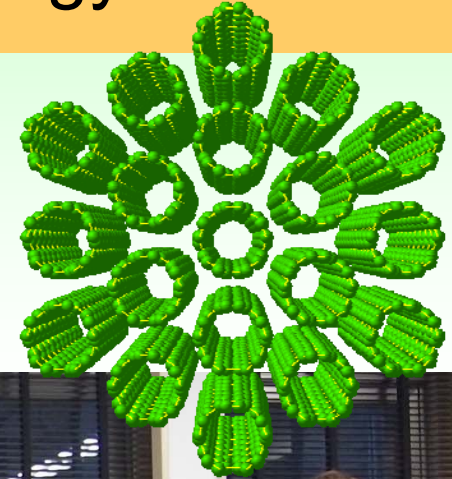


Workshop on Molecular Thermal Engineering @ Tokyo July 5, 2013

# Single-Walled Carbon Nanotubes for Energy Devices



**Shigeo Maruyama**

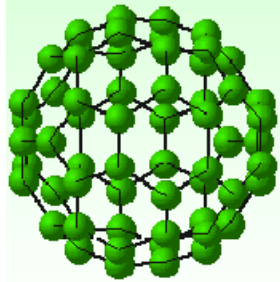
Department of Mechanical Engineering, The University of Tokyo



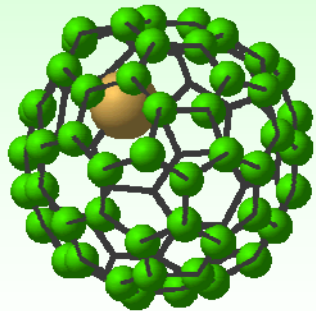
Research Society

# FNTG Research Society

<http://fullerene-jp.org/>

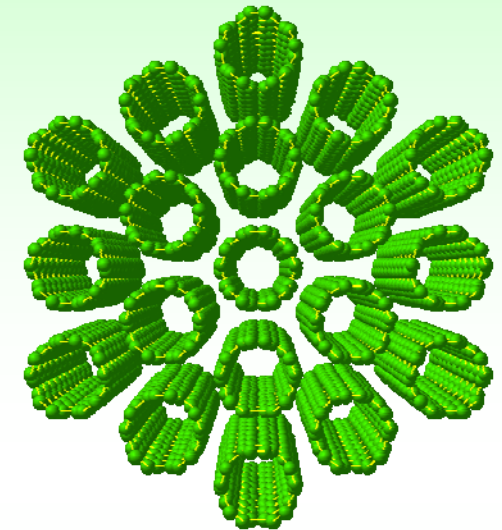
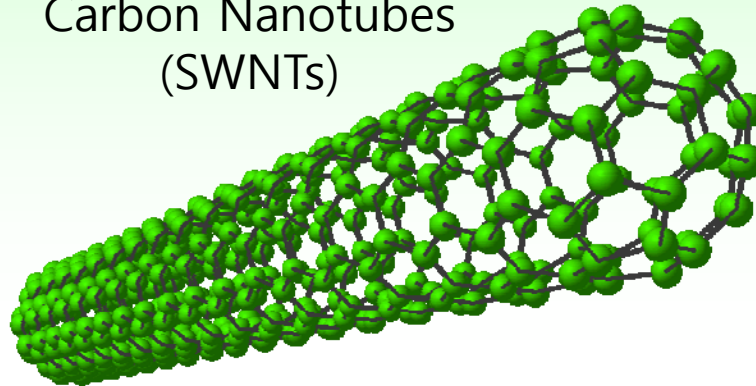


Fullerene

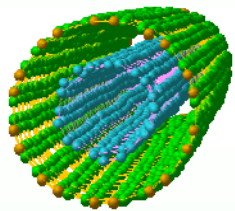


Metallofullerene

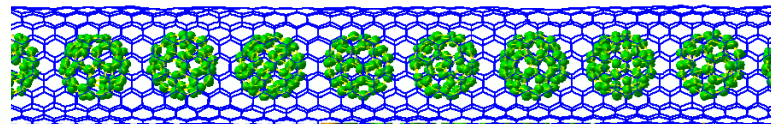
Single-Walled  
Carbon Nanotubes  
(SWNTs)



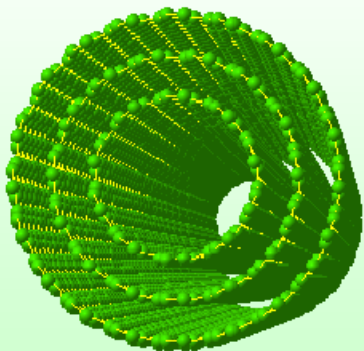
Bundle of SWNTs



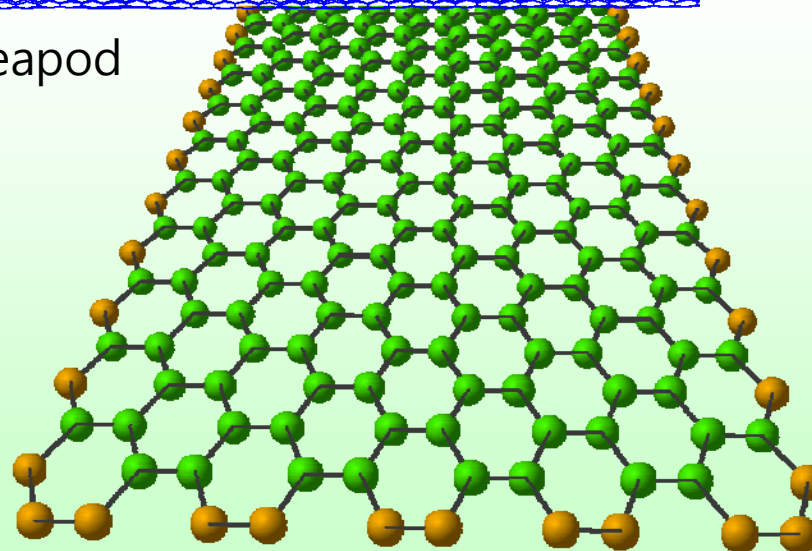
Double-Walled  
Carbon Nanotubes



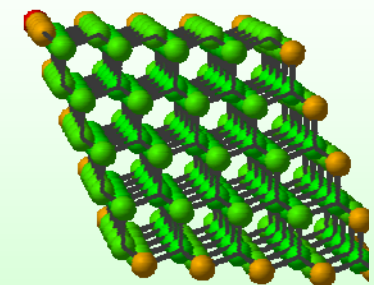
Peapod



Multi-Walled  
Carbon Nanotubes



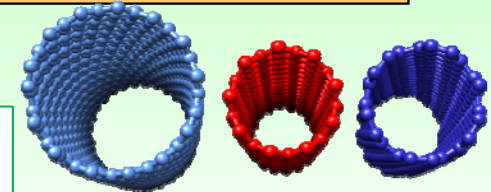
Graphene



Nano-Diamond

# Research Focus

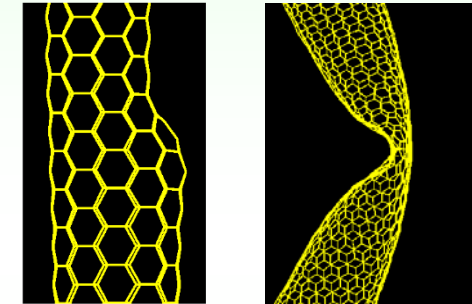
Growth Mechanism and Growth Control of SWNTs  
Structuring SWNTs



Structure Control

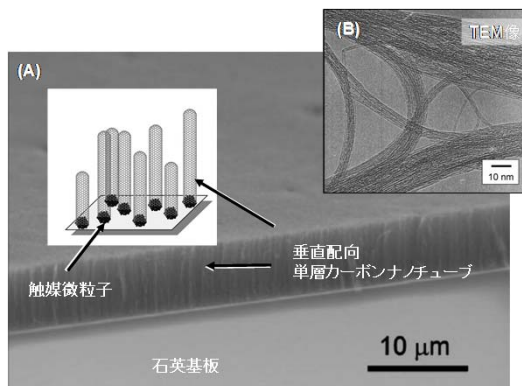


Devices Related with Energy

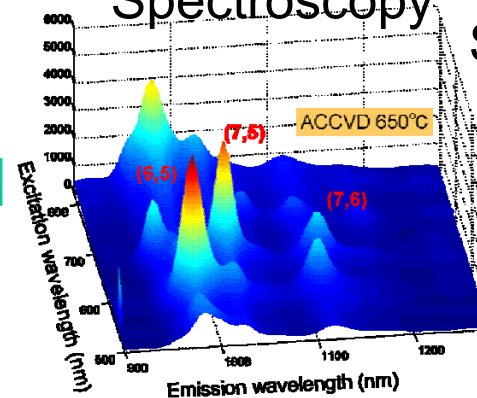


Defect Control

Growth of SWNTs

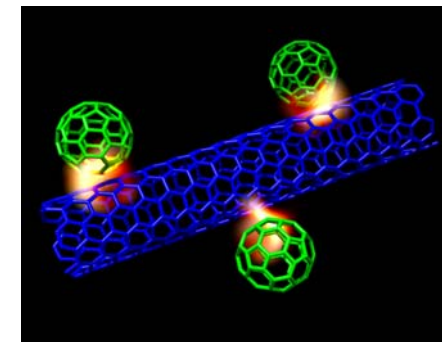


Optical Spectroscopy

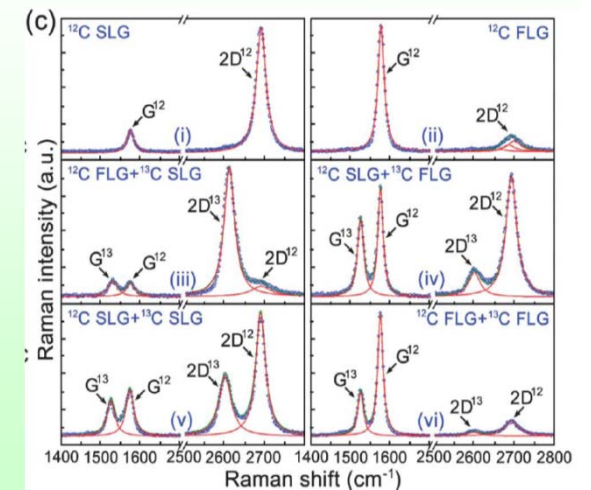
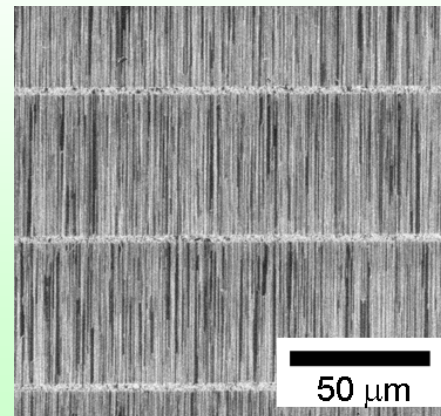
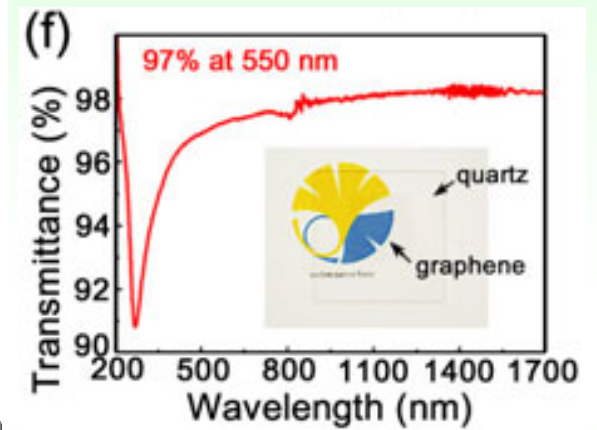
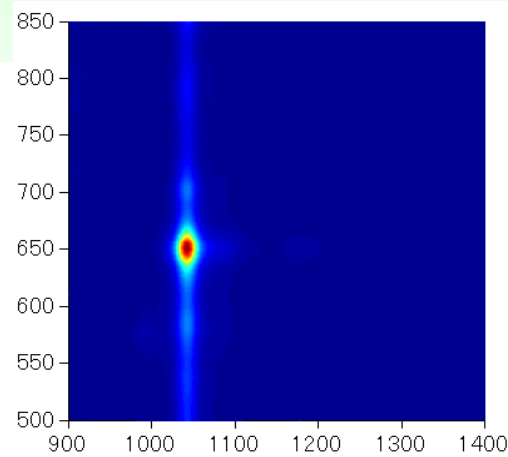
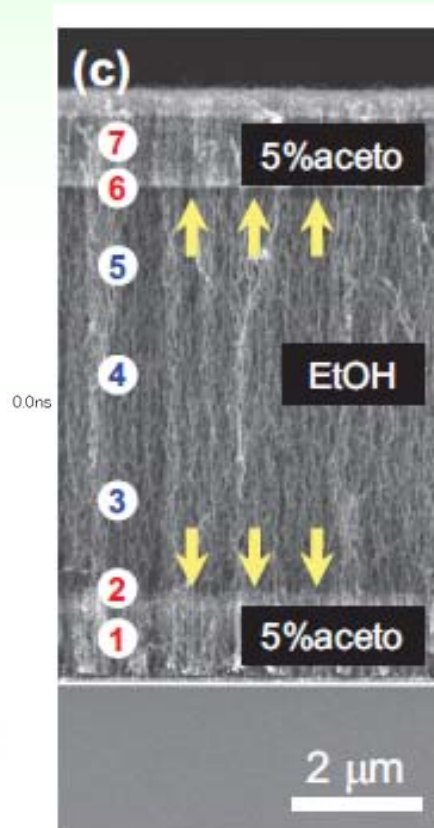
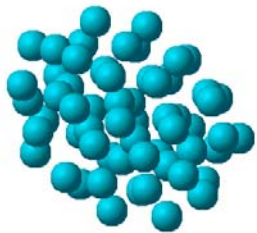


Structuring

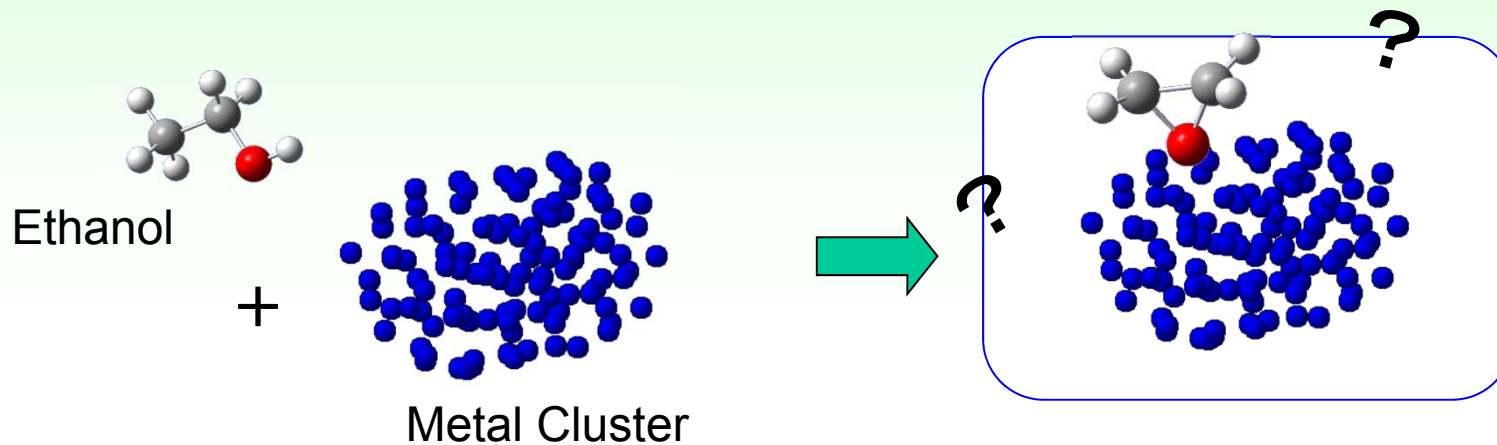
Energy Device



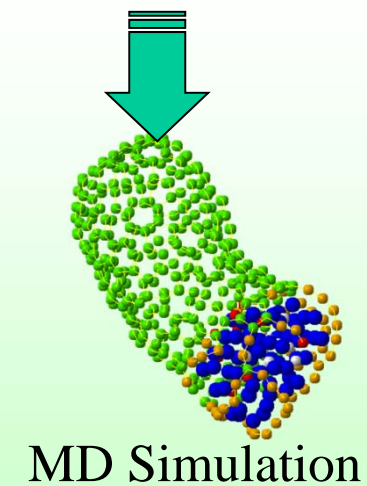
# CVD growth of SWNTs and Graphene by ACCVD



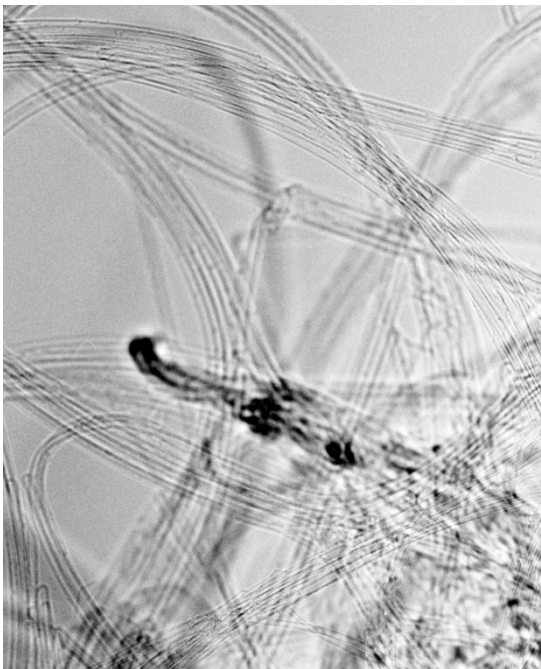
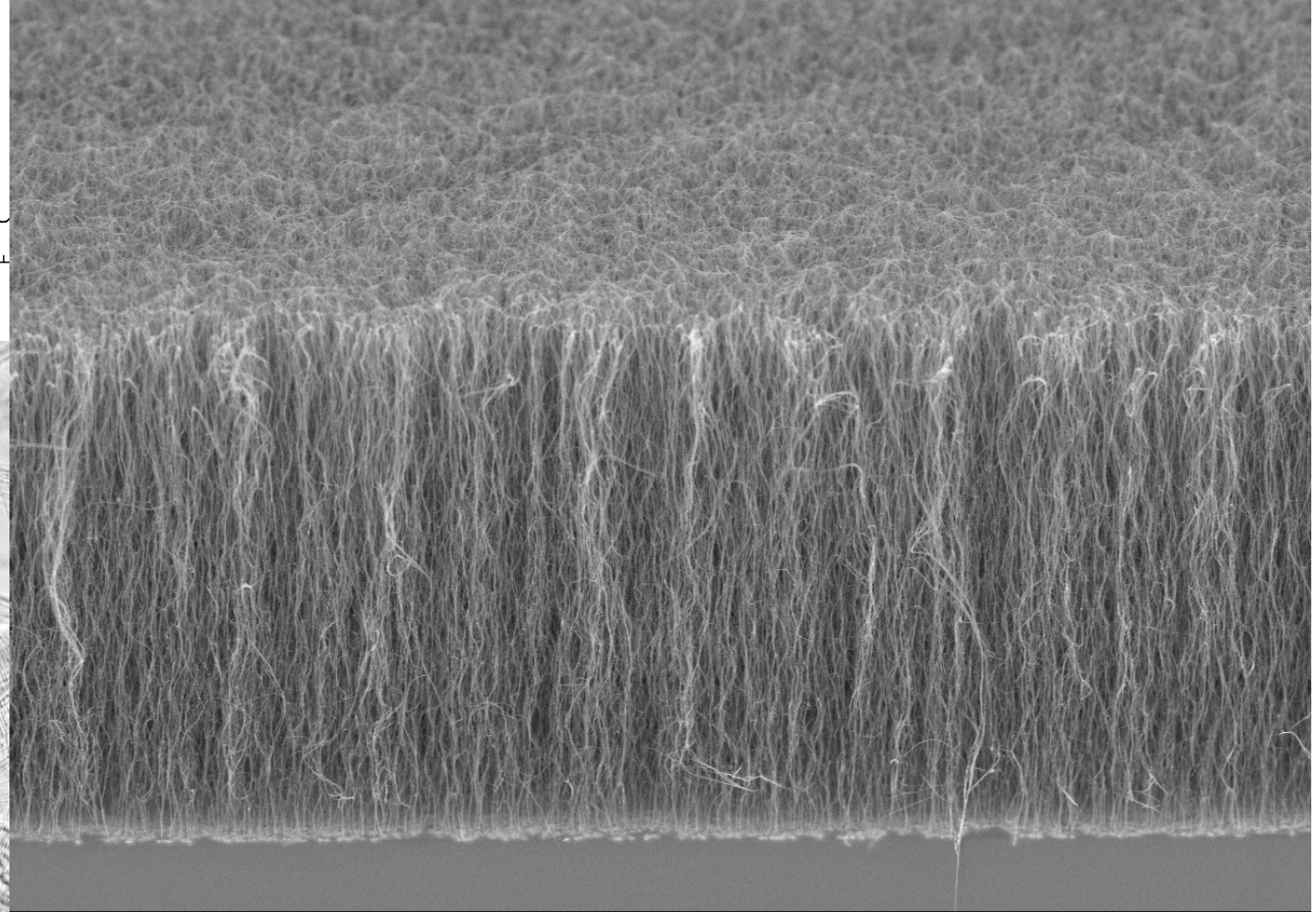
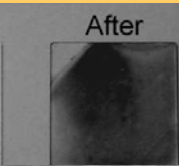
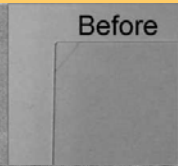
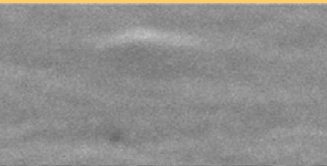
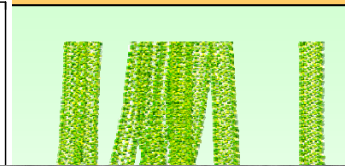
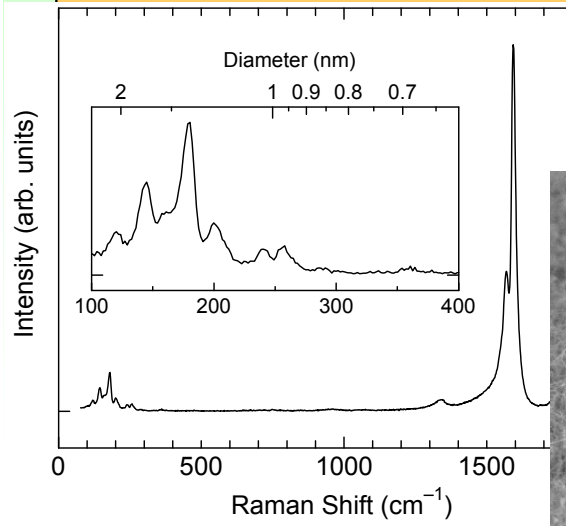
# Metal Surface Reaction by FT-ICR and ab initio Calculation



FT-ICR Mass spectrometer

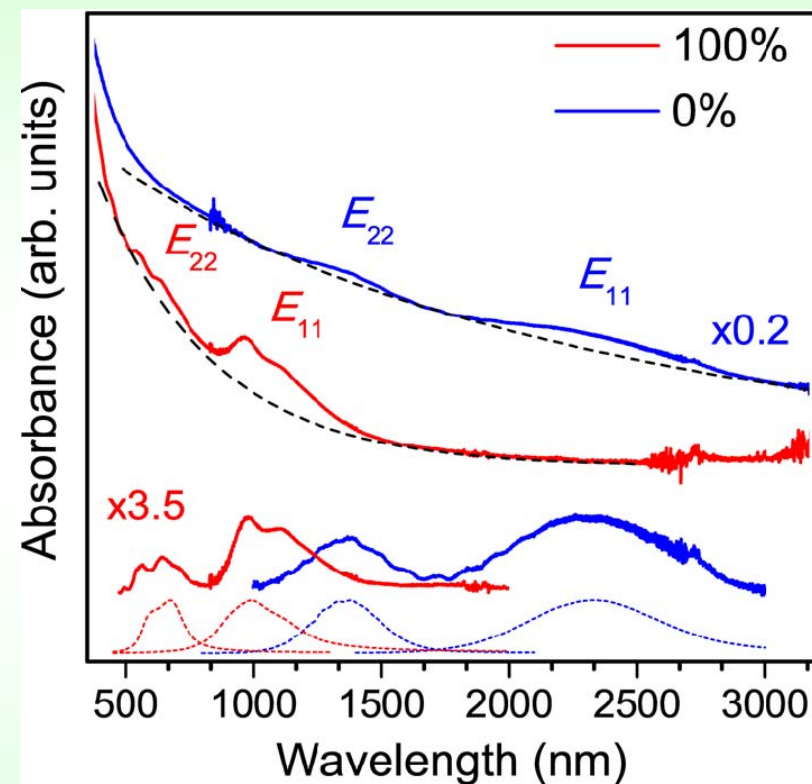
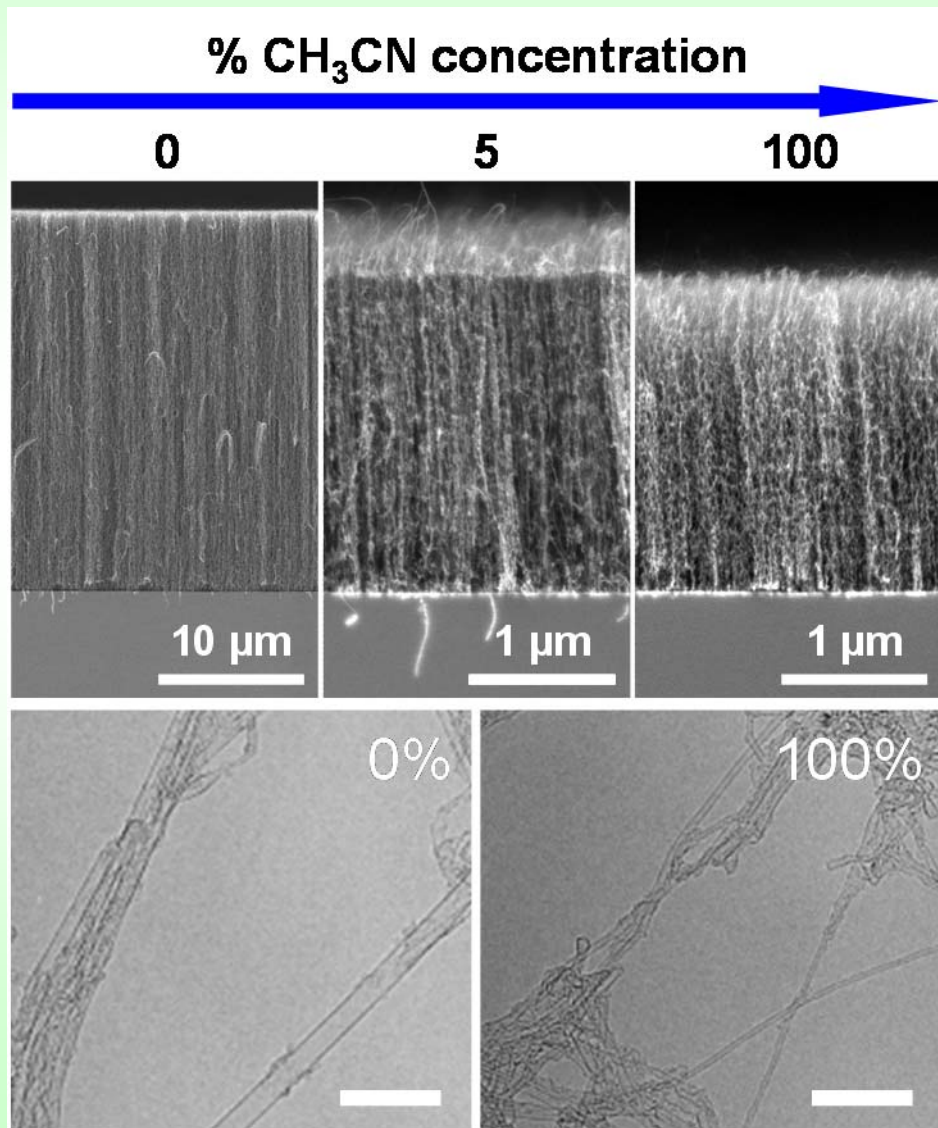


# Vertically Aligned SWNTs on Quartz Substrate



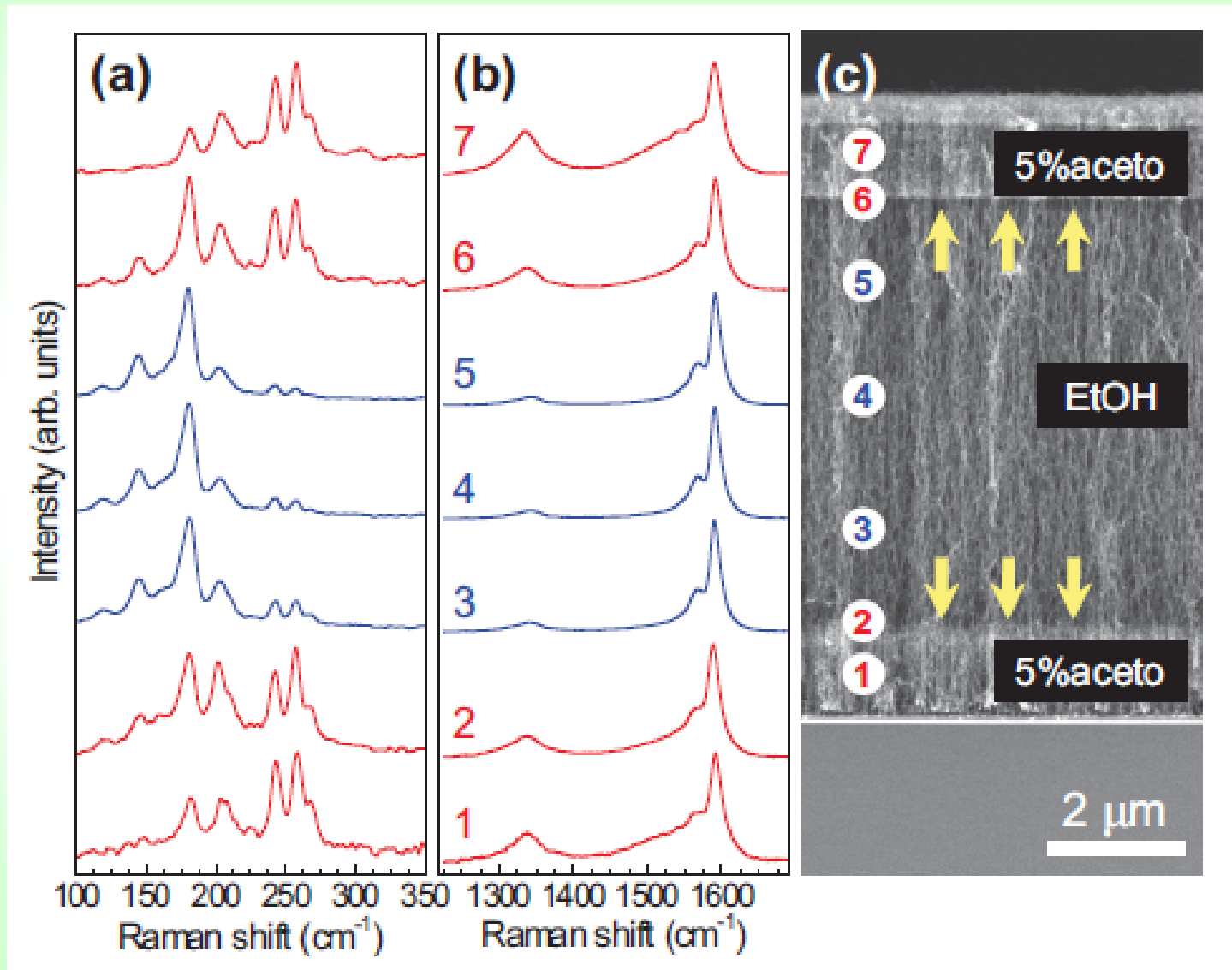
S-5500 1.5kV 0.5mm x10.0k SE 5.00um

# Growth of VA-SWNTs from Ethanol and Acetonitrile



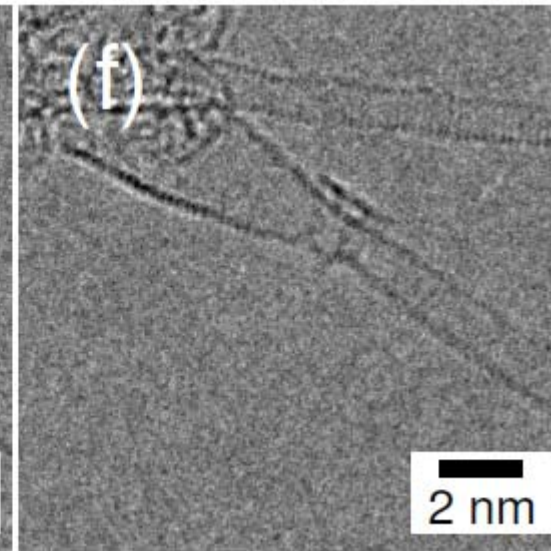
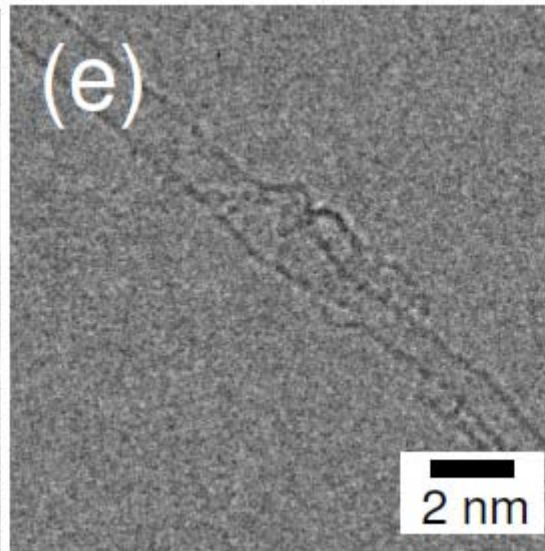
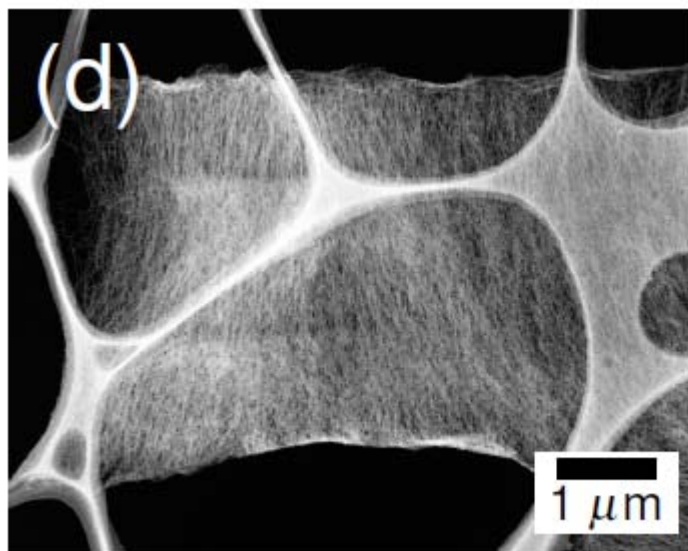
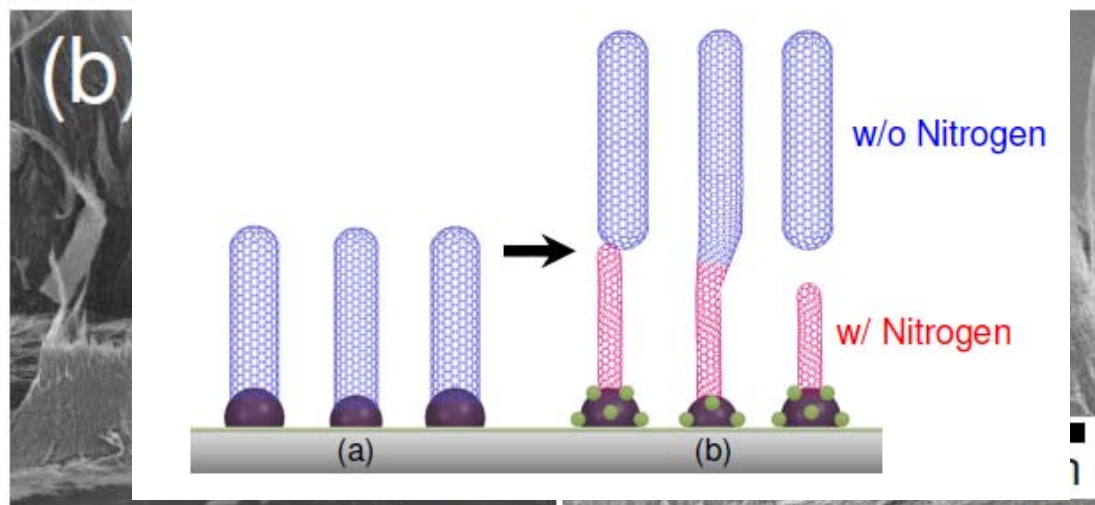
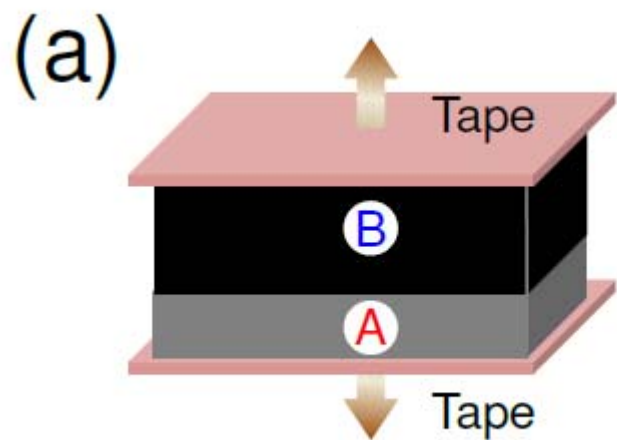
T. Thurakitsee, C. Kramberger, P. Zhao, S. Aikawa, S. Harish, S. Chiashi, E. Einarsson, S. Maruyama, Carbon 50 (2012) 2635.

# Multi-Step Growth





# Nanotube Junction



# Complex Structure

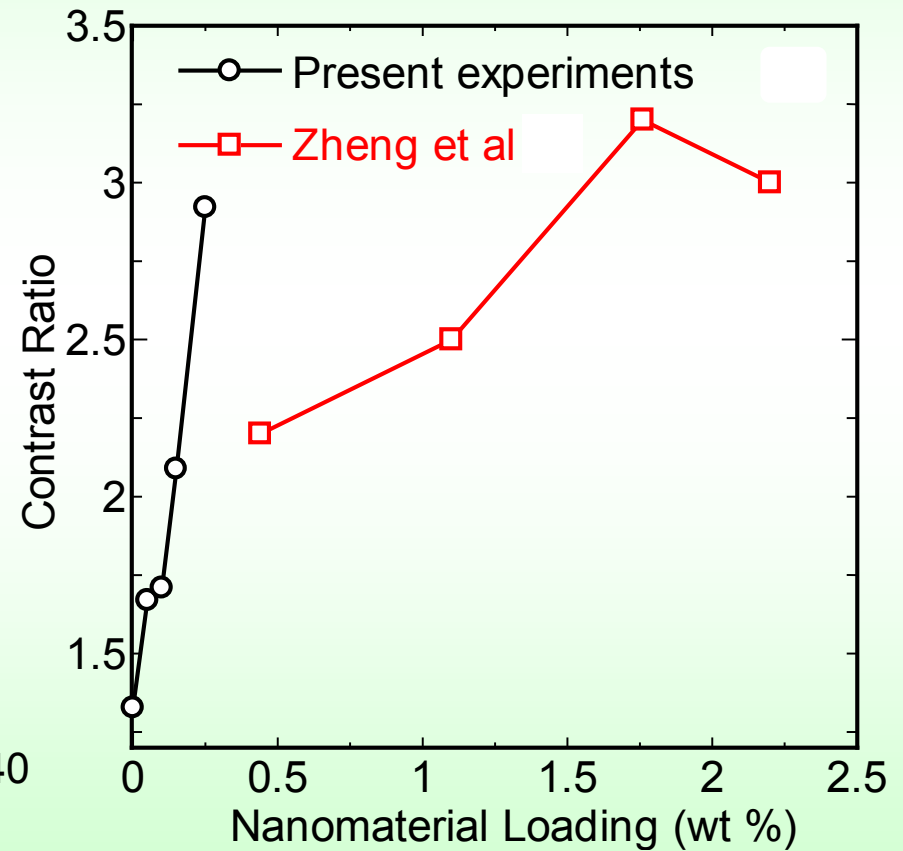
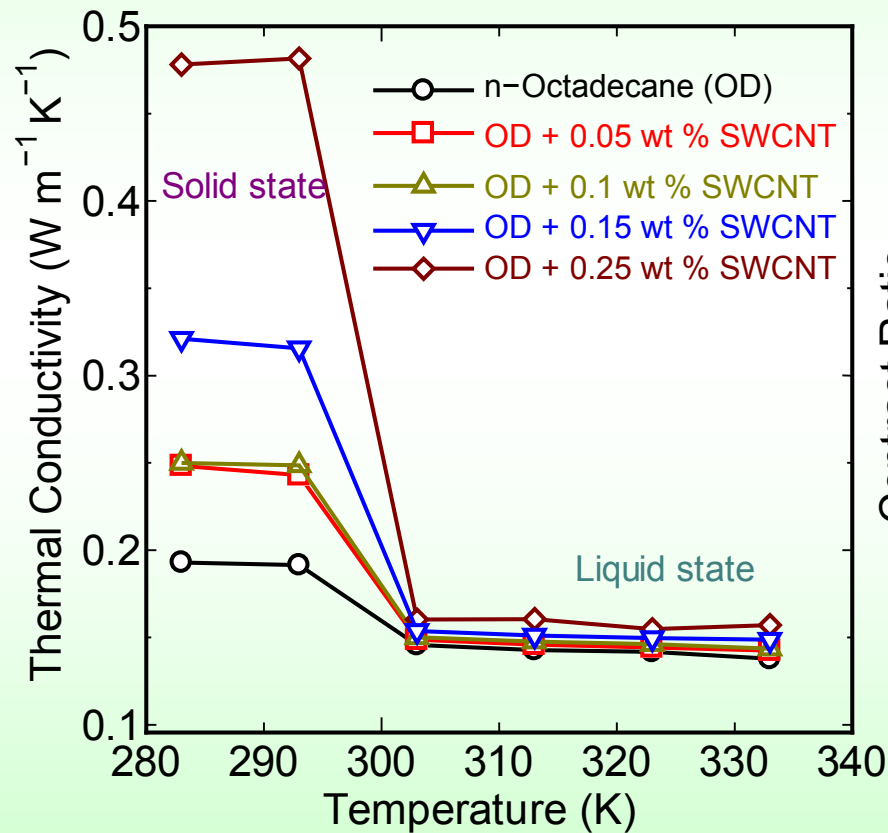
Thermal and Electrical Properties of Complex Structures

Nanofluid

3D and 2D composite

CGMD simulation of complex structure

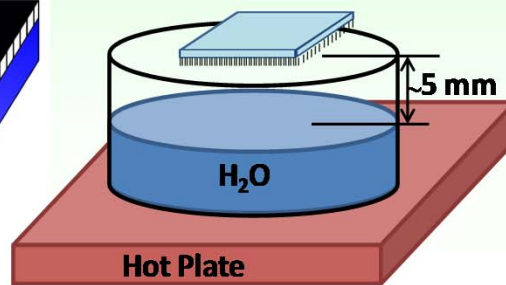
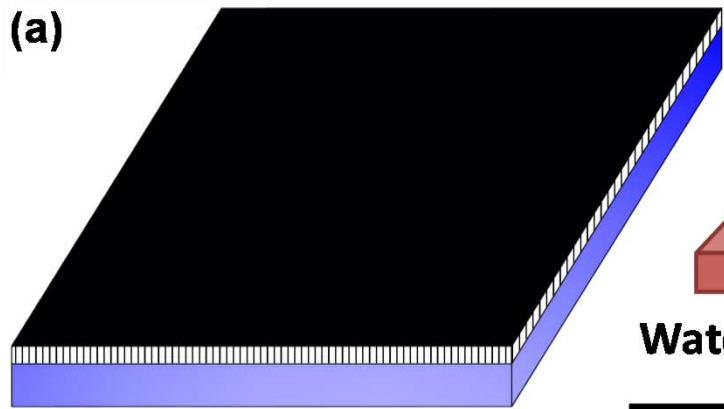
# SWNT Nanofluid for PCM



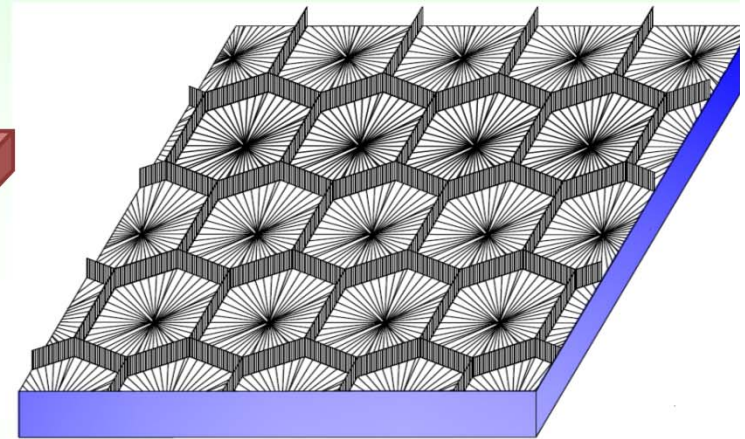
S. Harish, K. Ishikawa, S. Chiashi, J. Shiomi, S. Maruyama, J. Phys. Chem. C, (2013) in press.

# Self-organized Honeycomb Structure

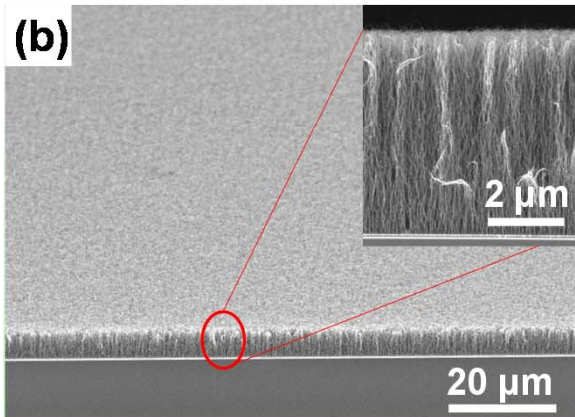
(a)



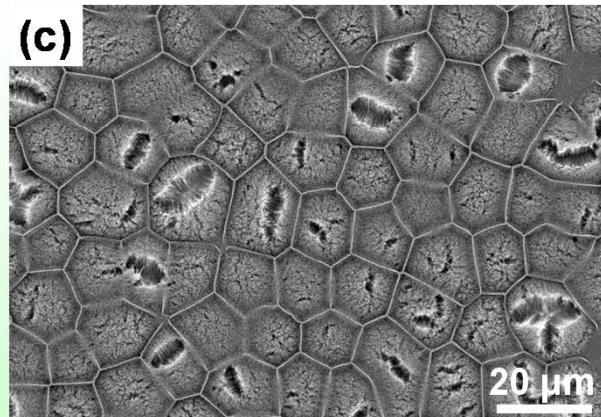
Water Vapor Treatment



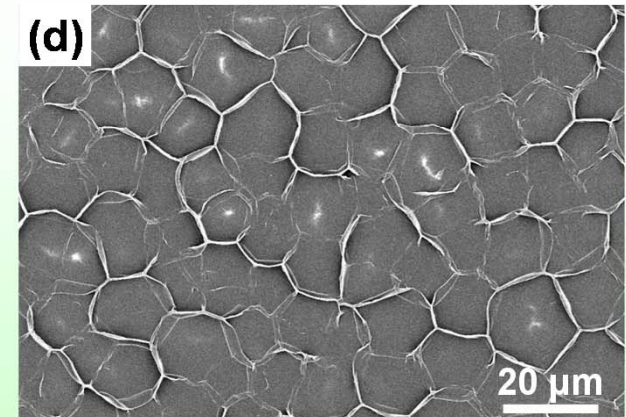
(b)



(c)

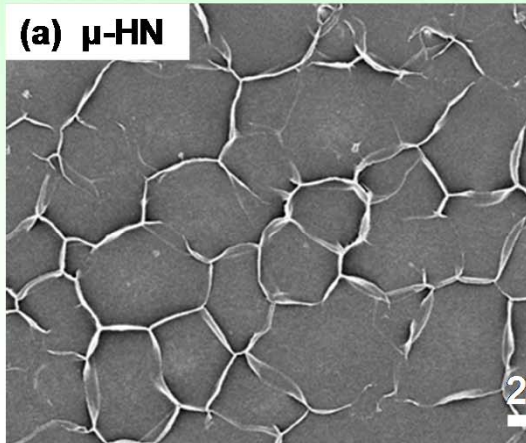


(d)



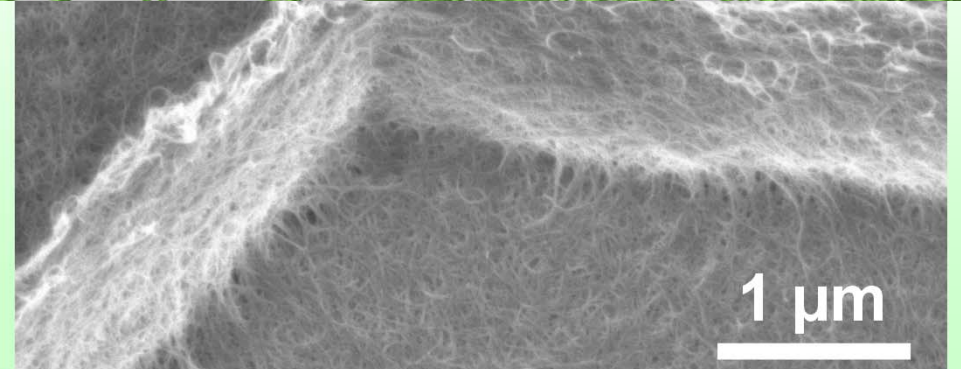
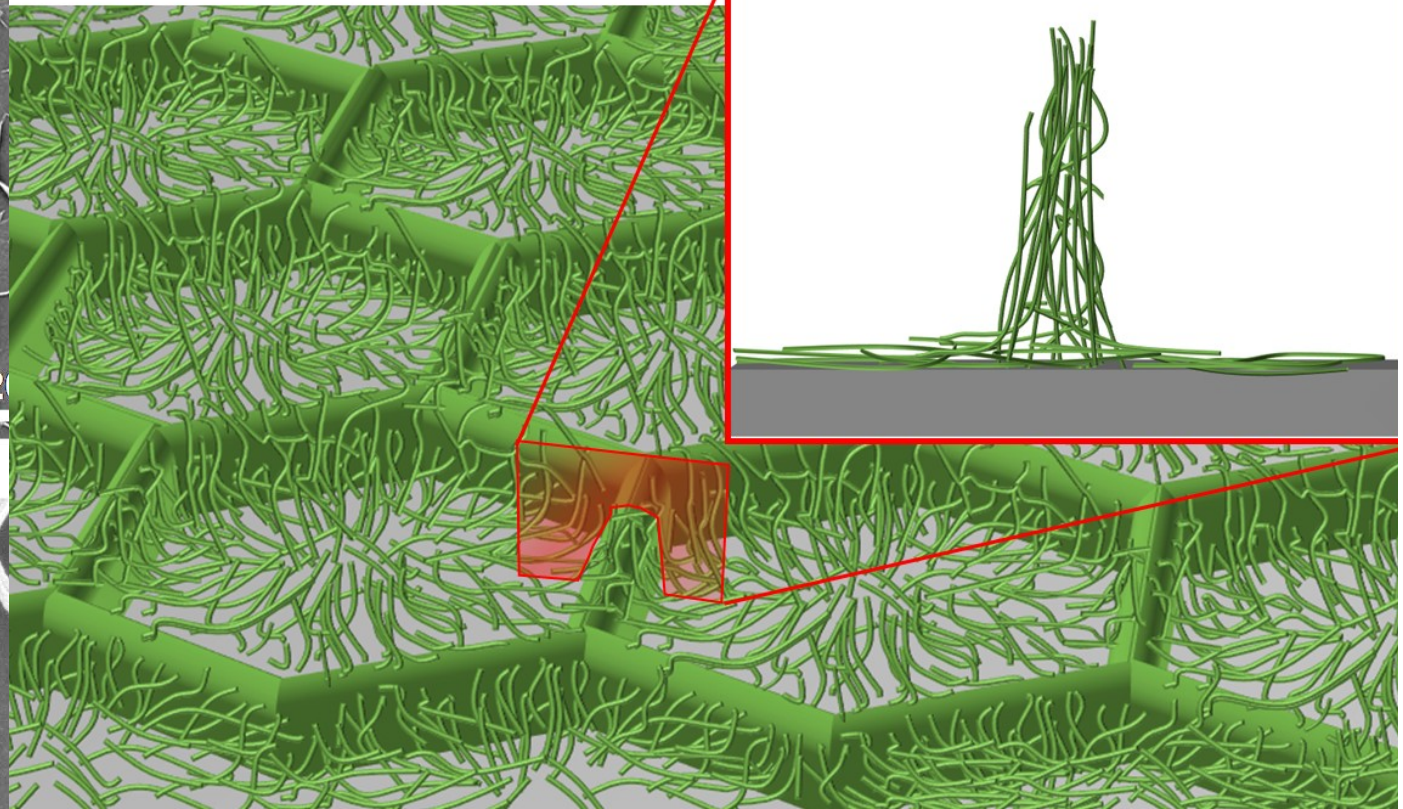
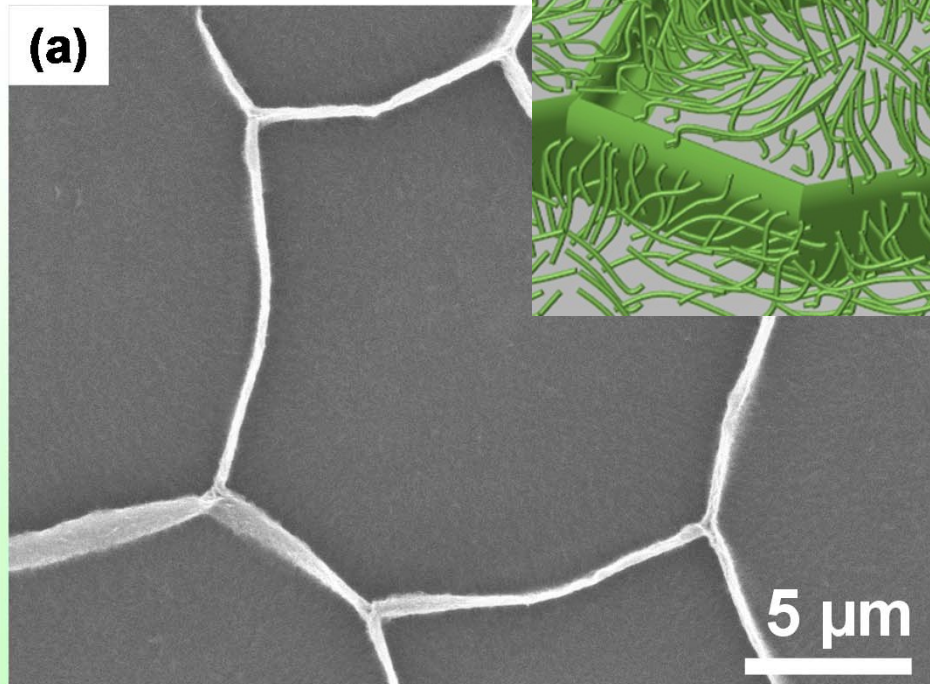
# Self-Assembled Micro-Honeycomb

(a)  $\mu$ -HN

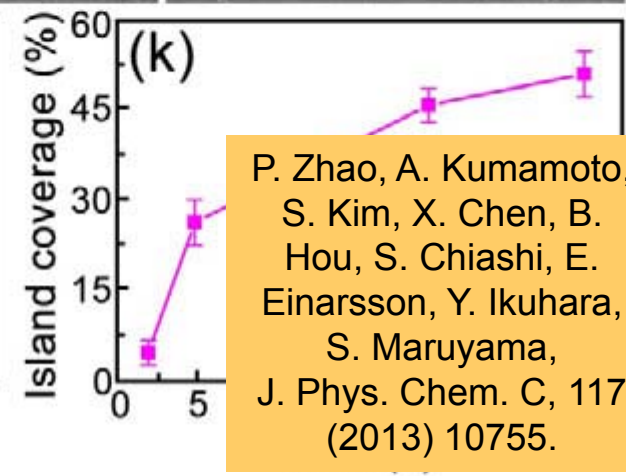
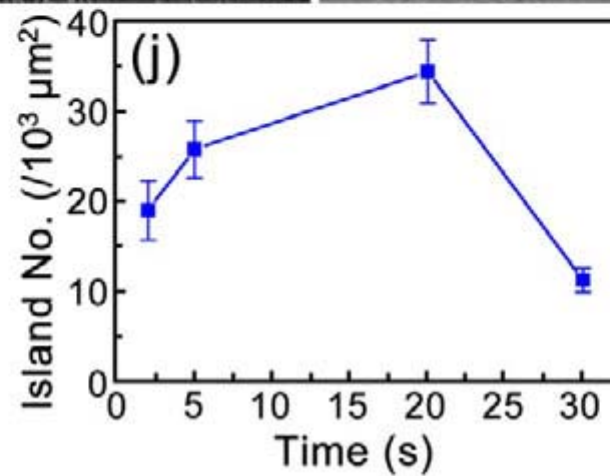
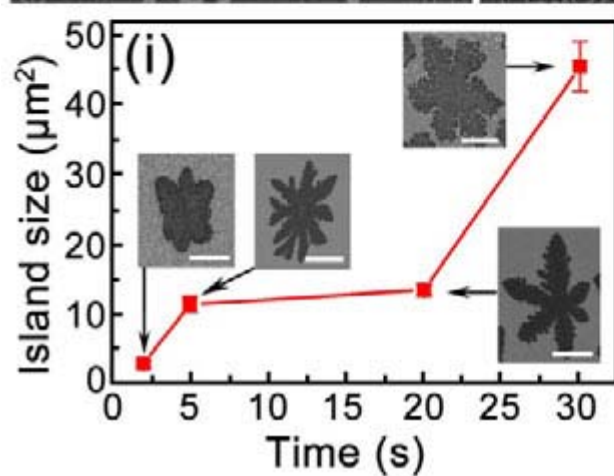
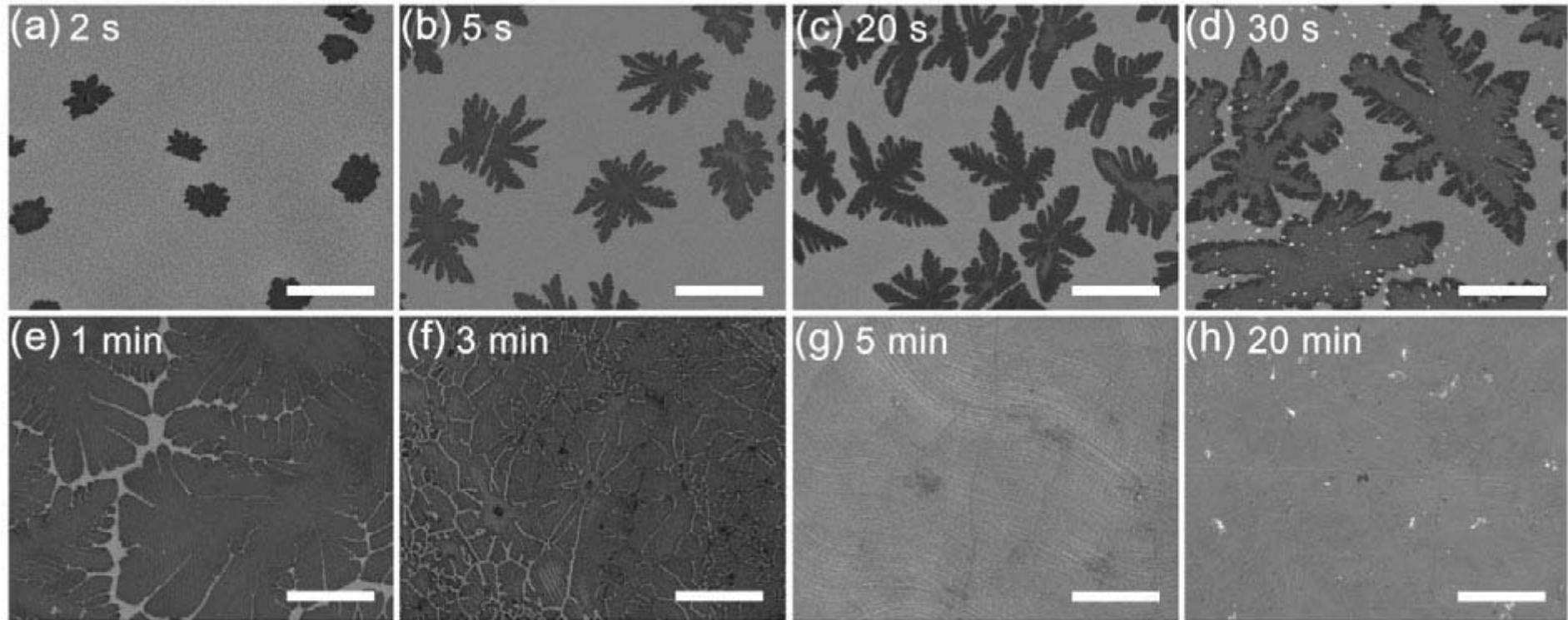


5 s, 80  $^{\circ}\text{C}$

(a)

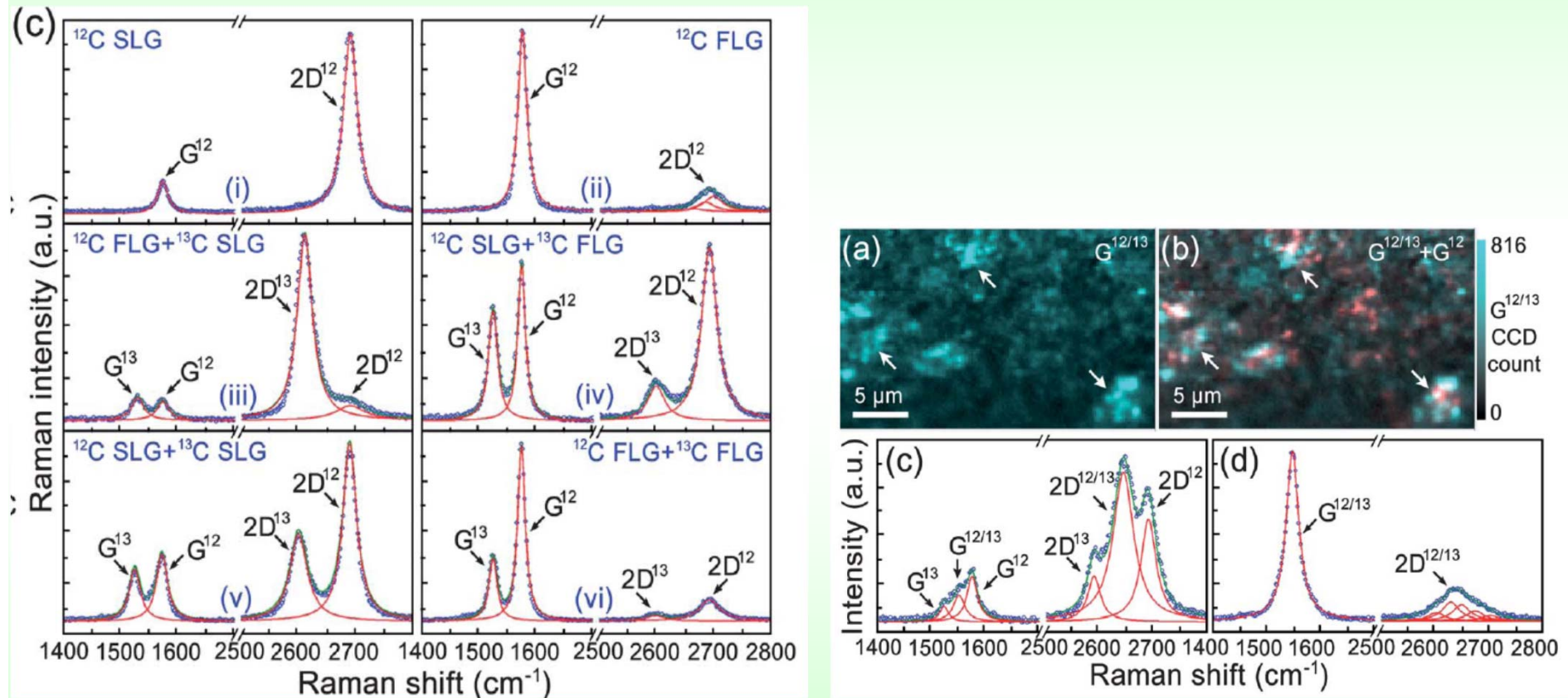


# Graphene Growth on Cu



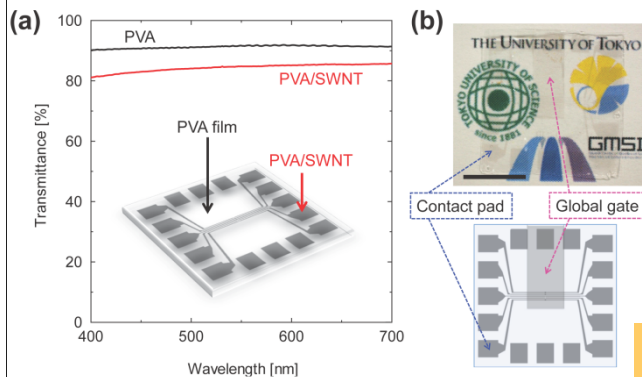
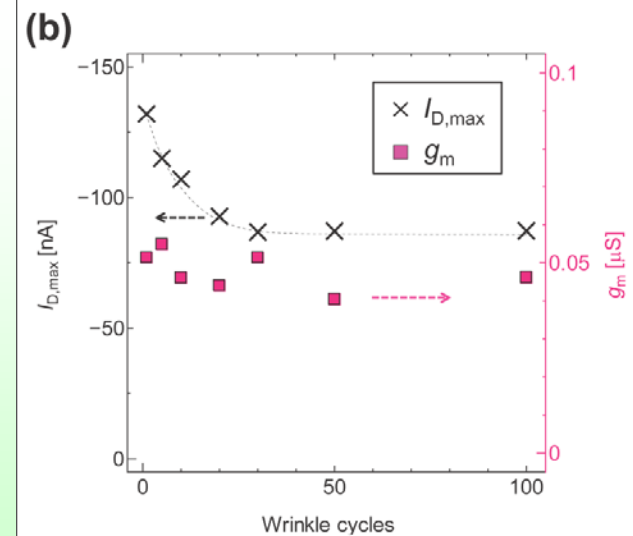
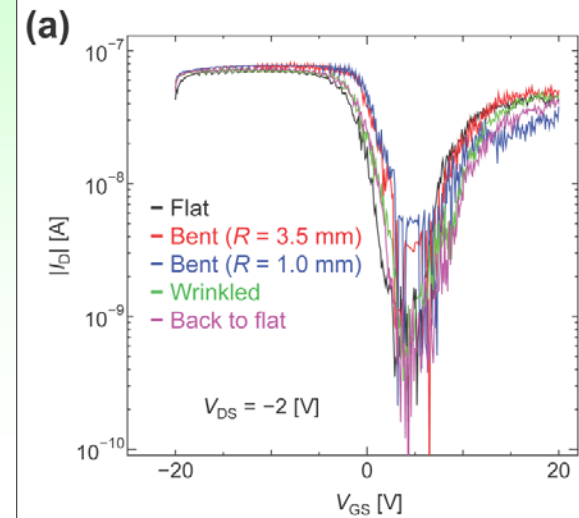
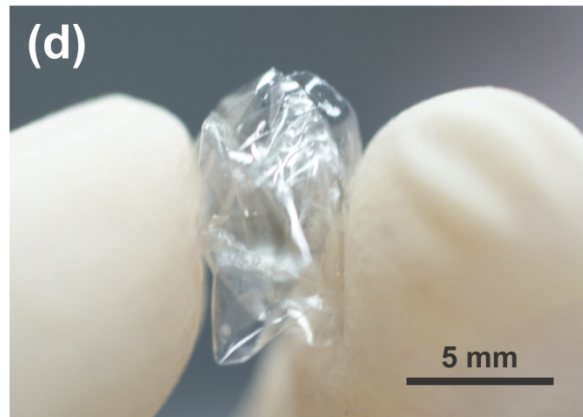
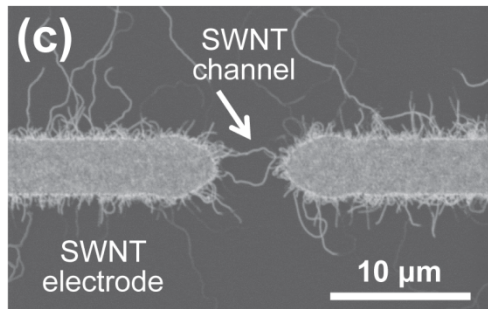
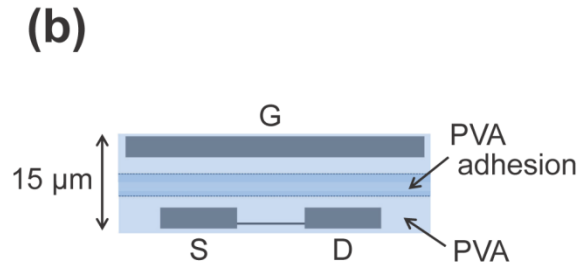
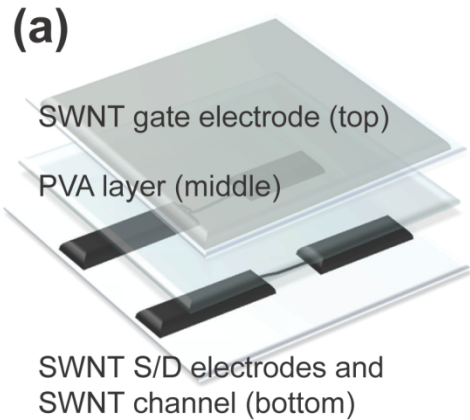
P. Zhao, A. Kumamoto, S. Kim, X. Chen, B. Hou, S. Chiashi, E. Einarsson, Y. Ikuhara, S. Maruyama, *J. Phys. Chem. C*, 117 (2013) 10755.

# Graphene Growth on Ni



P. Zhao, B. Hou, X. Chen, S. Kim, S. Chiashi, E. Einarsson, S. Maruyama, *Nanoscale*, (2013).

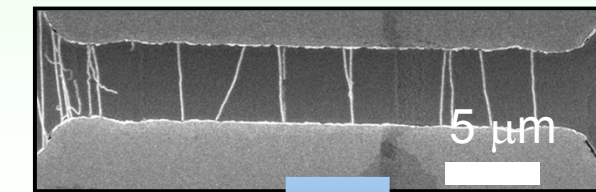
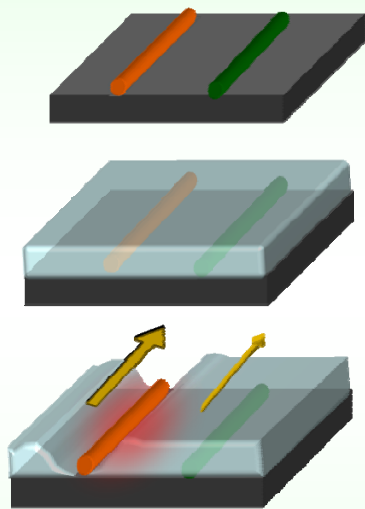
# Flexible all-SWNT FET



S. Aikawa, E. Einarsson, T. Thurakitserree, S. Chiashi,  
E. Nishikawa, S. Maruyama, Appl. Phys. Lett., 100 (2012) 063502



# Removal of Metallic Nanotubes or Direct Growth of Semiconductor CNTs

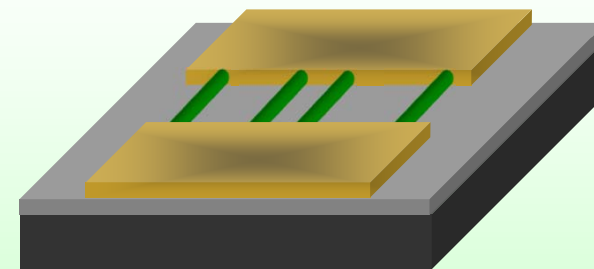
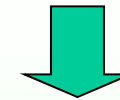
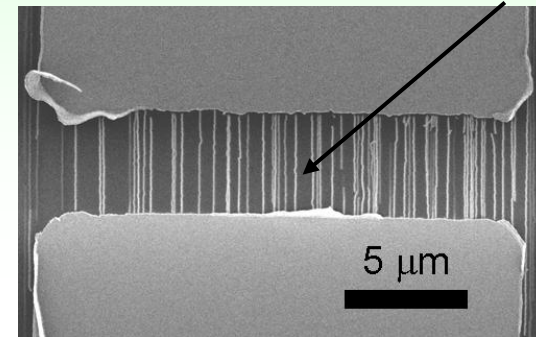


Spin-coat & Applying voltage



→ Removal of Metallic CNTs

Horizontally Aligned SWNTs

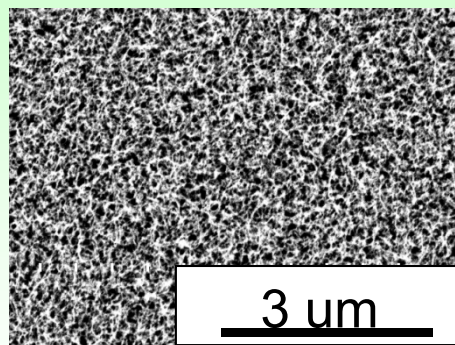
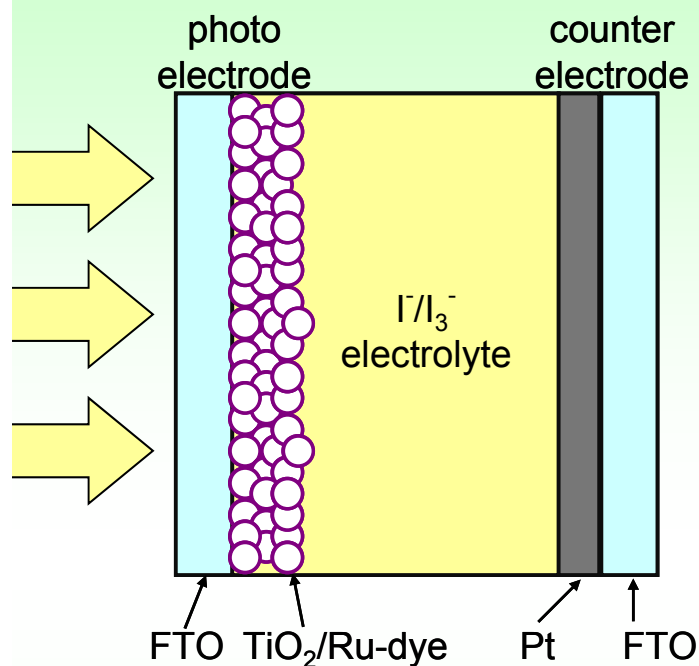


CNT FET

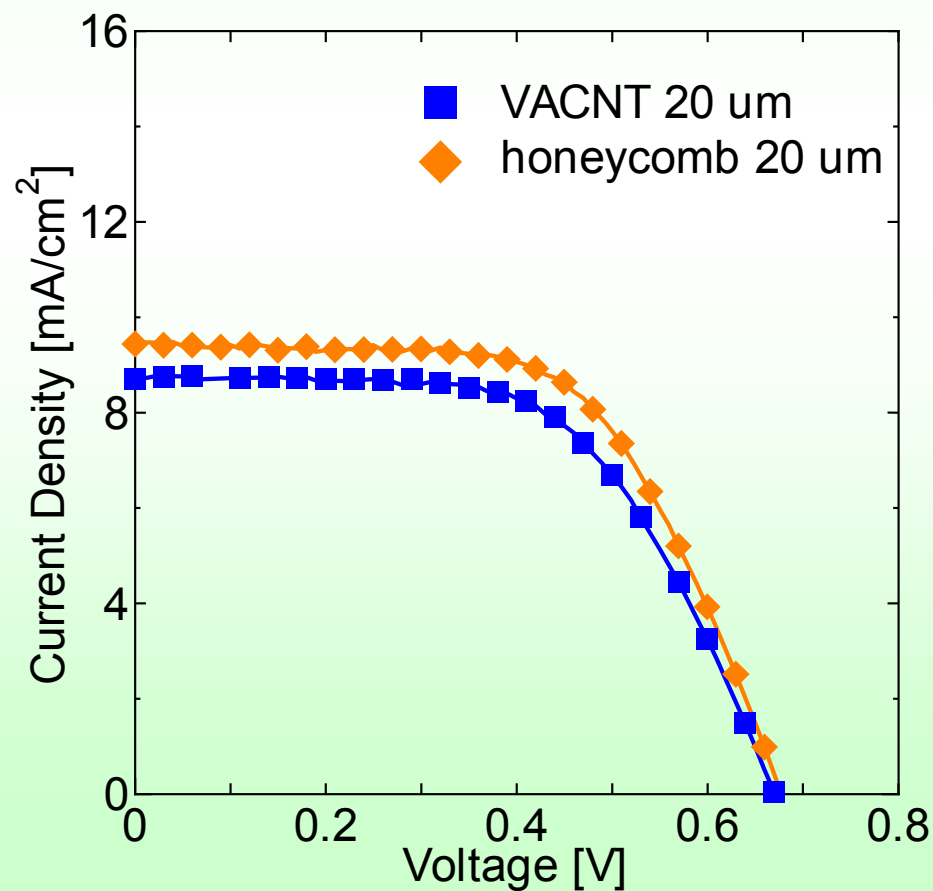
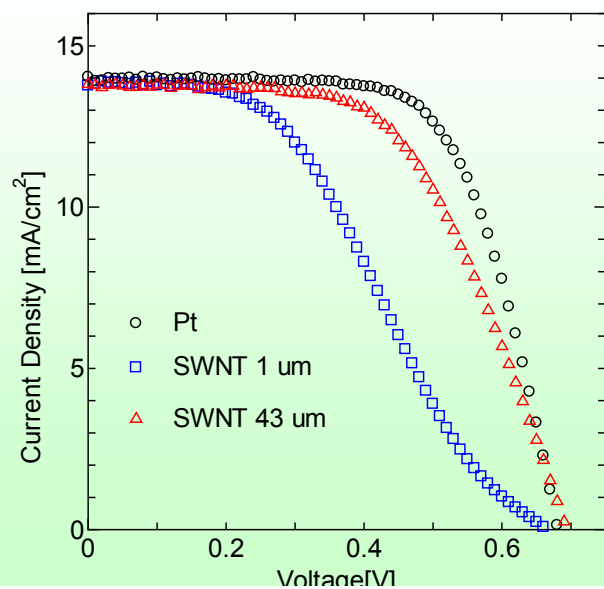
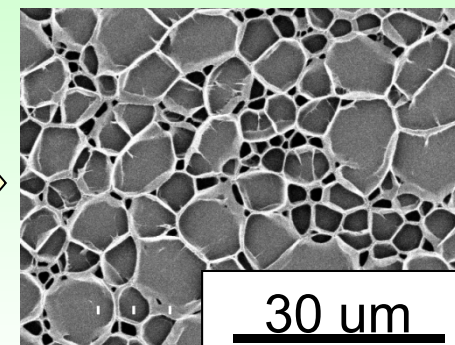
Cloning and Etching-based Selective growth of  
Semiconductor SWNTs

W Based Solid Catalyst for  
Single Chirality Growth

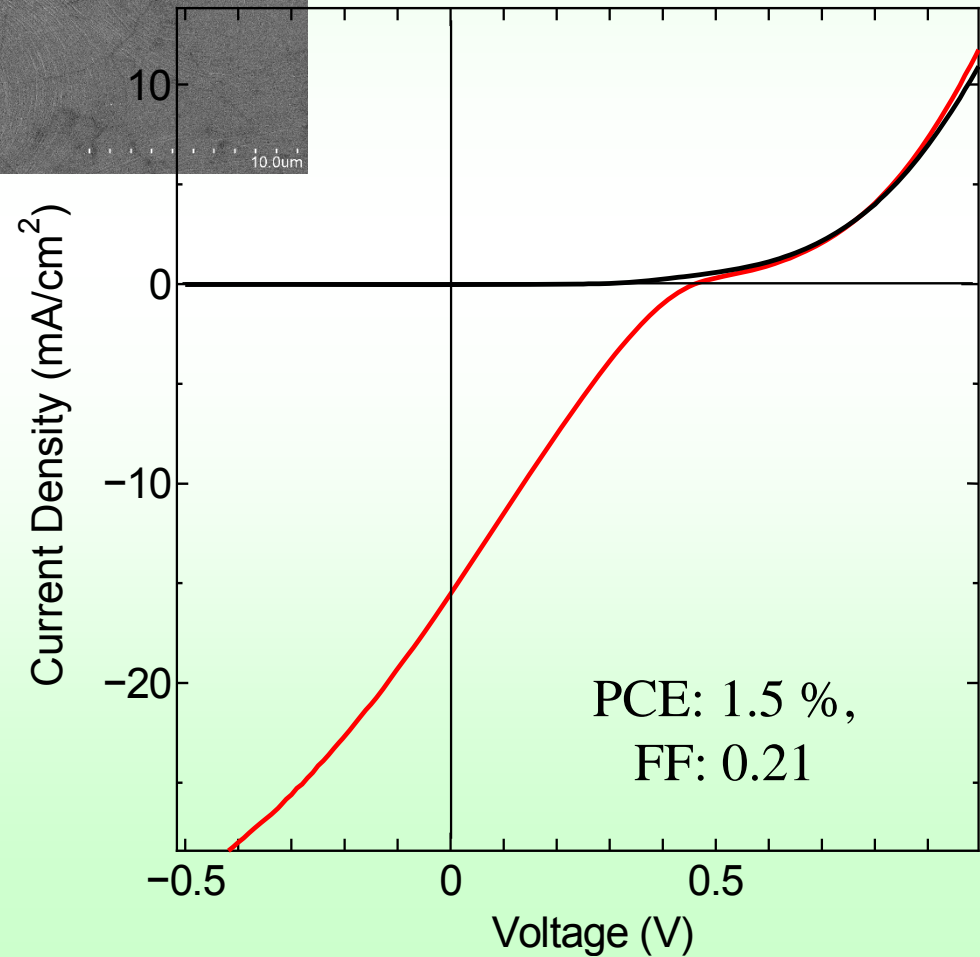
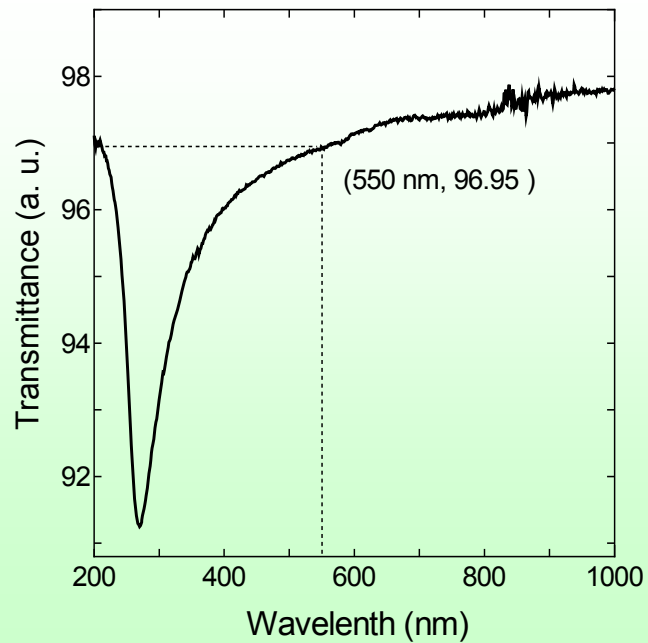
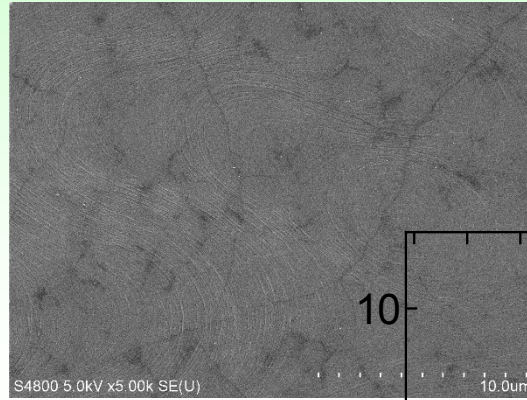
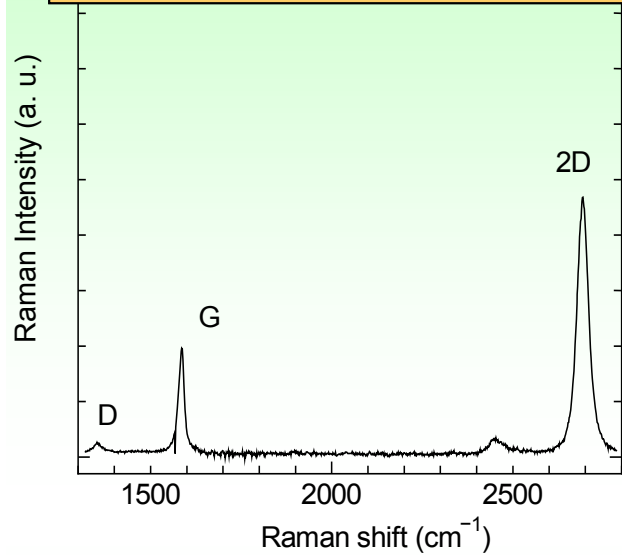
# Counter Electrode of Dye Sensitized Solar Cell



Vapor

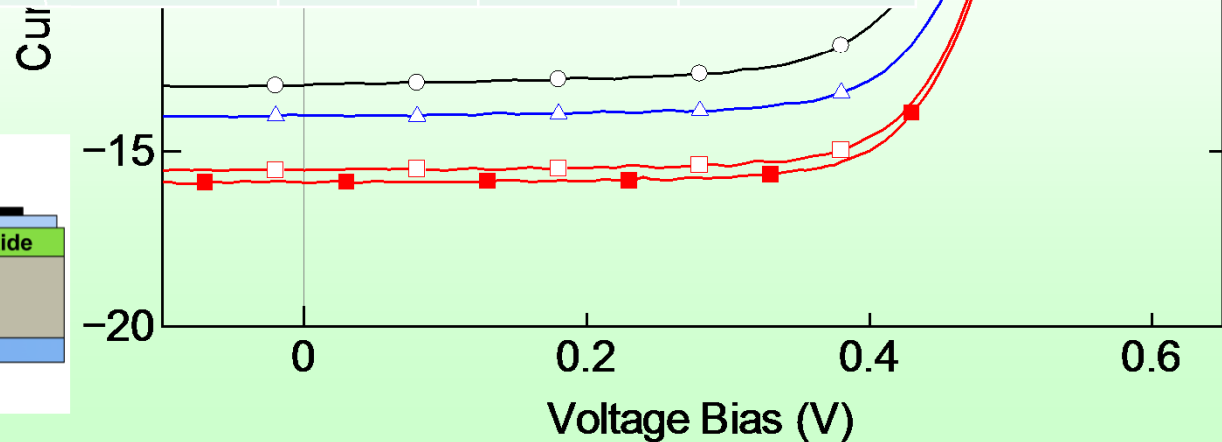
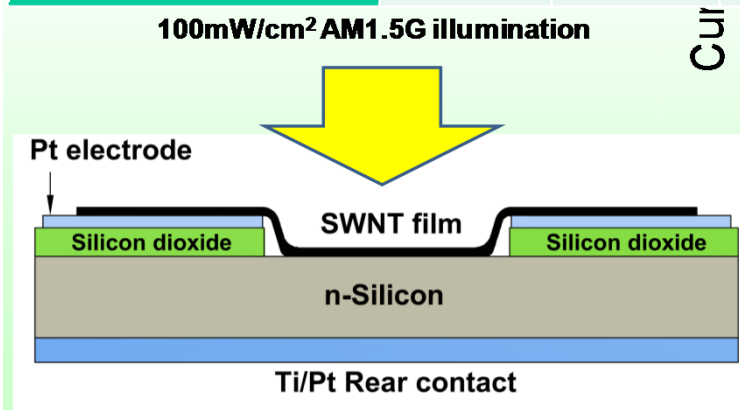


# Graphene grown on Cu

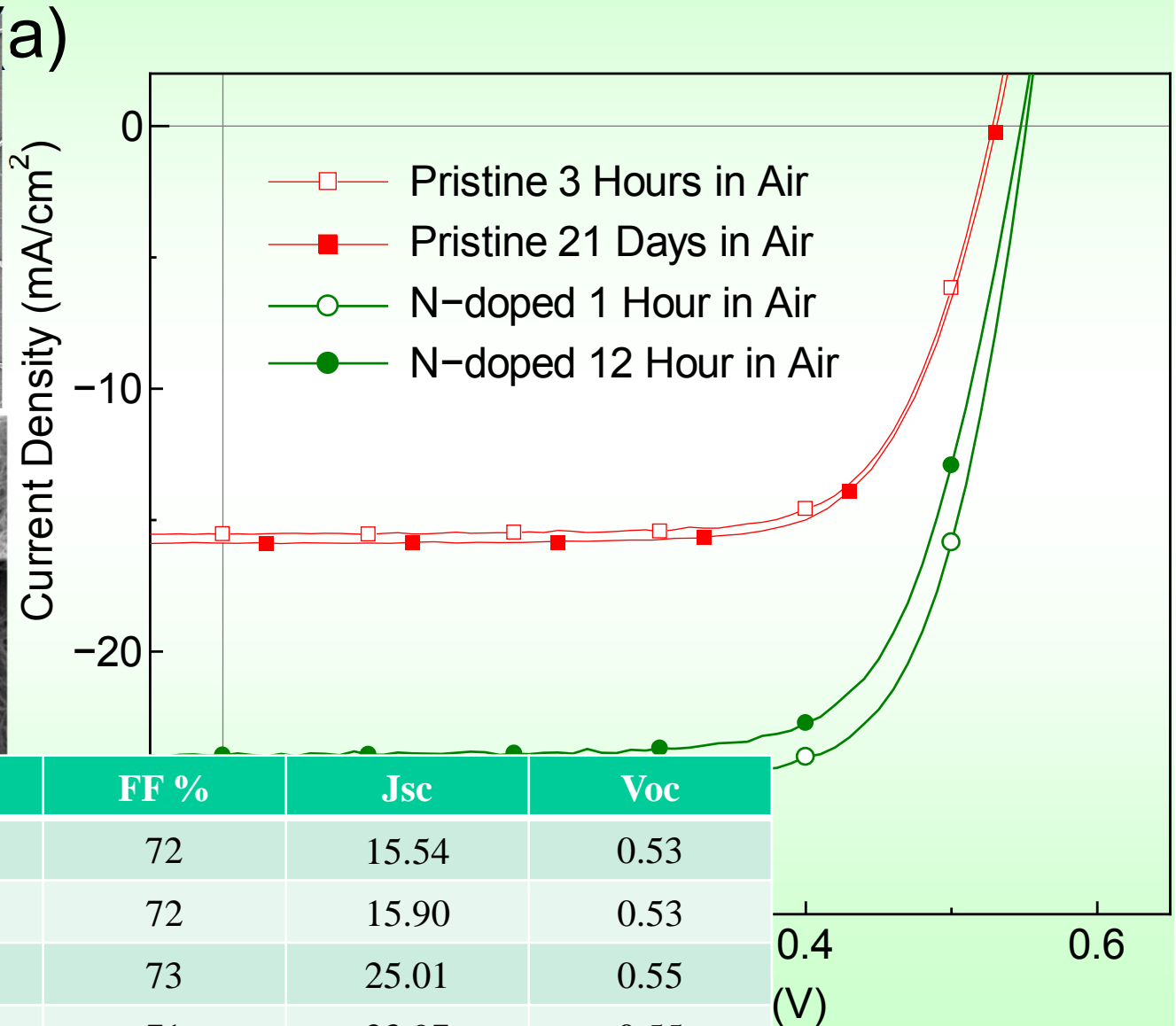
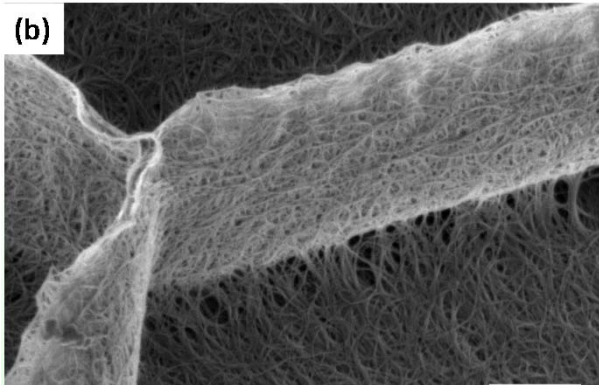
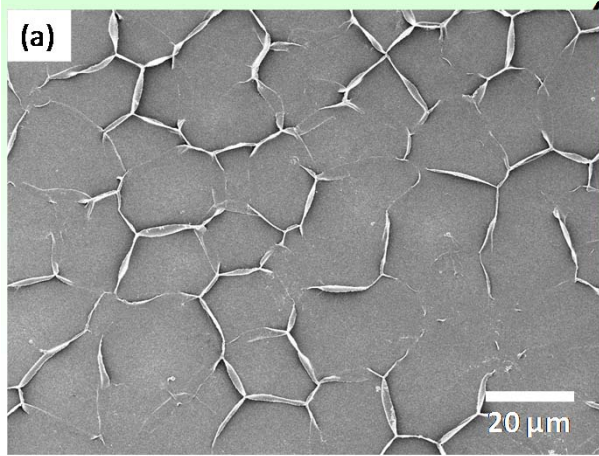


# Comparison of Structures

Morphology	Solar Cell Performance				Film Properties	
	PCE (%)	FF (%)	$J_{sc}$ (mA/cm <sup>2</sup> )	$V_{oc}$ (mV)	$R_{sh}$ ( $\Omega$ /sq.)	$T_{550}$ (%)
$\mu$ -HN	5.91	72	15.54	530	614	33.5
Collapsed HN	5.22	71	13.97	525	863	32.5
Porous HN	4.56	67	13.11	520	2397	26.6

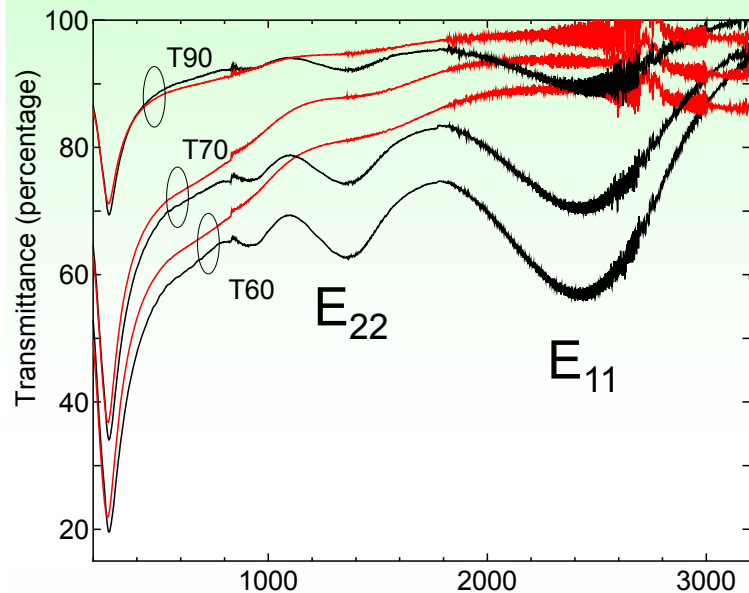


# Doped by HNO<sub>3</sub>

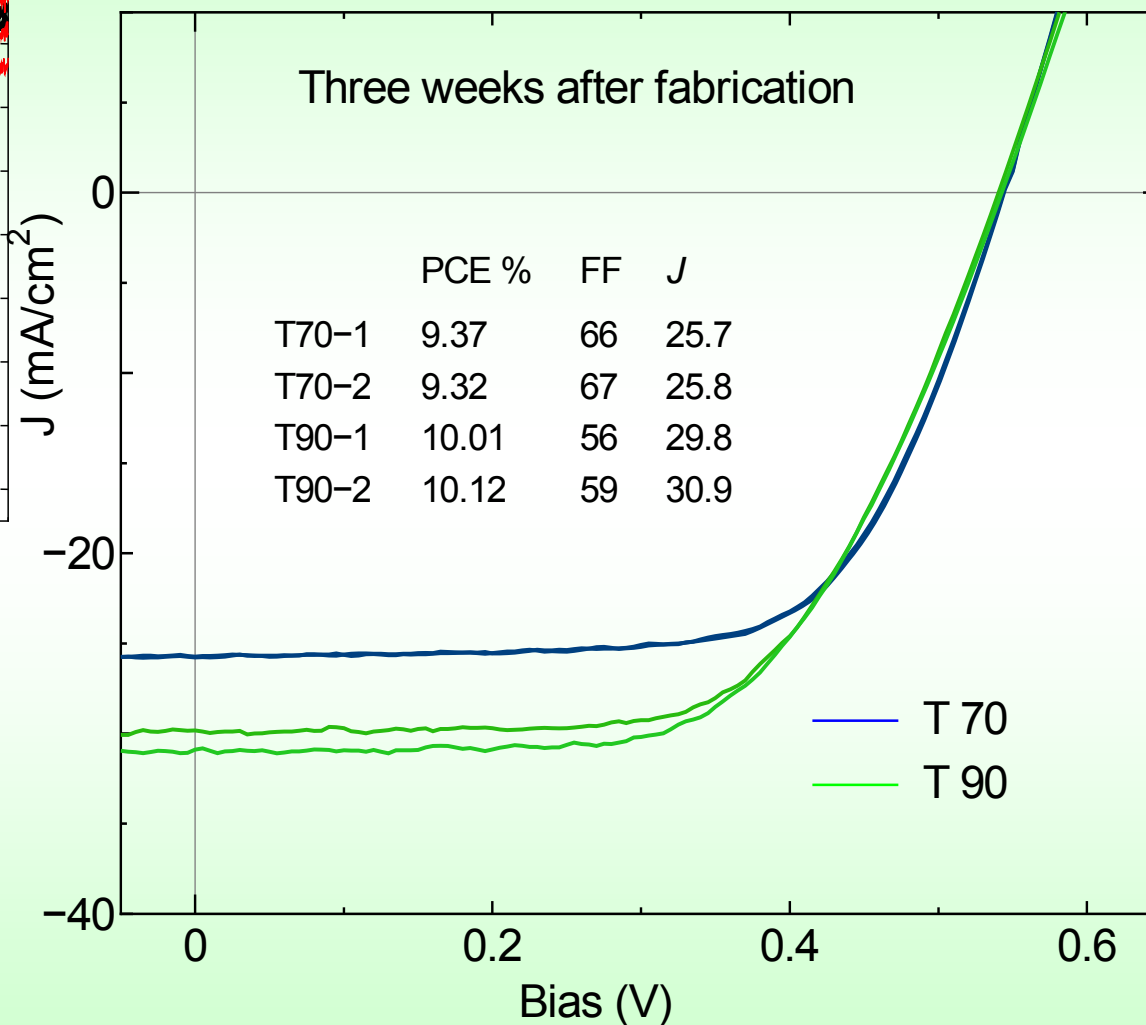
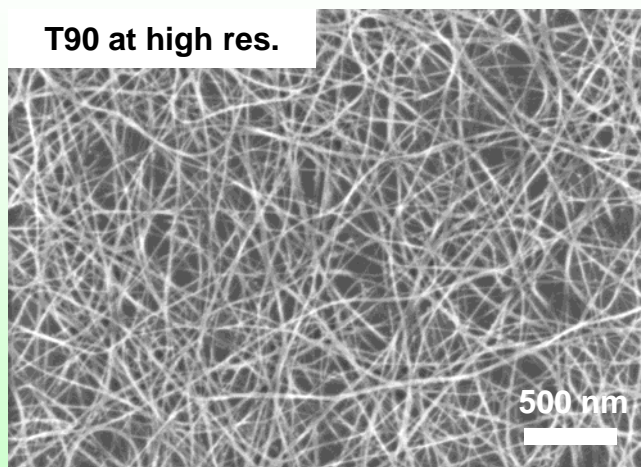


	PCE %	FF %	Jsc	Voc
Pristine 3hours	5.91	72	15.54	0.53
Pristine 21 days	6.04	72	15.90	0.53
Acid dope 1 hour	10.02	73	25.01	0.55
Acid dope 12 hour	9.29	71	23.97	0.55

# Transparent Conductive Film by Esko Kauppinen



T90 at high res.



Collaboration with Olivier Reynaud, Albert Nasibullin, Esko I. Kauppinen (Aalto Univ.)

# Enjoy the WorkShop

13:45~14:15 Yoichi Murakami (Tokyo Institute of Technology)

Photon upconversion: A technology for utilizing sub-bandgap wasted energies

14:15~14:30 Zhao Pei (The University of Tokyo)

Growth of single-layer and double-layer graphene from ethanol

14:30~15:00 Shinya Aikawa (NIMS)

InOx-based metal oxide semiconductors for TFT applications

15:00~15:30 Shohei Chiashi (The University of Tokyo)

Interaction between Single-walled Carbon Nanotubes and Water Molecules

15:30~16:00 Break

16:00~16:30 Yasushi Shibuta (The University of Tokyo)

Understanding formation mechanism of carbon nanotubes and graphene from numerical point of view

16:30~16:45 James Cannon (The University of Tokyo)

A Molecular Dynamics simulation study into the influence of surface characteristics on liquid-solid interaction during heating

16:45~17:00 Takuma Shiga (The University of Tokyo)

Lattice heat conduction analysis of thermoelectric materials from first-principles

17:00~17:30 Junichiro Shiomi (The University of Tokyo)

Phase interface phenomena and thermal energy engineering

17:30~18:00 Yuhei Miyauchi (Kyoto University)

Photophysics of a Dot in a Line

18:00~18:15 Erik Einarsson

18:45~ Farewell party

# NT05 at Goteburg in 2005

