2010 武漢大學參訪心得報告

計畫名稱：推動元智大學與武漢大學物理科學與技術學院共同合作研究計畫
訪問對象：武漢大學物理科學與技術學院(潘春旭副院長兼材料物理系之系主任)
訪問地點：武漢市 湖北省 大陸
訪問時間：2010 年 6 月 30 日 至 2010 年 7 月 5 日

化學工程與材料科學系 助理教授 **何政恩**

（一）武漢大學學術交流之相關行程

武漢大學(Wuhan University)為1893年創辦的自強學堂演進而來。該校坐落於中國大陸湖北省，為歷史悠久的著名學府。西元2000年，武漢大學、武漢水力電力大學、武漢測繪科技大學、湖北醫科大學合併組建成現在之武漢大學。根據2009年《中國大學評價》課題組所製作的中國大陸高校排行榜，武漢大學名列中國第10位，是大陸「985」和「211」工程重點建設高校。其中武漢大學理學院更是中國著名的理學院之一，其於《中國大學評價》獲得理學A等的評價。本次學術交流隸屬於理學院-物理科學與技術學院。主要參訪對象為該院之**潘春旭教授。潘教授目前擔任物理科學與技術學院副院長兼材料物理系之系主任**，負起統合系上的研究發展重任(潘春旭教授個人簡歷請參閱附件一)。

本次參訪行程期間為6月30日至7月5日，為期六天(含首、尾兩天之移動日)。主要目的為下列三點：

(一)帶領本學年度元智大學化材系學生參訪團，與武漢大學研究室進行學術交流、專題簡報、實驗室參訪等活動。

(二)了解該校之教育制度、學生發展、及建立雙方合作方案。

(三)參觀當地歷史古蹟文化、體驗當地生活、與學習環境。職係於當地時間6月30日下午4點抵達武漢市，並於7月5日清早啟程返台。Table 1是本次參訪之相關行程規劃。

Table 1：武漢大學學術交流行程。

時間	行程
06/30 (三)	1.移動日 2.與武漢大學-黃亞敏博士會面(曾於去年 3-9 月間參訪本校)，洽商隔日交流行程。
07/01 (四)	武漢大學物理科學與技術學院學術交流。
07/02 (五)	武漢大學-武當山，人文歷史巡禮。
07/03 (六)	武當山–襄陽城-宜昌，人文歷史巡禮。
07/04 (日)	宜昌(三峽大壩總工程)-武漢大學。
07/05 (一)	移動日。

(二) 學術交流經過與心得

本校參訪團係於6月30日下午4點抵達武漢市，接著前往黃鶴樓及用餐。並於當日下午8點，下塌旅館(軍悅假日酒店)。職係先與黃亞敏博士會面，洽商隔日造訪單位、規劃報告時間、與參訪動線。Table 2是本次武漢大學交流行程。

Table 2 武漢大學交流行程。

上午	
9:00	從軍悅假日酒店出發。
9:15	抵達武漢大學物理科學與技術學院，與劉昌院長、國際交流部港台辦領導、潭志傑副院長、和潘春旭教授等會見，商討聯合培養研究生等事宜。
10:00	職進行學術報告(歷時 1 hr 20 min)（物理學院 2 樓會議室）。並與物理學院老師、學生(元智大學實驗室代表，每位實驗室代表 10 min)進行交流。

12:10	上午學術報告結束，進行午餐（學校宴請）。
13:00	返回酒店，午休。
下午	
15:30	與相關課題組進行學術交流、參觀物理學院、與武漢大學校園。
17:30	全天行程結束。
18:00	返回酒店，進行晚餐。

7月1日武漢大學校內交流，主要以兩部份進行：

(一)學術交流：職進行1 hr 20 min口頭報告，報告內容分為兩大主體。第一部份係以職之研究為主題(Synchrotron X-ray Microscopy Study on Electromigration of Microelectronic Packaging Materials)，進行synchrotron 3D x-ray microdiffractionm原理介紹與應用；第二部份係以元智大學校況與發展特色為為主題，將兩校校風與發展概念進行交流(報告Power Point內容請參閱附件二)。在學生報告部分。本次交流報告因時間關係，規劃以實驗室為單位。由各實驗室推派代表，報告實驗室現況及核心研究(實驗室代表與報告主題如Table 3所列)。各代表進行10 min的報告，與武漢大學師學相互問答交流。Figure 1 為職及各實驗室報告代表報告情形，Figure 2為本參訪團與武漢大學教授合照。拍攝於報告交流會場。

Table 3 元智大學化材系之實驗室代表及報告主題。

實驗室名稱	實驗室代表
先進半導體封裝與材料	巫維翔(電遷移&界面反應)
分離技術	林宗翰(純化幾丁質酶)
電漿表面工程	劉又嘉(大氣電漿)
高分子電解質與燃料電池薄膜	王韋勝(電紡)
生物煉製及製程	張政勇(生物可降解高分子)

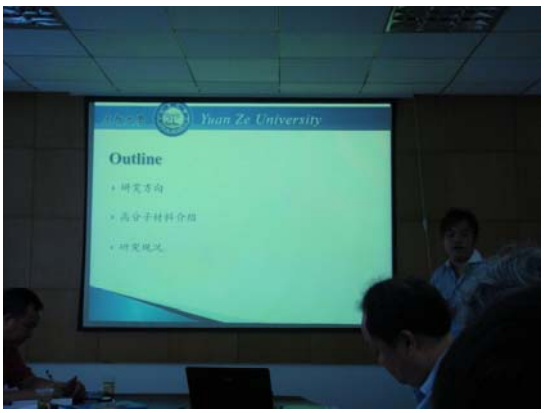
	
先進半導體封裝與材料-何政恩 助理教授	先進半導體封裝與材料-巫維翔
	
分離技術-林宗翰	電漿表面工程-劉又嘉
	
高分子電解質與燃料電池薄膜-王韋勝	生物煉製及製程-張政勇

Fig. 1：各實驗室代表報告情形，拍攝於武漢大學物理大樓會議室。

Fig. 2：報告會場元智大學代表團與武漢大學-譚志杰副院長、潘春旭副院長合照。

(二)校園巡禮與實驗室參訪：報告結束後著即與武漢大學教授共進午餐。其中多位貴賓，例如港澳台事務辦公所主任**盧江濱**、物理科學與技術學院院長**刘昌教授**亦撥冗前來與會。由於他們上午剛結束校內預算審核工作，隨即趕來會合，充分顯示武漢大學對於此次與元智大學交流的重視。午餐期間內，武漢大學教授與元智大學學生分享與交換學習經驗。對於台、陸間交換學生，武漢大學教授樂觀其成。此外對於去年多位武漢大學學生，能前來本校參與研究工作予以感謝之意。期間教授們對於多位學生多能於短時間，即發表SCI journals給予元智大學高度肯定。午休後，參觀武漢大學校內風光，了解武漢大學學生的學習環境。其中不乏許多古色古香建築，也見識到武漢大學歷史悠久與學校的優良傳統。Figure 3為午餐後合照，Figure 4為與潘春旭副院長合照於武漢大學校園。

Fig. 3：武漢大學午餐招待後合照，拍攝於武漢大學校內餐廳。

Fig. 4：與潘春旭教授(圖左)合照。拍攝地點：武漢大學代表性古建築。

7月2日、3日武當山-襄陽城-宜昌沉浸於歷史古城、陶冶人文氣息

武當山，聯合國公佈的世界文化遺產，中國國家重點風景名勝區、道教名山和武當拳發源地。武當山之盛名，主要由於它遠離繁華喧囂的寧靜和清秀、奇異的風光。登上武當山，山上能看到遼闊視野，放遠看清世界的脈動。參訪團原隔日攻上武當金頂，但受天候所限，基於安全考量，當日清晨及轉往巡禮歷史古城–襄陽城

。襄陽城，位於襄樊市區漢水南岸，三面環水一面靠山，是一座風景優美的古城。由於襄陽城的地理位置並且水路交通方便，是歷代兵家必爭之地。屢建屢毀，屢毀屢建。根據資料記載，襄陽城於元末時期大部分被毀，明洪武初年重築新城。城高約8米，周長7322米，四面建有6門，四角皆建子城。在襄陽城內可感受到歷史人文氣息，並沉浸於古色古香中。城內的歷史痕跡，訴說著許多古代歷史故事。其中不乏臥龍先生諸葛孔明的故事。諸葛孔明的高智慧，更是值得學生學習的對象。雖不能攻武當金頂，元智參訪團卻另有機會巡禮此一歷史名城，亦是旅途中之意外驚奇與收穫。

7月4日三峽大壩水利工程-三峽大壩總工程觀摩

三峽大壩，位於湖北省宜昌市西陵峽內的三斗坪，是當今世界上最大的水利工程。耗時17年的三峽工程中，參訪團見識到工程的浩大並且具備高細膩度。三峽工程主要分為大壩、水電站、通航建築物三大部分。大壩部分，壩頂全長2093米，高185米。景色之壯觀，超乎想像。根據相關工程記載，單單水電站部份，年平均發電量846.8億度足足是台灣石門水庫的400倍。元智參訪團體認到三峽大壩所帶來遠大效應，不光只是世界上最大的水利工程；通航建築物部分，也是三峽大壩特別的工程建築。階梯式的五級船閘原理也很有趣(如Figure 5a)。船進入閘極，將閘極內水位注入與下個閘極水位同樣高度。在將下個閘極門打開，船進入下個閘極階段。重複上述步驟，即可渡過三峽大壩，但須耗費三小時以上。

Fig. 5：三峽大壩景觀照：(a)三峽大壩通航建築五級船閘；(b)交流團全體合照，拍攝於三峽大壩下游觀景台。

(三) 合作計畫提案

本次學術交流除了學生與學生間的交流報告外，另外一方面就屬共同合作計畫的討論最為重要。職擬與潘春旭教授，在未來能持續交流合作。職與潘教授的結識，始於本校國際暨兩岸事務試所推展之兩岸交流活動。由於潘教授是大陸方面為金屬界面形成機理之專家，因此與職的研究內容有極高的共通性。本次有幸

能與潘教授單獨進行兩小時以上的會談。會中我們規劃下面兩項具體合作方案：

I. Mechanical Properties and the Corresponding Crystal Orientations of Intermetallic Compounds Formed in Microelectronic Solder Joints

職目前從事微電子元件之導線金屬工作。例如，現今微電子工業將電子零件組裝到印刷電路板上(Printed Circuit Board, PCB)係以銲接(soldering)的金屬化方式來進行。銲接是熔融的銲料與金屬銲墊(metallization pads)相接觸一個過程。在此過程中，銲料與銲墊進行的是液固反應。銲料與銲墊在接觸時會產生界面生成物或介金屬化合物(Intermetallic compound, IMC)。介金屬的生長情形在銲接的過程中扮演著相當重要的角色。銲點界面若無介金屬的生成，則與零件無法緊密接合，容易造成線路短路或零件鬆脫的情形發生。相反的，若介金屬層太厚則其易脆(embrittlement)的特質將會損壞界面之機械性質。介金屬層的生長情形直接反映整個電子產品之可靠度早已是不爭的事實。因此有關介金屬機械性質的精準量測就顯得相當重要。

武漢大學貴儀中心之奈米壓痕刮痕系統(潘教授負責管理)，正好可提供職在量測(或計算)介金屬之機械性質上許多寶貴的訊息。其中包括介金屬硬度(hardness, H)、彈性模數(elastic modulus, E)或楊氏模數(Young's modulus)是最常利用壓痕荷重對位移的關係求得之機械性質。此外由於壓痕法使用方便和迅速，以成為最常用來量測機械性質的技術。透過記錄壓痕時負載和卸載之全部周期，依彈性變形模式求取最大荷重時接觸面積與彈性模數的關係。由獲得的面積函數關係或形狀函數關係以估計接觸面積，運用此方法量測硬度與彈性模數。Figure 5 武漢大學奈米壓痕技術系統。

將奈米壓痕技術系統量測出的介金屬機械性質，搭配電子微探儀(Electron Probe X-ray Micro-Analysis, EPMA)進行成分與組成的分析。透過此二技術分析，即可獲得不同組成下的介金屬對上機械性質的關係圖。此外，介金屬在不同的晶

面上之機械特性，也會因為晶格常數與原子位置而有所不同。晶粒鑑定主要可以透過電子背向散射繞射(Electron Back-Scattered Diffraction, EBSD)、X光繞射(X-ray Diffraction)、低能電子繞射儀 (Low Energy Electron Diffractometer, LEED)等。潘教授也正是EBSD的行家，這與職過去在美國所進行的3-D x-ray microdiffraction (Argonne National Lab., APS, U.S.A.)技術，有很高的互補性。

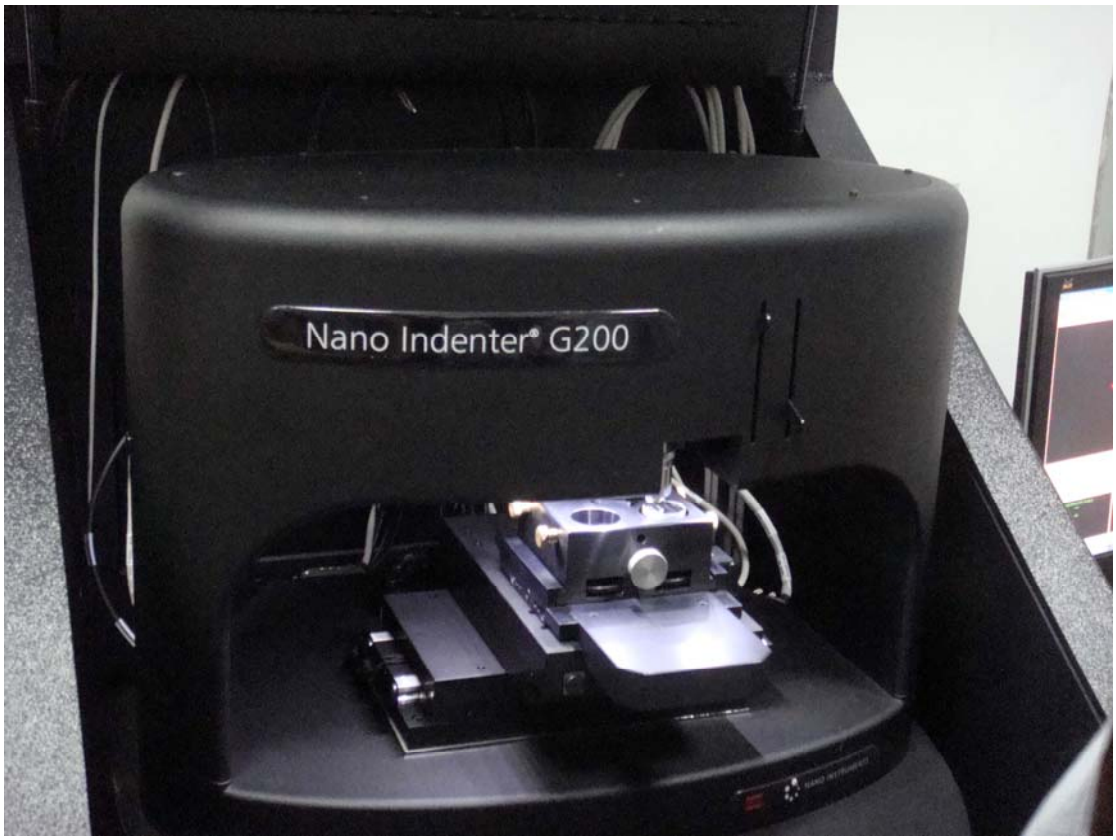


Fig. 5：奈米壓痕技術儀器，型號MTS-G200。

EBSD分析主要可應用下列四種分析，如Fig. 6所示。該圖中清楚的呈現：(I)結晶方向。透過背向散射電子對結晶進行彈性繞射行為，將可得到的菊池線(Kikuchi lines)來進行結晶方位分析。不同菊池線的相交角度表示晶格平面間的夾角，故可鑑定晶體結構及其幾何方位(crystal orientation)。Figure 6中不同顏色代表不同的晶粒取向，對照圖右之晶體legends即可清楚知道晶粒取向；(II)晶界。

相鄰兩晶粒的方向差異(misorientation)亦可利Orientation Imaging Microscopy (OIM)分析；(III)晶粒尺寸、形狀。EBSD可正確的將晶界顯示出來，並進行相關數據統計分析，故可獲得真實的晶粒尺寸、形狀與分佈。如Figure 6所示，式樣晶界，晶粒的尺寸、形態清楚的呈現於此圖中。Figure 6分析範圍為7.5 μm × 10 μm，這是一般XRD較難達到的微區分析範圍。透過EBSD的分析，可以充分獲得晶體織構資訊。搭配奈米壓痕技術即可獲得晶體結構對機械性質上的影響，對於介金屬之機械性質將有極深入的了解。

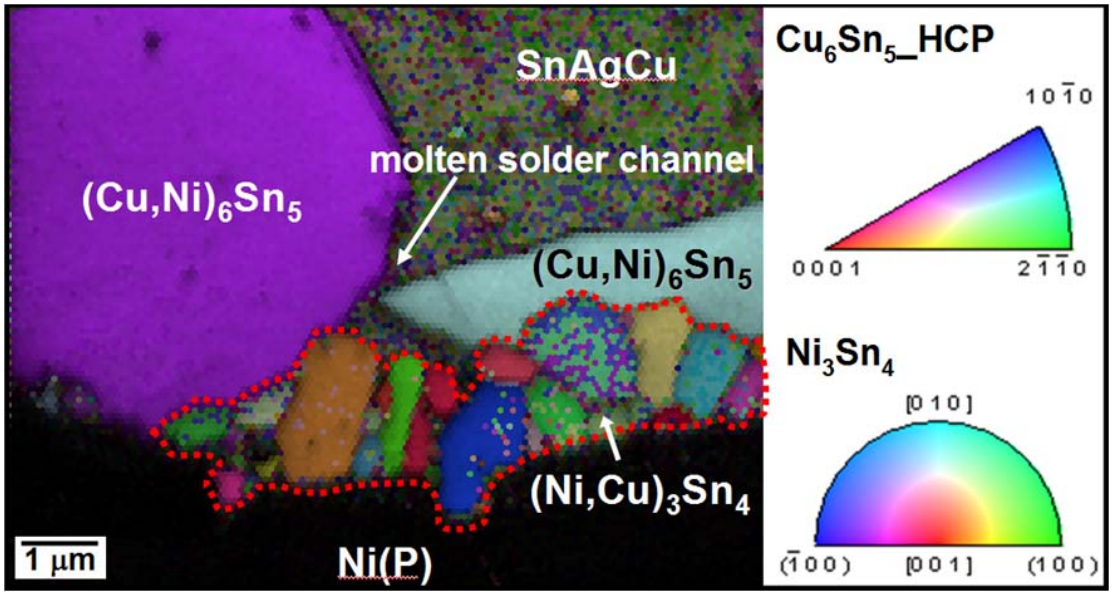


Fig. 6 職實驗室於EBSD的初步研究成果(尚未發表)。

II. In-Situ Observation on the Growth of Tin Whiskers in Electron Microscopy

錫鬚(tin whiskers)一直以來為影響電子元件可靠度的重點觀察對象之一。當錫鬚不斷生長與相鄰間線路接觸，便可能會造成電路短路，使電子系統失效。錫鬚的生長主要由於Sn膜內部壓縮硬力不斷的產生，當此應力超過一臨界壓力，便以生長錫鬚的方式釋放壓縮應力。近年來微電子導線尺寸縮小的效應下，會使部份區域所承載之電流密度拉高。這可能引發電遷移(electromigration)效應，而觸

發錫鬚生長。Figure 7即為電遷移效應下，所引發錫鬚的生長。

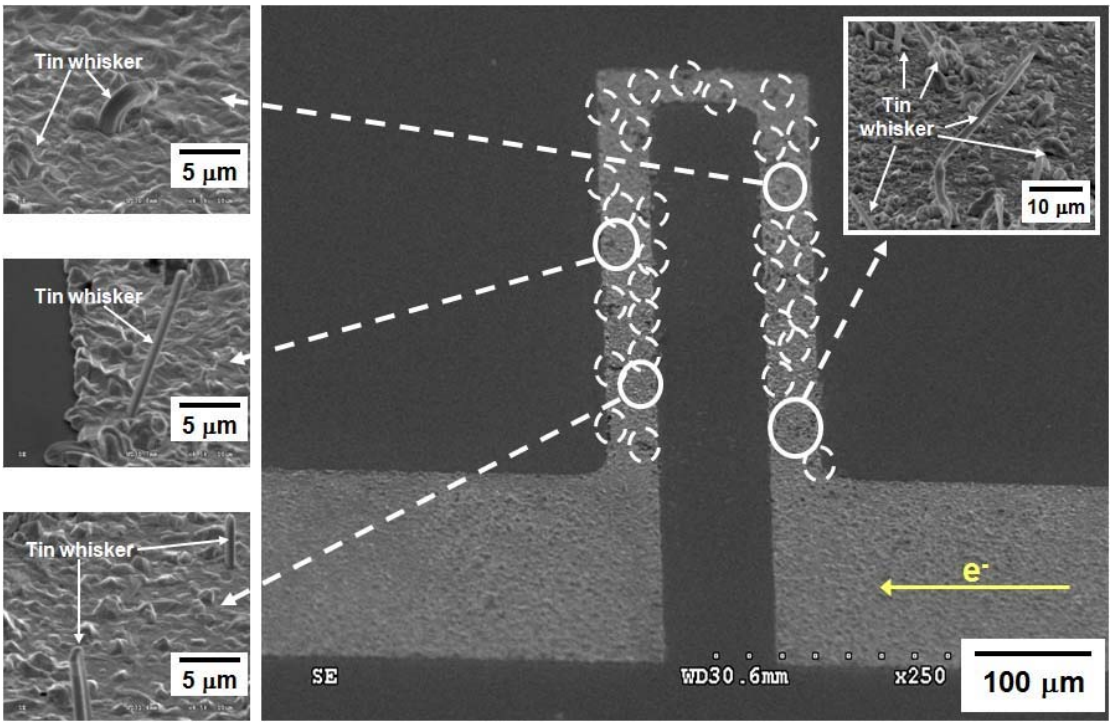


Fig. 7: Current stressing-induced tin whiskering.

過去錫鬚的觀察，主要以ex-situ的方式呈現。原因在於受限於分析儀器的高規範。掃描試電子顯微鏡(Scanning Electron Microscopy, SEM)與穿透式電子顯微鏡(Transmission Electron Microscopy, TEM)高真空規範，使得通電與加熱無法於儀器內部輕易的進行。造成了許多觀察的限制。武漢大學貴重儀器中心所設置的SEM系統，其內部裝設機械臂。可由外部操作，進行樣品的移動、通電...等多元性的功能。在與潘教授經過詳細的討論與評估後，一致認為在此儀器條件下可以嘗試錫鬚in-situ一系列的觀察。In-situ與ex-situ最大的差別在於in-situ是即時性的原位追蹤，在實驗不中斷的情形下(如通電、加熱)持續對樣品進行觀察。在應力累積不中斷的情況下，對於錫鬚的了解必會有突破性的發現。其中之一重要的觀察要點，錫鬚的生長機制在過去只獲得由底部向上生長的訊息，但對於錫鬚生長模式尚未有明確的發現。錫鬚生長前是否具有孕育期(incubation time)?錫鬚的生長是否以同等速率持續生長?是值得深入探討的議題。藉由此次與武漢大學教授

們的交流討論，職深感榮幸並且獲益頗豐。透過兩校的合作，並能使研究向上提升一個層次，也是此次最大的收穫。以上是職本次參與學生國際與兩岸學術交流之心得報告。最後，再次感謝元智大學給予支持與相關補助。

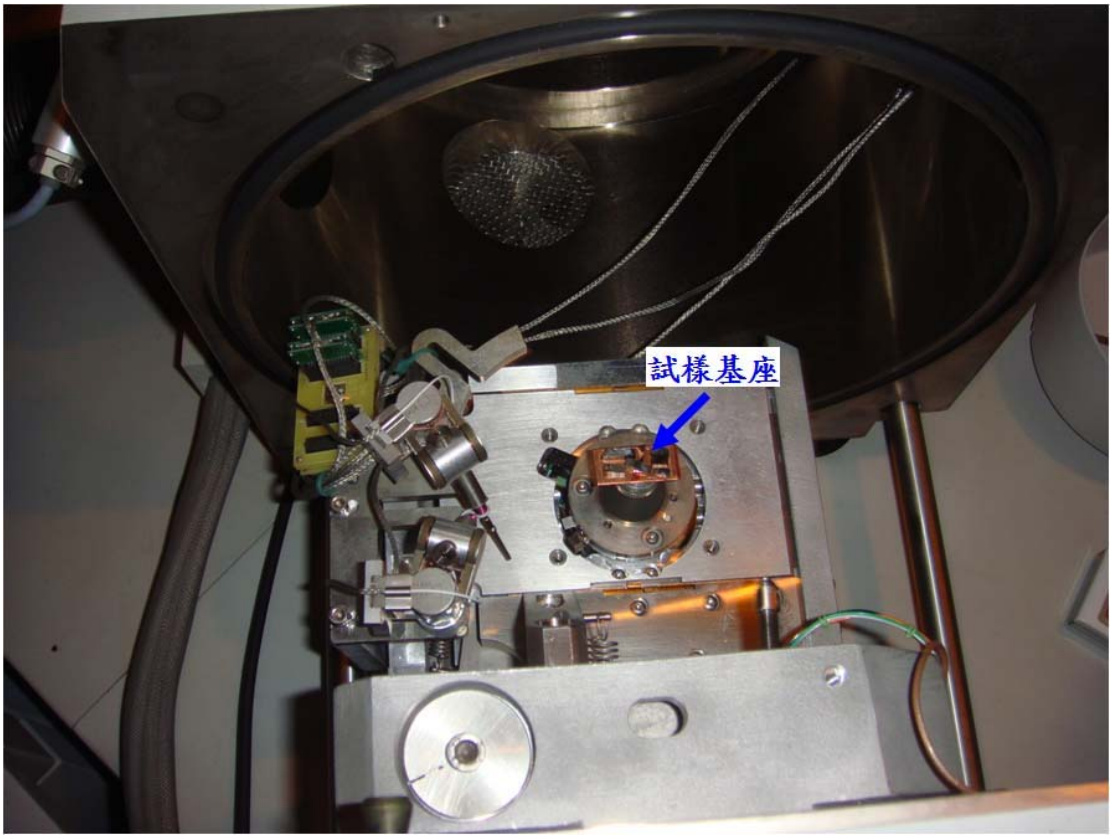


Fig.8：武漢大學貴儀中心，SEM內部機械臂裝置圖。

附　件

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Professional Experience

2001-present: Professor, Vice-Chair, Department of Physics, Wuhan University, Wuhan, China. Responsible for the graduate education and international student exchange program in the department.
1999-2001: Visiting Research Scholar, Center for Robotics and Manufacturing Systems (CRMS), College of Engineering, University of Kentucky, USA.
1997: Training in Japan. Training Course: "Steel Properties and Its Applications", Organized by "Japan International Cooperation Agency (JICA)", Kyushu International Centre, JAPAN
1983-2001: Lecturer (1989), Associate Professor (1993), Professor(1998), Chair (1997-2001), Department of Materials Science and Engineering, Wuhan Transportation University.

Research Areas

1） **Air Decontamination Mechanism and Service Behavior of TiO2 Photo-catalytic Materials:** Materials synthesis, photo-catalytic property, calculation and modulation.
2） **Novel nanomaterials synthesis, properties and applications:** carbon nanotubes and nanofibers, one-dimension metal oxide nanoneedles (ZnO, CuO and Fe_2O_3, etc.);
3） **elding metallurgy:** aluminum alloy welding, microstructure – property relationships of dissimilar and similar steel welded joints;
4） **Electron microscopy:** SEM, TEM, HRTEM, EBSD and EDS;
5） **Surface modifications:** Micro-arc oxidation on light alloy surface;
6） **Materials science in archeology.**

Awards & Honors:

1) "*The 1999-2003 Chinese Physical Society Outstanding Member Award*", Chinese Physical Society, 2003.
2) "The *2002 National Excellent Doctoral Dissertation (NEDD) Award (Top 100)*", Government of China, 2002.
3) "The *4th Excellent Doctoral Dissertation Award of Hubei Province*", Government of Hubei Province, China, 2001.
4) Project "*Elevate Temperature Failure Analysis of ROF Inner Cover*" won the "*Third Prize Award of Science and Technology Progress*", Government of Hubei Province, China, 2000.
5) "*Outstanding Youth Educational Worker Award*", Ministry of Communication, China, 1999.
6) Project "*Research and applications of F12 steel welding*" won the "*Second Prize Award of Science and Technology Progress*", Government of Hubei Province, China, 1998.

7) Project "*Microstructural study of F12 steel welded joints*" won the "*First Prize Award of Mechanical Science and Technology Progress*", Mechanical Industry Department of Hubei Province, China, 1997

Memberships:

1. **Member for the review panel:** *Materials Protection* (2008 – present)
2. **Committee Member**: 5th Committee of Chinese Materials Research Society (C-MRS) (2007 – present).
3. **Teaching Advisory Committee Member**: Materials Science and Engineering Division, Ministry of Education, China, (2006 – present).
4. **Committee Member**: 7th Committee of Chinese Electron Microscopy Society, 2004 – present).
5. **Chairman of the Committee Board**: Hubei Society of Physical Testing and Chemical Analysis of Hubei Province (2006-present).
6. **Vice-Chairman of the Committee Board**: Society of Electron Microscopy of Hubei Province, (2001-2006, 2006 – present).
7. **Vice-Chairman of the Committee Board**: Hubei Society of Heart Treatment, 1999 – 2004, 2004-present).
8. **Standing Committee Member & Secretary-General**: Physical Society of Hubei Province, (2001 – 2006, 2006 – present).
9. **Honorary Professor**: Wuhan University of Technology, (2006-2008)
10. **Member for the review panel:** *Nanoscience & Nanotechnology* (2006 – present).
11. **Referee for numerous prestigious Journals**: *Chinese Physics Letters*, *Acta Metallugica Sinica*, *The Chinese Journal of Nonferrous Metals, Journal of Inorganic Materials, Journal of Materials Science, etc.*

Patents

1. "A Method for Synthesizing Carbon Nanotubes", (No. ZL 01 1 28416.1); Nov. 10, 2004.
2. "A Method for Synthesizing Carbon Nanofibers", (ZL 02 1 15886.X) Jun. 8, 2005.
3. A new route to synthesize diamond from novel solid carbon nanofibers under unexpectedly low temperature and low pressure, Pending, No. 200810048382.X, July 11, 2008
4. "A method for Synthesis one-dimension metal oxide nanoneedles", Pending, No. 200710051712. March 22, 2007.
5. "Applications of one-dimension CuO nanoneedles", Pending, No. 200710051255.0，March 22, 2007...

Book Publication:

1) Chunxu Pan, et al.: " ***A Experimental Course in Materials Physics and Chemistry***", ***Zhongnan University Press***, Hunan, Changsha, CHINA, 2008.
2) Chunxu Pan: ***Dissimilar Steel and Dissimilar Metal Welding – Microstructural Characterization and Transformation Behavior***, ***People'S Communication Press***, Beijing, CHINA, 2000.
3) **Chunxu Pan**, Yamin Huang, Qiang Fu: "A Novel "In-situ-tracking" Approach for Evaluating Microstructural Variations Using SEM, EDS and EBSD and Its Applications in Materials Science". ***Modern Research and Educational Topics in Microscopy (Volume II)*** (Editors: Antonio Mendez Vilas, Jesus Diaz Alvarez, 2007), Pages 697-703. ISBN of Collection (13): 978-84-611-9418-6, ISBN Vol. II (13): 978-84-611-9420-9

Selected Peer-Reviewed Journal Publications (2005-2009):

2009 年

[1] 杨春艳，潘春旭："电爆法制备纳米铜颗粒的微结构特征及其氧化行为研究"，*中国材料科技与设备*，2009 年 3 月，第 2 期将发表。

[2] Yamin Huang, Youming Wu and Chunxu Pan: "A EBSD study of solidification characteristics of an austenitic stainless steel weld pool", ***Materials Science and Technology***, 2008, accepted. (In English)

[3] ZHANG Guoqing, PAN Chunxu, ZHANG Guodong: "Magnetoresistance Plateau in La2/3Ca1/3BixMn1-xO3 Granular System", ***Journal of Wuhan University of Technology-Materials Science Edition***, will appear soon. (In English)

[4] Wen Yu and Chunxu Pan: “Low Temperature Thermal Oxidation Synthesis of ZnO Nanoneedles and the Growth Mechanism”, ***Materials Chemistry and Physics***，2009, 115: 74–79. (In English)

Yamin Huang, Youming Wu, and Chunxu Pan: “Oxidation Mechanism of austenitic stainless steel during super high temperature service”, ***Journal of Zhengzhou University*** (Engineering Science Edition), 2009，30(1): 53-56. (In Chinese)

[5] ZHOU Fufang, ZHAI Baogai, SHE Zhuoran, HUANG Yuanming, PAN Chunxu: “Mechanical Grinding: An Effective Method to Control the Conductivity of p-toluene Sulfonic Acid Doped Polypyrrole”, ***Key Engineering Materials***, 2009, 407-408: 573-576.

[6] PAN Chunxu, QI Xiang: “Research Progress in Synthesis of One-Dimensional Carbon Nanoscale Heterojunctions”, ***New Carbon Materials***，2009, 24 (01): 44-50. (In Chinese)

2008 年

Yamin Huang, Youming Wu, Qiang Fu, and Chunxu Pan:A novel “in-situ-tracking” approach using SEM and EBSD for studying microstrctural development of austenitic stainless steel and its welded joint during super-high temperature service”, ***Journal of Chinese Electron Microscopy Society***，2008, 27 (6): 432-438. (In Chinese)

Yueli Liu, Chunxu Pan, Ying Dai, Wen Chen: “Diameter-controlling growth Of solid-cored carbon nanofibers On a pulse plated iron nanocrystalline substrate in flames”, ***Materials Research Bulletin***, 2008, 2008, 43(12): 3397-3407 (In English)

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Chen Chao， Pan Chunxu， Fu Qiang: "Micro-Residual Stress Measurement Using Vickers Micro-Indentation", ***Materials for Mechanical Engineering***,，2007, 31(1): 8-11. (In Chinese).

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Qiangliang Bao and Chunxu Pan: ‘‘Agglomerating growth of one-dimension carbon nano-materials synthesized from ethanol flames’’，***Journal of Wuhan University – Nature Science Edition***，2006, 11(3): 581-584. (In English)

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Synchrotron X-ray Microscopy Study on Electromigration of Microelectronic Packaging Materials

何政恩 (Cheng-En Ho)

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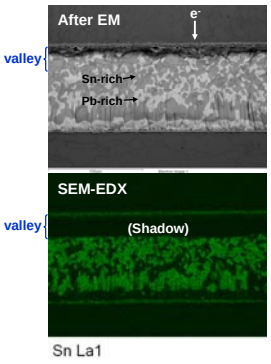
Wuhan University, the 1st July, 2010

Why Synchrotron?

- ✓ Non-destructive method
- ✓ Surface topology has no influences
- ✓ High energy X-ray provides means for probing higher depths (~70 μm for PbSn alloys)
- ✓ Provides crystallographic information/precise residual lattice strains (0.01%)
- ✓ Provides concentration profiles of various ions without shadow effect



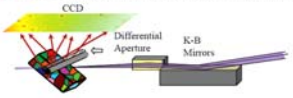
Outline

- ◆**How synchrotron x-ray microscopy (in Argonne) work?**
- ◆**Recent x-ray microscopy studies on**
  - **(1) EM in eutectic PbSn solder joints**
  - **~~(2) Tin whisker growth~~**
- ◆**Submicron XRD beamline in TPS**
  (Principal PI: Prof. Haydn Chen, Tunghai University)
- ◆**Summary**

Brief Introduction to 3-D X-Ray Structural Microscopy at 34-ID-E

Studies of materials on mesoscopic length-scales require a penetrating structural probe with submicron point-to-point spatial resolution.

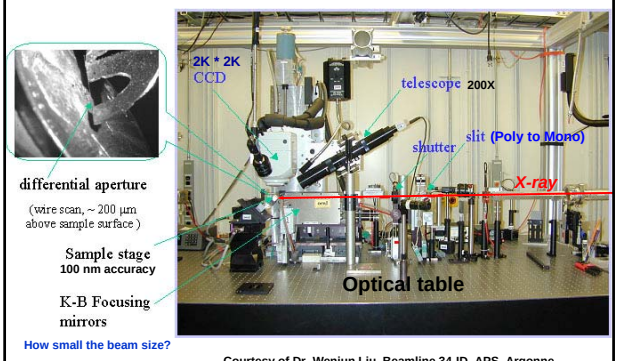
(Gene Ice et. al)



- The differential-aperture x-ray microscopy (DAXM) method is general and applicable to single crystal, polycrystalline, composite, deformed, and functionally-graded materials, etc.
  - White beam Laue patterns from x-ray microbeams provides local structure, orientation, and elastic strain tensors with 3D submicron spatial resolution. *[B. C. Larson et al, Nature 415, 887 (2002)]*
  - Monochromatic DAXM techniques have been recently developed as well for measuring absolute lattice parameter with 3D. *[Lyle E. Levine et al, Nature Materials, 5, 619 (2006)]*
- These capabilities provide a direct link to theory, simulations, and modeling of the actual materials microstructure and evolution on mesoscopic length scales.

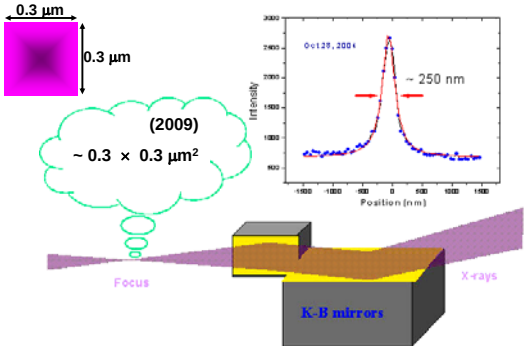
Courtesy of Dr. Wenjun Liu, Beamline 34-ID, APS, Argonne 5

Microbeam 3-D Diffraction Microscopy

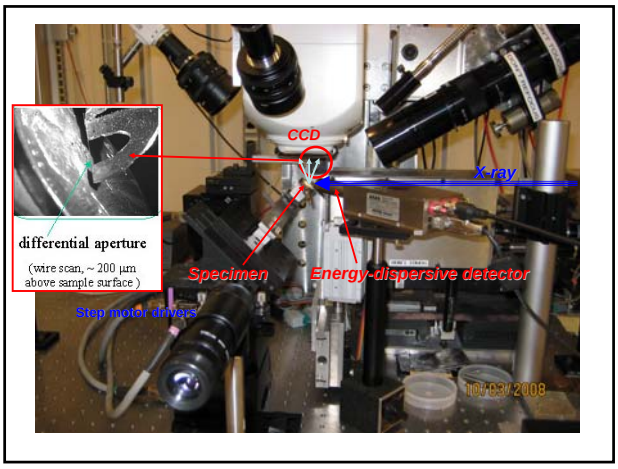


Courtesy of Dr. Wenjun Liu, Beamline 34-ID, APS, Argonne

Spot Size of Beamline 34-ID

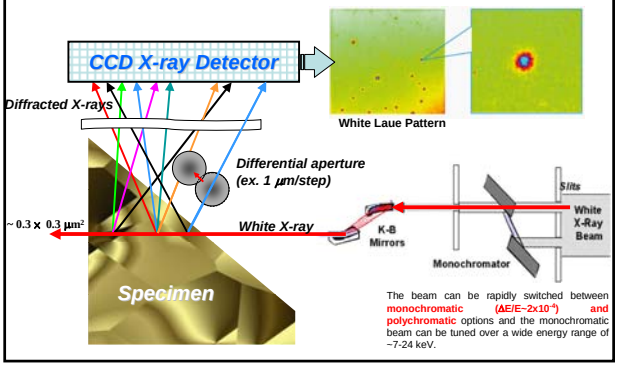


Courtesy of Dr. Wenjun Liu, Beamline 34-ID, APS, Argonne



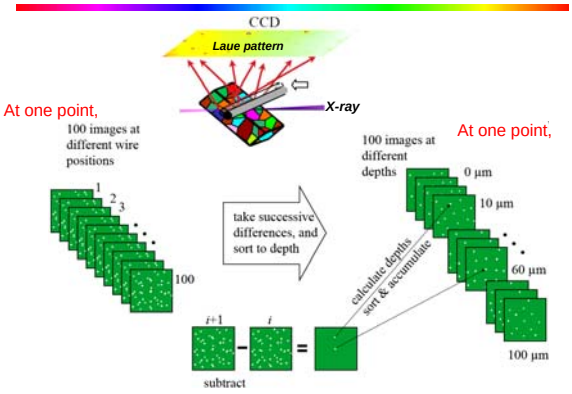
How 3-D X-Ray Microscope Works?

Larson, B. C., Yang, W., Ice, G., Budai, J. D. & Tischler, J. Z. Three-dimensional X-ray structural microscopy with submicrometre resolution. ***Nature*** 415, 887-890 (2002).



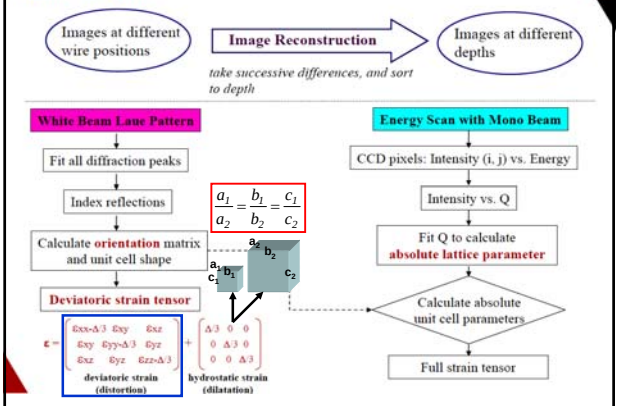
The beam can be rapidly switched between **monochromatic** (ΔE/E~2x10⁻⁴) and **polychromatic** options and the monochromatic beam can be tuned over a wide energy range of ~7-24 keV.

Sorting from Wire to Depth



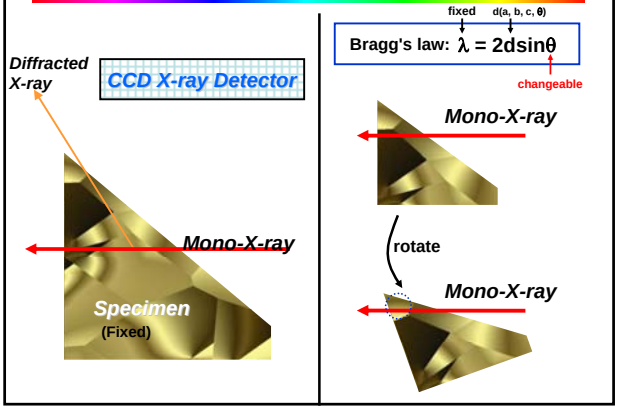
Courtesy of Dr. Wenjun Liu, Beamline 34-ID, APS, Argonne

Data Analysis

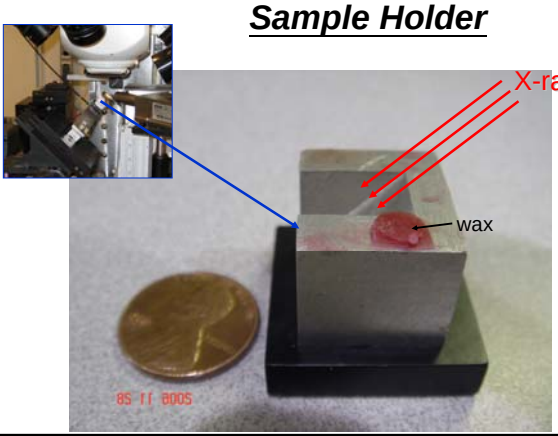


Courtesy of Dr. Wenjun Liu, Beamline 34-ID, APS, Argonne

Why White Light?

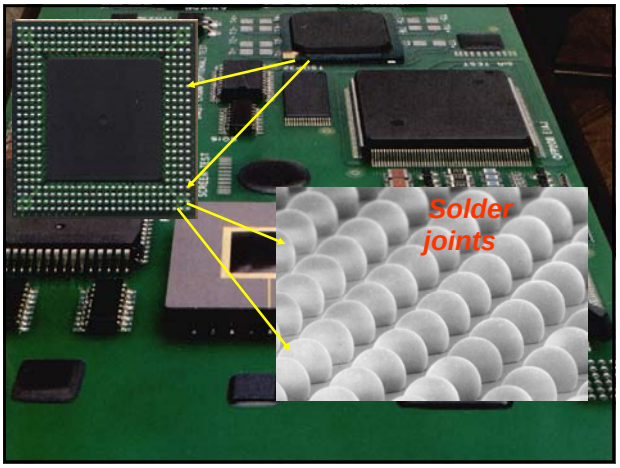


Sample Holder

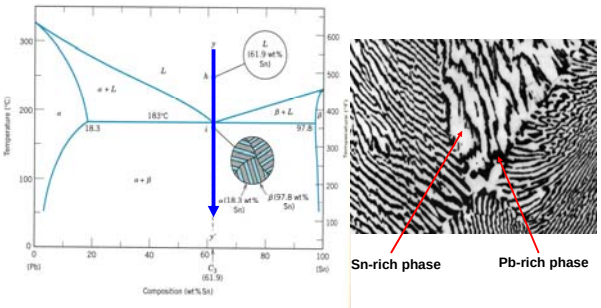


Outline

- How synchrotron x-ray microscopy (in Argonne) work?
- Recent x-ray microscopy studies on
  - (1) EM in eutectic PbSn solder joints
  - (2) Tin whisker growth
- Submicron XRD beamline in TPS
  (Principal PI: Prof. Haydn Chen, Tunghai University)
- Summary

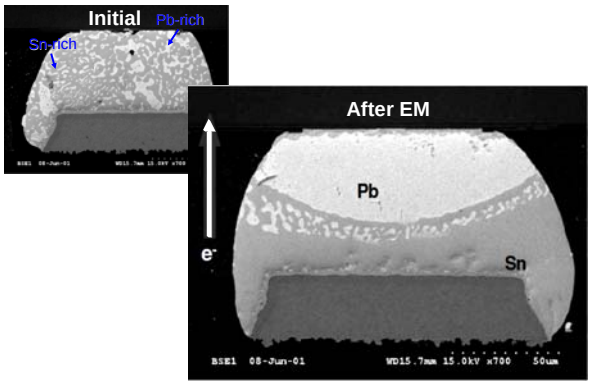


Pb-Sn Binary System

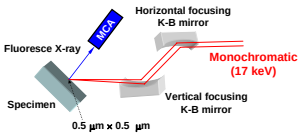


William D. Callister, Jr., Materials Science and Engineering: An Introduction, 4th ed., John Wiley & Sons, Inc., New York (1996).

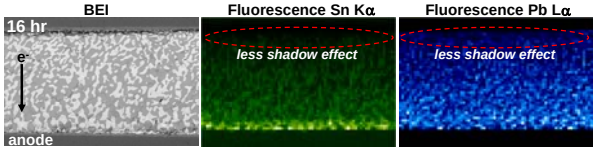
EM in Eutectic PbSn Alloy



X-ray Fluorescence Spectroscopy

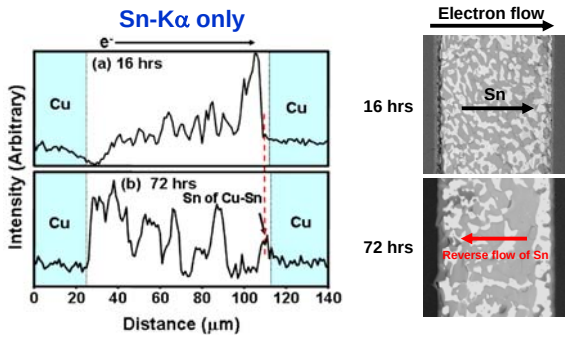


- A narrowly focused, high energy (17 keV, $\Delta E/E \approx 10^{-4}$) monochromatic synchrotron x-ray radiation of a spot size of about 0.5 x 0.5 μm^2 was used as the source to excite x-ray fluorescence emissions from the specimen.
- X-ray of 17 keV had attenuation lengths of about 10 and 50 μm in Pb and Sn, respectively, providing an integrated elemental concentration to corresponding depths.
- Aging@150°C under 10^4 A/cm^2



C. E. Ho, A. Lee, K. N. Subramanian, and W. Liu, "Early stage of material movements in eutectic SnPb solder joint undergoing current stressing at 150°C," ***Applied Physics Letters***, 91, p.021906, **2007**.

X-ray Fluorescence Spectroscopy

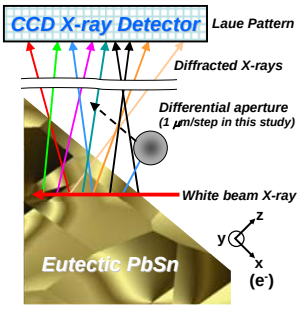


◆ **Microbeam x-ray fluorescence spectroscopy is a very valuable tool to obtain quantitative distribution of atoms, which no surface manifestation can be noted in contrast with other characterization techniques.**

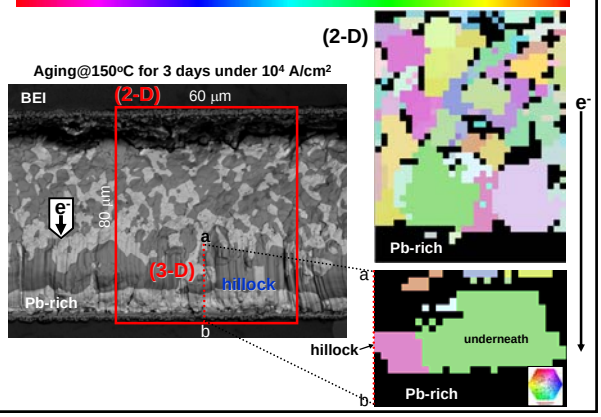
Synchrotron X-ray Microdiffraction

- White beam X-ray can penetrate pure **tin** & pure **lead** to about **100** & **15 μm**, respectively.
- In **2-D (without differential aperture)**, the scanning steps along both x- and y-axis (direction of electron flow and the width of the joint) were **2 μm/step**.
- In **3-D** (depth-scanning), the scanning steps along x-axis was 2 μm/step, and the depth profiling step size was 1 μm when the differential aperture X-ray microscopy technique was used.
- In crystal orientation maps, the misorientation sensitivity is about **0.01°**.

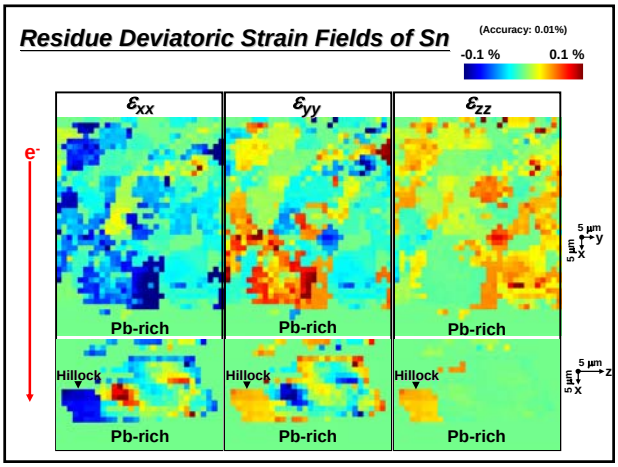
Differential-Aperture X-ray Microscopy in Beamline 34-ID, APS, Argonne



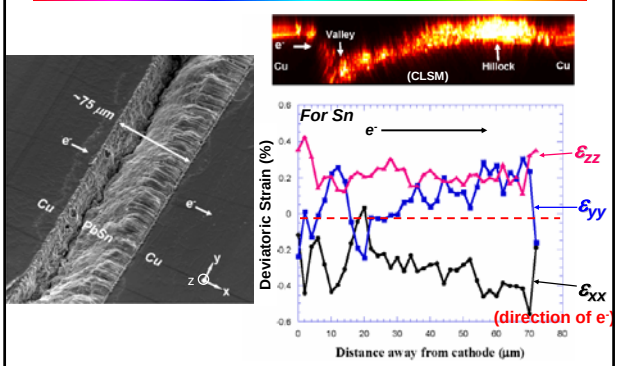
OIM of the Sn-rich Phase after EM



Residue Deviatoric Strain Fields of Sn



Integrated Deviatoric Strains of Sn

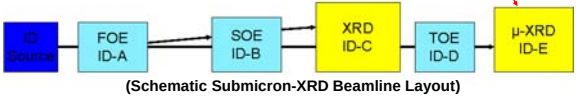


A. Lee, W. Liu, C. E. Ho, and K. N. Subramanian, "Synchrotron X-ray microscopy studies on electromigration of a two-phase material," *Journal of Applied Physics*, 102, p.053507, 2007.

Construction of An Undulator Beamline for Materials Research in TPS (2014)

Principal PI: Prof. Haydn Chen, Tunghai University

◆ Our beamline is to split the ID beam into two parts: a pink beam side station for general purpose diffraction (XRD) and a dedicated end station specifically designed for **microbeam 3-D diffraction microscopy (μ-XRD)**.



(Schematic Submicron-XRD Beamline Layout)

Optical Enclosures and Experimental Hutches:

- FOE: the first optical enclosure.
- SOE: the second optical enclosure.
- XRD Hutch: experimental station for powder diff.; general diff. & scattering.
- TOE: the third optical enclosure.
- μ-XRD Hutch: experimental station for 3D micro/nano diffraction.

Preliminary Plan for Submicron-XRD End Station in TPS

	34ID-E (before July, 2009)	TPS (2014)
Key items	**Specification**	**Specification**
Optical table and enclosure	100 nm stability	<50 nm (mechanical and thermal)
Area detectors	**CCD (2K x 2K pixels) 0.3 Hz**	**PE detectors 15 Hz**
KB mirror system (mirrors + control box)	**~0.3 microns**	**~0.1 microns**
High performance 3D sample stage	100 nm accuracy, 1 inch travel range	<20 nm accuracy, 1 inch travel range
Differential aperture 3D stage	100nm accuracy, 1 inch travel range	<20 nm accuracy, 1 inch travel range
Energy-dispersive detector	KETEK or Vortex	KETEK or Vortex
Optical microscope	200X	Keyence digital
Apertures, slits, ion chambers	standard	standard
VME, Stepper motor drivers, Electronics	standard	standard
Computer for data analysis	PC or MAC	cluster

Summary

- **3-D X-Ray Microscopy** is general and applicable to single crystal, polycrystalline, composite, deformed, and functionally-graded materials, etc.
- Diffracted beam profiling provides the basis of point-to-point 3D x-ray structural microscopy with **submicron spatial resolution and high angular resolution** for local crystal structure, orientation, strain tensor measurements.
- **Quantitative, non-destructive** investigations of the microstructure and structural evolution of materials have been demonstrated as electromigration and metal deformation cases.
- These capabilities provide a direct link to theory, simulations, and modeling of the actual materials microstructure and evolution on mesoscopic length scales.

Introduction to

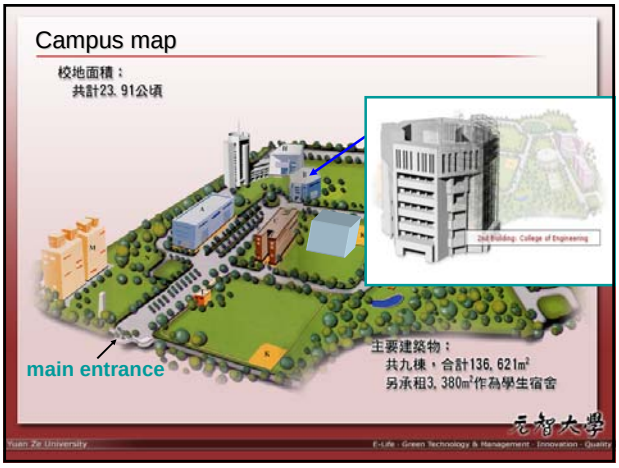
- Yuan Ze University
- Department of Chemical Engineering and Materials Science

Yuan Ze University

A private university founded by Far Eastern Group.

1989 Established as
Yuan Ze Institute of Technology

1997 Upgraded & Renamed as
Yuan Ze University



Yuan Ze University

5 Colleges at Yuan Ze University

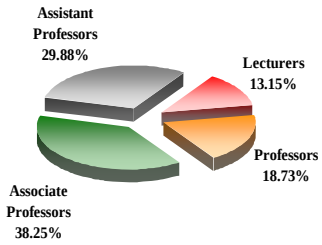
- College of Engineering
- College of Management
- College of Informatics
- College of Humanities and Social Sciences
- College of Electrical and Communication Engineering

Yuan Ze University

Degree Program	Student Number
PhD	254
MS	905
MS (part-time)	1170
Undergraduate	5889
Undergraduate (part-time)	973
Total	9191

Yuan Ze University

Faculties：**282**
Staffs: **247**

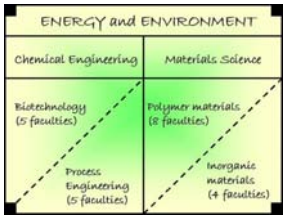


Introduction to

- Yuan Ze University
- Department of Chemical Engineering and Materials Science

CEMS Faculty (full time) in YZU

Title	Number
Professor	11
Associate Professor	5
Assistant Professor	5
Lecturer	1
Total	22(+3)



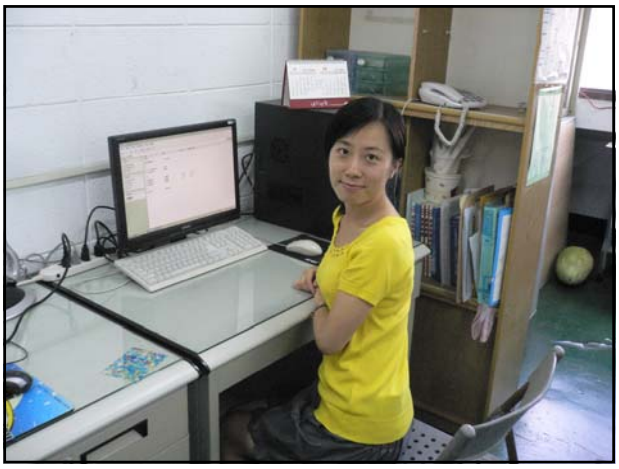
- 5 of faculty members in Biotechnology area.
- 5 of faculty members in Process Engineering area.
- 8 of faculty members in Polymeric Material area.
- 4 of faculty members in Inorganic Material area.

Students at CEMS in YZU

	Undergraduate	MS program (full time)	MS program (part time)	PhD program
Students	~450	~ 100	~ 60	~ 15

International Activity

- **Student exchange program offers great opportunities to enrich the knowledge and to extend the globalization view.**
- **Many exchange students coming from the world, e.g. *India, Bangladesh, and French students* study in this department for *internship* and *graduate program*.**



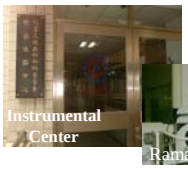
Departmental layout

- Total Area : **3869.6 m²**
- **19** Research lab
- **5** Undergraduate teaching lab
- **1** Instrumental center
- **10** Graduate student meeting room
- **1** Departmental administration office

8

Instrumental Center

1. Scanning Electron Microscope **SEM, FESEM**
2. X-ray Diffractometer **XRD**
3. Atomic Force Microscope **AFM**
4. Elemental Analyzer **EA**
5. FTIR, FTIR-Microscope
6. Inductively Coupled Plasma **ICP**
7. Gas Chromatography **GC**
8. Ultraviolet-Visible Spectrophotometer **UV**
9. Micromeritics ASAP2000 **ASAP**
10. Digital Universal Material Testing Machine Instron 2518-800 **Instron**
11. Thermogravimetry **TGA**
12. Polarized Optical Microscopy **POM**



Research and Development

Biochemical Engineering Group	1. Biodegradable plastics--PHAs 2. Fine chemicals—Surfactin, glucosamine	6 faculties
Energy and Environmental Group	1. Fuel cell 2. Biofuel cell 3. Organic/inorganic solar cell 4. Sustainable energy carrier	15 faculties
Soft Material Group	1. Liquid crystal 2. Nano-particle 3. Conducted polymer	12 faculties


of Electromigration in Cu/Sn/Ni Diffusion Couple
先進半導體封裝與材料實驗室 何政恩助理教授
Advanced Semiconductor Packages and Materials Lab.

Thank you!