Professor Stephen J. Skinner 和Professor John Kilner研究團隊，進行參觀與訪問，09:10抵達倫敦帝國大學皇家礦業學院大樓(圖21)，材料系便位於該棟建築物內部，09:30先於其一樓大廳(圖22和圖23)辦理報到手續，櫃台小姐電話通知Professor

Skinner前來與楊員碰面，簡短寒暄後，帶至其辦公室與會議室進行交流(圖23)與報告(如附錄九所示)，題目：Metal-Supported Solid Oxide Fuel Cell at INER，報告時間為30分鐘，彰顯本所於第三代固態氧化物燃料電池相關領域研發成果與近況，藉由參訪機會進行交流討論並瞭解倫敦帝國大學最新之燃料電池相關研發現況，尋求可能之技術推廣及合作機會，建立與強化彼此合作關係及增益本所研發技術，俾利於本所研發計畫及執行相關委託研究計畫工作之順利及加速推動。

圖21倫敦帝國大學皇家礦業學院大樓

圖22倫敦帝國大學皇家礦業學院大樓一樓大廳

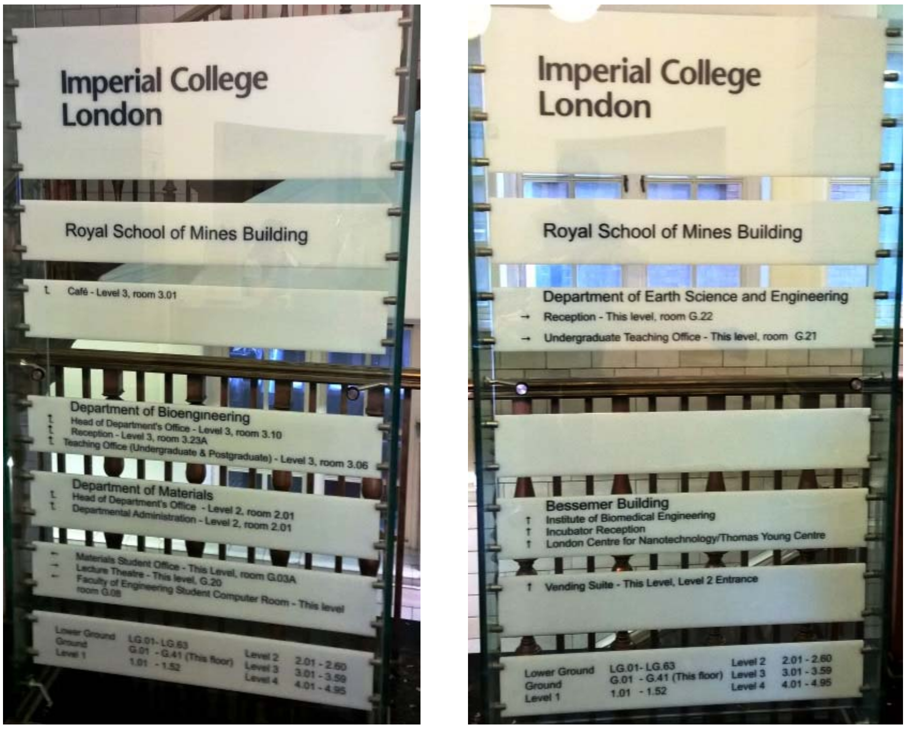


圖23倫敦帝國大學皇家礦業學院大樓共有3個系所

Professor Skinner緊接著闡述他們研究團隊開發離子氧化物導體(Oxide ion conductor) 或離子傳導型氧化物(Ion conducting oxide) La_2MoO_9於SOFC和固態氣體偵測器的應用。如何使用X射線和中子粉末繞射技術(X-ray and Neutron Powder Diffraction Techniques)、二次離子質譜儀(Secondary Ion Mass Spectrometry)和低能量離子散射(Low Energy Ion Scattering)等高溫技術針對離子氧化物導體的特性及結構進行科學探討。

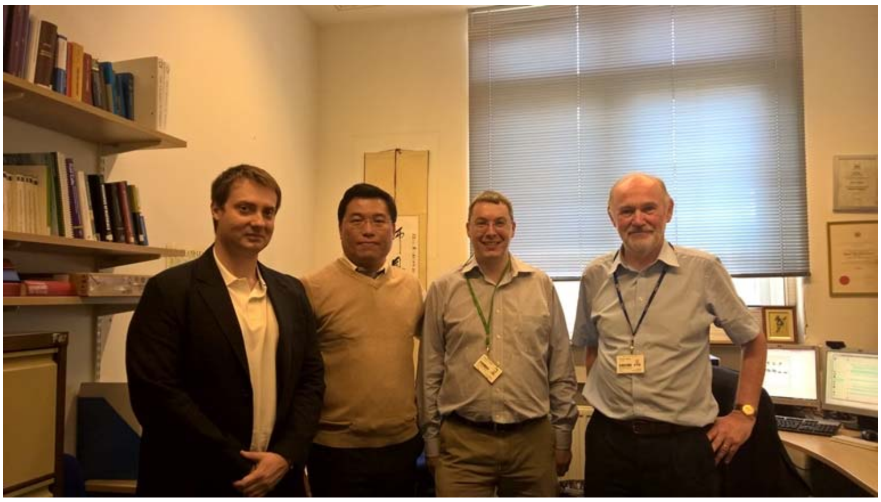


圖24楊昇府博士和Professor Skinner、Professor Kilner、國際學者合影

簡報結束後，在Professor Skinner的引導下參觀材料系的相關實驗室與貴重儀器設備。主要包括高壓光電質譜儀、低能量離子散射儀、穿透式電子顯微鏡與X光繞射儀和燃料電池特性量測設備。

A. 高壓光電質譜儀(High Pressure Photoelectron Spectroscopy, HiPPES)

高壓光電質譜儀(VG Scienta R4000 HiPP-2 XPS/UPS analyzer) (圖25)主要由X射線光電質譜儀(X-ray Photoelectron Spectroscopy, XPS)和紫外光光電質譜儀(Ultra-Violet Photoelectron Spectroscopy, UPS)組成，用來分析材料的表面，獲得材料元素的組成和電子特性等關鍵資訊。相關設備包括X-ray (MX650 monochromated X-ray source)、UV (VG Scienta VUV5000 monochromated UV source)、低能量電子槍(FG 300 flood gun)、電子能量偵測器和高壓可調式腔體，操作腔體壓力由超真空到25 mbar皆可量測，可調控樣品分析溫度為-140℃到1000℃，樣品製備前處理腔體有Argon Sputter和Electron Beam Annealing來做表面清潔和局部加熱。

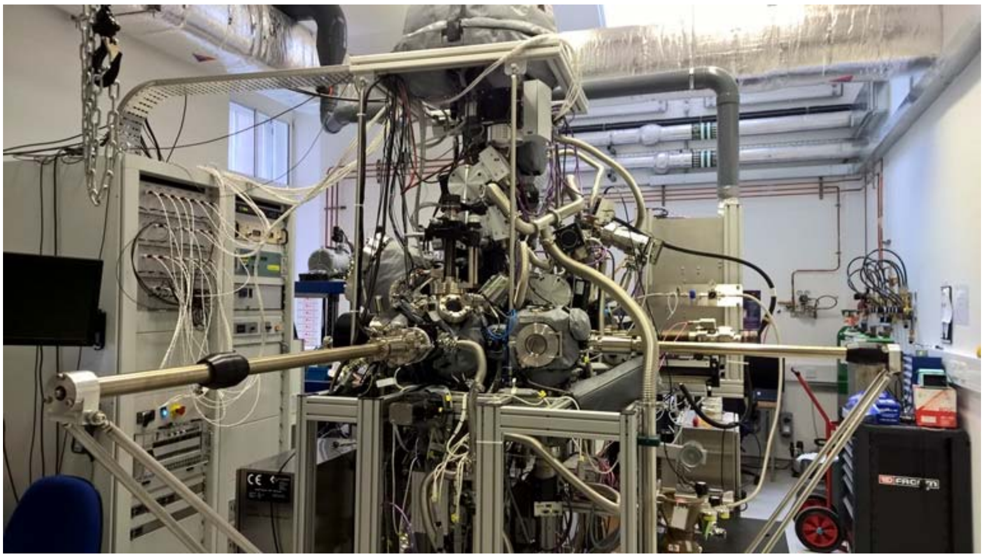


圖25 高壓光電質譜儀(High Pressure Photoelectron Spectroscopy, HiPPES)

B. 低能量離子散射儀(Low Energy Ion Scattering)

低能量離子散射儀具有很高的表面敏感度，可以僅量測第一原子單層(First Atomic Monolayer)的化學組成，這台設備在英國是獨一無二，在世界上也是少有。材料系將低能量離子散射儀和飛行時間二次離子質譜儀(Time of Flight Secondary

Ion Mass Spectrometer)組態結合在一起，形成IONTOF TOF.SIMS5-Qtac100LEIS (圖26)，增加研究的廣度和深度。

圖26 低能量離子散射儀結合飛行時間二次離子質譜儀

C. 穿透式電子顯微鏡與X光繞射儀

穿透式電子顯微鏡(Transmission Electron Microscopy, TEM)與X光繞射儀(X-Ray Diffraction, XRD)在材料科學領域是重要的分析技術和方法，在國內也相當常見。在倫敦帝國大學材料系TEM至少兩台(圖27)，XRD至少6台(包括4台一般型和2台精密型)如圖28所示。研究資源相當充足，可為借鏡。

圖27穿透式電子顯微鏡

圖28 一般型和精密型X光繞射儀

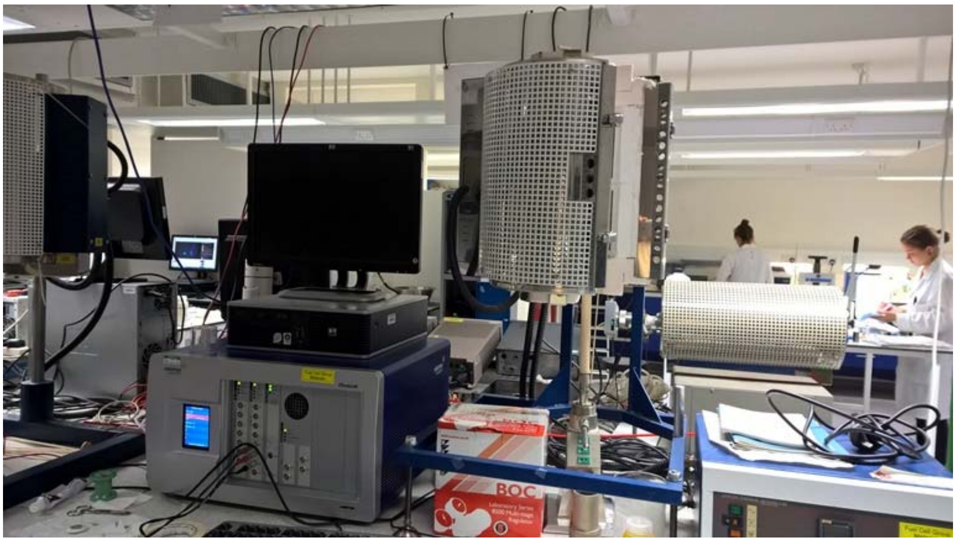


圖29 電池電性量測設備

D. 燃料電池特性量測設備

燃料電池特性量測設備為確認電池性能表現的工具之一，倫敦帝國大學材料系電池製作尺寸主要為Button Cell，注重於基本科學研究與探討，相當深入且扎實，提供商業化電池片務實的性能改善及減少成本建議。功能層則藉由網版印刷技術，將之網印於支撐材上，經由燒結獲得電池片，置於烘箱中保存。該系電池特性量測設備加熱爐體主要有立式和臥式兩種，至少都有四台以上，供學生與研究人員使用，進行測試與量測，立式量測電性表現(如圖29)，臥式則測量阻抗(如圖30)。

圖30 電池阻抗量測設備

4. 回程

本次參加國際會議口頭發表論文及參觀訪問倫敦帝國大學，於英國時間2015年8月3日下午結束，楊員於8月4日返程，回程路線及航班安排同來程，由倫敦希斯洛國際機場起飛，返回台灣桃園國際機場。

A. 8月4日(星期二)

20:00於倫敦希斯洛國際機場辦理完成出境手續，21:35搭乘長榮航空公司BR-68班機返回台灣桃園國際機場。

B. 8月5日(星期三)

於21:10抵達台灣桃園國際機場，順利完成出國公差任務。

三、心得

(一) 楊昇府博士本次赴英國蘇格蘭格拉斯哥市參加第十四屆國際固態氧化物燃料電池研討會並順利完成口頭論文發表。國際固態氧化物燃料電池研討會於1989年開始舉辦，每兩年舉辦一次，持續至今已26年，為國際SOFC領域最重要的資訊交流平台。本次大會舉辦總計共有24場學術研討會，來自世界各地45個國家六百餘專業人士參加，420篇論文投稿，口頭發表268篇，海報發表152篇，為歷年之最(SOFC-XI、SOFC-XII及SOFC-XIII分別為 363篇、349篇及373篇)。參加人員主要來自歐美國家、日本、中國與韓國，台灣僅有6個單位，分別為核能研究所、成功大學、中央大學、元智大學、交通大學、台灣科技大學等，共投稿論文9篇。本所在台灣為固態氧化物燃料電池研究與發展的領頭羊，在此大型國際會議與重要新能源議題，站上講台為所與台灣發聲實屬難得，未來應該提供充足經費與支援，持續派人參加此SOFC重要會議，站上國際講台為所與台灣在此研究領域發聲與國際人士進行交流。

(二) 國際固態氧化物燃料電池研討會提供國際間從事SOFC研究的研發人員及業界一個優質的交流平台，並建立國際間彼此的連結及促進友好關係。本次公差主要接觸的國際學者有會議主席美國西北太平洋國家實驗室Dr. Subhash C. Singhal、加州大學聖地牙哥分校能源研究中心Dr. Nguyen Minh、九州大學Professor Tatsumi Ishihara進行討論與交流，楊員於會議期間展現研究成果，於會後分享研究心得，研發成果受到肯定。

(三) 英國倫敦帝國大學為世界知名一流大學，於固態氧化物燃料電池研究發展領域、關鍵性技術、研發設備、專業人力等具有相當高的水準。該校由材料系、化學系、化工系、電子工程系、機械工程系和地球科學與工程學系的幾位教授與研究人員組成一Fuel Cell Network，如圖31所示，針對陽極、電解質和陰極等功能層材料進行研究開發及基礎研究。本次參觀與訪問倫敦帝國大學，主要拜訪Professor Stephen J. Skinner 和Professor John Kilner研究團隊，進行交

流與報告，彰顯本所於第三代固態氧化物燃料電池相關領域研發成果與近況，藉由參訪機會進行交流討論並瞭解倫敦帝國大學最新之燃料電池相關研發現況，尋求可能之技術推廣及合作機會，建立與強化彼此合作關係及增益本所研發技術。Professor Skinner闡述他們研究團隊開發離子氧化物導體(Oxide ion conductor) 或離子傳導型氧化物(Ion conducting oxide) La_2MoO_9於SOFC和固態氣體偵測器的應用。雖然於應用於SOFC尚有待進一步驗證，但應用於固態氣體偵測器具有相當好的表現，本所若開發離子氧化物導體除了考量於燃料電池的應用外，在相同原理之下，也可衡量該材料於固態氣體偵測器的使用。

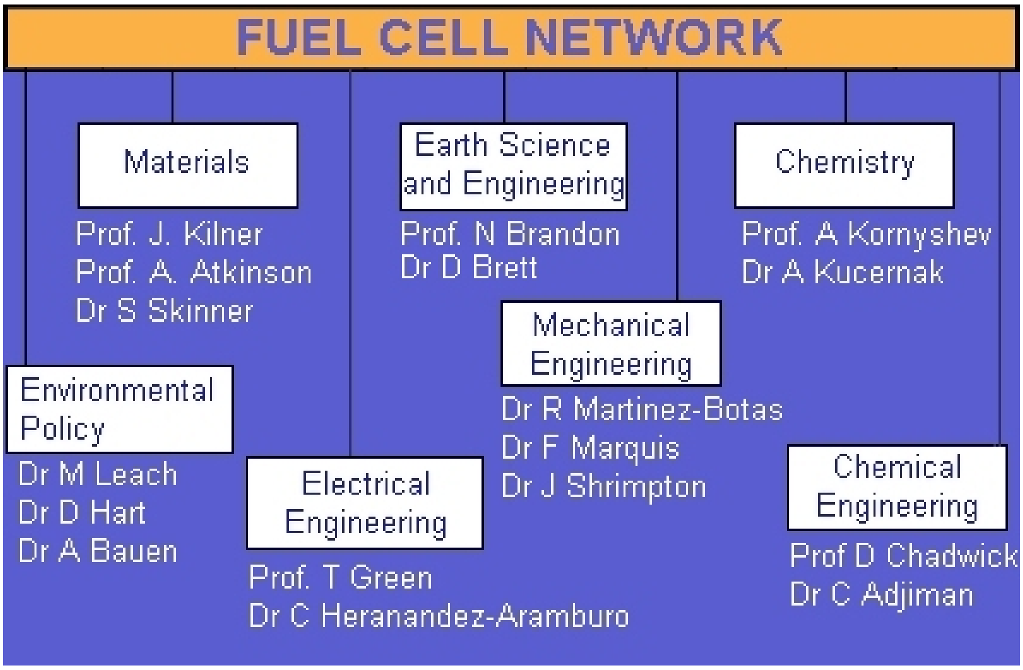


圖31 英國倫敦帝國大學燃料電池研究團隊

(四) Professor Skinner的引導下參觀材料系的相關實驗室與貴重儀器設備。主要包括高壓光電質譜儀、低能量離子散射儀、穿透式電子顯微鏡與X光繞射儀和燃料電池特性量測設備。高壓光電質譜儀主要由X射線光電質譜儀和紫外光光電質譜儀組成，用來分析材料的表面，獲得材料元素的組成和電子特性等關鍵資訊，可調控樣品分析溫度為-140℃到1000℃。低能量離子散射儀具有很高的表面敏感度，可以僅量測第一原子單層(First Atomic Monolayer)的化學

組成，這台設備在英國是獨一無二，在世界上也是少有，該系將之與飛行時間二次離子質譜儀，結合在一起，形成IONTOF TOF.SIMS5-Qtac100LEIS增加研究的廣度和深度，對於基礎科學研究相當有幫助。

(五) 穿透式電子顯微鏡與X光繞射儀在材料科學領域是重要的分析技術和方法，在國內也相當常見。在倫敦帝國大學材料系TEM至少兩台，XRD至少6台(包括4台一般型和2台精密型)，研究資源相當充足。政府於培植重點研究型大學或研究機構在提供經費時可為借鏡，有足夠的且優良的工具，方能培養出一流學生與品質優良的研究結果。

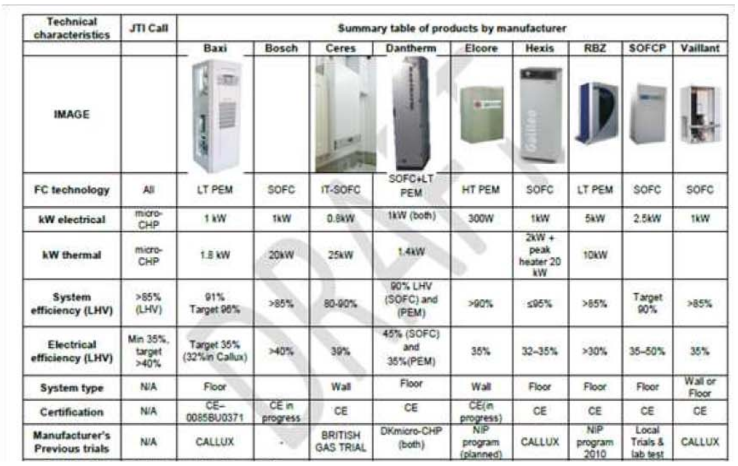
(六) 倫敦帝國大學材料系電池製作尺寸主要為Button Cell，注重於基本科學研究與探討，相當深入且扎實，提供商業化電池片務實的性能改善及減少成本建議。燃料電池特性量測設備加熱爐體主要有立式和臥式兩種，至少都有四台以上，供學生與研究人員使用，進行測試與量測，立式量測電性表現，臥式則測量阻抗，學生與研究人員皆有足夠的量測設備，不會因設備整修或使用量大須排隊，延誤研究時程，可以即時測得燃料電池的相關電性。

(七) 參訪英國倫敦帝國大學時間為8月3日星期一早上09:30，考量天候及交通因素提早於09:10到達，因此發現該校學生於暑假星期一早上仍到學校，且已開始進行所負責相關實驗，一流大學學生的研究精神與熱忱可以做為國內大學的典範。

(八) 固態氧化物燃料電池科技在商業化開發部份有很大的進展，特別在1 kW級SOFC結合汽電共生(Combined Heat and Power, CHP)的民生住宅應用和200 kW級定置式SOFC電力產生器(Stationary Power Generation)。為了讓燃料電池獲得更好的電性表現和系統穩定度，燃料電池相關的研究和發展仍然是相當重要的，還可進一步減少建置成本，使得燃料電池科技可以被普遍接受和使用。

(九) 歐盟燃料電池暨氫氣聯合企業(Fuel Cells and Hydrogen Joint Undertaking, FCH-JU)在2008年設立，主要在加強產業間、歐盟區域國家層級與歐盟層級

的研究單位之間彼此橫向聯繫，增進所有相關公、私部門之間彼此的配合與努力，以確保區域、國家和歐盟各層級間研究單位、工業和政府部門能密切合作，加速燃料電池及氫氣新能源技術發展，朝商業化目標邁進。FCH-JU藉由鼓勵增加固態式氧化物燃料電池單元於運輸與定置式系統於歐盟區域的應用和普及化(圖32)，在經費與政策推動上相當支持，來達到減少成本的目標。FCH-JU在過去6年共補助155個計劃，共4億5千萬歐元的經費，其中1億6百萬歐元的經費用於補助發展SOFC和SOEC技術相關的37個計畫，超過補助能源領域計畫經費的一半，顯示固態氧化物燃料電池或電解電池相對於太陽能與風力等再生能源具有潛力及可靠的效率，因此歐盟燃料電池暨氫氣聯合企業積極投入SOFC和SOEC相關材料及系統之研發及測試，希望達到初期市場應用如手提式設備及攜帶式發電機；定置型燃料系統的應用上如家用與商業用汽電共生系統；在大型市場應用上如交通運輸工具的應用。



Technical characteristics	JTI Call	Summary table of products by manufacturer								
		Baxi	Bosch	Ceres	Dantherm	Elcore	Hexis	RBZ	SOFCP	Vaillant
IMAGE										
FC technology	All	LT PEM	SOFC	IT-SOFC	SOFC+LT PEM	HT PEM	SOFC	LT PEM	SOFC	SOFC
kW electrical	micro-CHP	1 kW	1kW	0.8kW	1kW (both)	300W	1kW	5kW	2.5kW	1kW
kW thermal	micro-CHP	1.8 kW	20kW	25kW	1.4kW		2kW + peak heater 20 kW	10kW		
System efficiency (LHV)	>85% (LHV)	91% Target 96%	>85%	80-90%	90% LHV (SOFC) and (PEM)	>90%	≤95%	>85%	Target 90%	>85%
Electrical efficiency (LHV)	Min 35%, target >40%	Target 35% (32%in Callux)	>40%	39%	45% (SOFC) and 35%(PEM)	35%	32–35%	>30%	35–50%	35%
System type	N/A	Floor		Wall	Floor	Wall	Floor	Floor	Floor	Wall or Floor
Certification	N/A	CE–0085BU0371	CE in progress	CE	CE	CE(in progress)	CE	CE	CE	CE
Manufacturer's Previous trials	N/A	CALLUX	-	BRITISH GAS TRIAL	DKmicro-CHP (both)	NIP program (planned)	CALLUX	NIP program 2010	Local Trials & lab test	CALLUX

圖32 在12個歐盟國家中9家製造商近千組燃料電池單元系統分佈情形

(十) 日本SOFC相關研究計畫主要由經濟產業省(Ministry of Economy, Trade and Industry, METI)轄下的獨立行政法人新能源產業綜合開發機構(NEDO)來組織、管理、執行和宣傳成果。PEFC-based CHP系統(ENE-FARM)和SOFC-based CHP系統(ENE-FARM type S)分別在2009和2011開始有商業化的產品販售，2015年2月的統計數據顯示兩種系統建置數量合起來超過113,000套，但是2015年年底日本政府將取消對於該燃料電池的補助，未來若是進一步的商業

化推廣，如何減少建置成本和增加耐久性方面仍然是一個非常重要的議題，而且上述問題需要被進一步改善。NEDO於2013年開始執行促進固態氧化物燃料電池商業化技術發展的計畫(2013~2017)，如圖33所示。NEDO預計日本在醫院、旅館和辦公大樓等商業化使用SOFC，總共需要750 MW的發電量，目前kW級以上的SOFC發電系統仍處於基本R&D階段，希望藉由該計畫的執行可以加速發展百kW級以上的SOFC發電系統，並期望於2017年實現。

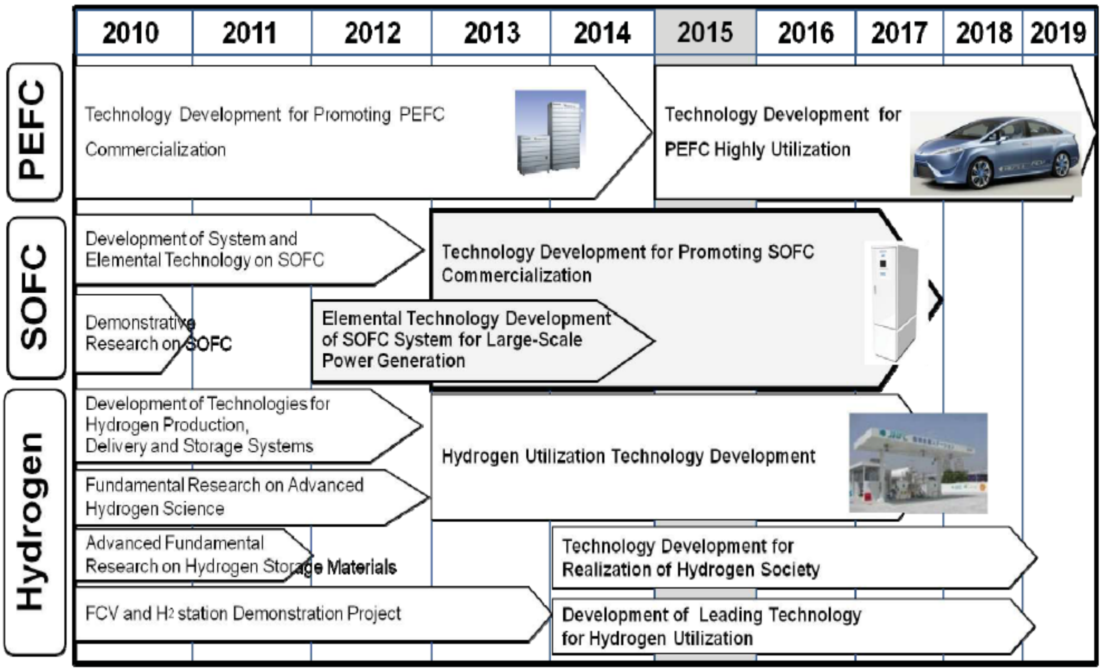


圖33 促進固態氧化物燃料電池商業化技術發展計畫藍圖

(十一) 美國能源部國家能源技術實驗室(NETL)主導、執行與推動固態氧化物燃料電池研究發展的部門，為讓產業、學術及研究機構更緊密地合作，NETL成立固態能源轉換聯盟(Solid State Energy Conversion Alliance, SECA)，主要發展低成本、高效率固態氧化物燃料電池系統，以天然氣或煤碳為發電主要燃料來源，同時達到碳捕抓的目的。SECA針對SOFC商業化所需克服的幾個問題如封裝、電池電力密度、穩定度和低成本連接板等開發，獲得了進展，目前電池測試的表現和衰退率是可以被接受，所以現在SECA計畫目標正聚焦於藉由更大的電池堆和複合式系統的測試(圖34和圖35)來改善

電池堆和系統的表現、可靠度、耐久性。SECA SOFC計畫技術發展的成熟度目前已達到TRL 5系統證明階段(圖36)，商業化等級50 kW電池堆原型系統在真實環境下測試與使用。現階段技術發展成熟度TRL 6的2組60kW和2組125 kW電池堆整合的實驗性系統已持續在真實環境下測試與使用，驗證熱自持電池堆技術(Thermally Self-Sustaining Stack Technology)和電池堆內部燃料重組(In-Stack Fuel Reformation)，操作時間超過1000小時，衰退率每一千小時小於0.5%，2015年年底之前將通入天然氣，發電輸出交流電到電網，預計測試運轉2500小時。產品評估階段TRL 7~8分別為2座400 kW(2016開始以天然氣為燃料，進行實場測試)和MW等級的SOFC商品，預計將在2020左右準備好正式商品佈建工作。由IGFC或NGFC而來合成氣燃料搭配10 MW SOFC結合碳捕抓封存系統，將在2020年之後開始驗證。在一系列重要的大電池堆驗證和系統設置之後，50 MW系統結合IGFC或NGFC預計於2025~2030期間將可完成。

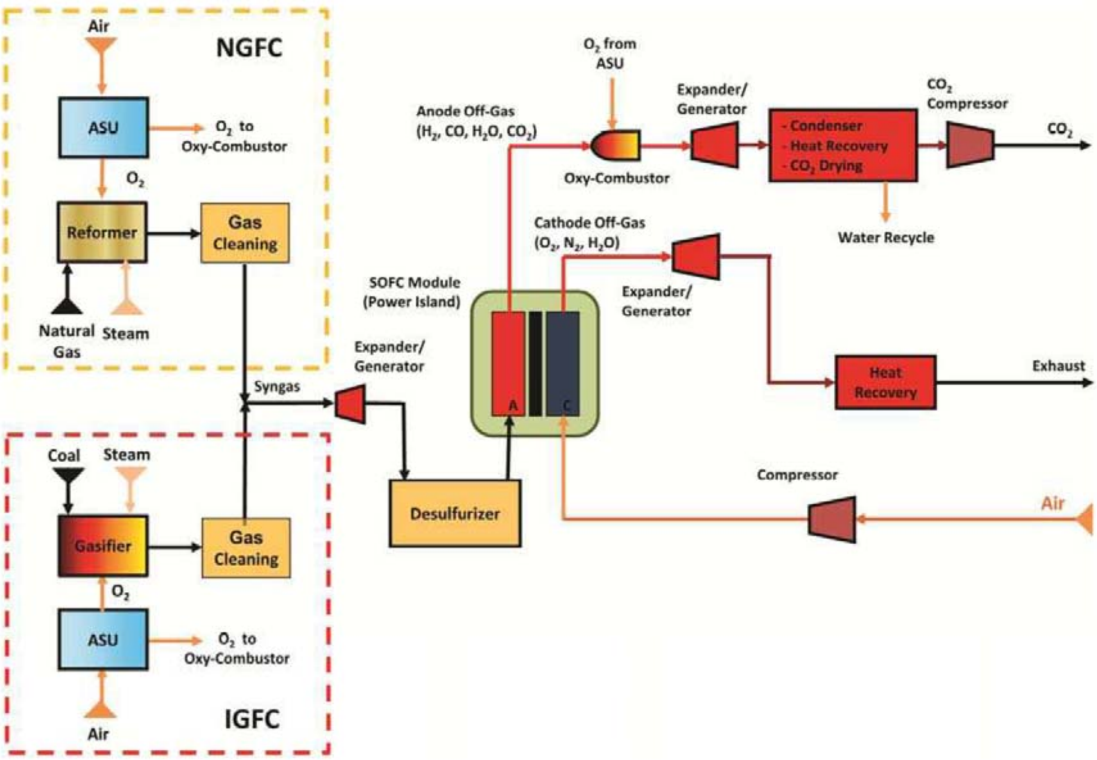


圖34 SECA SOFC複合式系統流程圖

Component	2000		2015	
Interconnect	Dense La-chromite	Expensive, requires high sintering temp.	Stamped Ferretic Stainless Steel + Coating	Low-cost, post-processing possible
Cathode	LSM	High Resistance	LSM+YSZ, LSCF-doped-Ceria	Low Resistance
Electrolyte	Thick YSZ	High Resistance, mechanical support	Thin YSZ + doped-Ceria Barrier Layer	Low Resistance
Anode	Thin Ni-YSZ	Screen-printed Functional Layer	Medium Thickness (~500 microns) Ni-YSZ	Tape-cast, mechanical support
Key Takeaways	High Resistance Requires Operating Temperatures Above ~800C	Cell Power Density Modest (<300 mW/cm2 at 0.6V)	Cheaper Materials and Manufacturing.	High Power Density (>300 mW/cm2 at 0.8V) at Lower Temperatures (600-800C)

圖35 電池功能層的發展與其性能表現

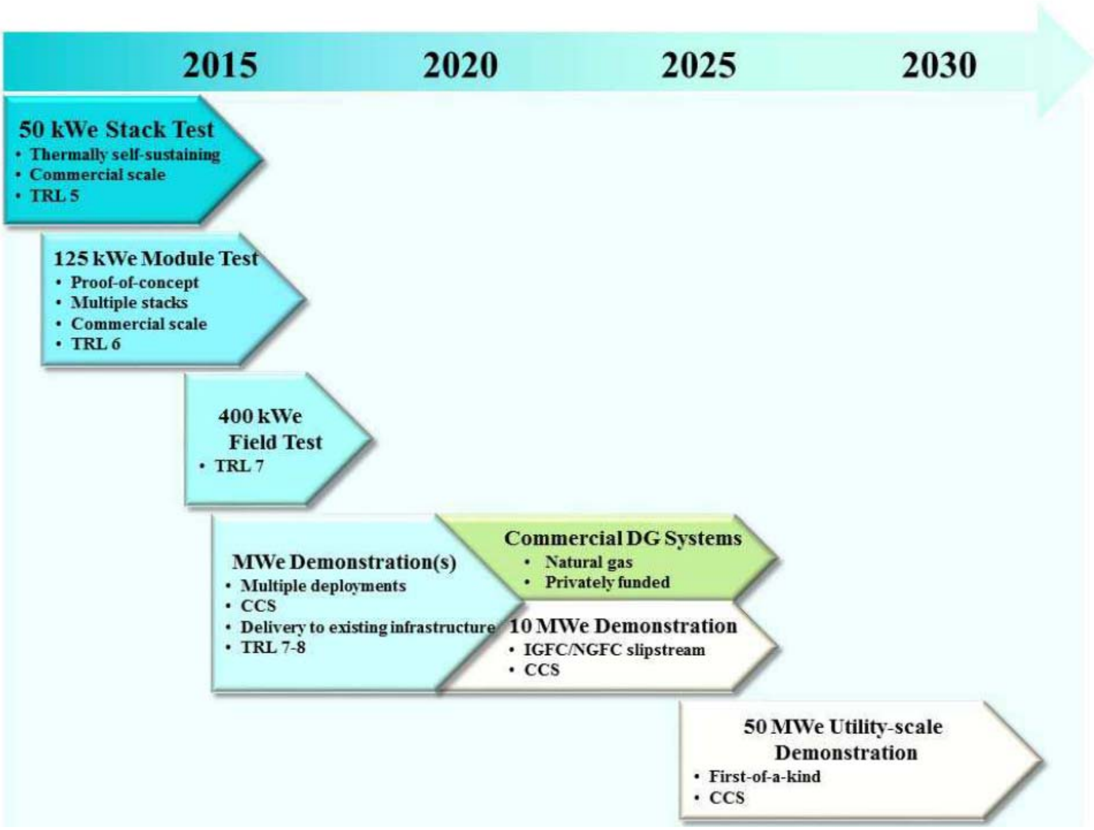


圖36 SECA SOFC計畫發展時間表

四、建議事項

本次出國公差前往英國蘇格蘭格拉斯哥參加由美國電化學學會主辦之第十四屆國際固態氧化物燃料電池研討會口頭發表論文、汲取國際第一手研究內容與參訪英國倫敦帝國大學國際一流專家學者討論互動，個人建議如下：

(一) 由此屆國際會議的發表論文數目(口頭發表268篇，海報發表152篇)、參加人數(超過600人)與國家(非洲、亞洲、澳洲、歐洲、北美洲和南美洲更45個國家)可以發現，世界上對於SOFCs和SOECs的研究及商業化發展的關注持續增加。每兩年舉辦一次的國際固態氧化物燃料電池研討會，儼然成為國際間SOFC 領域的一個相當重要且主要的交流平台。建議計畫未來應持續規劃與派員參加該國際會議，真實呈現國內的研發成果、研究近況、拓展國際人脈關係，加速計畫之進展，使得所內與國內SOFC的研發可與國際接軌，並掌握國際間之發展現況及未來趨勢。

(二) 此屆國際固態氧化物燃料電池研討會每天皆有3個口頭論文發表場地同時進行，總計共有24場學術研討會，另外還有3場海報論文發表研討會於晚間18:00~20:00進行。經由親身參與口頭發表論文，可以促進及充實本職學能，參與會議期間向與會專家學者請益，本所SOFC能源領域議題備受重視及肯定。建議於會議結束後，對於可能互訪或合作之事宜，仍需持續關注或追蹤。

(三) 金屬支撐固態氧化物燃料電池的論文發表逐漸增加，世界知名大學如劍橋大學和倫敦帝國大學皆有相關論文發表，且在口頭報告時聽講人數與之後受到與會者們的踴躍提問可以發現對此研究領域的關注越來越多，相較於本屆會議所發表的固態氧化物燃料電池相關數據而言，本所研發的金屬支撐型固態氧化物燃料電池具有領先的優勢，建議未來可投入更多人力與經費，持續掌握領先優勢，積極研發朝實用化的角度去發展。

(四) 此次英國出國公差參訪倫敦帝國大學，為雙方首次彼此互動和交流，建議未來可以本次所建立的合作管道為基礎，進行互訪、合作或派員交流實習，促

進技術與學術交流，掌握關鍵技術，並了解國際趨勢，有助於計畫之執行，並對我國SOFC領域研發有很大的助益。透過雙方緊密的國際交流與專家討論會議，可拓展研究深度與提升國際同業審查應對能力，並提升本所固態氧化物燃料電池相關技術能力。

(五)歐盟、美國和日本等世界上主要國家，皆由政府單位或國家級研究機構負責管理與協調研究團隊之合作、決定技術發展優先次序及方法，整合產、官、學、研，積極加強所有相關公、私部門之間彼此的配合與努力，以確保各層級間研究單位、工業和政府部門能密切合作，並且提供相當充足的經費。國際各先進國家於SOFC橫向及縱向聯繫整合、能源政策、經費投入程度的相關作為，值得國內各界的參考與借鏡。

五、附錄

附錄一、第十四屆國際固態氧化物燃料電池研討會邀請函

the society for solid-state and electrochemical science and technology

The Electrochemical Society
65 South Main Street
Building D
Pennington, New Jersey
08534-2839
USA

tel 609 737 1902
fax 609 737 2743

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May 19, 2015

Dr. Sheng-Fu Yang
Institute of Nuclear Energy Research
No. 1000, Wenhua Rd., Jiaan Village, Longtan Township,
Taoyuan County, 32546
Taiwan

Dr. Sheng-Fu Yang

We are pleased to inform you that the following submission has been accepted for presentation at the ECS Conference on Electrochemical Energy Conversion & Storage with SOFC-XIV in Glasgow, Scotland (July 26 – 31, 2015):

Abstract Number/Title: # A-0116: Ni-Mo Porous Alloy Fabricated As Supporting Component for Metal-Supported Solid Oxide Fuel Cell and Cell Performance by S. F. Yang, Z. Y. Chuang Shie, C. S. Hwang, C. H. Tsai, C. L. Chang, T. J. Huang, and R. Y. Lee
Presentation Type: Oral
Date/Time/Location: July 28, 2015 / 18:00h / Lomond Auditorium
Symposium: A: Solid Oxide Fuel Cells XIV (SOFC-XIV)

The entire technical program, including abstracts, for the meeting, as well as meeting registration and hotel reservations, is available on the meeting website: ECS website.

MEETING REGISTRATION: All authors attending the Meeting, including invited speakers, must pay the registration fee in order to present their paper. Online registration is open now. The Early-Bird registration deadline is **June 15, 2015**.

HOTEL RESERVATIONS: Glasgow City Marketing Bureau is the official accommodation provider for the conference and has negotiated specially discounted rates with a wide range of hotels. Accommodations will be sold on a first come, first served basis and the published rates will be available until June 15, 2015. Book now to avoid disappointment and secure your discounted rate! When your room is reserved you will receive an immediate confirmation by email. View accommodations and reserve your room now by visiting http://www.peoplemakeglasgow.com/ECSC2015 ! For assistance, telephone, or group bookings please contact the Glasgow City Marketing Bureau at +44 (0) 141 566 0877 / 0820 or accommodation@glasgowcitymarketingbureau.com.

PRESENTATION INFORMATION: Symposium Organizers reserve the right to determine the format of your presentation, whether oral or poster, and therefore may have changed your requested format to fit their symposium schedule. All posters must be displayed in English, on a board approximately .85 meters high by .85 meters wide (33.5 inches high by 33.5 inches wide), and correspond to the abstract number and day of presentation as detailed in the final program. The paper title, number, names, and affiliations of all authors MUST be at the top of the display. Posters for symposia B and C may be displayed during the length of the conference (Monday, Tuesday, and Thursday nights). While posters in symposium A may also display their posters on all three nights, the author(s) MUST be personally present during their primary evening, as noted in the presentation details above. Posters for all three symposia may be mounted between 1200-1600h Monday July 27. The Student Poster Award Presentation for symposium C will take place on Thursday in Hall 2.

PUBLICATIONS: All authors who give a presentation at the meeting are encouraged to submit their paper(s) to the ECS journals (http://ecsdl.org/). All authors are eligible to submit a full-text manuscript to *ECS Transactions* (ECST), the proceedings publications of ECS. Please review the Call for Papers for your symposium to determine the deadline to submit your ECST manuscript. Even if your presentation is accepted in ECS Transactions, you are encouraged to submit your work to the Society's technical journals.

VISA INFORMATION: This letter is frequently used by foreign travelers to obtain a Visa. If you have any questions, please contact meetings@electrochem.org.

Your paper represents an important contribution to the success of the Glasgow ECS Meeting and we appreciate your participation.

Sincerely,

Dr. Johna Leddy; ECS Third Vice-President
Chair, Symposium Planning Advisory Board & Meetings Subcommittee

附錄二、英國倫敦帝國大學邀請函

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Imperial College London

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01 June 2015

Prof. Stephen Skinner FIMMM, FRSC

Dr Sheng-Fu Yang
Associate Engineer, Physics Division
Institute of Nuclear Energy Research (INER)
1000 Wenhua Road, Jiaan Village
Longtan District,
Taoyuan City 32546
Taiwan (ROC)

Dear Dr Yang

Following on from my previous email discussion with Dr Kuan-Ting Wu of ICNER, Japan and Dr Tai-Nan Lin of INER, Taiwan, I am happy to confirm that I will be delighted to host your visit to the Department of Materials at Imperial College London on 3rd August, 2015.

I understand that you will also visit SOFCXIV meeting in Glasgow and I am sure that this will stimulate considerable discussion of mutual interest. It would be useful to explore in our discussions possible collaboration between INER and Imperial College London in the area of solid oxide fuel cells, and I will introduce you to the rest of the group. We would also welcome a short talk from you on the work ongoing at INER.

I look forward to welcoming you to London in August.

Yours sincerely

Prof. Stephen Skinner

附錄三、會議投稿摘要接受通知

寄件者：	abstracts@electrochem.org
收件者：	楊昇府; d95541006@ntu.edu.tw
主旨：	ECS Conference on Electrochemical Energy Conversion & Storage with SOFC-XIV: Accepted Abstract Notification
日期：	2015年4月30日 下午 11:59:01

ECS – The Electrochemical Society
65 South Main Street
Pennington, NJ 08534

April 28, 2015

Dr. Sheng-Fu Yang

,

Dear Dr. Sheng-Fu Yang:

We are pleased to inform you that your abstract has been accepted for presentation at the ECS Conference on Electrochemical Energy Conversion & Storage with SOFC-XIV (July 26-31, 2015) in Glasgow as follows:

Abstract Number/Title/Authors: # A-0116: Ni-Mo Porous Alloy Fabricated As Supporting Component for Metal-Supported Solid Oxide Fuel Cell and Cell Performance by Sheng-Fu Yang, Zong Chuang Shie, Chang-Sing Hwang, Chun-Huang Tsai, Chun-Liang Chang, Te-Jung Huang, Ruey-Yi Lee
Presentation Type: Oral
Date/Time/Location: July 28, 2015 / 8:20h - 8:40h / Lomond Auditorium
Symposium: A: Solid Oxide Fuel Cells XIV (SOFC-XIV)

The entire technical program, including abstracts, for the meeting, as well as meeting registration and hotel reservations, is available on the meeting website:
http://www.electrochem.org/meetings/satellite/glasgow/

MEETING REGISTRATION: All authors/presenters attending the Meeting, including invited speakers, must pay the registration fee in order to present their paper. **Please register online no later than June 15, 2015** to take advantage of discounted Early-Bird registration fees. Registration will open on or about April 29, 2015.

HOTEL RESERVATIONS: Glasgow City Marketing Bureau is the official accommodation provider for the conference and has negotiated specially discounted rates with a wide range of hotels. Accommodations will be sold on a first come, first served basis and the published rates will be available until June 15, 2015. Book now to avoid disappointment and secure your discounted rate! When your room is reserved you will receive an immediate confirmation by email. View accommodations and reserve your room now by visiting http://www.peoplemakeglasgow.com/ECSC2015 ! For assistance, telephone, or group bookings please contact the Glasgow City Marketing Bureau at +44 (0) 141 566 0877 / 0820 or accommodation@glasgowcitymarketingbureau.com.

PRESENTATION INFORMATION: Symposium Organizers reserve the right to determine the format of your presentation, whether oral or poster, and therefore may have changed your requested format to fit their symposium schedule.

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VISA INFORMATION: Should you require a visa to enter the United States, we strongly encourage you to start the visa application process immediately by completing the online form here https://www.electrochem.org/jw/meetings/visa_mtg_form.jsp. Please complete this online form to have an electronic copy of your letter on ECS letterhead sent to you within three (3) business days.

Your paper represents an important contribution to the success of the ECS Conference on Electrochemical Energy Conversion & Storage with SOFC-XIV and we appreciate your participation.

Sincerely,

Dr. Johna Leddy
ECS 3rd Vice-President
Chair, Symposium Planning Advisory Board
Chair, Meetings Subcommittee
===

附錄四、會議投稿全文接受通知

寄件者：	ecs@confex.com
收件者：	楊昇府
主旨：	ECS Transactions: Manuscript # Decision Letter
日期：	2015年4月1日 上午 11:59:43

Dear Dr. Sheng-Fu Yang,

I am pleased to inform you that your manuscript, "Ni-Mo Porous Alloy Fabricated As Supporting Component for Metal-Supported Solid Oxide Fuel Cell and Cell Performance", has been reviewed and accepted for publication in the Solid Oxide Fuel Cells XIV (SOFC-XIV) issue of "ECS Transactions" (ECST) from the ECS Glasgow meeting. This issue is scheduled to be published on July 26, 2015.

Authors whose papers will be published in ECST are also urged to submit their papers to an ECS journal. ECS recently began publishing three new peer-reviewed scientific journals, which join the Society"s flagship Journal of The Electrochemical Society. This exciting news was covered in the spring 2012 issue of Interface magazine. Click here to read about it: http://www.electrochem.org/dl/interface/spr/spr12/spr12_p017_027.pdf. While the expectation is that six months is sufficient time to revise an ECST paper to meet the stricter standards of the journals, there is no deadline for submission. Submissions to the journals must be made using the online submission system. Click here for author instructions: http://ecsdl.org/site/ecs/manuscript_submissions.xhtml.

Thank you for contributing your work to ECST. If you have any questions or comments, please feel free to contact the ECST staff at ecst@electrochem.org.

Sincerely,

Dr. Subhash C Singhal
Editor, Solid Oxide Fuel Cells XIV (SOFC-XIV)
"ECS Transactions", Volume 68

Further Reviewer Comments (if any):

The manuscript has been re-formatted.
==

附錄五、會議議程

A Solid Oxide Fuel Cells XIV (SOFC-XIV)

Sponsor(s): High Temperature Materials, Battery, Energy Technology, SOFC Society of Japan

Lead Organizer: Subhash C Singhal (Pacific Northwest National Laboratory)
Co-organizer: Koichi Eguchi (Kyoto University, Kyoto, Japan)

Monday, 27 July 2015

Monday | Tuesday | Wednesday | Thursday | Friday | top

09:00-12:00

SOFC-XIV: Plenary Session and SOFC Systems
Lomond Auditorium
Chair(s): Subhash Singhal and Koichi Eguchi

14:00-17:40

SOFC-XIV: Cathodes 1
Boisdale
Chair(s): Koji Amezawa and John Kilner

SOFC-XIV: Cells and Stacks 1
Lomond Auditorium
Chair(s): Tatsumi Ishihara and Kevin Kendall

SOFC-XIV: Systems 1
Alsh
Chair(s): Yoshio Matsuzaki and Mark C. Williams

18:00-20:00

SOFC-XIV: Poster Session 1 (SOFC Systems, Cathodes and Interconnects, and SOECs)
Hall 2
Chair(s): Koichi Eguchi and Subhash Singhal

Tuesday, 28 July 2015

Monday | Tuesday | Wednesday | Thursday | Friday | top

08:20-12:00

SOFC-XIV: Cathodes 2
Boisdale
Chair(s): Alan Atkinson and P. Tsiakaras

SOFC-XIV: Cells and Stacks 2
Lomond Auditorium
Chair(s): Robert Steinberger-Wilckens

SOFC-XIV: Systems 2
Alsh
Chair(s): Ludger Blum and Mark Cassidy

14:00-17:40

SOFC-XIV: Cathodes 3
Boisdale
Chair(s): Tatsuya Kawada and Eric D. Wachsman

SOFC-XIV: Cells and Stacks 3
Lomond Auditorium
Chair(s): Nigel P. Brandon and Harumi Yokokawa

SOFC-XIV: Interconnects and Interconnect Coatings
Alsh
Chair(s): Minfang HAN and Mihails Kusnezoff

18:00-20:00

SOFC-XIV: Poster Session 2 (SOFC Fuels, Anodes, and Modeling)
Hall 2
Chair(s): Koichi Eguchi and Subhash Singhal

Wednesday, 29 July 2015

08:20-12:00

Monday | Tuesday | Wednesday | Thursday | Friday | top

SOFC-XIV: Anodes 1
Boisdale
Chair(s): Martin Andersson and Anke Hagen

SOFC-XIV: Cells and Stacks 4
Lomond Auditorium
Chair(s): Teruhisa Horita and Julie Mougin

SOFC-XIV: Modeling 1
Alsh
Chair(s): André Weber

Thursday, 30 July 2015

08:20-12:00

Monday | Tuesday | Wednesday | Thursday | Friday | top

SOFC-XIV: Anodes 2
Boisdale
Chair(s): John T. S. Irvine and Haruo Kishimoto

SOFC-XIV: Cells and Stacks 5
Lomond Auditorium
Chair(s): Scott A Barnett and Uday Bhanu Pal

SOFC-XIV: Modeling 2
Alsh
Chair(s): Naoki Shikazono and Alain Thorel

14:00-17:40

SOFC-XIV: Anodes 3
Boisdale
Chair(s): Enrico Traversa

SOFC-XIV: Cells and Stacks 6
Lomond Auditorium
Chair(s): Kazunari Sasaki and Stephen J. Skinner

SOFC-XIV: Solid Oxide Electrolysis/Reversible Cells 1
Alsh
Chair(s): Jong-Ho Lee and Keiji Yashiro

18:00-20:00

SOFC-XIV: Poster Session 3 (SOFC Electrolytes, Cells and Stacks)
Hall 2
Chair(s): Koichi Eguchi and Subhash Singhal

Friday, 31 July 2015

Monday | Tuesday | Wednesday | Thursday | Friday | top

08:20-12:00

SOFC-XIV: Cells and Stacks 7
Lomond Auditorium
Chair(s): Olivera Kesler and Toshiaki Matsui

SOFC-XIV: Fuels and Fuel Compatibility
Boisdale
Chair(s): Viola Birss and Nguyen Minh

SOFC-XIV: Solid Oxide Electrolysis/Reversible Cells 2
Alsh
Chair(s): Suddhasatwa Basu and Xiao-Dong Zhou

14:00-16:00

SOFC-XIV: Cells and Stacks 8
Lomond Auditorium
Chair(s): Hiroyuki Uchida and Katsuhiko Yamaji

SOFC-XIV: Electrolytes
Boisdale
Chair(s): Rajendra Nath Basu and San Ping Jiang

SOFC-XIV: Solid Oxide Electrolysis/Reversible Cells 3
Alsh
Chair(s): Norbert H. Menzler and Anil V. Virkar

16:00-17:00

SOFC-XIV: Closing Session
Lomond Auditorium
Chair(s): Subhash Singhal and Koichi Eguchi

附錄六、楊昇府等人之口頭論文發表摘要

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- At-A-Glance
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- Canceled Presentations

Meeting Information

When:
July 26 - 31, 2015
Where:
Glasgow, Scotland

116
Ni-Mo Porous Alloy Fabricated as Supporting Component for Metal-Supported Solid Oxide Fuel Cell and Cell Performance

Tuesday, 28 July 2015: 08:20
Lomond Auditorium (Scottish Exhibition and Conference Centre)

S. F. Yang, Z. Y. Chuang Shie, C. S. Hwang, C. H. Tsai, C. L. Chang, T. J. Huang, and R. Y. Lee (Institute of Nuclear Energy Research)

In this study, continuous manufacturing processes including spray drying, compression molding and sintering are developed and constructed to produce molybdenum (Mo)-containing nickel (Ni)-based porous alloy as a supporting component for metal-supported solid oxide fuel cell (SOFC). The porous interconnected networks of Ni-Mo alloy are made of introducing pyrolyzable filler during fabrication processes. The particle size distribution analysis results showed d_{50} of starting material (E.g., Ni, Mo, pyrolyzable filler and binder) after spray drying is 40.7 um. A compression load of 35 ton is applied to form a specimen with size of 60×60×1.2 mm and then sintered at 1200°C to obtain porous alloy. The anode ($Ce_{0.55}La_{0.45}O_{2-\delta}$-Ni, LDC-Ni), electrolyte ($La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_{3-\delta}$, LSGM) and cathode ($Sm_{0.5}Sr_{0.5}CoO_{3-\delta}$, SSC) is coated by using an atmospheric plasma spraying (APS) technique. The active electrode area of the cell is 16cm^2 and the open circuit voltage (OCV) is higher than 1.0 V under cell performance testing from 600 to 750 °C, indicating that a fully dense layer of LSGM electrolyte is successfully fabricated via APS coating process. The measured maximum output power densities (@0.6V) of this cell have reached 1196, 1012, 716 and 415 mW/cm^2 at 750, 700, 650 and 600 °C respectively, by employing H_2 as fuel and air as oxidant.

SOFC-XIV: Cells and Stacks 2

Tuesday, 28 July 2015: 08:20-12:00
Lomond Auditorium (Scottish Exhibition and Conference Centre)

Chair: *Robert Steinberger-Wilckens*

08:20	**116**	Ni-Mo Porous Alloy Fabricated as Supporting Component for Metal-Supported Solid Oxide Fuel Cell and Cell Performance *S. F. Yang, Z. Y. Chuang Shie, C. S. Hwang, C. H. Tsai, C. L. Chang, T. J. Huang, and R. Y. Lee (Institute of Nuclear Energy Research)*
08:40	**117**	Multi Length-Scale Quantification of Hierarchical Microstructure in Designed Microtubular SOFC Electrodes *S. J. Cooper, T. Li (Imperial College London), R. S. Bradley (University of Manchester), K. Li, N. P. Brandon, and J. A. Kilner (Imperial College London)*
09:00	**118**	Design and Fabrication of a 600W Anode Supported Flat Tubular SOFC Stack *W. Ji (University of Science and Technology of China, G-cell technology Co. Ltd,), L. Zhang (G-cell technology Co. Ltd), L. Ming (University of Science and Technology. of China, G-cell technology Co. Ltd,), Y. Jiang (G-cell technology Co. Ltd), and B. Xie (University of Science and Technology of China, G-cell technology Co. Ltd,)*
09:20	**119**	Development of a Novel Co-fired SOFC at Murata *N. Mori, Y. Sato, H. Nakai, M. Iha, T. Takada, and T. Konoike (Murata Manufacturing Co., Ltd.)*
09:40	**120**	Development of Modelling and Testing for Analysis of Degradation in Solid Oxide Fuel Cells *J. G. Maillard (University of Birmingham) and R. Steinberger-Wilckens (University of Birmingham,UK)*
10:00		Break
10:20	**121**	Beyond the 3rd Generation of Planar SOFC: Development of Metal Foam Supported Cells with Thin Film Electrolyte

附錄七、林泰男等人之海報論文發表摘要

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- Canceled Presentations

Meeting Information

When:
July 26 - 31, 2015
Where:
Glasgow, Scotland

54
Fabrication of $SmBa_{0.5}Sr_{0.5}Co_2O_{5+\delta}$ Cathode Material and Its Application for Sr- and Mg-Doped $LaGaO_3$ Electrolyte-Supported Solid Oxide Fuel Cell

Monday, 27 July 2015
Hall 2 (Scottish Exhibition and Conference Centre)

T. N. Lin (Chem. Eng. Division, Institute of Nuclear Energy Research), R. Y. Lee, J. Y. Kuo (Institute of Nuclear Energy Research), T. Ishihara, and K. Hosoi (Department of Applied Chemistry, Kyushu University)

The layered samarium and strontium doped perovskite oxide $SmBa_{0.5}Sr_{0.5}Co_2O_{5+\delta}$ (SBSC) was synthesized by glycine nitrate combustion process (GNC). The structure, microstructure, conductivity, coefficient of thermal expansion properties were investigated. The crystallinity of SBSC powder showed pure perovskite phase above 1000 °C according to the XRD and TGA results. With the calcination temperature increased, the crystallinity improved and the powders grew larger and agglomeration occurred. The conductivity of SBSC powders increased with elevated temperature while the coefficient of thermal expansion was 22.6 × 10^{-6} K^{-1}. SBSC powders were utilized as cathode materials in Sr- and Mg-doped $LaGaO_3$ (LSGM)-based electrolyte-supported solid oxide fuel cell for power performance test. The cell with structure of (NiFe + CMF) | LSGM | SBSC was operated from 700 to 800 °C with humidified H_2 as a fuel and ambient air as oxidant. The maximum power densities are 550 and 170 mW cm^{-2} at 800 and 700 °C, respectively. The experimental results indicate that SBSC is a promising cathode material for intermediate temperature solid oxide fuel cell (IT-SOFC).

SOFC-XIV: Poster Session 1 (SOFC Systems, Cathodes and Interconnects, and SOECs)

Monday, 27 July 2015: 18:00-20:00
Hall 2 (Scottish Exhibition and Conference Centre)

Chairs: *Koichi Eguchi and Subhash Singhal*

38 The Uk's First Commercially Funded SOFC Micro CHP Progarmme: Experience to Date
J. Cape (iPower Energy Ltd)

39 Development of Micro Power Generator Using LPG-Fueled Microtubular Solid Oxide Fuel Cells
H. Sumi, T. Yamaguchi, T. Suzuki, H. Shimada, K. Hamamoto, and Y. Fujishiro (National Institute of AIST)

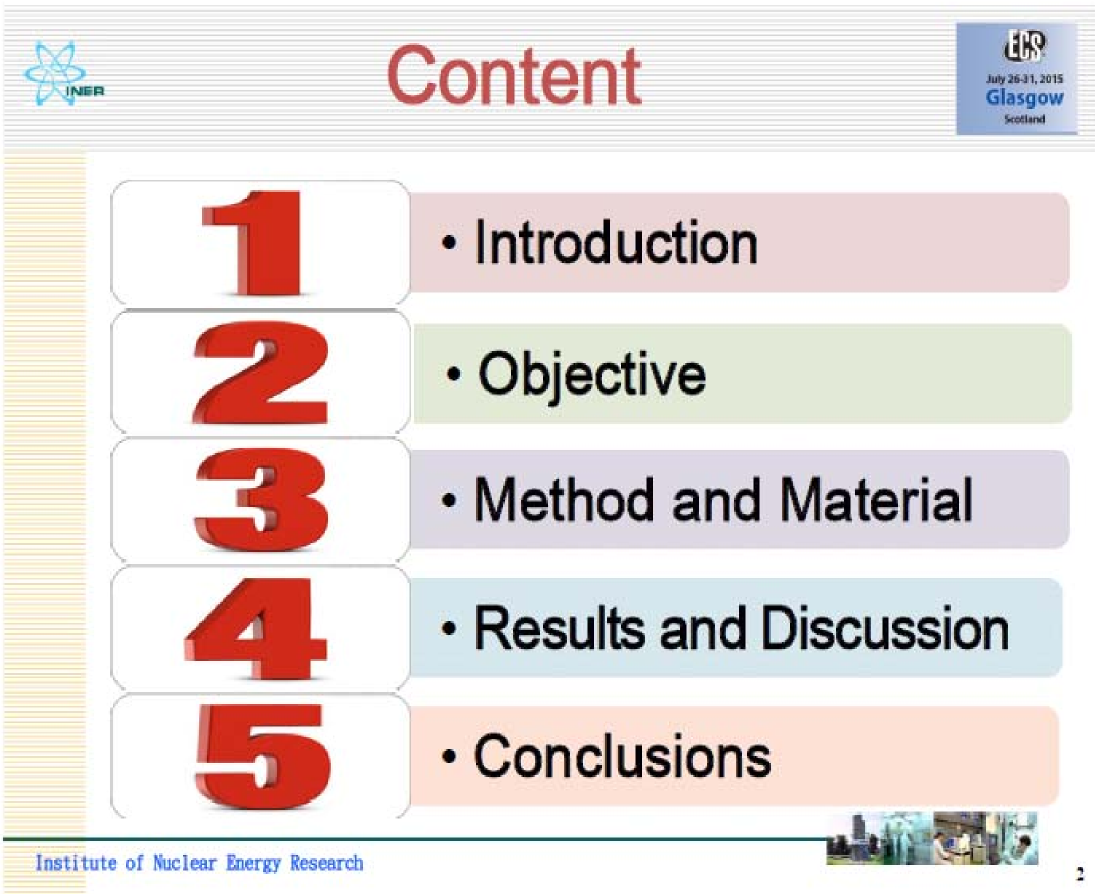
40 Preliminary Results on a 5W Portable Butane MT-SOFC Stack As a Battery Charger
H. K. Jung (Pohang University of Science and Technology), J. E. Hong, A. Dhir, A. J. Majewski, B. Hari (University of Birmingham), R. Steinberger-Wilckens (University of Birmingham,UK), Y. S. Chung, J. G. Sung, J. S. Chung, and N. M. Sammes (Pohang University of Science and Technology)

41 Numerical Simulation of SOFC System Performance at 90% Fuel Utilization with or without Anode Off-Gas Recycle for Enhancing Efficiency
Y. Tanaka, T. Terayama, A. Momma, and T. Kato (National Institute of Advanced Industrial Sci. Technol.)

42 Framework for Analysis of Irreversible Fuel Cell Heat Engine Hybrids
M. C. Williams (URS), R. Gemmen (U.S. Department of Energy, NETL), and K. Gerdes (U.S. DOE, National Energy Technology Laboratory)

43 Analysis of Transient Behavior of Fuel Reformer to Fuel Supply Variation in Solid Oxide Fuel Cell Systems with Anode Off-Gas Recycle
T. Terayama, A. Momma, Y. Tanaka, T. Kato (National Institute of

附錄八、楊員口頭發表論文簡報檔案



Introduction

Solid Oxide Fuel Cell (SOFC)

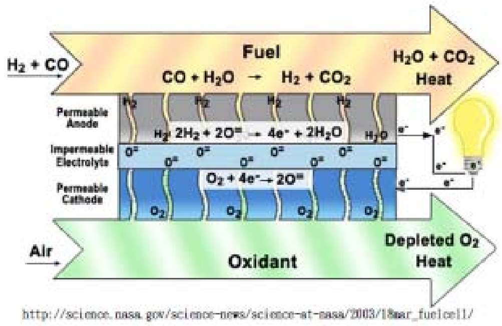
Advantage

- Convert chemical energy directly into electrical energy
- High efficiency
- High power density
- Fuel flexibility
- Low levels of pollution emissions

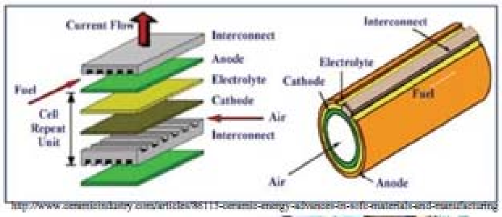
Types

- Tubular SOFC
- **Planar SOFC**

Solid Oxide Fuel Cell



http://science.nasa.gov/science-news/science-at-nasa/2003/18mar_fuelcell/



Introduction

Metal-Supported SOFCs, the third generation of cells have been obtaining popularity in the recent years.

In comparison to traditional all ceramic cells, the advantages are listed as below:

Advantage

- High thermal conductivity
- Improve heat transfer
- High electrical conductivity
- High redox stability
- High mechanical strength

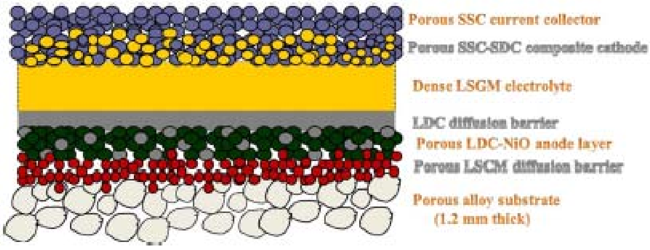
Advantage

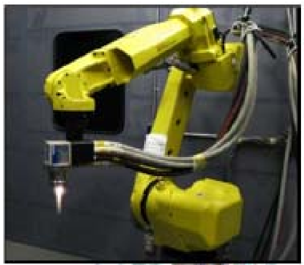
- Lower operation temperature
- Lower material cost
- Easier cells assembling
- Ability to withstand repeated and rapid thermal cycles.

Introduction

Atmospheric plasma spraying (APS) is a fast sintering process, it allows to reduce the interaction between metallic substrate and functional layers that can be caused during conventional high temperature sintering processes.

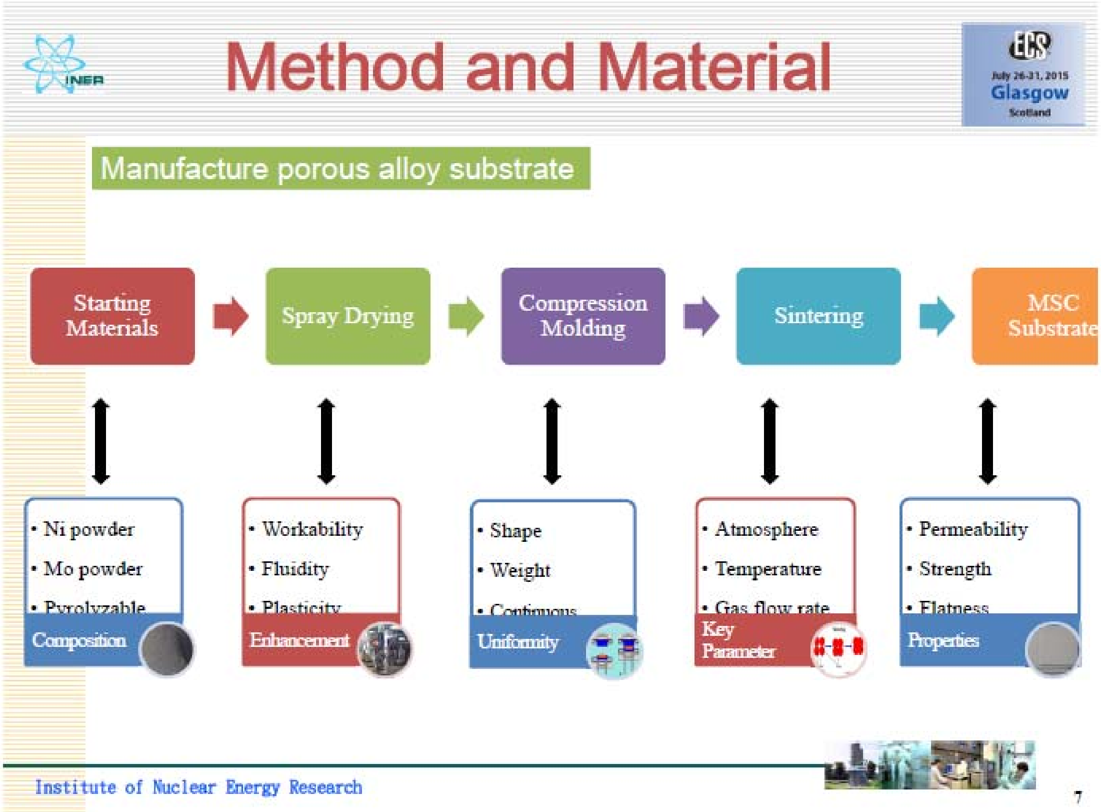
APS have high material deposition rate, can change component composition and microstructure through adjustment of plasma spray operation parameters.





Objective

- To construct spray drying, compression molding and sintering processes for producing Ni-Mo porous alloy substrate.
- To fabricate positive, electrolyte and negative functional layers by using Atmospheric Plasma Spraying technique.
- To evaluate the electrical performance of planar MS-SOFC.



Method and Material
July 26-31, 2015
Glasgow
Scotland
Manufacture porous alloy substrate
Starting Materials
Spray Drying
Compression Molding
Sintering
MSC Substrate
• Ni powder
• Mo powder
• Pyrolyzable
Composition
• Workability
• Fluidity
• Plasticity
Enhancement
• Shape
• Weight
Uniformity
• Atmosphere
• Temperature
• Gas flow rate
Key Parameter
• Permeability
• Strength
• Flatness
Properties
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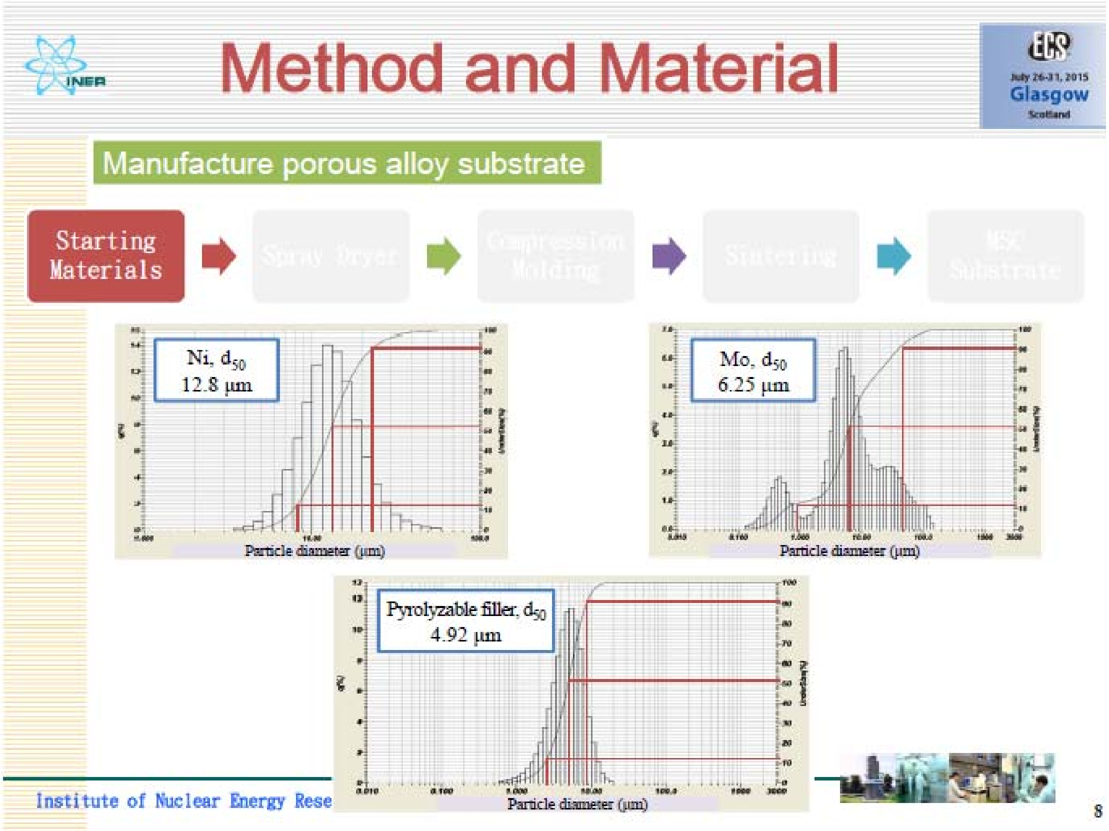
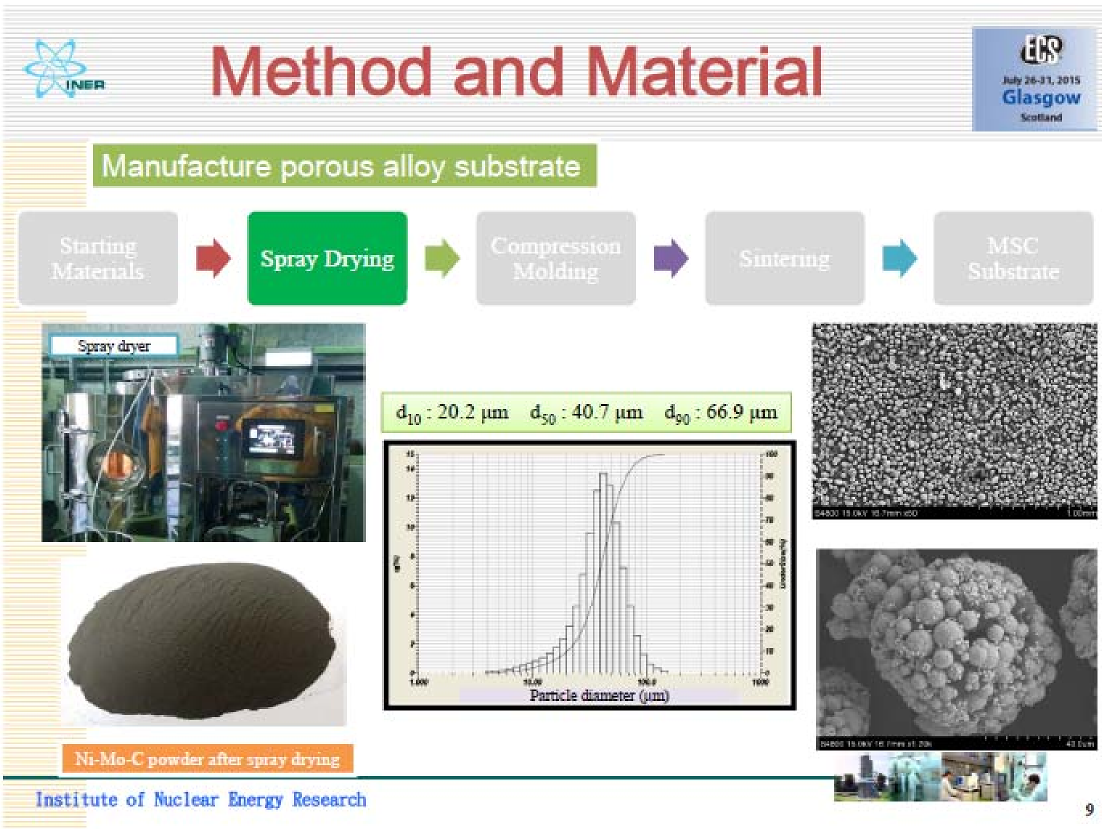
7


Method and Material
INER
July 26-31, 2015
Glasgow
Scotland
Manufacture porous alloy substrate
Starting Materials
Spray Dryer
Compression Molding
Sintering
MSC Substrate
Ni, d_{50} 12.8 μm
Particle diameter (μm)
Mo, d_{50} 6.25 μm
Particle diameter (μm)
Pyrolyzable filler, d_{50} 4.92 μm
Particle diameter (μm)
Institute of Nuclear Energy Rese
8


Method and Material
INER
July 26-31, 2015
Glasgow
Scotland
Manufacture porous alloy substrate
Starting Materials
Spray Drying
Compression Molding
Sintering
MSC Substrate
Spray dryer
d_{10} : 20.2 μm d_{50} : 40.7 μm d_{90} : 66.9 μm
Particle diameter (μm)
Ni-Mo-C powder after spray drying
Institute of Nuclear Energy Research
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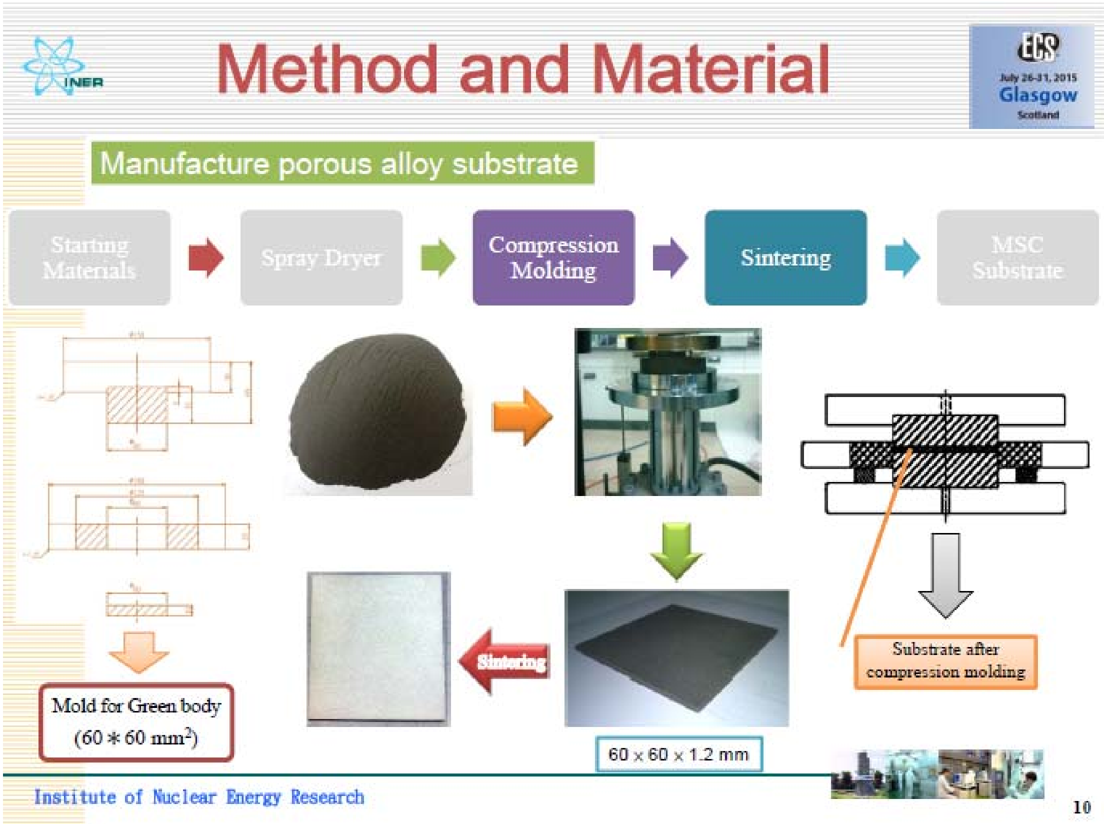

Method and Material
July 26-31, 2015
Glasgow
Scotland
Manufacture porous alloy substrate
Starting Materials
Spray Dryer
Compression Molding
Sintering
MSC Substrate
Substrate after compression molding
Sintering
Mold for Green body
(60 * 60 mm²)
60 x 60 x 1.2 mm
Institute of Nuclear Energy Research
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Method and Material

Fabricate MS-SOFC by APS technique

Fanuc Robot ARC Mate 120iB and TriplexPro 200

LSCM: $La_{0.75}Sr_{0.25}Cr_{0.5}Mn_{0.5}O_{3\text{-}d}$

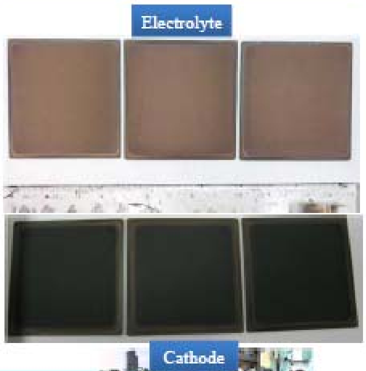
LDC: $La_{0.45}Ce_{0.55}O_{2\text{-}d}$

LDC-NiO: $La_{0.45}Ce_{0.55}O_{2\text{-}d}$-NiO

LSGM: $La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_{3\text{-}d}$

SDC: $Sm_{0.15}Ce_{0.85}O_{3\text{-}d}$

SSC: $Sm_{0.5}Sr_{0.5}CoO_{3\text{-}d}$



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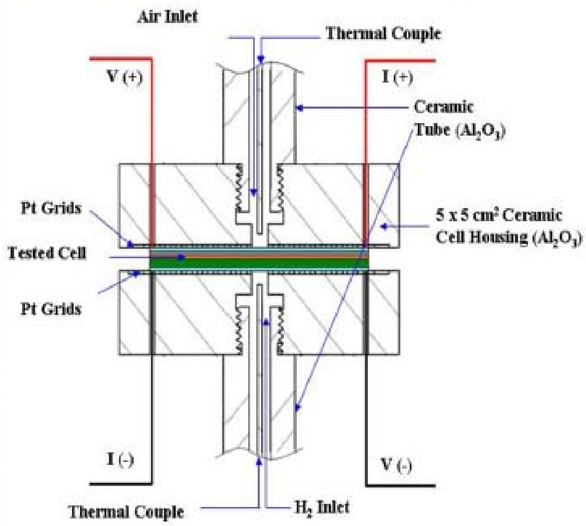
Method and Material

Cell performance measurement



Fuel: H_2 (335 mL/min)

Oxidant: Air (670 mL/min)

Test Temp: 650~750°C

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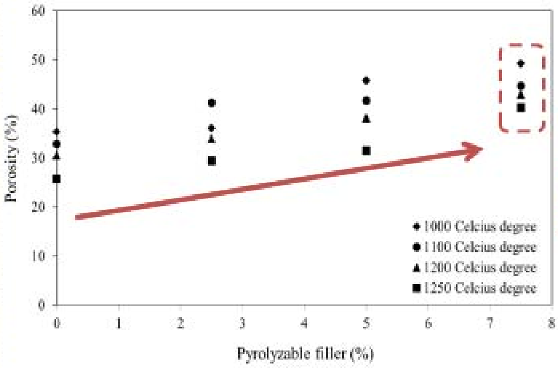
Results and Discussion

Porosities of Porous Ni-Mo alloy substrate



$$Bulk\,density\,(g\,cm^{-3}) = \frac{W_1}{\frac{W_2 - W_3}{D_w} - \frac{W_2 - W_1}{D_{wax}}}$$

W_1 = mass of specimen in air, g,
W_2 = mass of water-proof specimen in air, g,
W_3 = mass of water-proof specimen in water, g,
D_w = density of water at immersion temperature, g cm-3,
D_{wax} = density of wax, g cm-3.

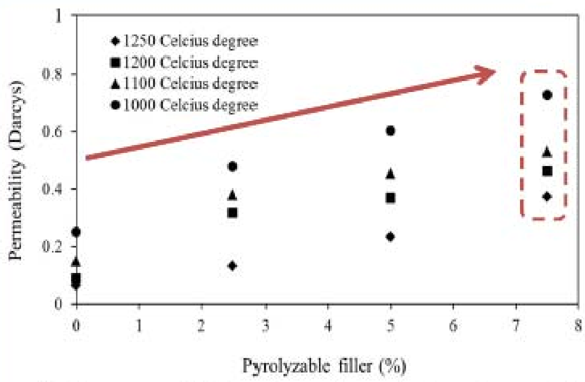
$$Porosity\,(\%) = \left(1 - \frac{Bulk\ density}{True\ density}\right) \times 100$$

The higher sintering temperature results in more sintering shrinkage and the percentage of volume reduction is 16%–27.8% from 1000°C to 1250°C.

Through reactions that occur in the period of sintering,strengthening and densification of porous alloy takes place, leading to a reduction in volume and porosity.

Results and Discussion

Permeability of porous Ni-Mo alloy substrate



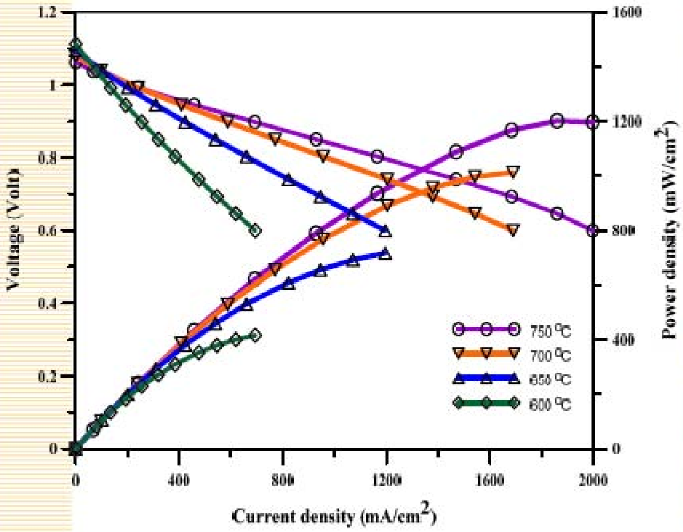
	1000℃	1100℃
Size of green body (mm^2)	60 x 60	60 x 60
After sintering (mm^2)	55 x 55	54 x 54
	1200℃	**1250℃**
Size of green body (mm^2)	60 x 60	60 x 60
After sintering (mm^2)	52 x 52	51 x51

The permeability of specimen without introducing pyrolyzable filler at 1250°C is 0.064 Darcy.

After the pyrolyzable filler is added (Range, 2.5%－7.5%), the permeability increases and rise to the range of 0.13 Darcy－0.37 Darcy.

Results and Discussion

Cell performance



SUMMARY

1. The open circuit voltages (OCVs) are 1.11, 1.09, 1.08 and 1.06 V.
2. The maximum power densities at 0.6 V are 415, 716, 1,012 and 1,196 mW/cm^2.
3. Our previous work with Ni-Mo-Fe alloy substrate, the maximum power densities are 317, 497, 666 and 788 mW/cm^2.

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Conclusions

A proper and effective fabricating process is revealed to produce porous alloy substrate as a supporting component for MS-SOFC.

The large-scale porous alloy specimen with size of 120×120×1.2 mm needs more efforts to be realized.

The properties (e.g. mechanical strength, oxidation behavior and thermal expansion coefficient) of porous alloy substrate will discuss in the further study.

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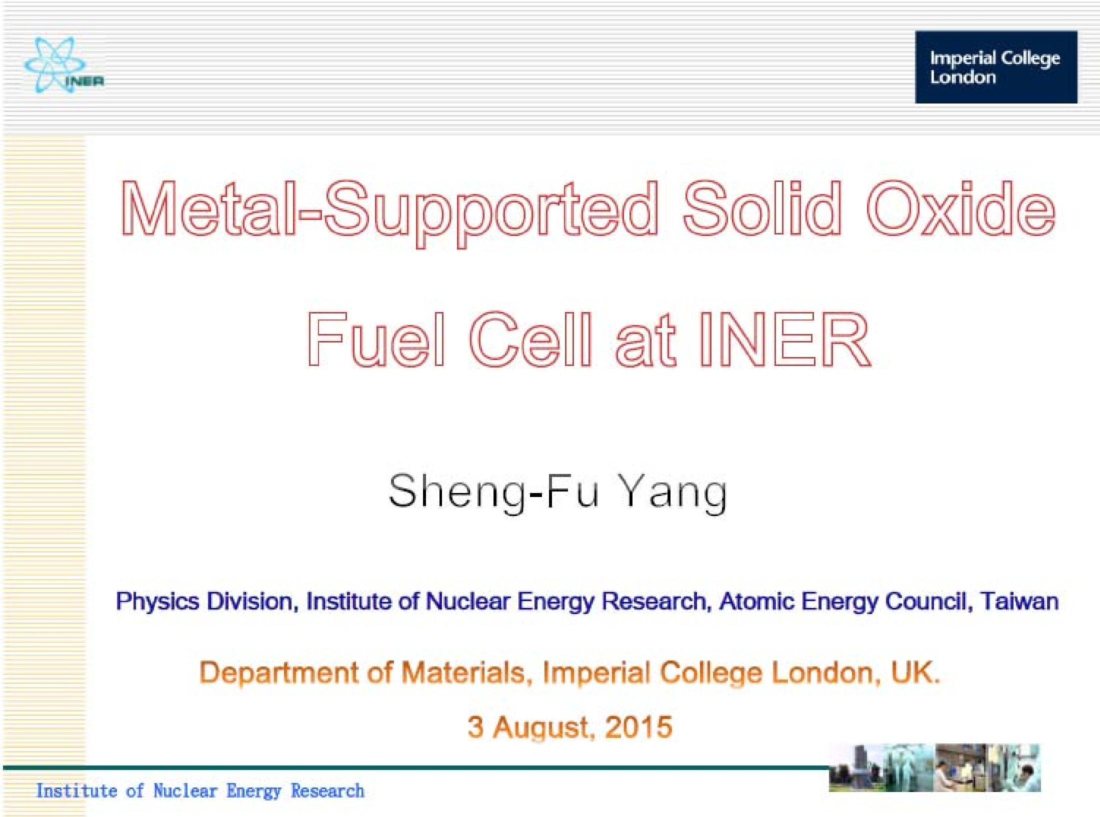
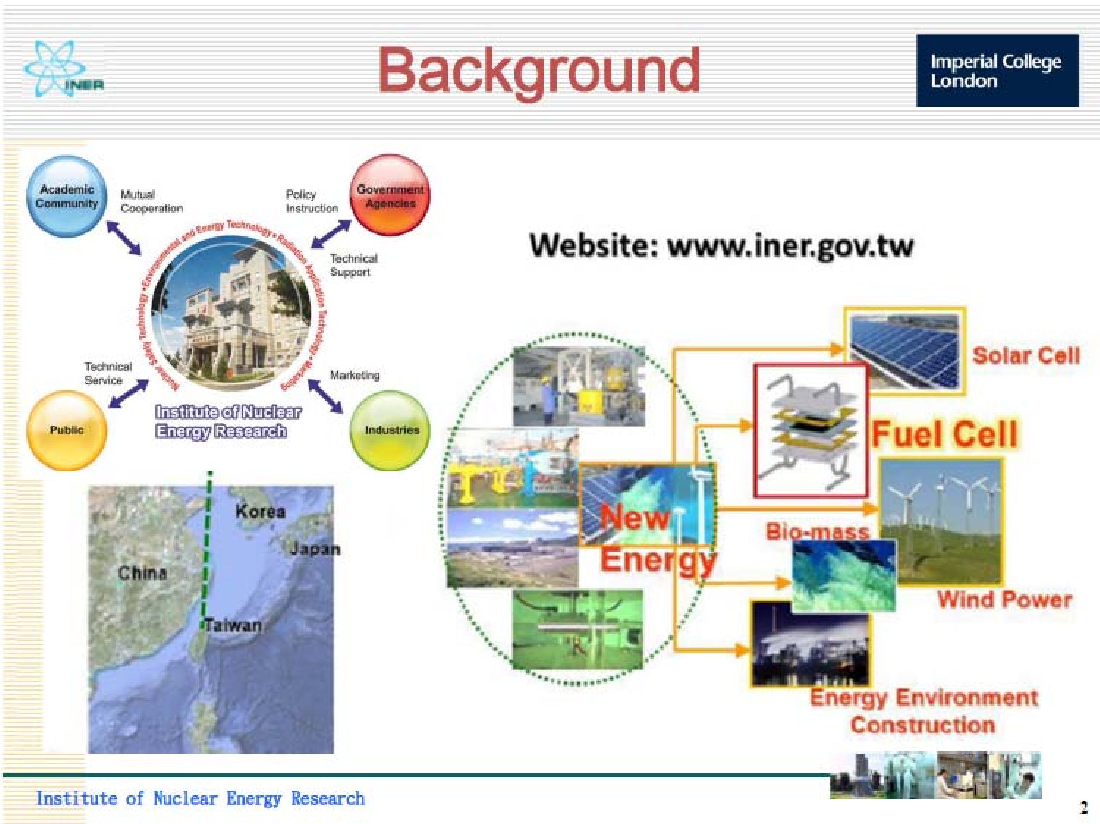
Acknowledgements

Special thanks to INER SOFC project manager Dr. Ruey-Yi Lee, MSC group leader Dr. Chang-Sing Hwang and thanks all the co-workers of SOFC team at INER.

Thank you ~

附錄九、楊員參訪英國倫敦帝國大學簡報檔案





Introduction

Imperial College London

Solid Oxide Fuel Cell (SOFC)

Advantage

- Convert chemical energy directly into electrical energy
- High efficiency
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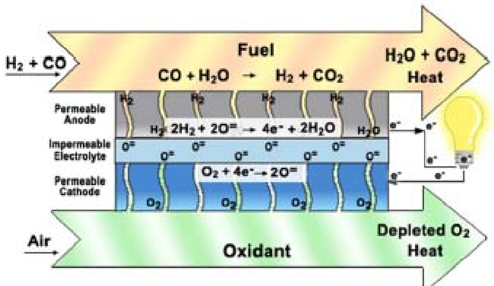
- Fuel flexibility
- Low levels of pollution emissions

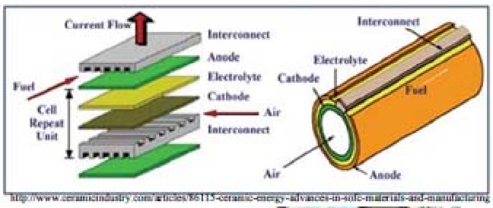
Types

- Tubular SOFC
- **Planar SOFC**

Solid Oxide Fuel Cell



http://science.nasa.gov/science-news/science-at-nasa/2003/18mar_fuelcell/



http://www.ceramicindustry.com/articles/86115-ceramic-energy-advances-in-sofc-materials-and-manufacturing

Introduction

Imperial College London

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Advantage

- High thermal conductivity
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Imperial College London

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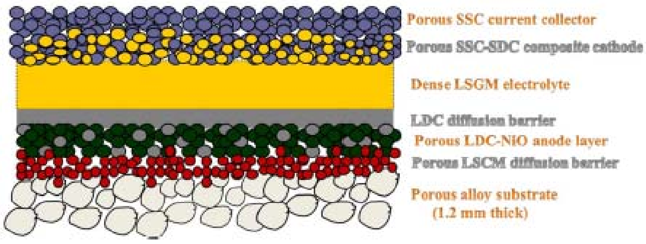


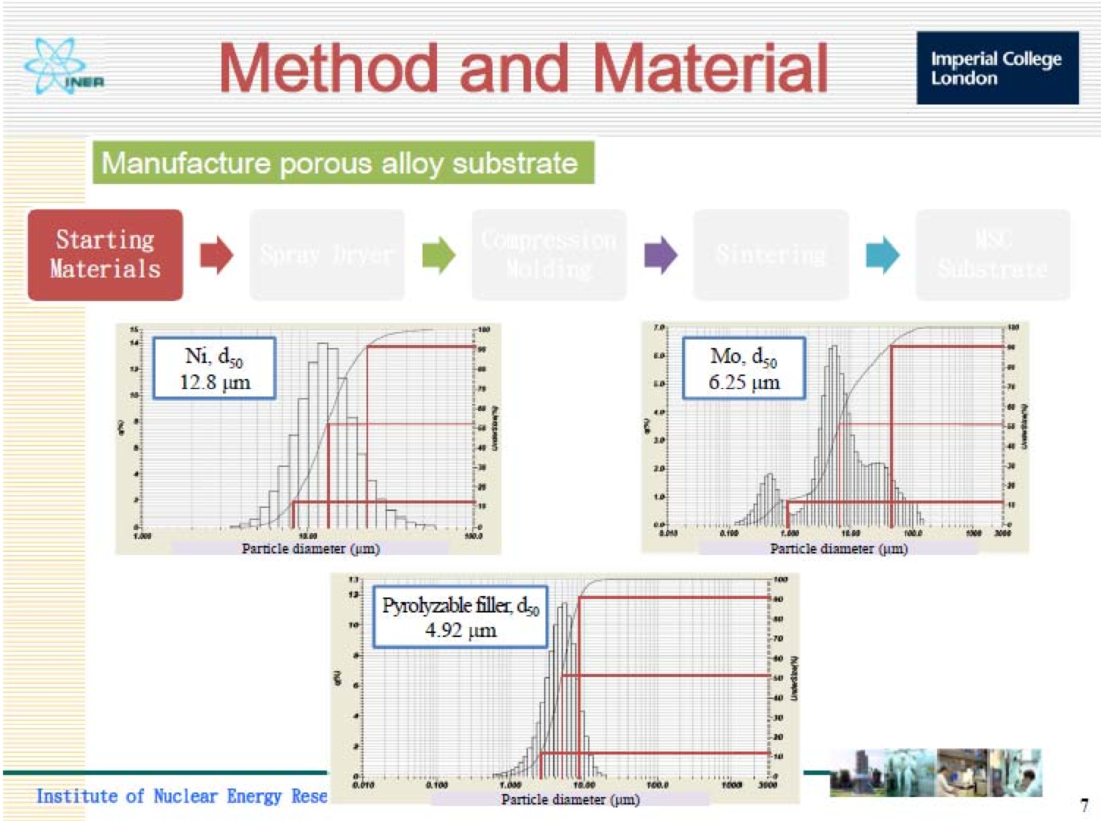
Method and Material

Imperial College London

Manufacture porous alloy substrate

Starting Materials → Spray Drying → Compression Molding → Sintering → MSC Substrate

- Composition: Ni powder; Mo powder; Pyrolyzable
- Enhancement: Workability; Fluidity; Plasticity
- Uniformity: Shape; Weight; Continuous
- Key Parameter: Atmosphere; Temperature; Gas flow rate
- Properties: Permeability; Strength; Flatness


Method and Material
Imperial College London
Manufacture porous alloy substrate
Starting Materials
Spray Dryer
Compression Molding
Sintering
MSC Substrate
Ni, d_{50} 12.8 μm
Particle diameter (μm)
Mo, d_{50} 6.25 μm
Particle diameter (μm)
Pyrolyzable filler, d_{50} 4.92 μm
Particle diameter (μm)
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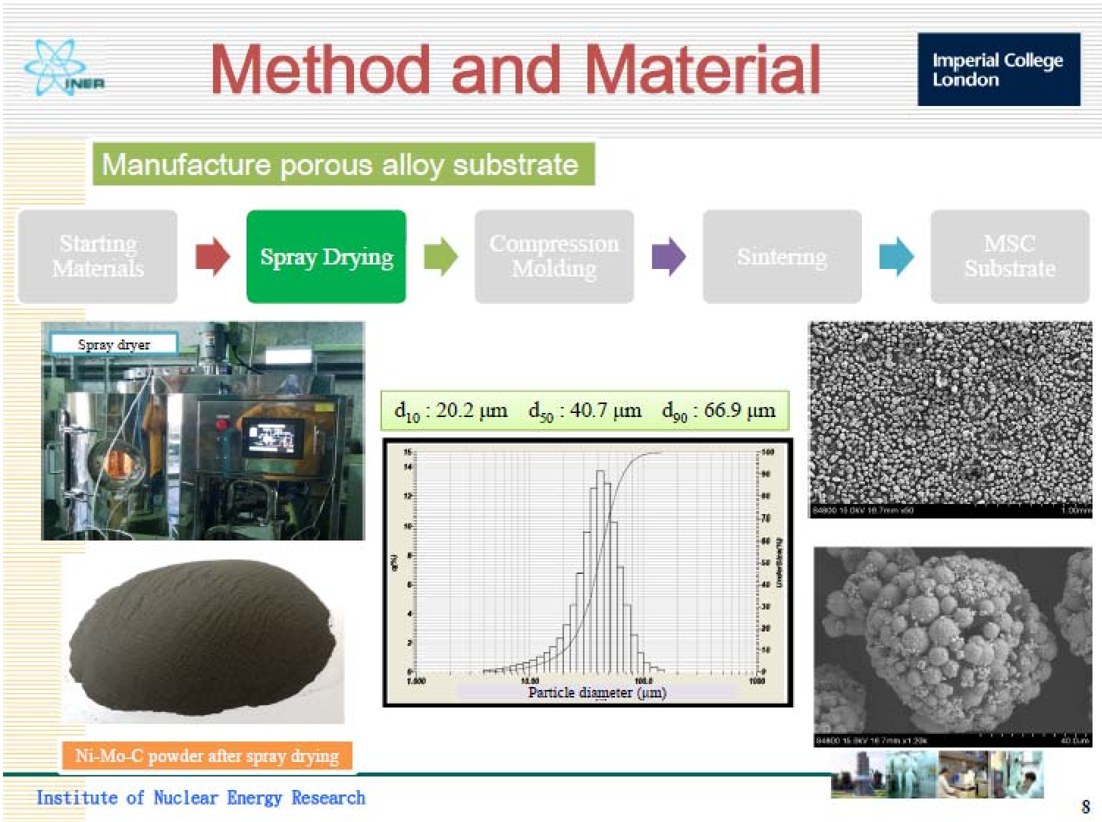
Method and Material
Imperial College London
Manufacture porous alloy substrate
Starting Materials
Spray Drying
Compression Molding
Sintering
MSC Substrate
Spray dryer
d_{10} : 20.2 μm d_{50} : 40.7 μm d_{90} : 66.9 μm
Particle diameter (μm)
Ni-Mo-C powder after spray drying
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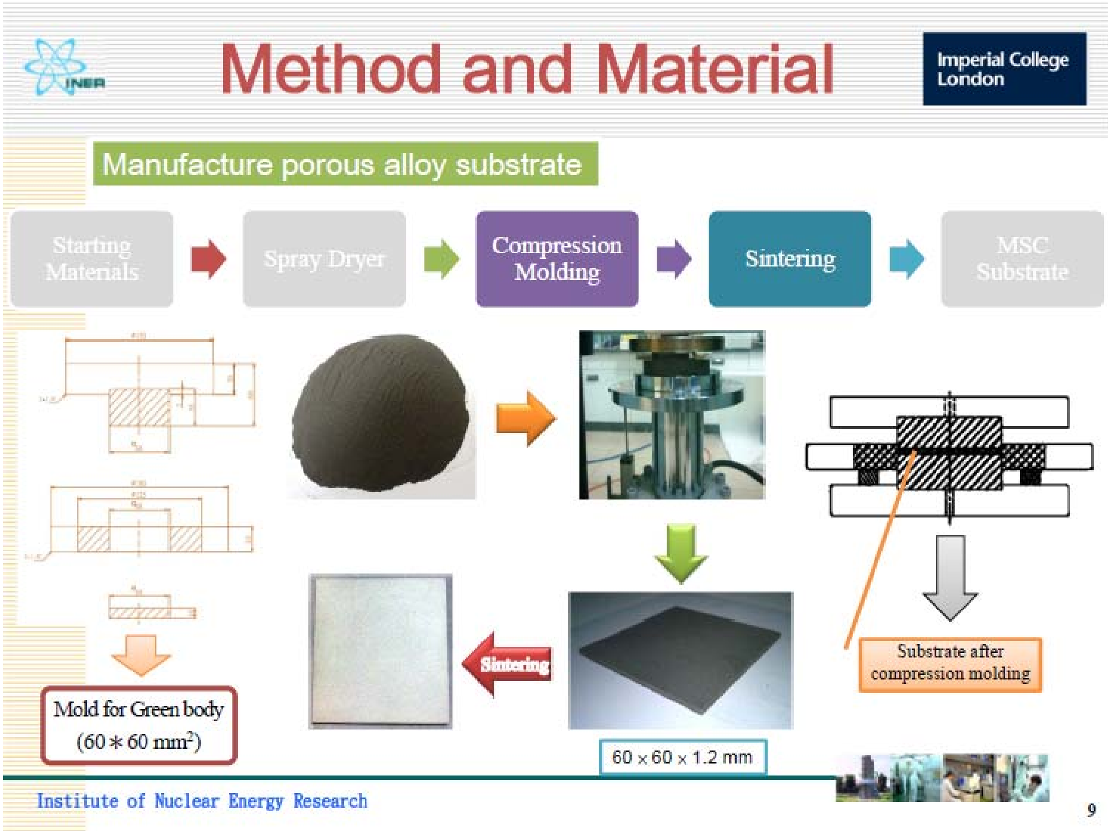

Method and Material
Imperial College London
Manufacture porous alloy substrate
Starting Materials
Spray Dryer
Compression Molding
Sintering
MSC Substrate
Sintering
Substrate after compression molding
Mold for Green body
(60＊60 mm²)
60 x 60 x 1.2 mm
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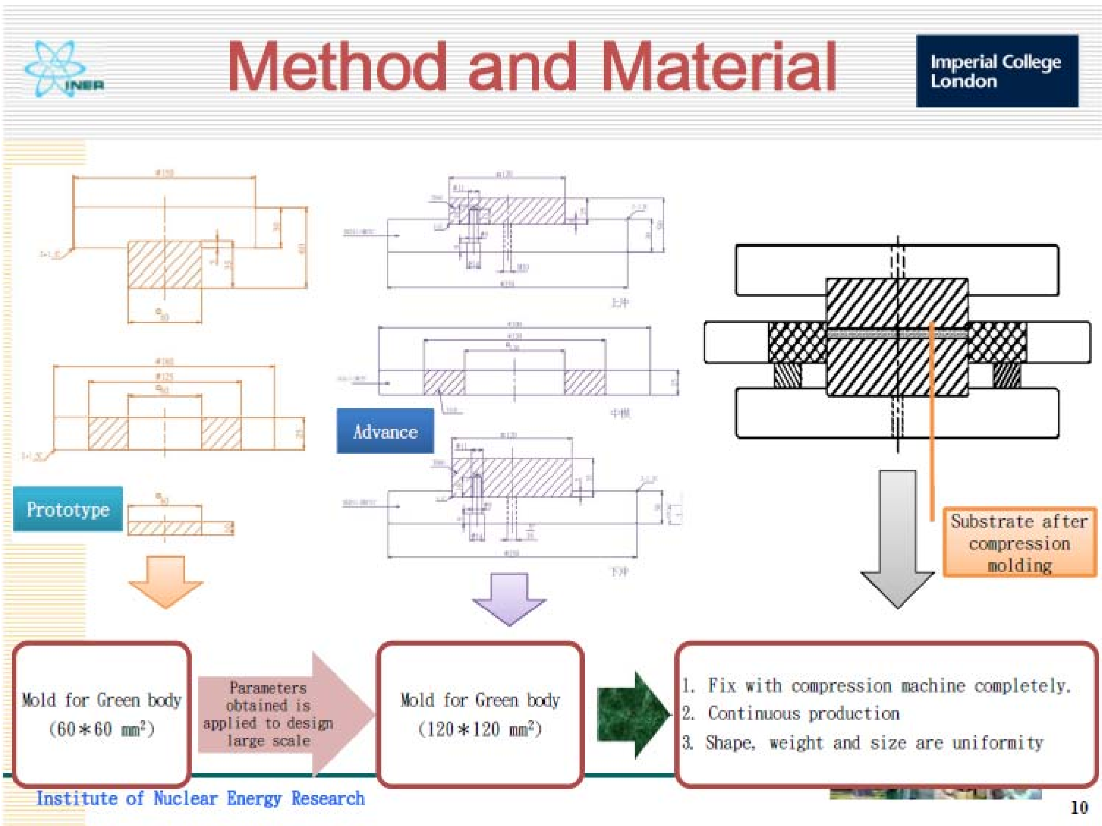

Method and Material
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Advance
Prototype
Substrate after compression molding
Mold for Green body
(60＊60 mm²)
Parameters obtained is applied to design large scale
Mold for Green body
(120＊120 mm²)
1. Fix with compression machine completely.
2. Continuous production
3. Shape, weight and size are uniformity
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Method and Material

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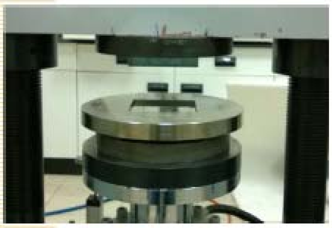

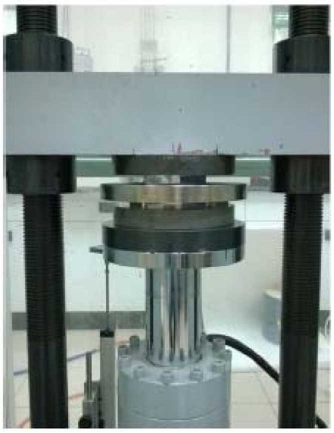

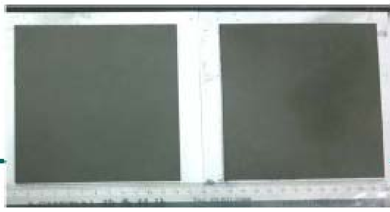

Size: 120 * 120 mm^2

Method and Material

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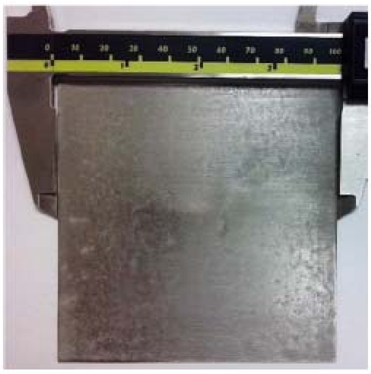
Sintering in Hydrogen at 1250℃



120 * 120 mm^2 Green Body

100 * 100 mm^2 Alloy Substrate

Method and Material

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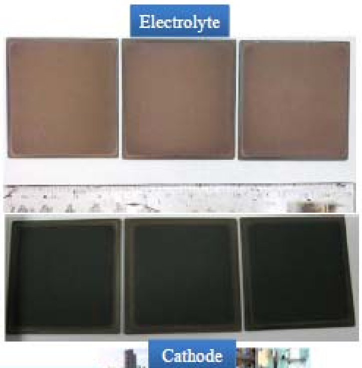
Fabricate MS-SOFC by APS technique

Fanuc Robot ARC Mate 120iB and TriplexPro 200

- LSCM: $La_{0.75}Sr_{0.25}Cr_{0.5}Mn_{0.5}O_{3-d}$
- LDC: $La_{0.45}Ce_{0.55}O_{2-d}$
- LDC-NiO: $La_{0.45}Ce_{0.55}O_{2-d}$-NiO
- LSGM: $La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_{3-d}$
- SDC: $Sm_{0.15}Ce_{0.85}O_{3-d}$
- SSC: $Sm_{0.5}Sr_{0.5}CoO_{3-d}$



Method and Material

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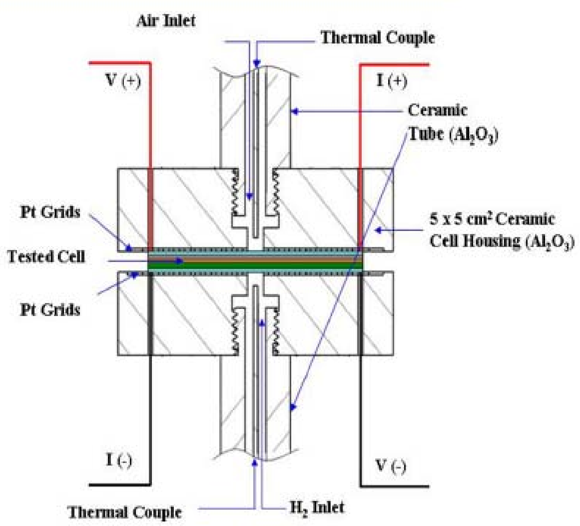
Cell performance measurement



Fuel: H_2 (335 mL/min)

Oxidant: Air (670 mL/min)

Test Temp: 650~750°C

Results and Discussion

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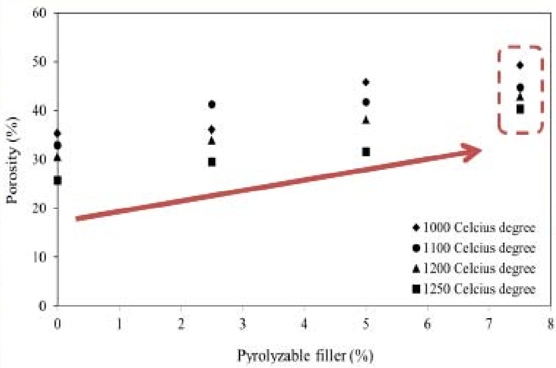
Porosities of Porous Ni-Mo alloy substrate



$$Bulk\,density\,(g\,cm^{-3}) = \frac{W_1}{\dfrac{W_2 - W_3}{D_w} - \dfrac{W_2 - W_1}{D_{wax}}}$$

W_1 = mass of specimen in air, g,
W_2 = mass of water-proof specimen in air, g,
W_3 = mass of water-proof specimen in water, g,
D_w = density of water at immersion temperature, g cm-^{3},
D_{wax} = density of wax, g cm-3.

$$Porosity\,(\%) = \left(1 - \frac{Bulk\ density}{True\ density}\right) \times 100$$

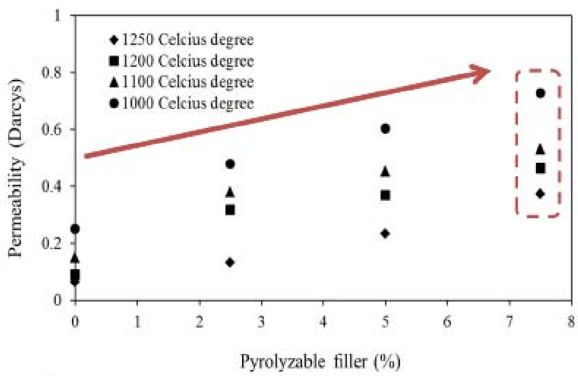
The higher sintering temperature results in more sintering shrinkage and the percentage of volume reduction is 16%–27.8% from 1000°C to 1250°C.

Through reactions that occur in the period of sintering,strengthening and densification of porous alloy takes place, leading to a reduction in volume and porosity.

Results and Discussion

Imperial College London

Permeability of porous Ni-Mo alloy substrate



	1000℃	1100℃
Size of green body (mm^2)	60 x 60	60 x 60
After sintering (mm^2)	55 x 55	54 x 54
	1200℃	**1250℃**
Size of green body (mm^2)	60 x 60	60 x 60
After sintering (mm^2)	52 x 52	51 x51

The permeability of specimen without introducing pyrolyzable filler at 1250°C is 0.064 Darcy.

After the pyrolyzable filler is added (Range, 2.5%－7.5%), the permeability increases and rise to the range of 0.13 Darcy－0.37 Darcy.

Results and Discussion

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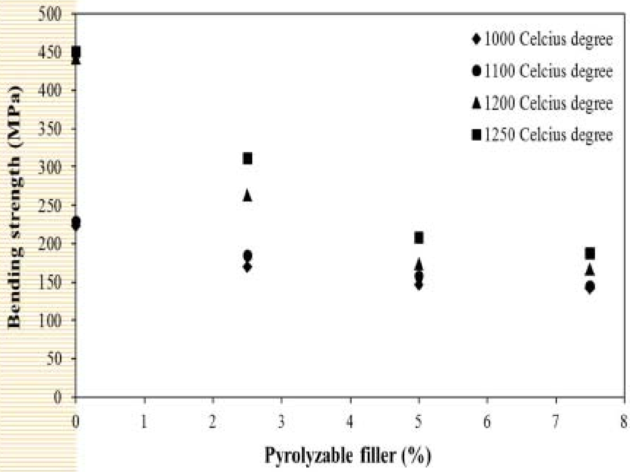
Bending Strength of porous Ni-Mo alloy substrate



Results and Discussion

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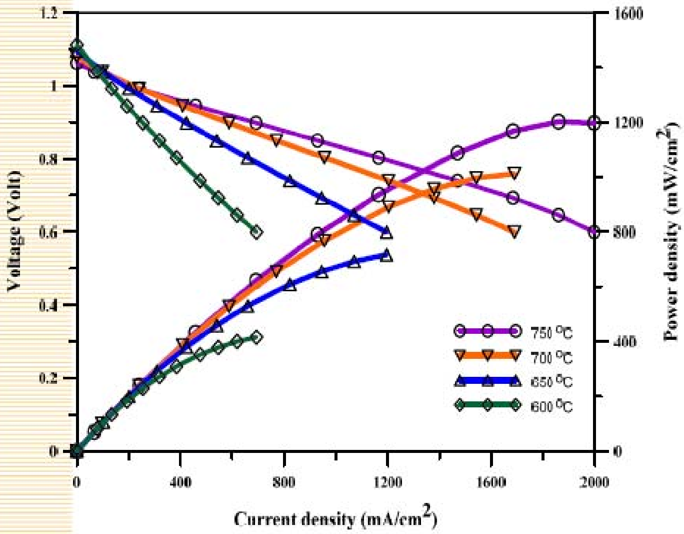
Cell performance



SUMMARY

1. The open circuit voltages (OCVs) are 1.11, 1.09, 1.08 and 1.06 V.
2. The maximum power densities at 0.6 V are 415, 716, 1,012 and 1,196 mW/cm².
3. Our previous work with Ni-Mo-Fe alloy substrate, the maximum power densities are 317, 497, 666 and 788 mW/cm².

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We sincerely invite Professor SKINNER to visit the Institute of Nuclear Energy Research and give a lecture.

Thank you ~

Acknowledgements

Special thanks to INER SOFC project manager Dr. Ruey-Yi Lee, MSC group leader Dr. Chang-Sing Hwang and thanks all the co-workers of SOFC team at INER.