Lead-free Nanosolders and Nanowire Joining for Microelectronics/Nanoelectronics Assembly and Packaging

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Outline

Introduction

- Joining methods and applications
- Nanosoldering in electronics

Nanosolder Fabrication

Nanosolder Joint Formation

- Surface oxidation, flux effect and solder melting on substrates
- One-dimensional diffusion in segmented nanowire
- Nanowire assembly and nanosolder joint formation

Conclusion & Future Work

Acknowledgement

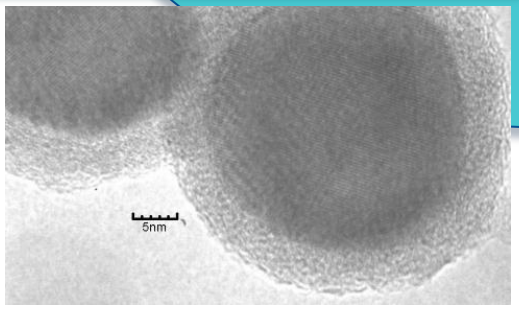
Nanosoldering in Nanotechnology

Replace conventional solder paste

Nanojoint formation

Nanoelectronics packaging

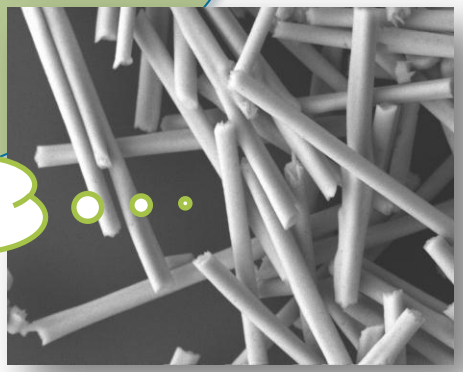
✓ nanoparticles in different materials such as Au, Ag, Cu, Sn, In and alloys in the form of **paste** or **inks**.



H. Jiang *et al*., Chem. Mater. 2007, 19, 4482 4485

✓ Interconnections between nanocomponents such as nanotube, nanowire…

We want to be connected



Introduction

Nanojoining methods

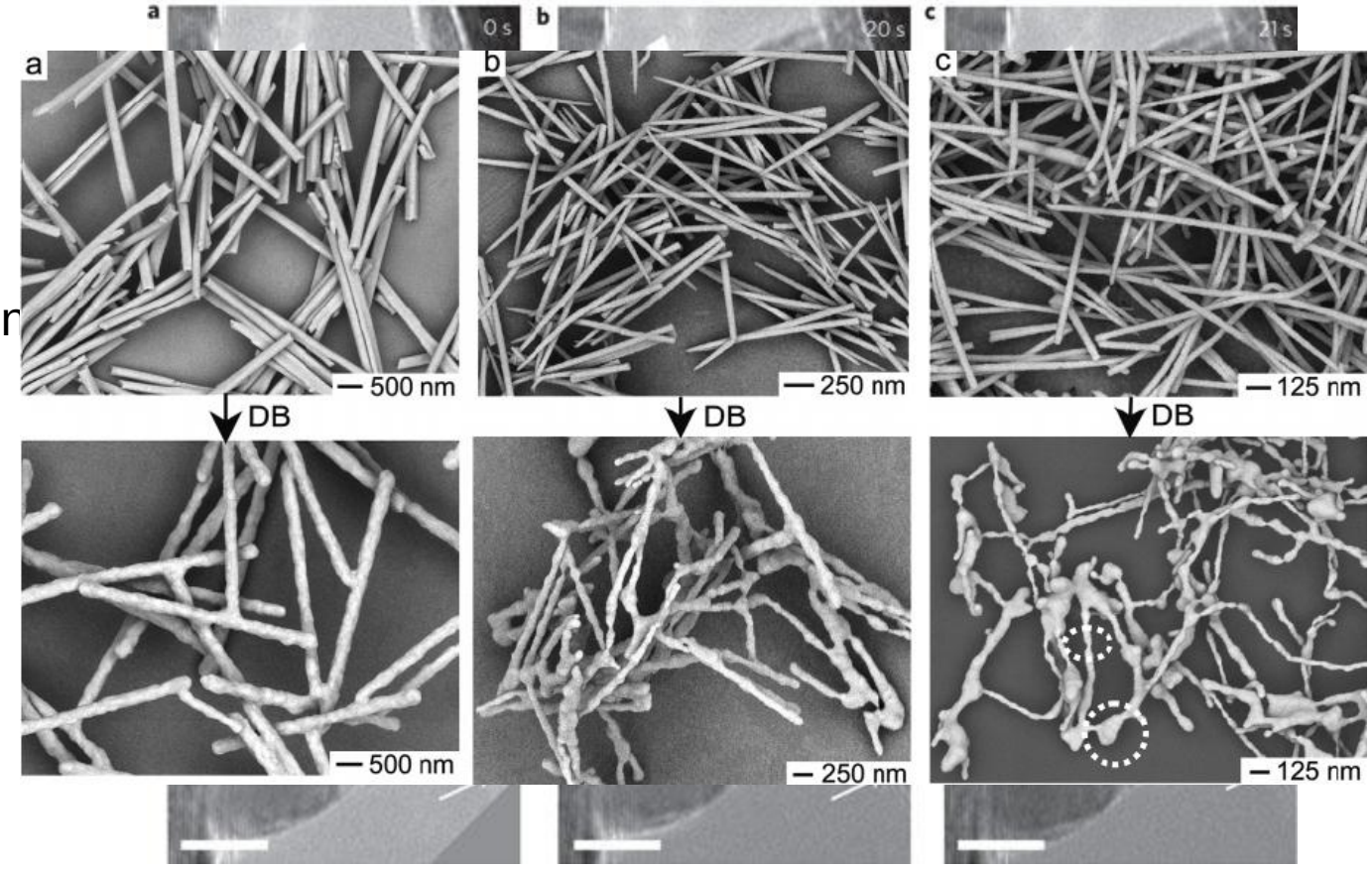
Electron beam (E-beam) / Focused ion beam (FIB)

Nano-welding

Sintering/Annealin

Atomic Diffusion

Nano-soldering

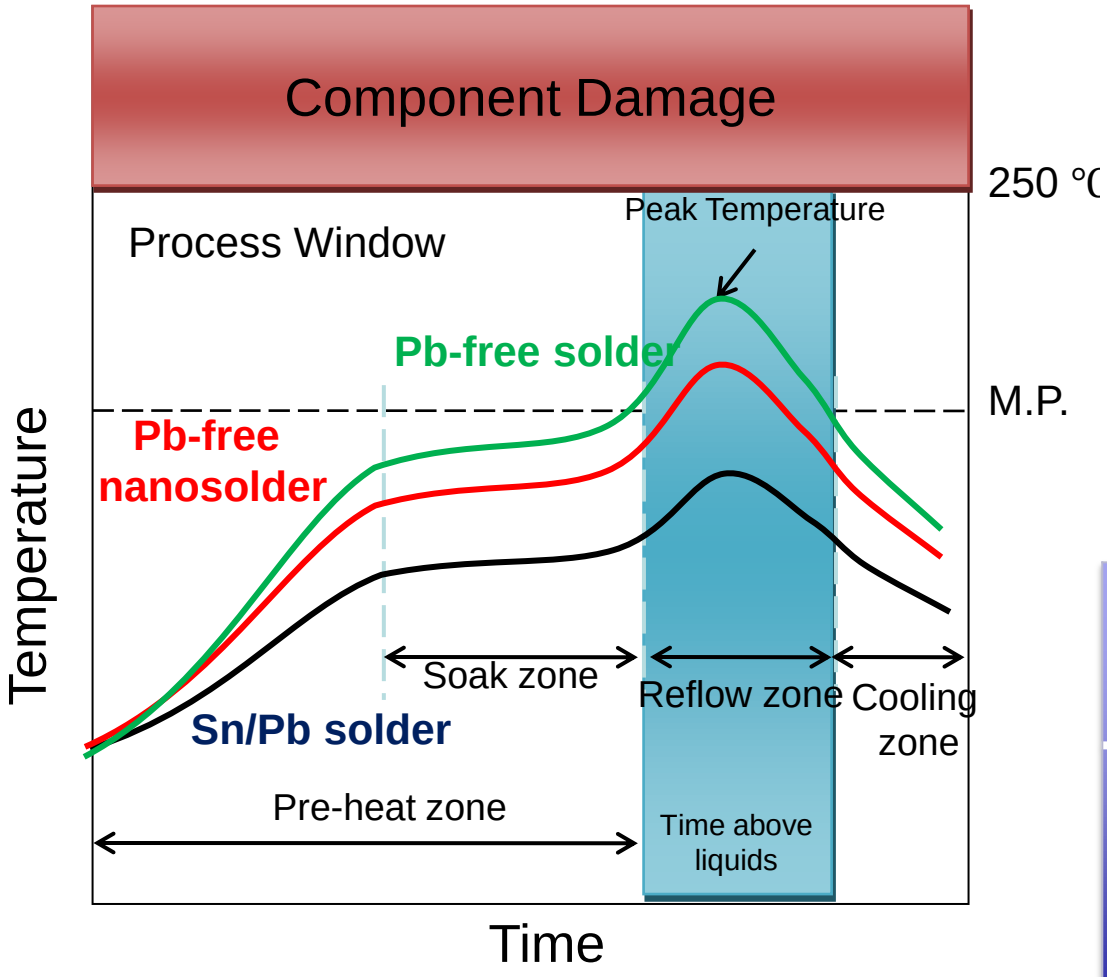


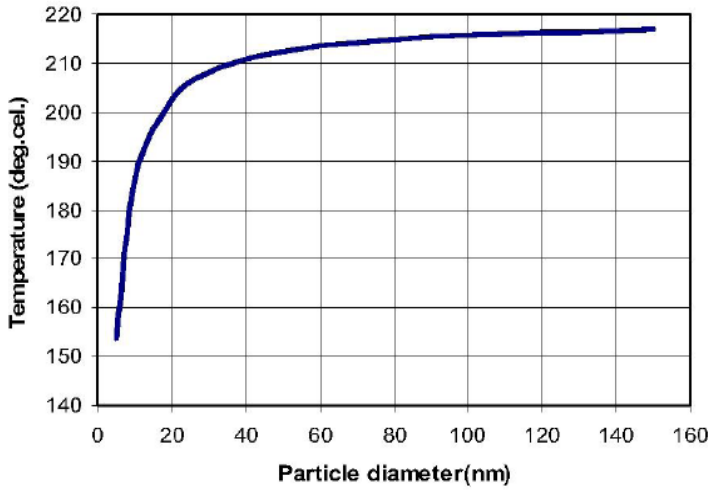
Z. Gu *et al.,* Langmuir 2007, 23, 979-982

Y. Lu *et al.*, Nature Nanotechnology 5, 218 - 224 (2010)

Introduction

Solder reflow for lead-free solde



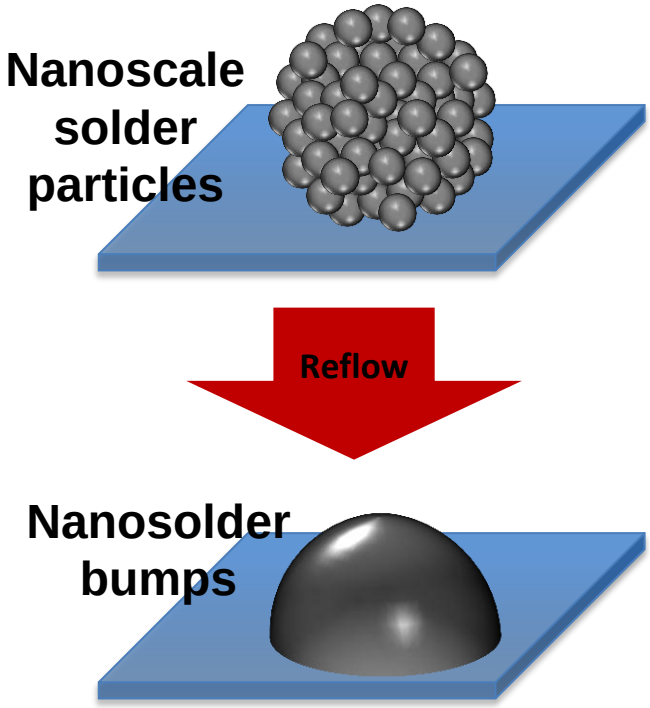


Theoretical plot of the melting point due to nanosize effect as function of particle size for Sn-4.0Ag-0.5Cu alloy.

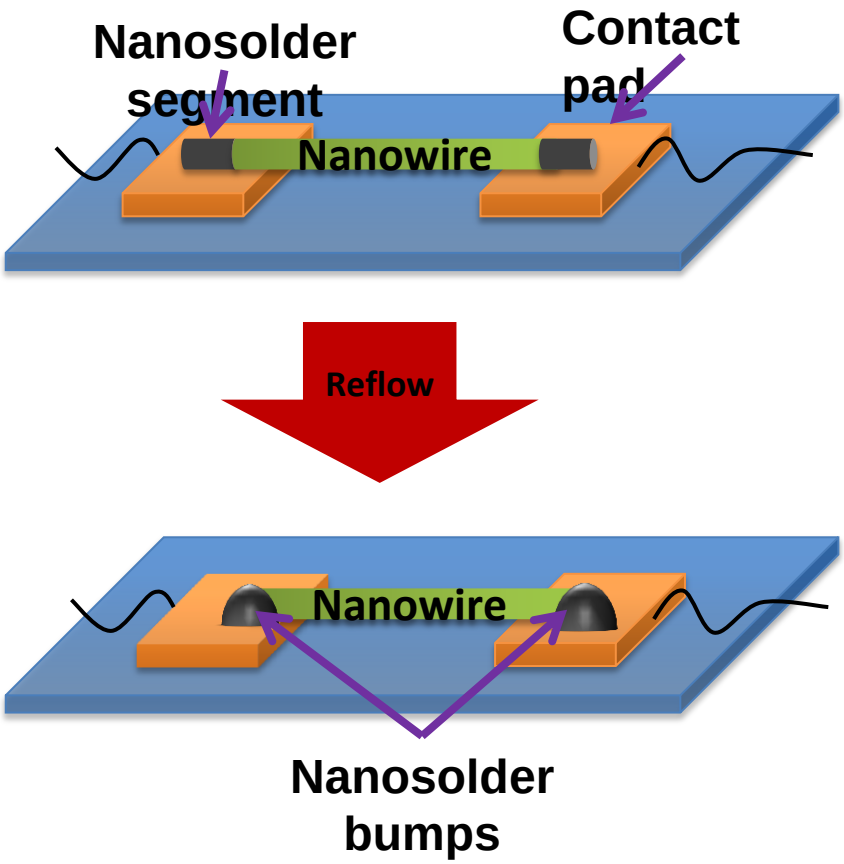
W.Guan el al. 2006 IEEE

Alloy system	Melting Point (℃) Bulk size
63Sn/37Pb	183
Sn	231
Sn/3.5Ag	221
Sn/3.8Ag/0.7Cu	217

Nanosolders Assembly and Packaging



2-dimensional interconnect
/nanoparticle solder
--close to the conventional soldering technique



1-dimensional interconnect
/nanowire bridge

F. Gao *et al*, *Proceedings of the 2011 Nanotechnology Conference, 2011, 2, 422-425*

Introduction

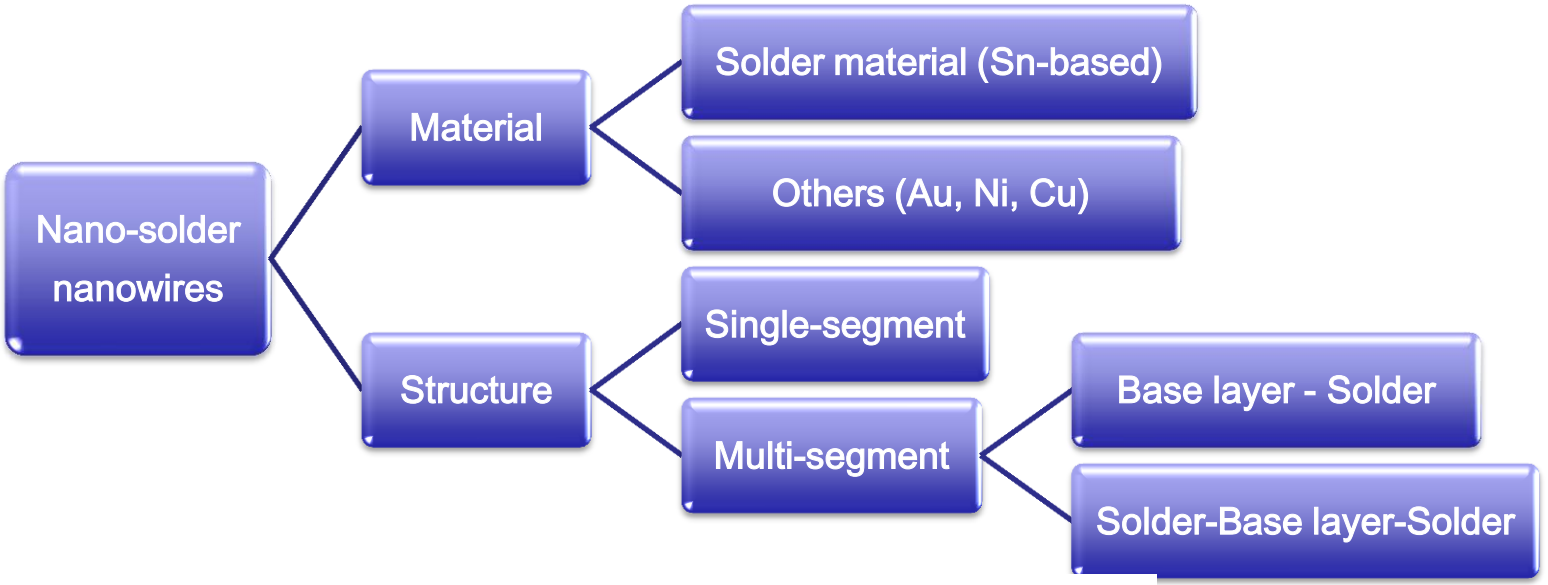
✓ **Nanosolder fabrication**

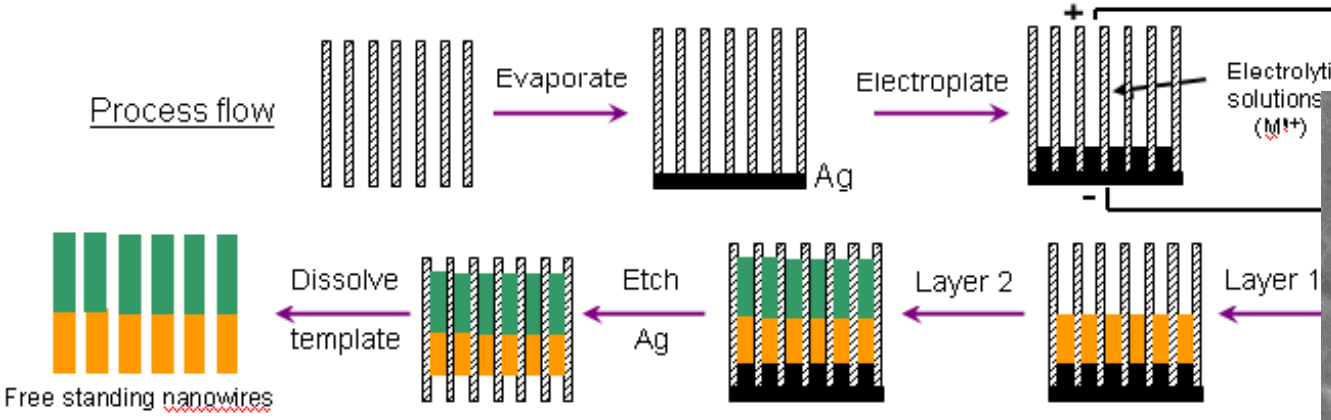
Surface oxidation, flux effect and solder melting on substrates

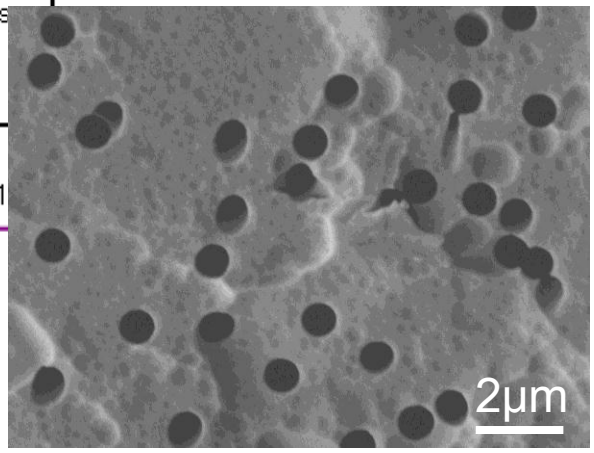
One-dimensional diffusion in segmented nanowire

Nanowire assembly and nanosolder joint formation

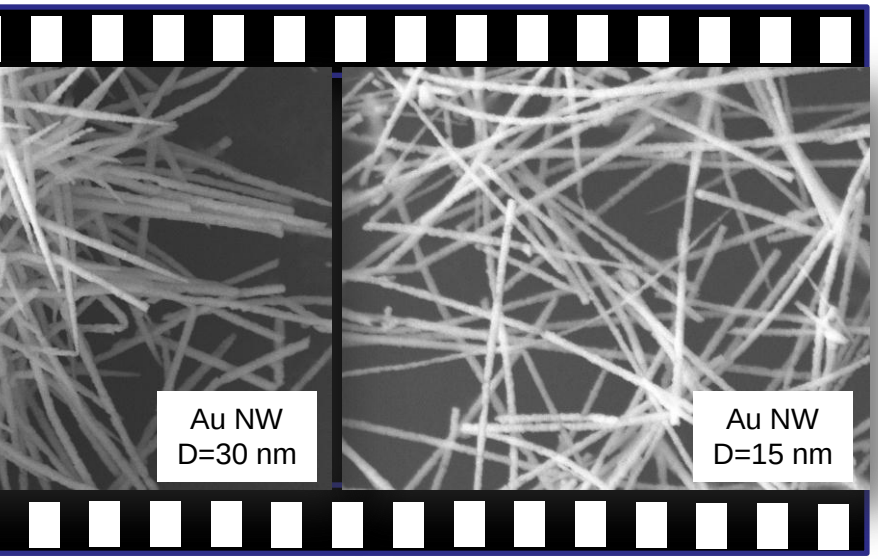
Nanowire Fabrication

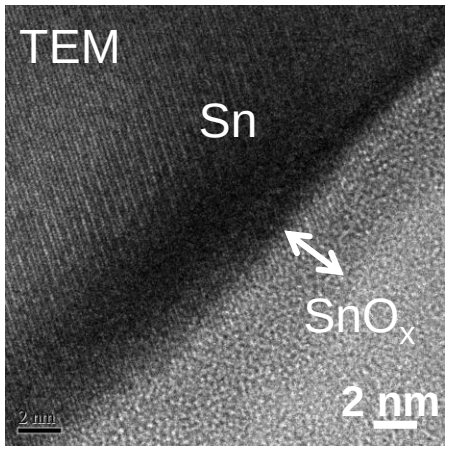


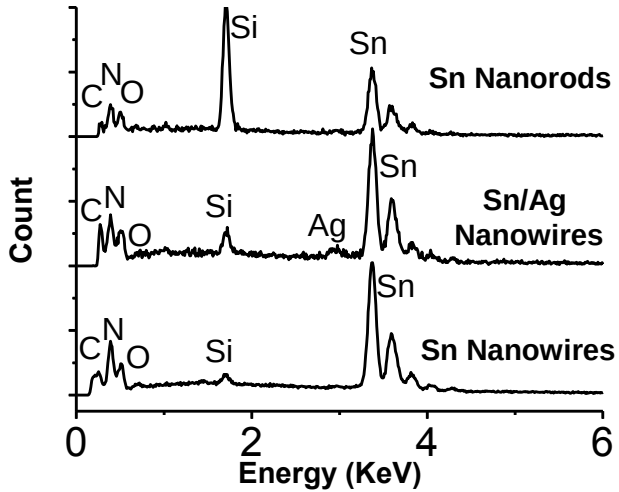




Nanowires

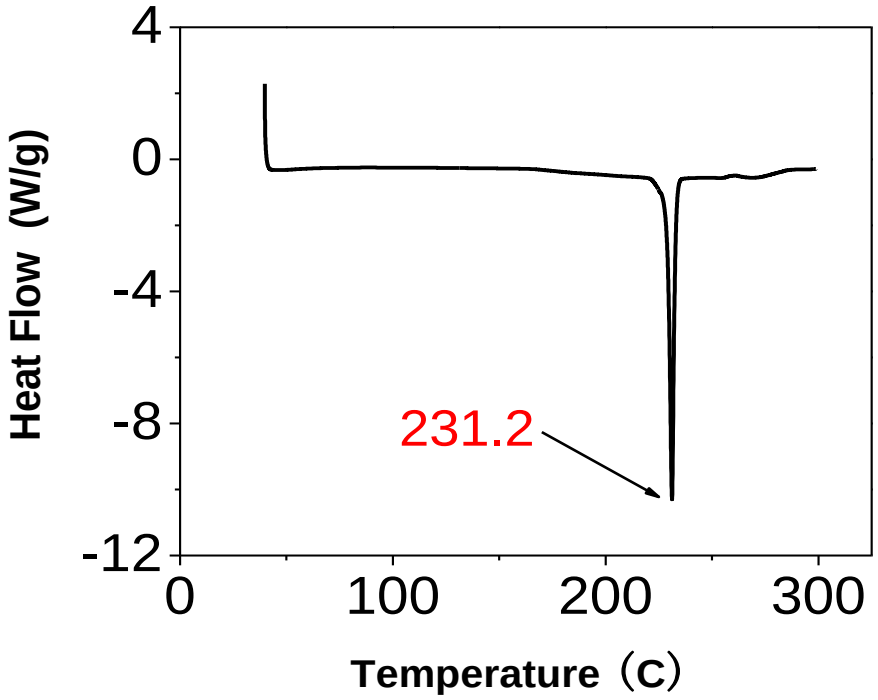

Au NW
D=30 nm
Au NW
D=15 nm


TEM
Sn
SnOx
2 nm
2 nm


Si
Sn
C
N
O
Sn Nanorods
Sn
C
N
Si
Ag
O
Sn/Ag
Nanowires
Sn
C
N
O
Si
Sn Nanowires
Count
0
2
4
6
Energy (KeV)

Melting Point of NWs

DSC—Melting point of pure tin nano-solder nanowire D=50nm, L=5μm



Melting point of bulk tin

231.9 ^{0}C

Only 0.7 ^{0}C ↓

F. Gao, S. Mukherjee, Q. Cui, Z. Gu, *J. of Phys. Chem. C* **2009**, *113 (22)*

Introduction

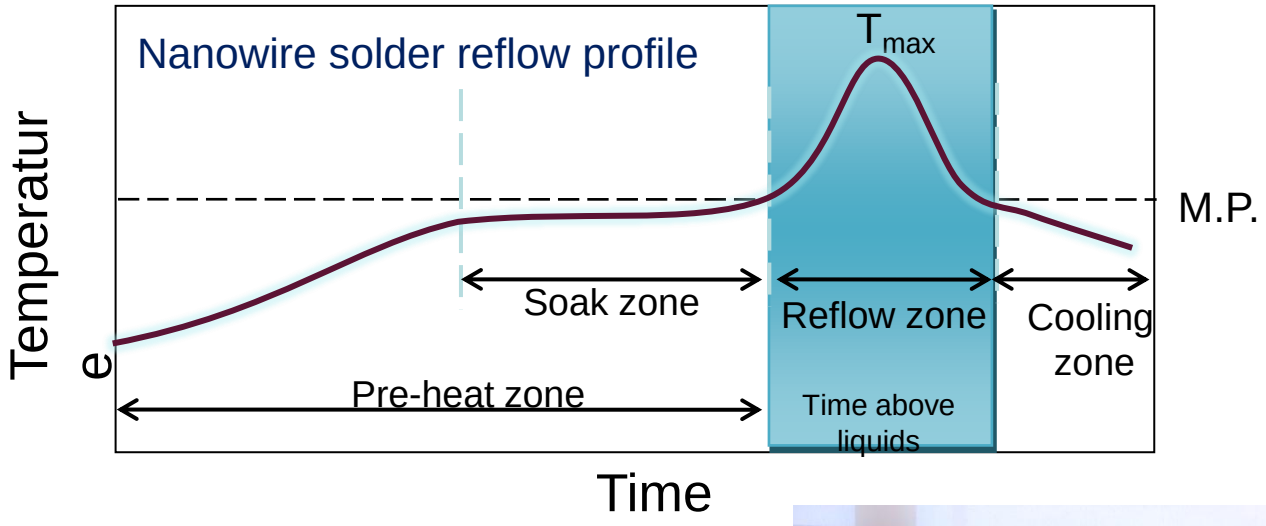
Nanosolder fabrication

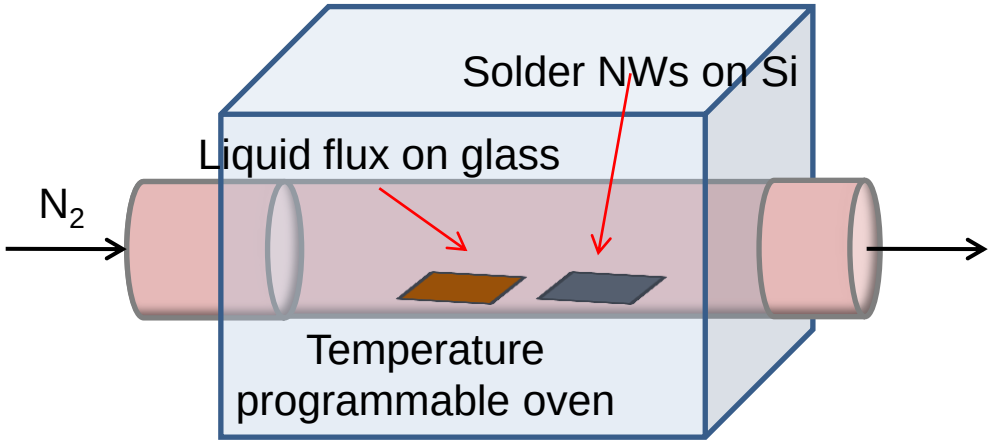
✓ **Surface oxidation, flux effect and solder melting on substrates**

One-dimensional diffusion in segmented nanowire

Nanowire assembly and nanosolder joint formation

Nanosolder Reflow and Setup

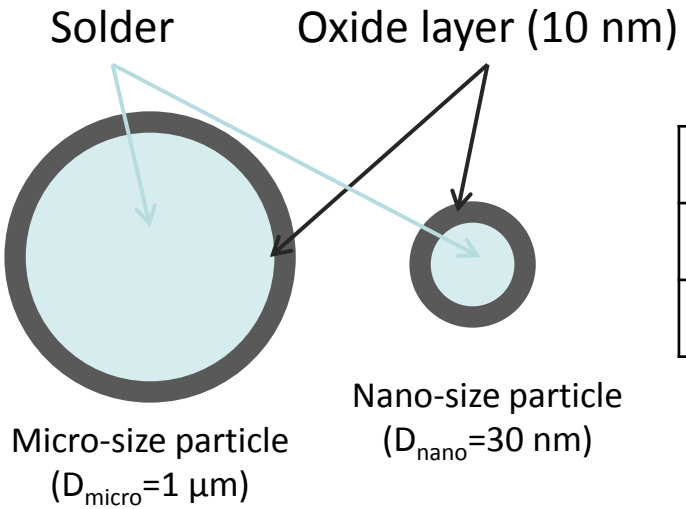




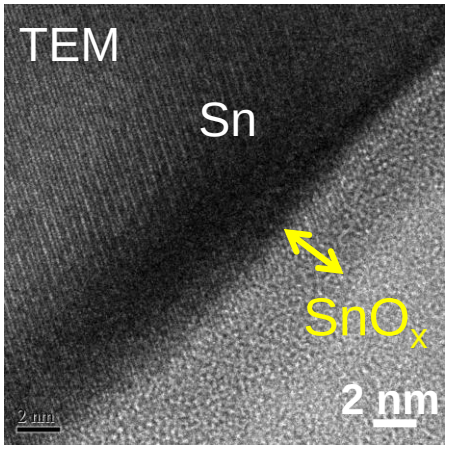
Temperature Programmed Tube Furnace

Bench top reflow oven
Torch Inc. T200N

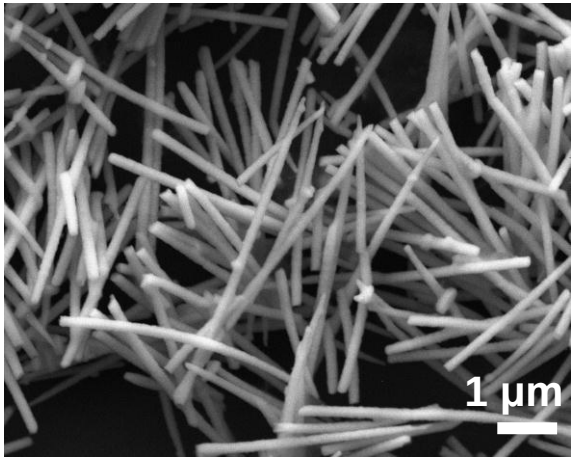
Solder Nanowire Oxidation

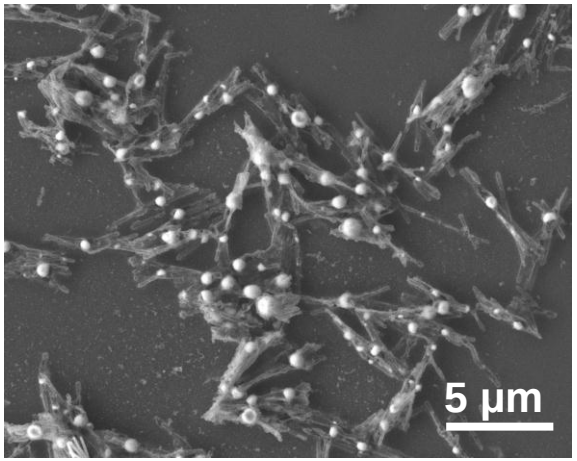


	D	Oxide
Micro	1 µm	0.01%
Nano	30 nm	11.11%



3-4 nm Oxide layer





F. Gao, K. Rajathurai, Q. Cui, G. Zhou, I. NkengforAcha, Z. Gu. *Applied Surface Science* 2012, 258, 7507-7514.

Flux Effect of Solder Reflow

Rosin based flux mainly formula:

$C_{19}H_{29}COOH$

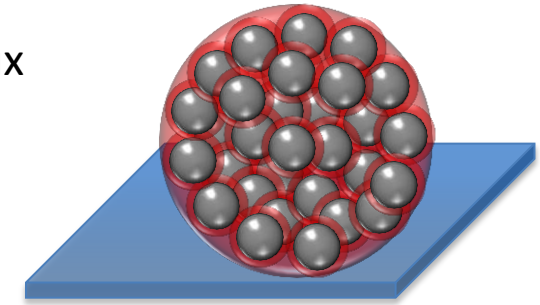
RCOOH + MX = RCOOM +HX

M= Sn, etc
X = oxide, hydroxide or carbonate

- Remove oxidation layer
- Enhance wettability

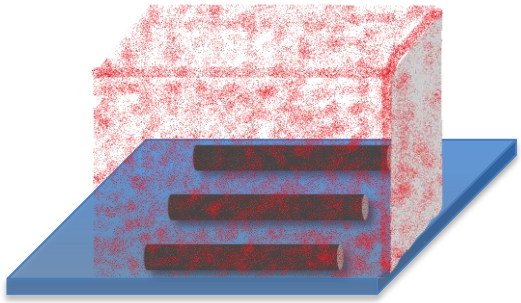
Flux Vapor Vs. Liquid Flux
- Quantity
- Cleaning residue

Micron-solder + semi-liquid flux



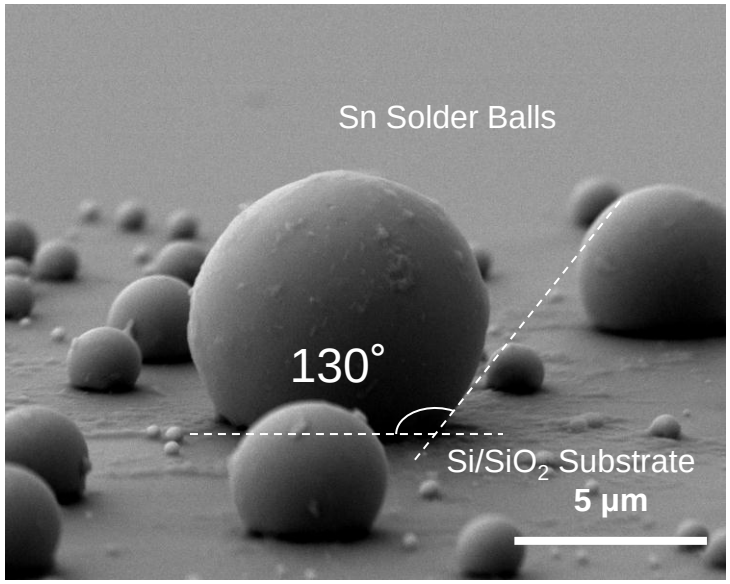
Flux

Nano-solder + flux vapor

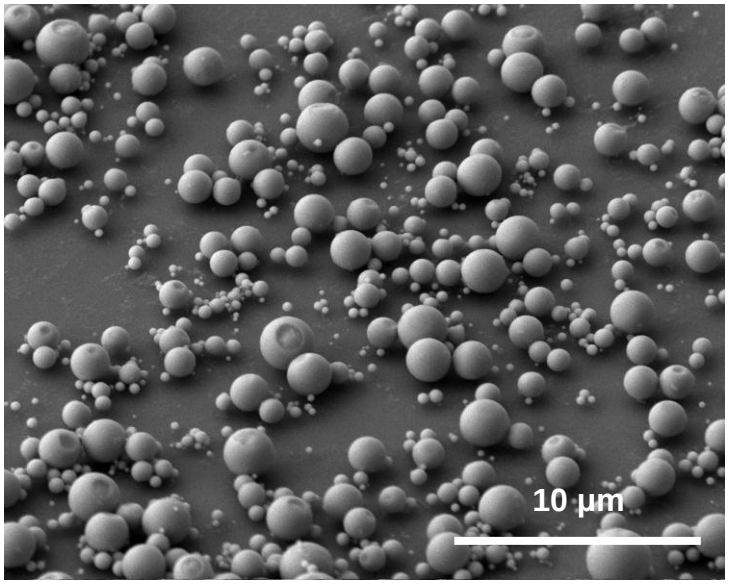


Solder

Flux Effect of Solder Reflow



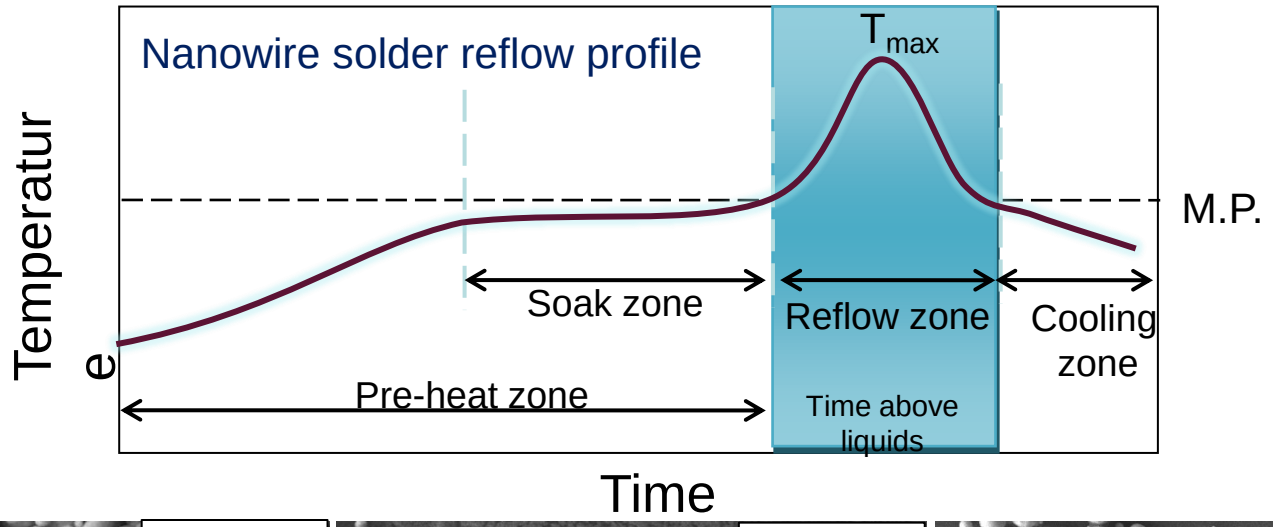
Sn nanowire solder

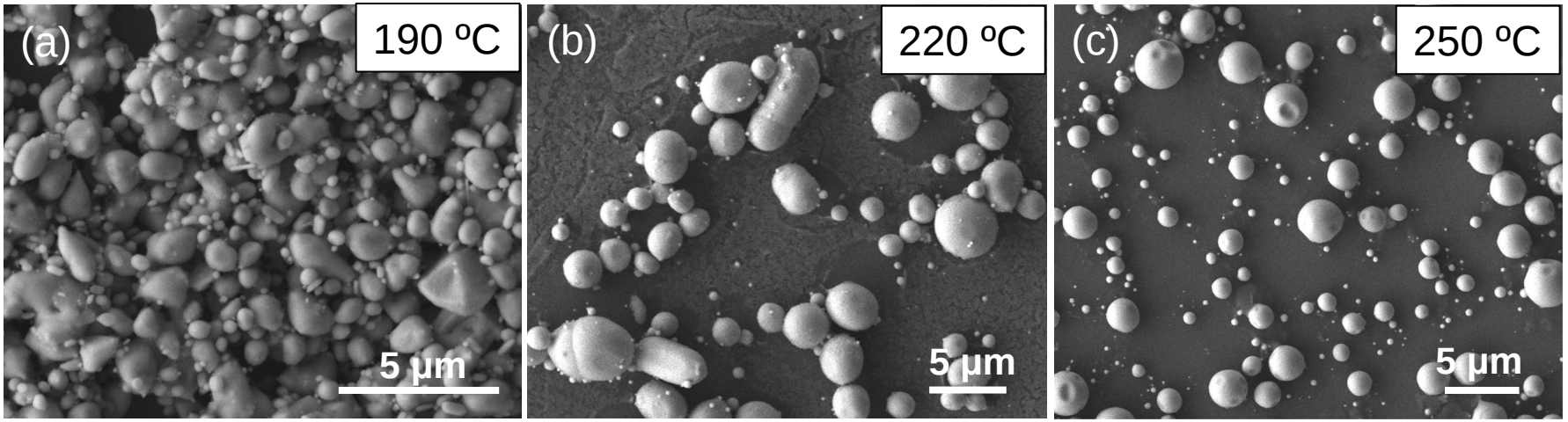


Sn/Ag nanowire solder

F. Gao, K. Rajathurai, Q. Cui, G. Zhou, I. NkengforAcha, Z. Gu. *Applied Surface Science* 2012, 258, 7507-7514.

Flux + Temperature Effect





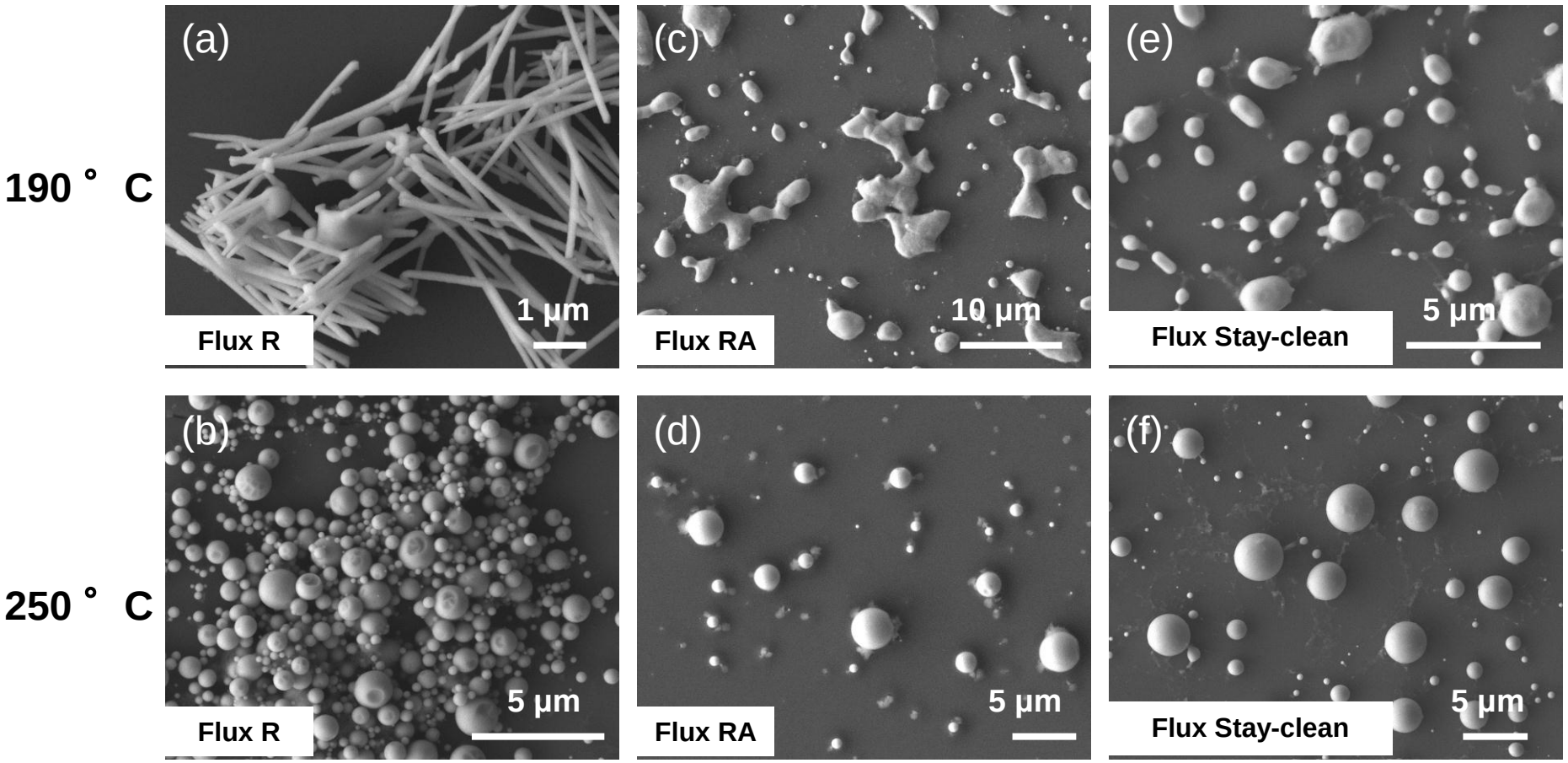
$T_{max} < T_{M.P.}$ $T_{max} \sim T_{M.P.}$ $T_{max} > T_{M.P.}$

F. Gao, K. Rajathurai, Q. Cui, G. Zhou, I. NkengforAcha, Z. Gu. *Applied Surface Science* 2012, 258, 7507-7514.

Flux Effect of Solder Nanowries

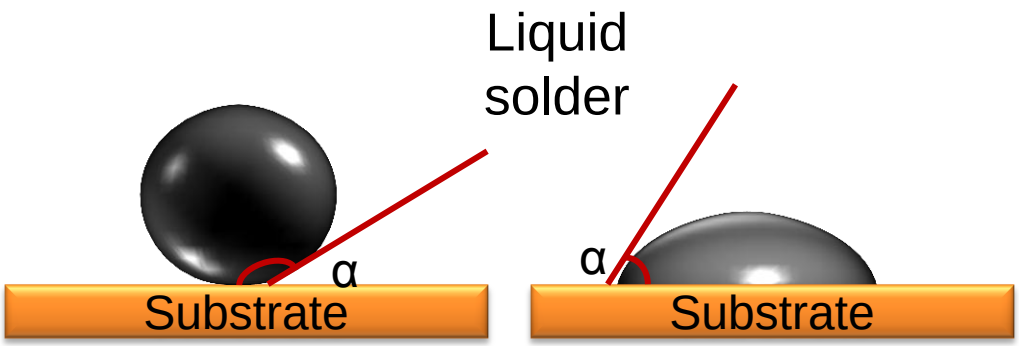
Flux Type		pH	Property
Rosin-based	R (Rosin)	3.02±0.32	Low activity
	RMA (Rosin Mild Activated)	2.74±0.38	Mildly activity
	RA (Rosin Activated)	2.43±0.29	High activity
Inorganic		0.29±0.05	High activity, high corrosion

Flux Effect of Solder Nanowries



F. Gao, K. Rajathurai, Q. Cui, G. Zhou, I. NkengforAcha, Z. Gu. *Applied Surface Science* 2012, 258, 7507-7514.

Substrate Effect of Solder Reflow



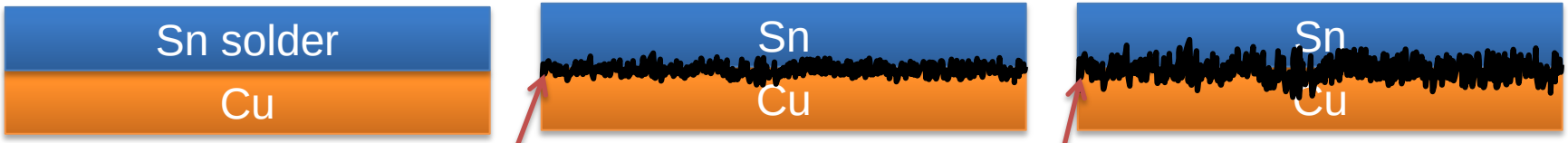
α > 90^0
Non-wetting

α < 90^0
Wetting

Room temperature

Proper reflow temperature

Above solder melting temperature (>> M.P.) (too much IMC)

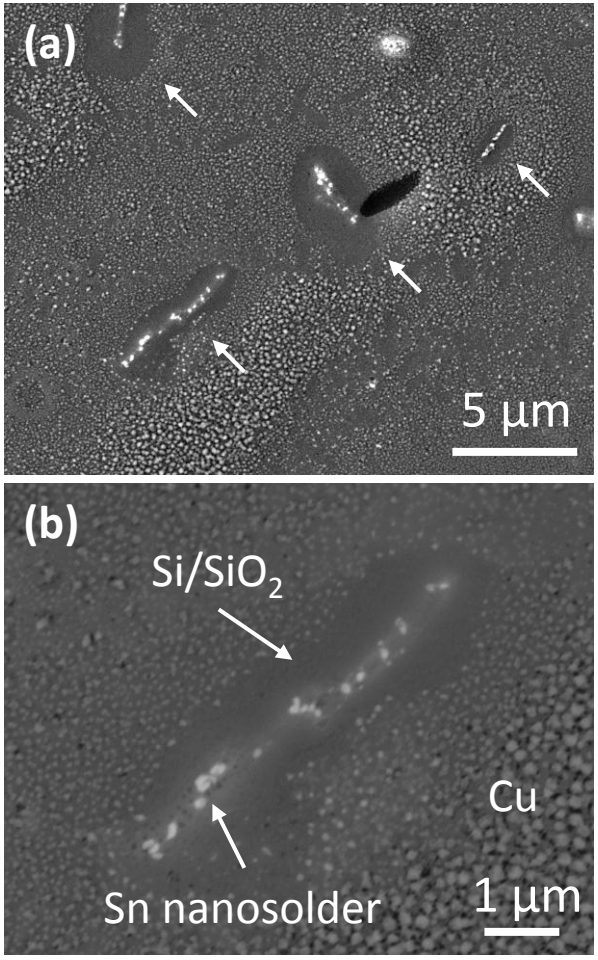


IMC

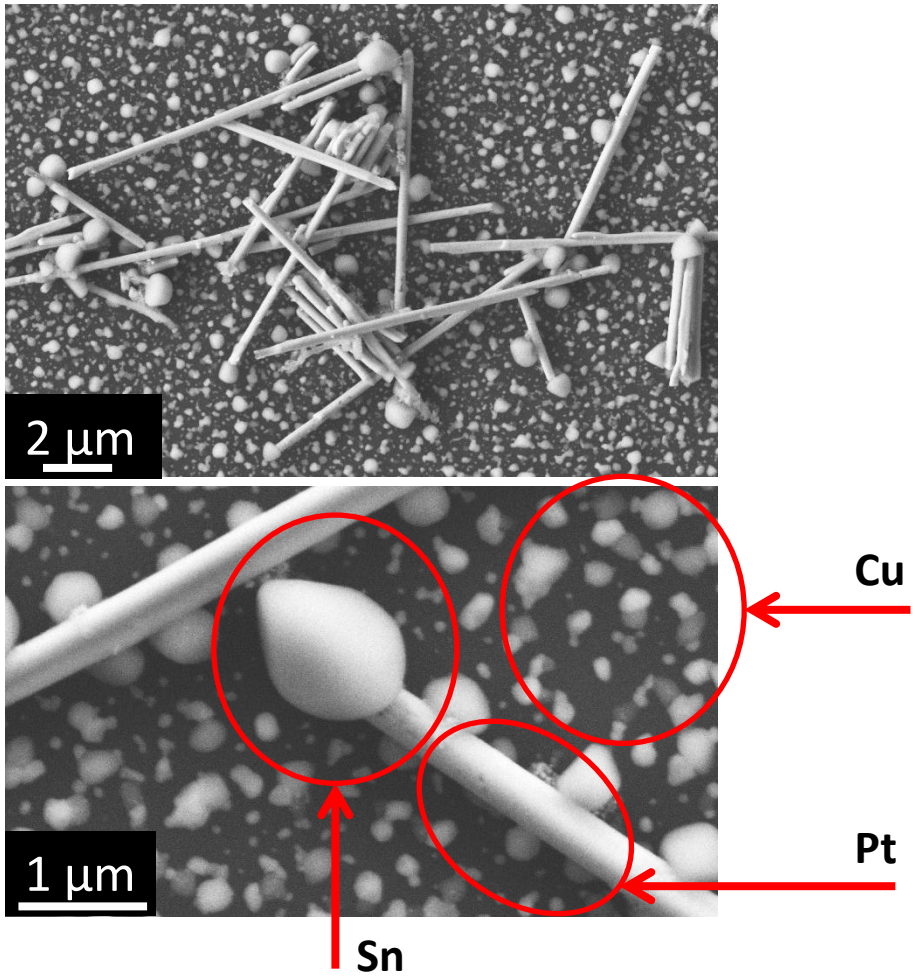
IMC growth

Solder Nanowire Reflow on Reactive Substrate

Pure Sn solder nanowires



Sn-Pt two-segment solder nanowires



Introduction

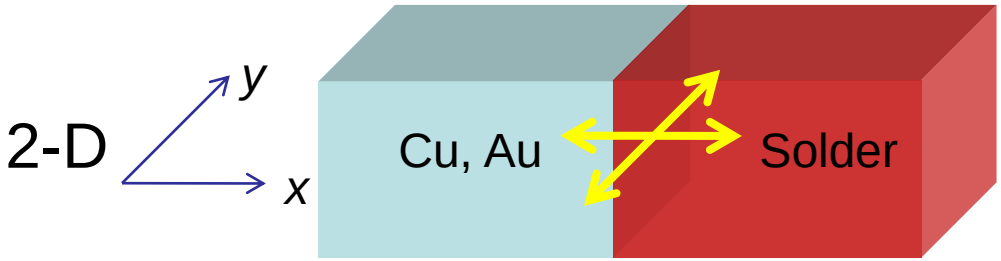
Nanosolder fabrication

Surface oxidation, flux effect and nanosolder melting on substrates

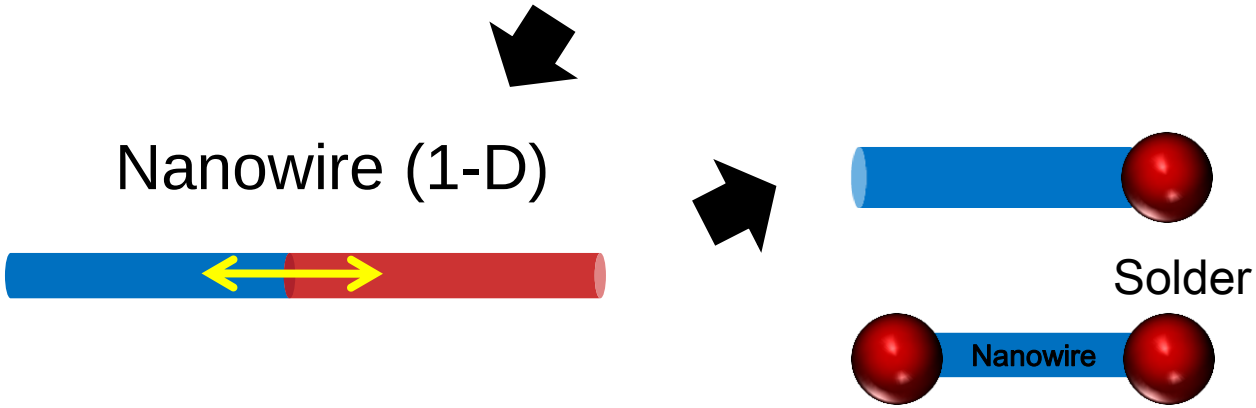
✓ **One-dimensional diffusion in segmented nanowire**

Nanowire assembly and nanosolder joint formation

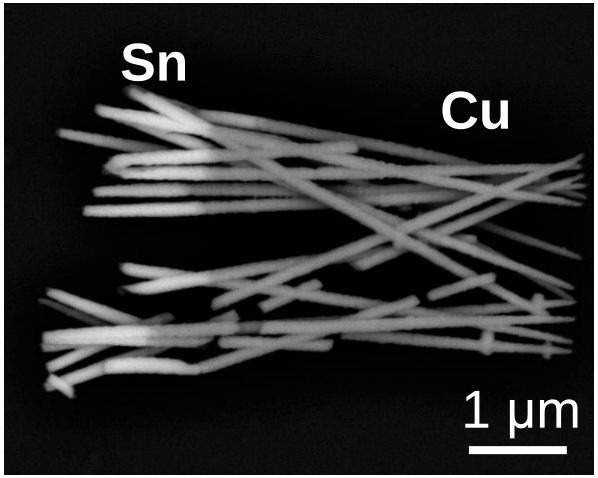
Intermetallic Diffusion and Nanowire

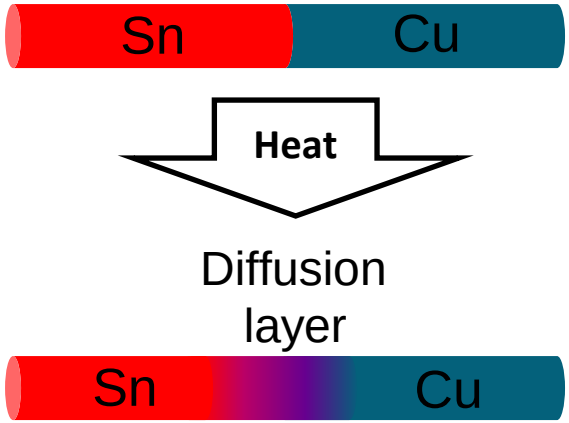


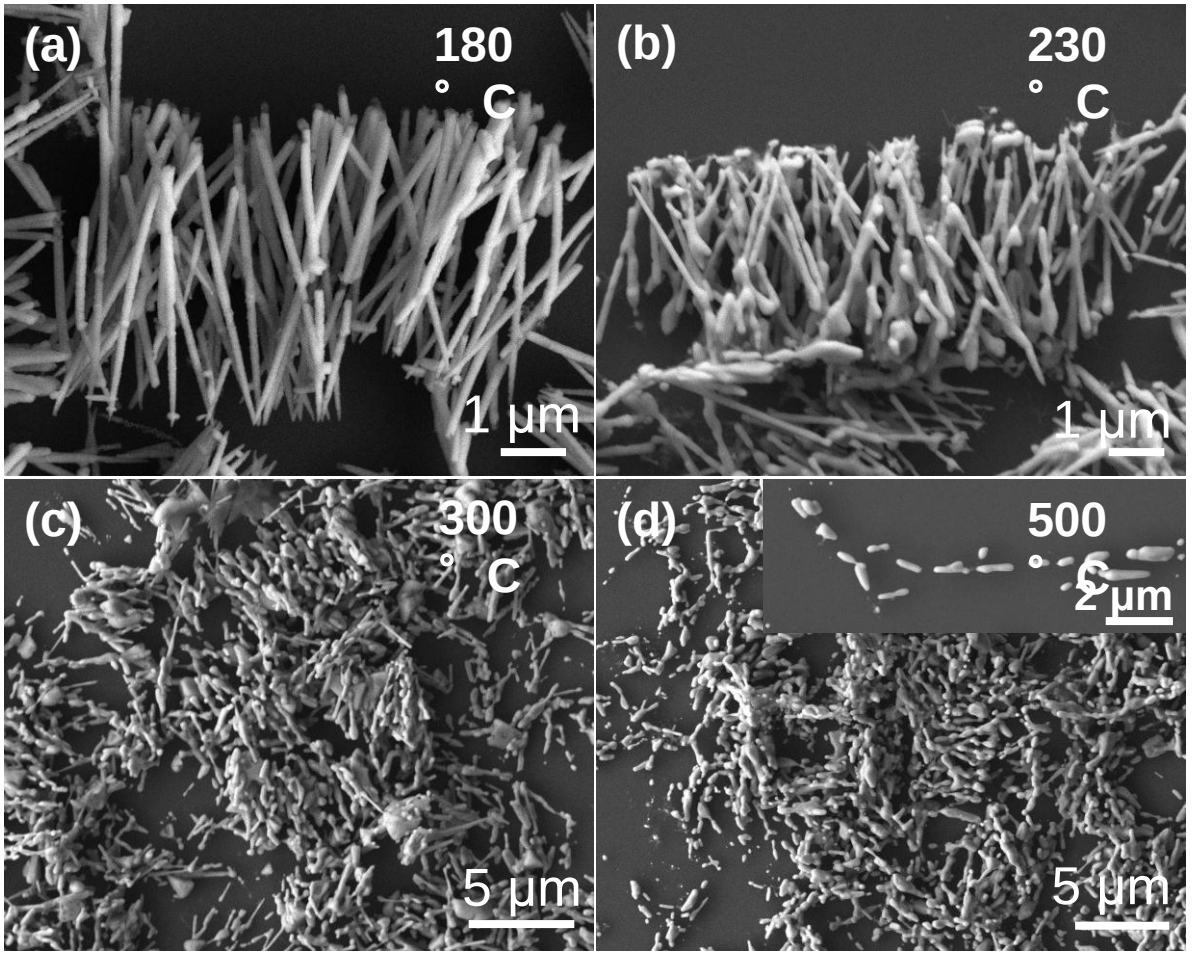
How much IMC in nanosolders?



Thermal Interdiffusion on Nanosolder

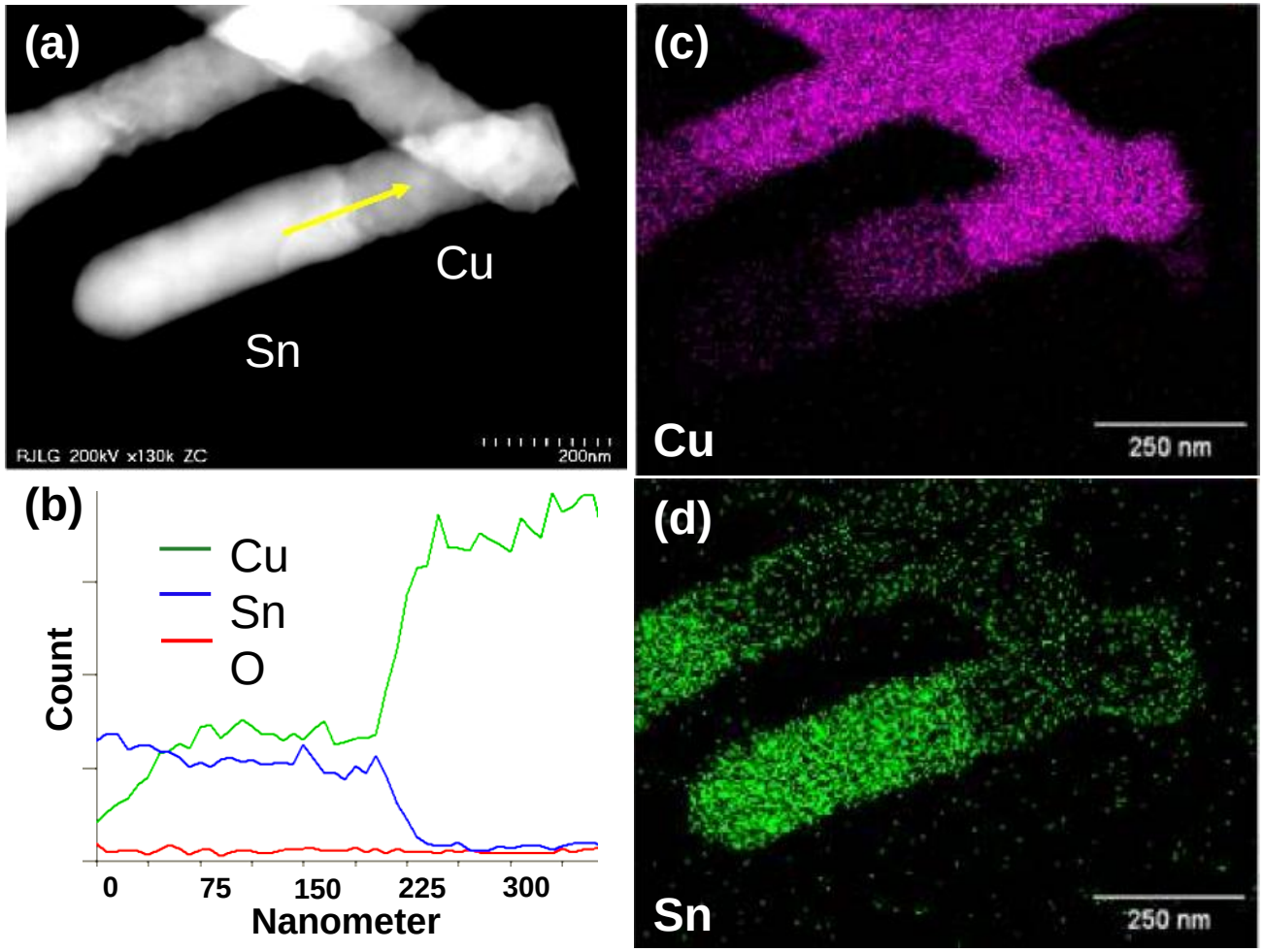






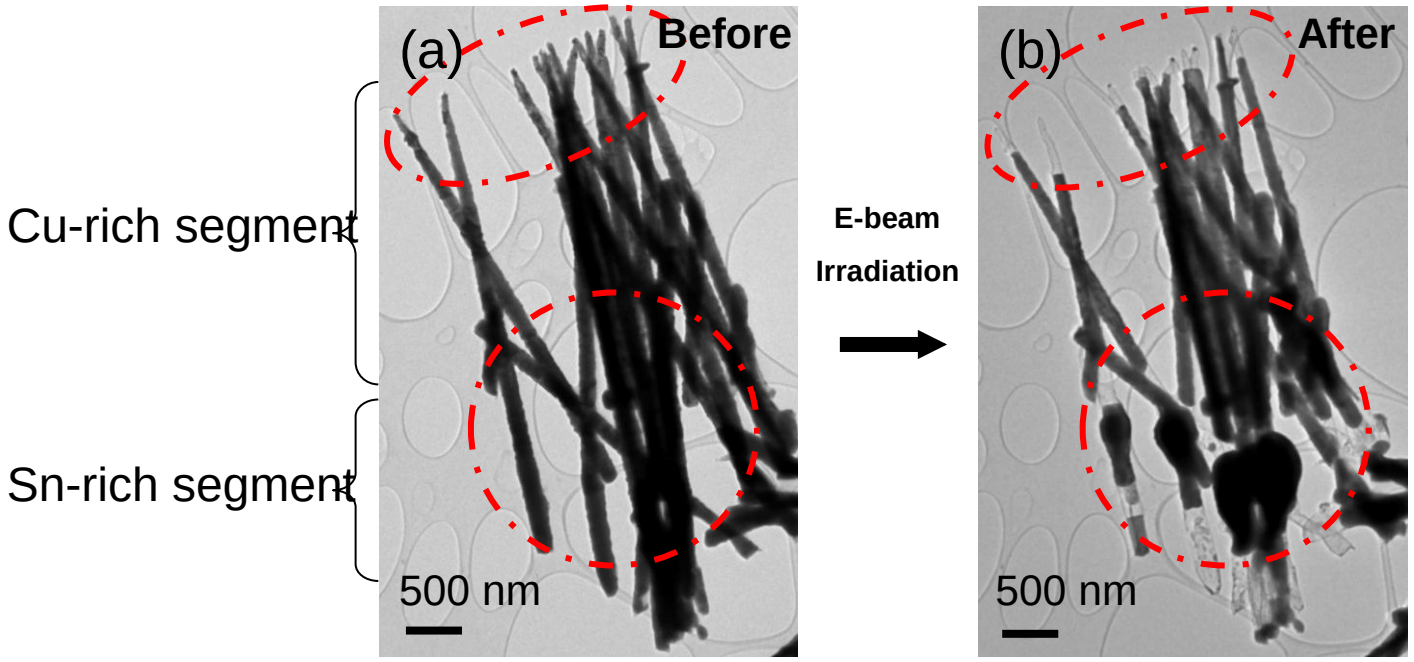
F. Gao *et al*, *Proceedings of the 2011 Nanotechnology Conference, 2011, 2, 422-425*

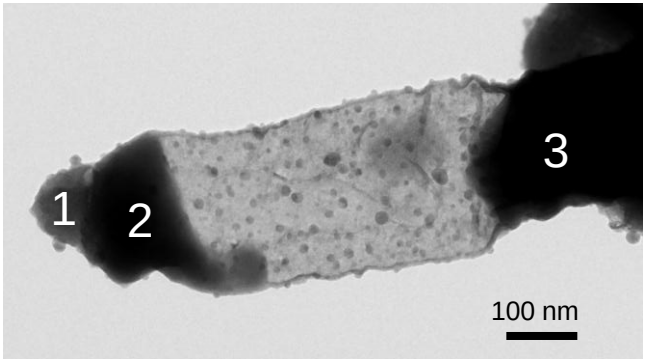
Interface Diffusion



F. Gao, Z. Liu, G. Zhou, J. C. Yang, Z. Gu, *Science of Advanced Materials* 2012, 4, 881-887

E-beam Irradiation Induced Fast Diffusion





Sn-rich Segment

Point	Element Weight %	
	Cu	Sn
1	37.79	62.21
2	19.46	80.54
3	51.02	48.98

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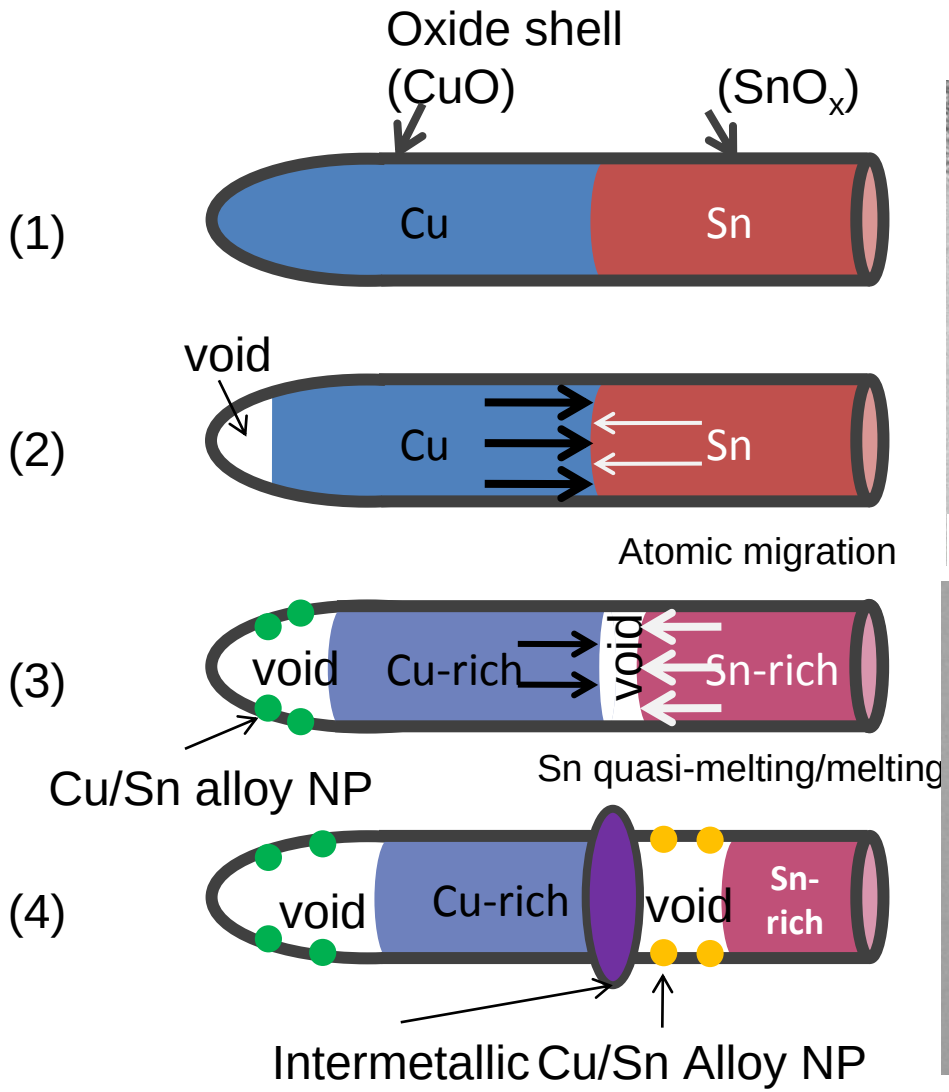
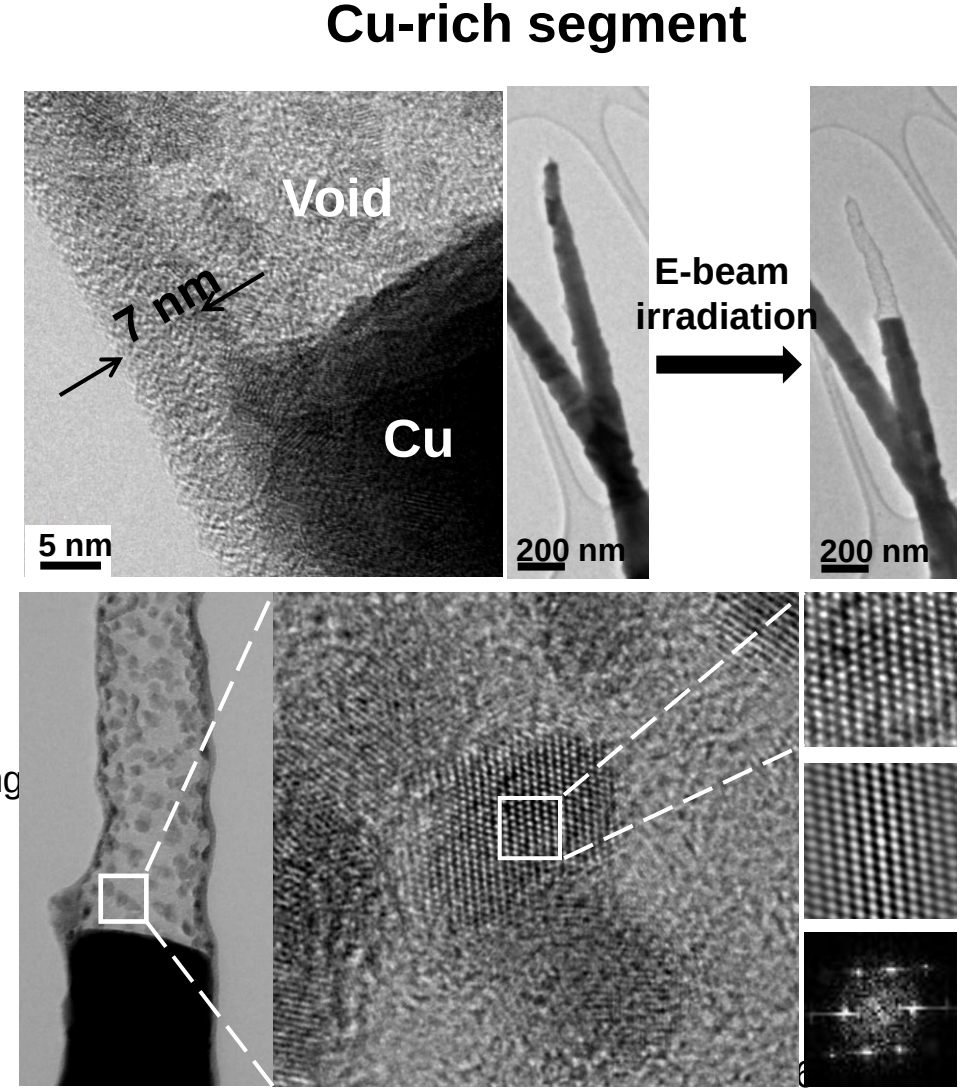
E-beam Irradiation Induced Fast Diffusion





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Introduction

Nanosolder fabrication

Nanosolder surface oxidation and flux effect

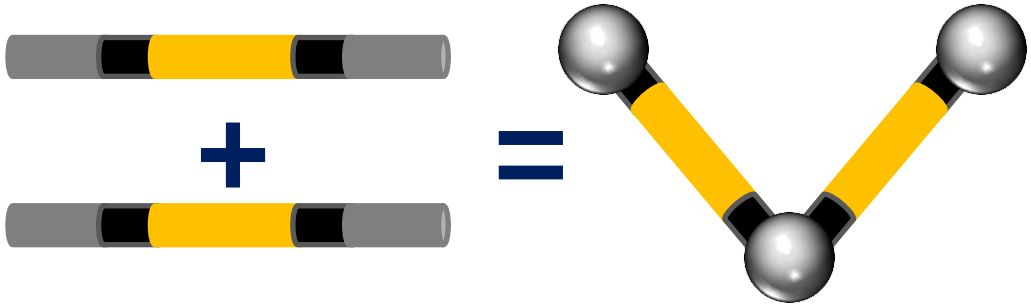
One-dimensional diffusion in segmented nanowire

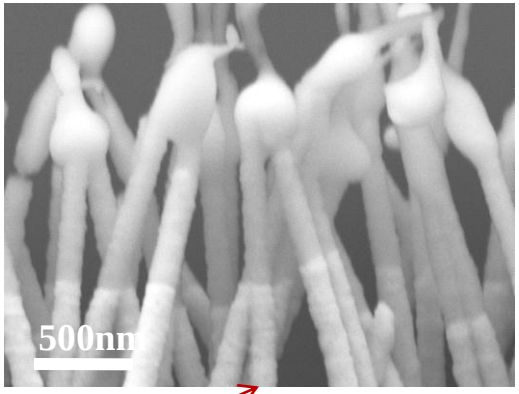
✓ **Nanowire assembly and nanosolder joint formation**

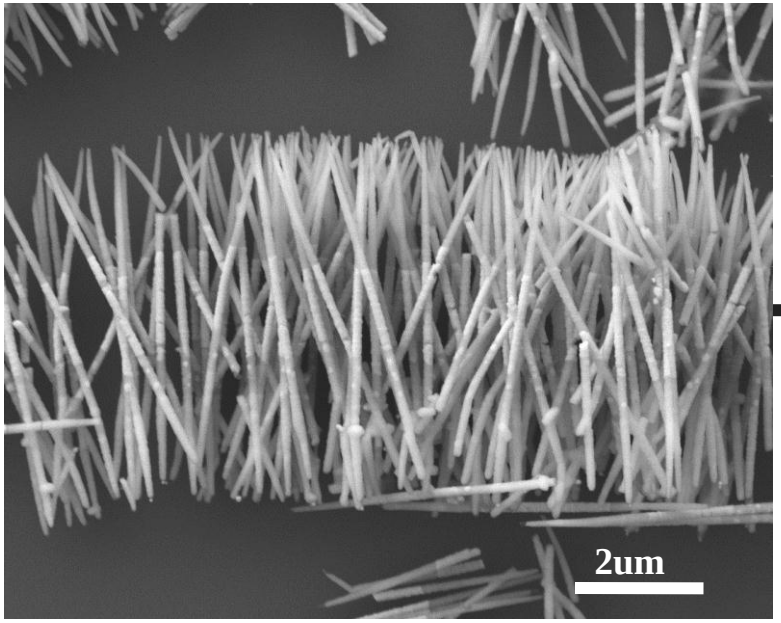
Solder Joint Formation

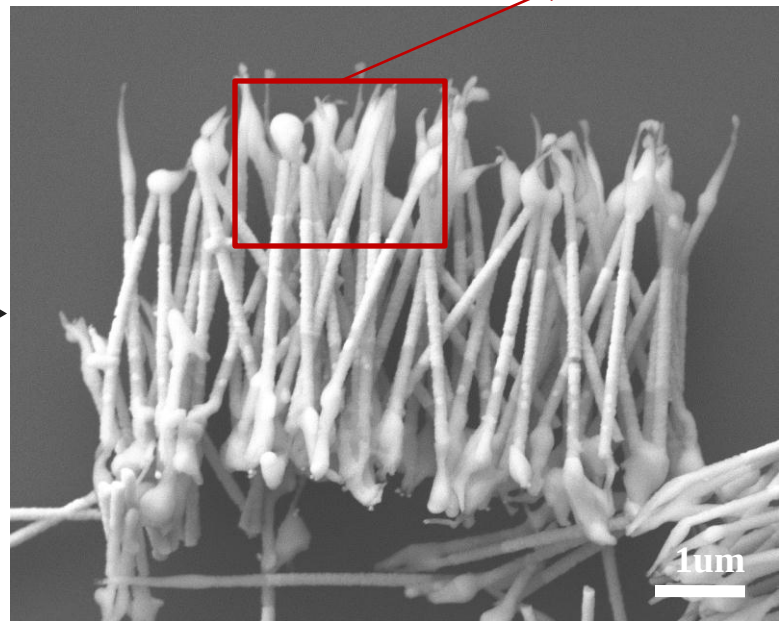
--Nanosolder reflow in vapor phase

Solder-Ni-Au-Ni-Solder







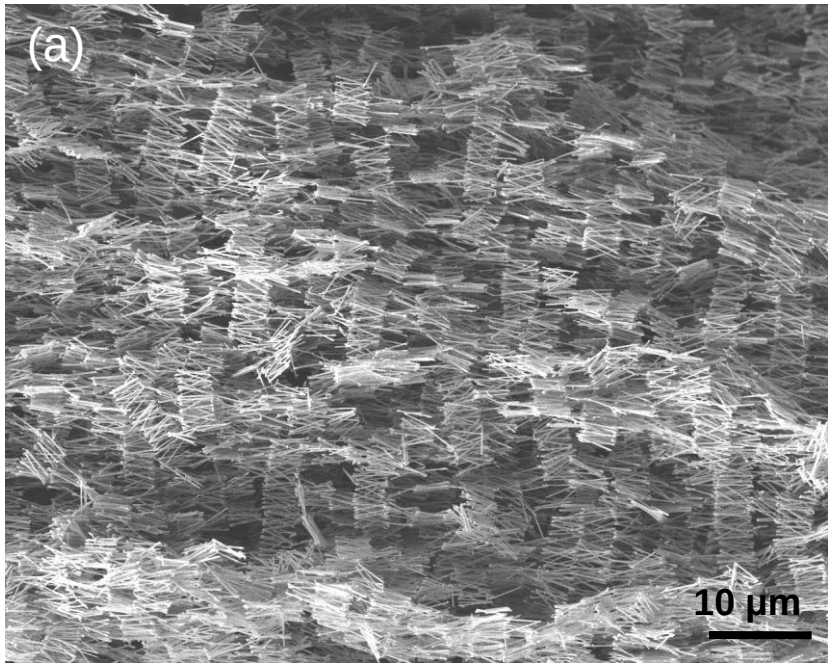


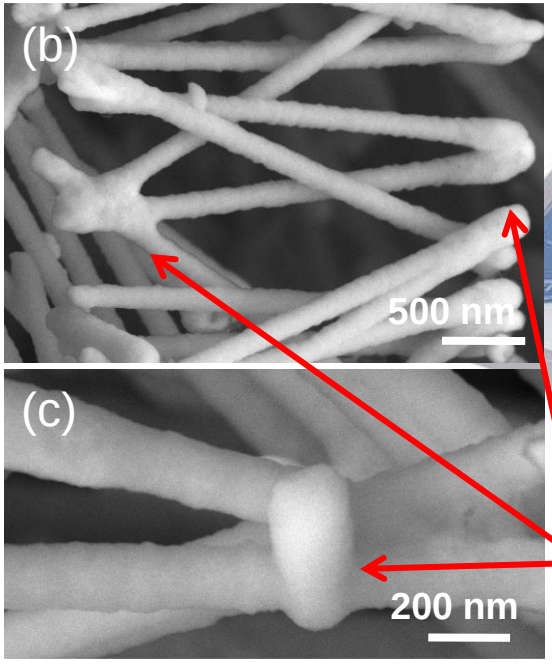
F. Gao, Z. Gu. *Nanotechnology* 21 (2010) 115604 (7pp)

Solder Joint Formation

--Nanowire assembly and Nanosolder joint formation in liquid phase

Magnetic nanowire segment + External magnetic field



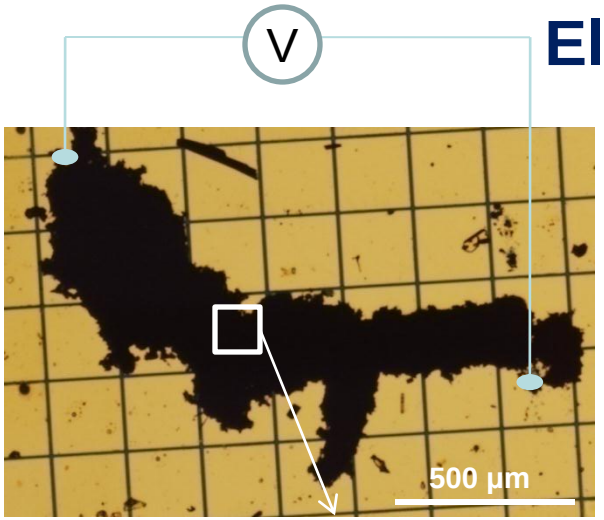


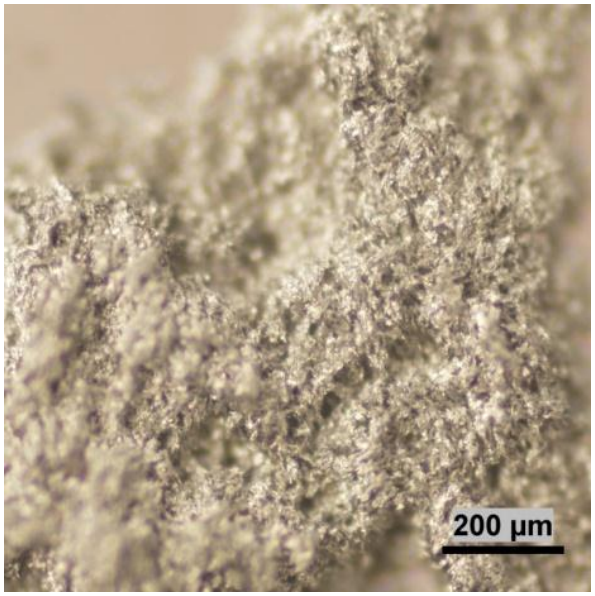
Solder joints

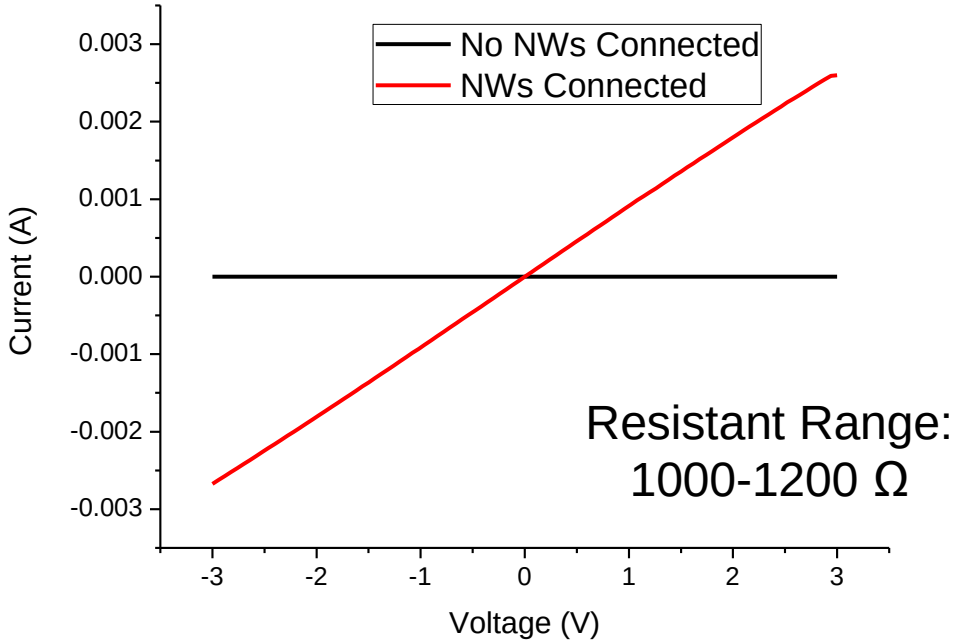
F. Gao, Z. Gu. *Nanotechnology* 21 (2010) 115604 (7pp)

Solder Joint Formation

Electrical Property







Left: optical microscope images of assembled ordered nanowires

Right: electrical measurement by probe-station

F. Gao, Z. Gu. *Nanotechnology* 21 (2010) 115604 (7pp)

Conclusion

- ✓ Nanosolder on multi-segment nanowires have been successfully fabricated by electrodeposition method;
- ✓ Flux assisted environment enhanced reflow result and micron scale solder spheroids formed on non-wetting Si substrate;
- ✓ Nanosolder reflow performance on reactive Cu substrate was studied;
- ✓ 1-D interdiffusion on Cu-Sn two-segment nanowire were observed through the thermal heating and e-beam irradiation;
- ✓ Nanojoints formed between nanowires and a network was constructed through quasi-reflow process in liquid.

Future Work

Material

- Diffusion kinetics modeling of confined nanowire in one-dimension;
- Nanosolder size effect for melting temperature depression;
- Different solder materials for various applications.

Processing and Applications

- Joint formation between nanowires for device packaging;
- Joint reliability study;
- Real device testing, e.g., nano-wire bonding.

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Thank you!

New England Lead Free Consortium Members 2000-2012

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Interested in Joining proposed Nano Solder Development Consortium in 2014?

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