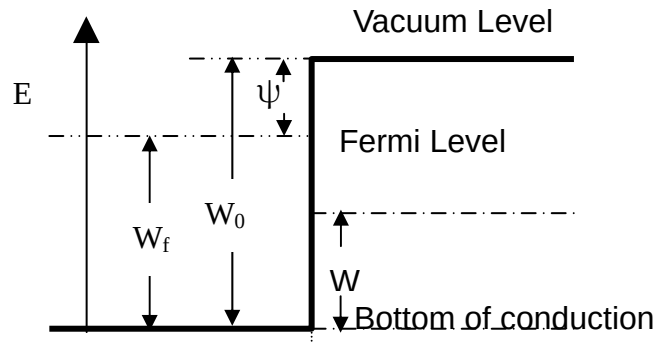
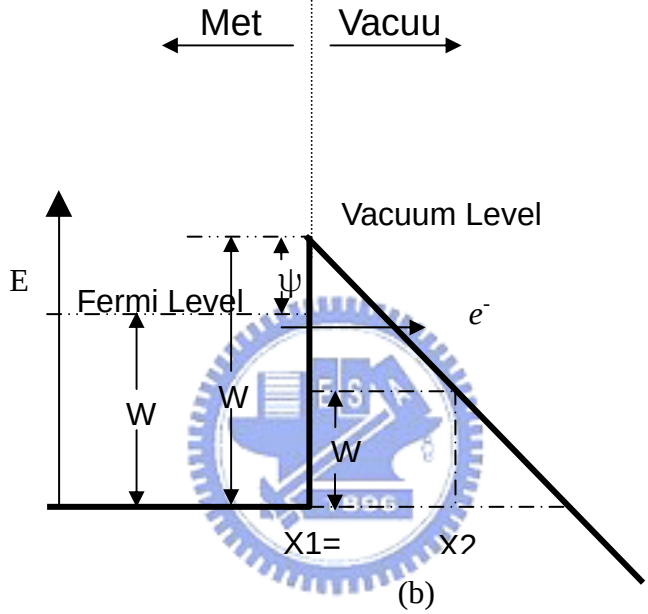
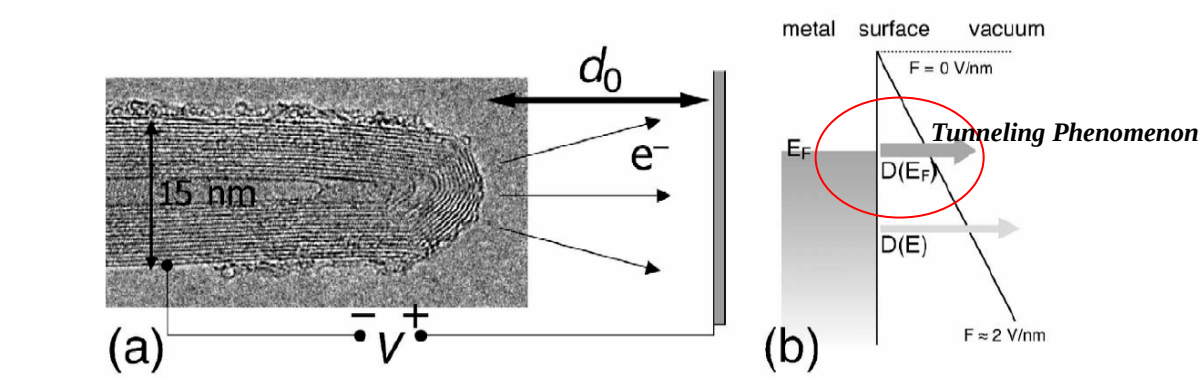


(a)

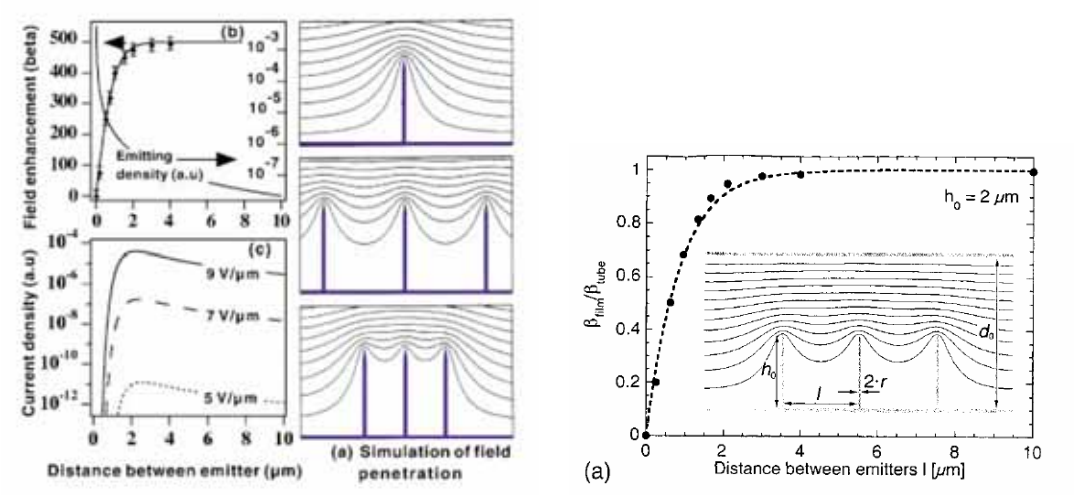


(b)

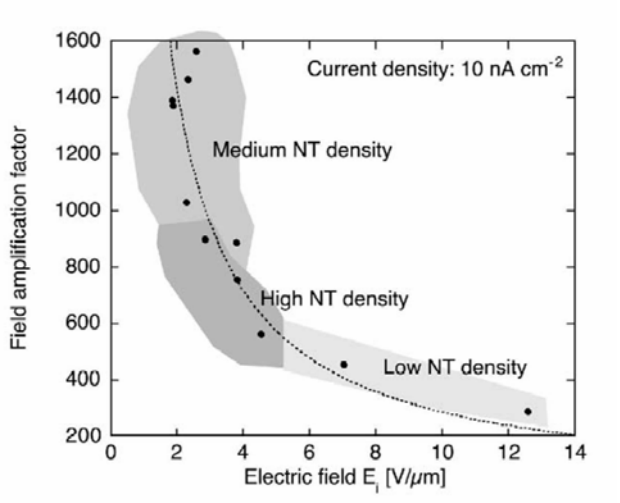


(c)

Fig. 1.1 Energy diagrams of vacuum-metal boundary: (a) without external electric field , (b) with an external electric field, and (c) Tunneling phenomenon [76].

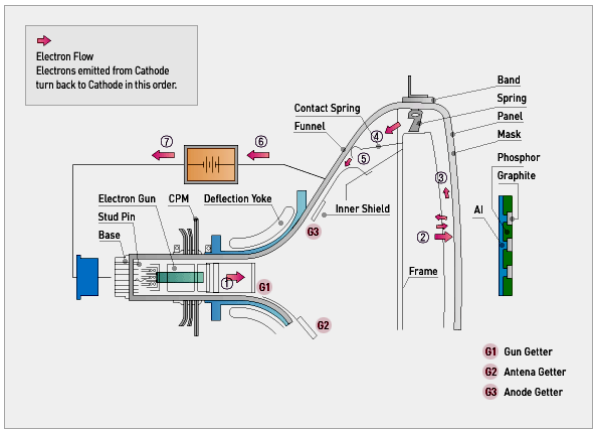


(a)

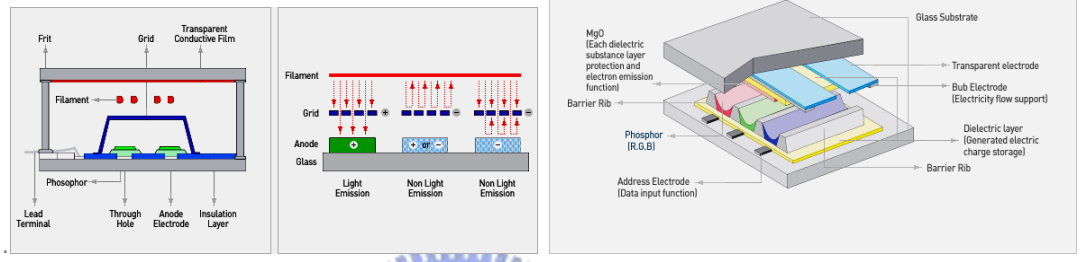


(b)

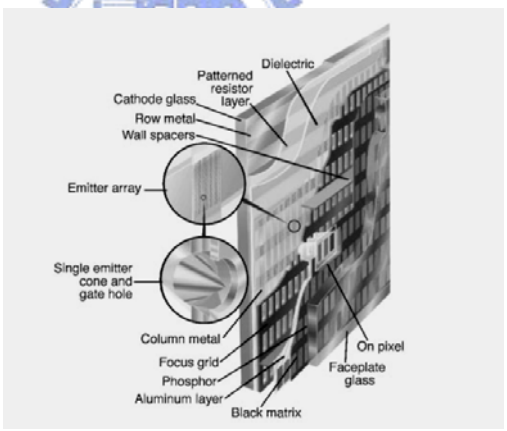
Fig. 1.2 (a) Simulation of the equipotential lines of the electrostatic field [77], (b) Field amplification factor *B* as a function of the onset field [76].

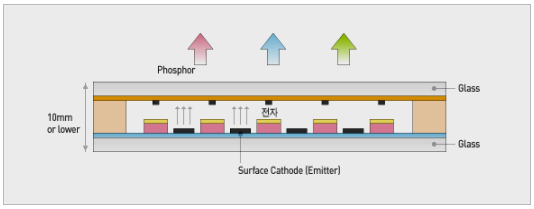


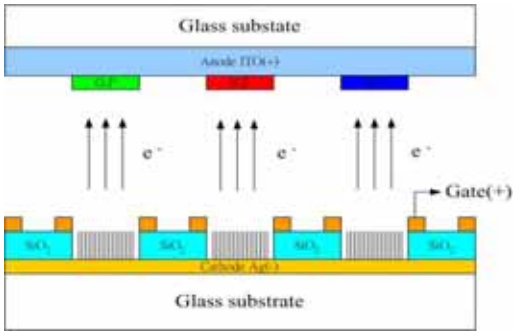
(a)



(b) (c)



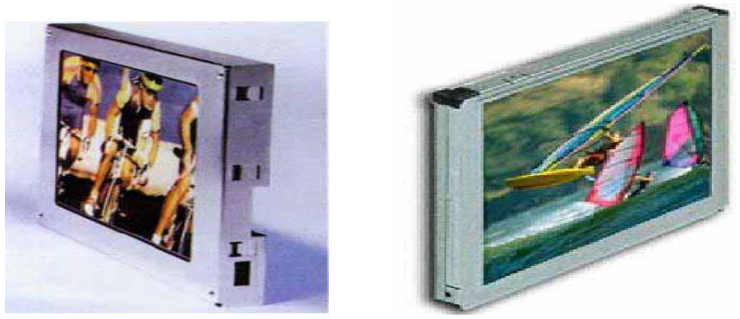




(d) (e)

Fig. 1.3 (a) CRT (Cathode Ray Tube), (b) VFD (Vacuum Fluorescent Display), (c) PDP (Plasma Display Panel), and (d)(e) FED (Field Emission Display).

(a) (b)

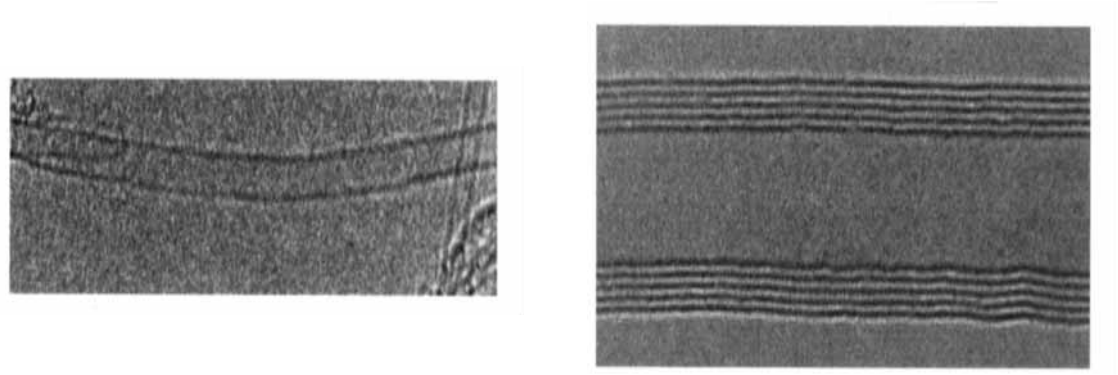


(c) (d)

(e)

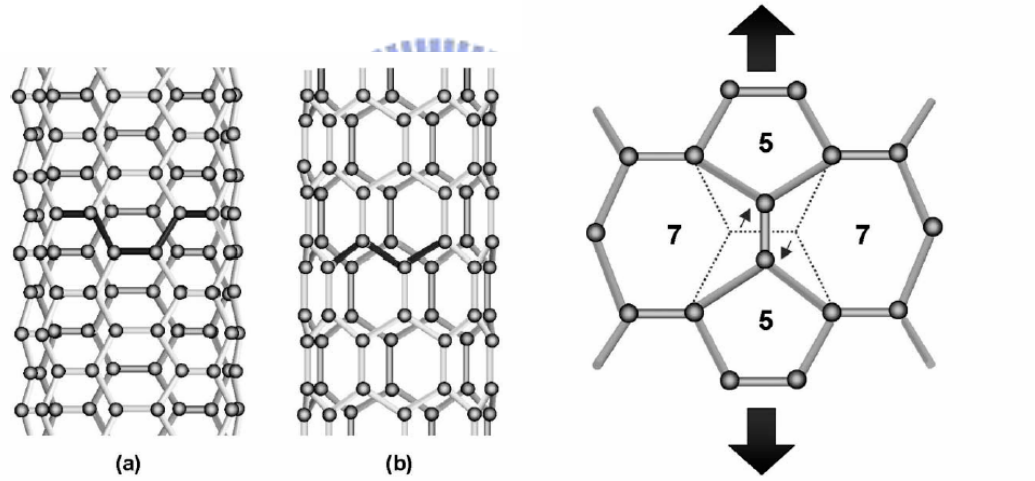
(f)

Fig. 1.4 (a) Sony portable DVD player using a Candescent field emission display [16], (b) Motorola 15" field emission display [16], (c) Motorola 5.6" color FED, (d) Pixtech 5.6" color FED, (e) Futaba 7" color FED, and (f) 7"color CNT FED from Samsung .



(a) (b)

Fig. 2.1 High-resolution transmission electron microscopy images of (a) single-walled nanotubes (SWNTs) and (b) multiwalled nanotubes (MWNTs). Every layer in the image (fringe) corresponds to the edges of each cylinder in the nanotube assembly.



(a) (b) (c)

Fig. 2.2 Illustrations of the atomic structure of (a) an armchair, (b) a ziz-zag nanotube, (c) The Stonne-Wales transformation occurring in an armchair nanotube under axial tension.

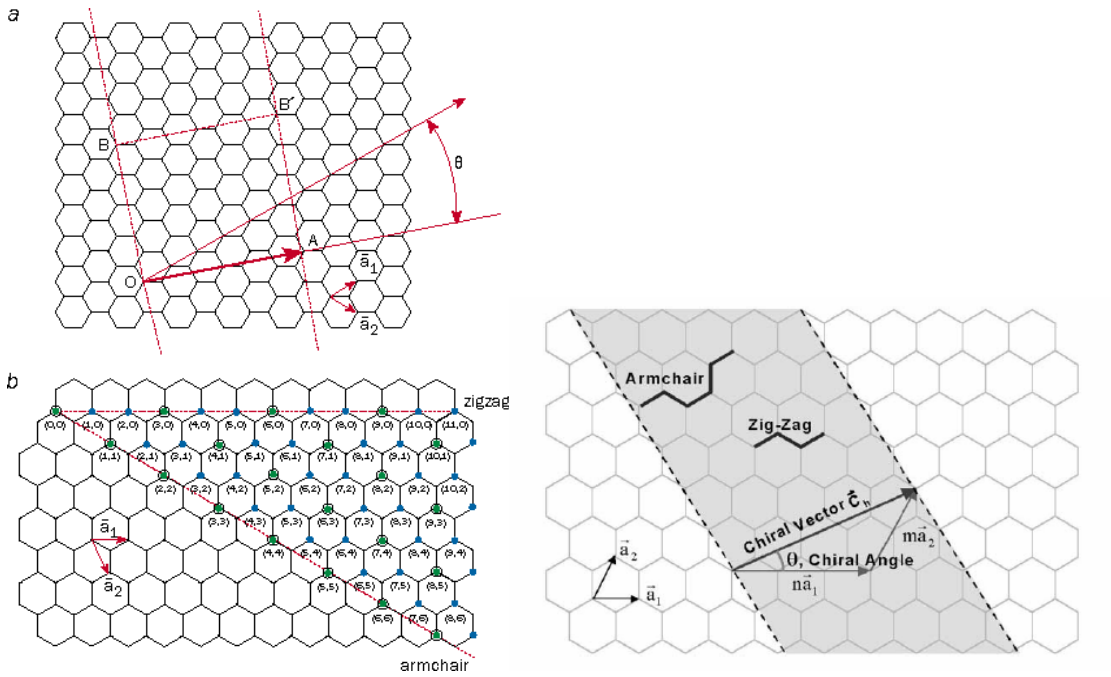


Fig. 2.4 (a) The chiral vector OA is defined on the honeycomb lattice of carbon atoms by unit vectors a1, a2 and the chiral angle θ with respect to the zigzag axis, (b) Possible vectors specified by the pairs of integers (n,m) for general carbon tubules, including zigzag, armchair, and chiral tubules, (c) Schematic diagram showing how a hexagonal sheet of graphite is 'rolled' to form a carbon nanotube.

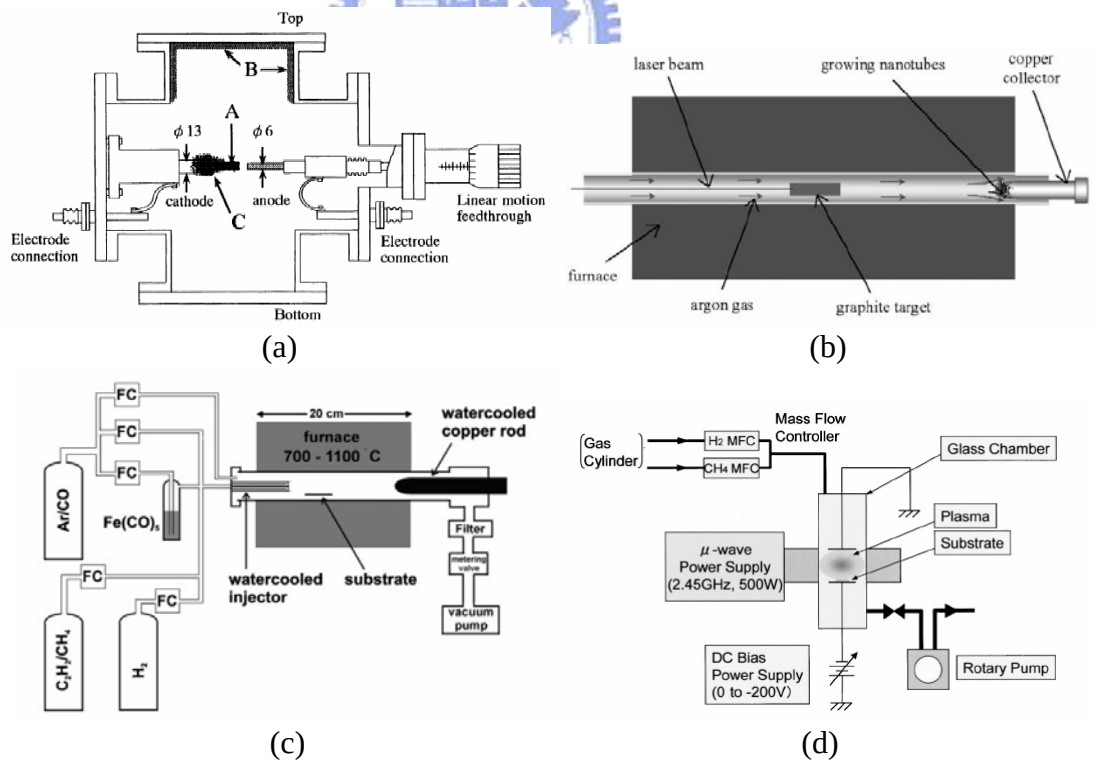


Fig. 2.5 (a) Schematic diagram of an arc evaporator, (b) Schematic of the laser ablation process, (c) Schematic of the thermal chemical vapor deposition, (d) Schematic of the microwave plasma enhanced chemical vapor deposition (MPECVD) [39][40][46].

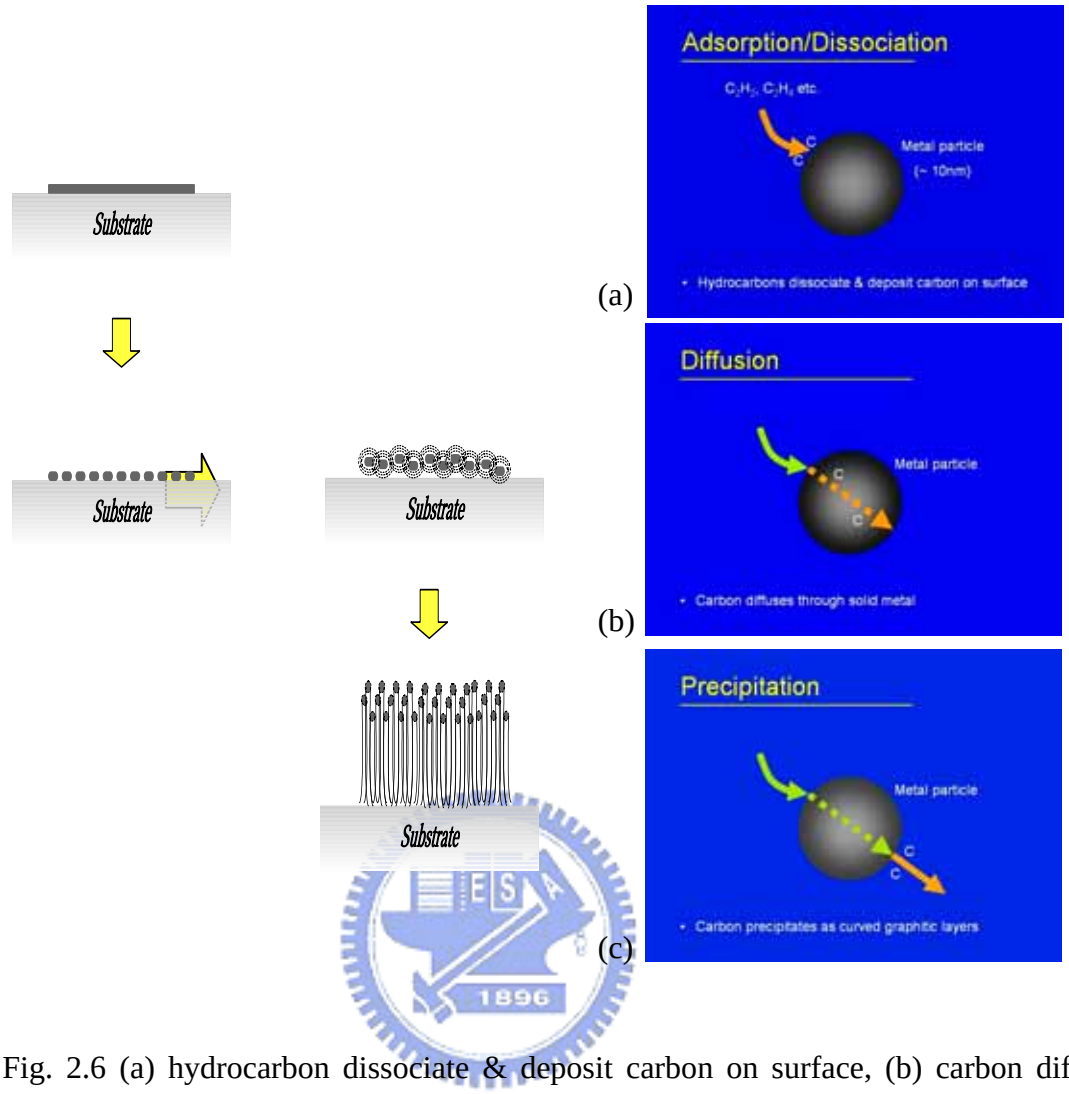


Fig. 2.6 (a) hydrocarbon dissociate & deposit carbon on surface, (b) carbon diffuses through solid metal, and (c) carbon precipitates as curved graphitic layers [78].

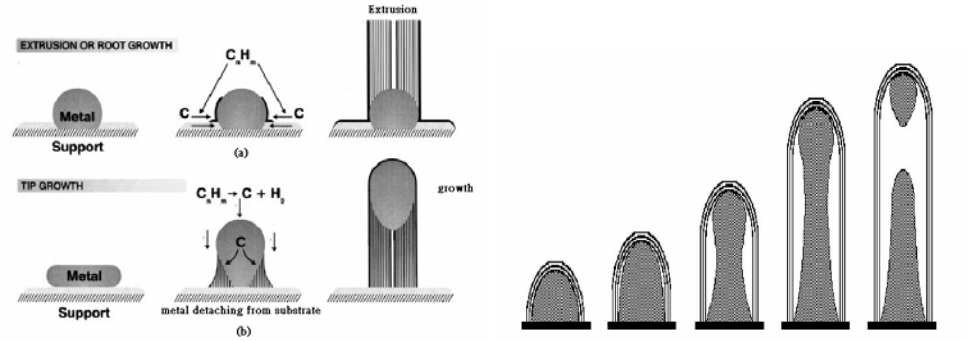


Fig. 2.7 Influence of the metal-support interaction on the mode of filamentous for (a) base growth (root growth) mode, (b) tip growth mode [53][54], and (c) Combined tip growth and base growth [59].

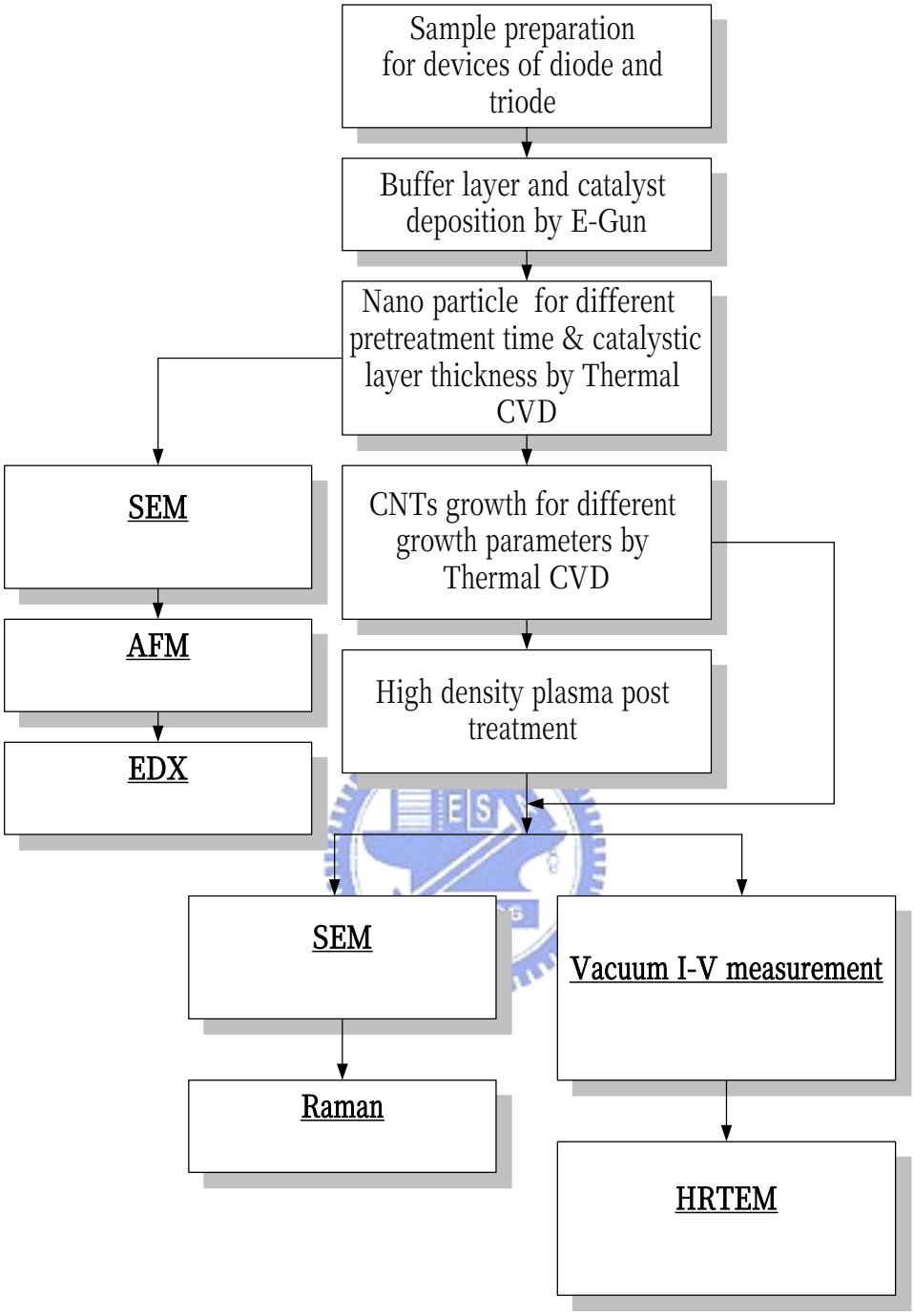


Fig. 3.1 Experimental procedures flow charts

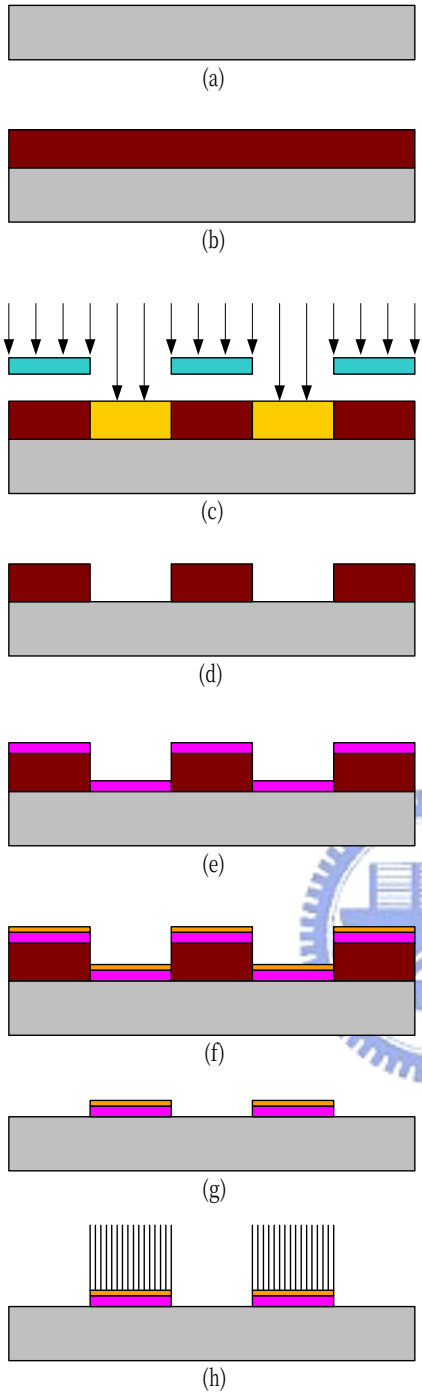


Fig. 3.2 (a)~(h) Fabrication procedure of the carbon nanotubes for diode structure field emission device

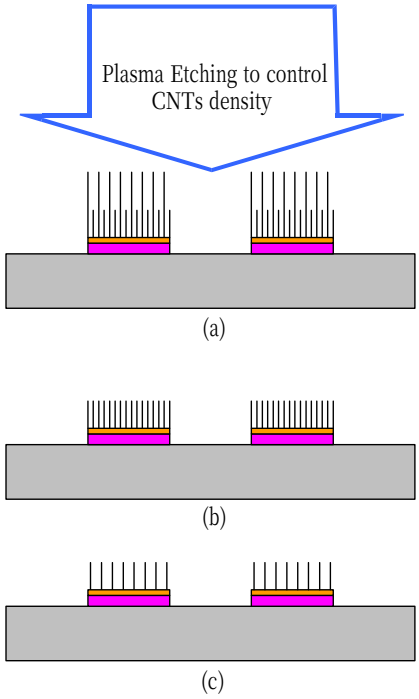
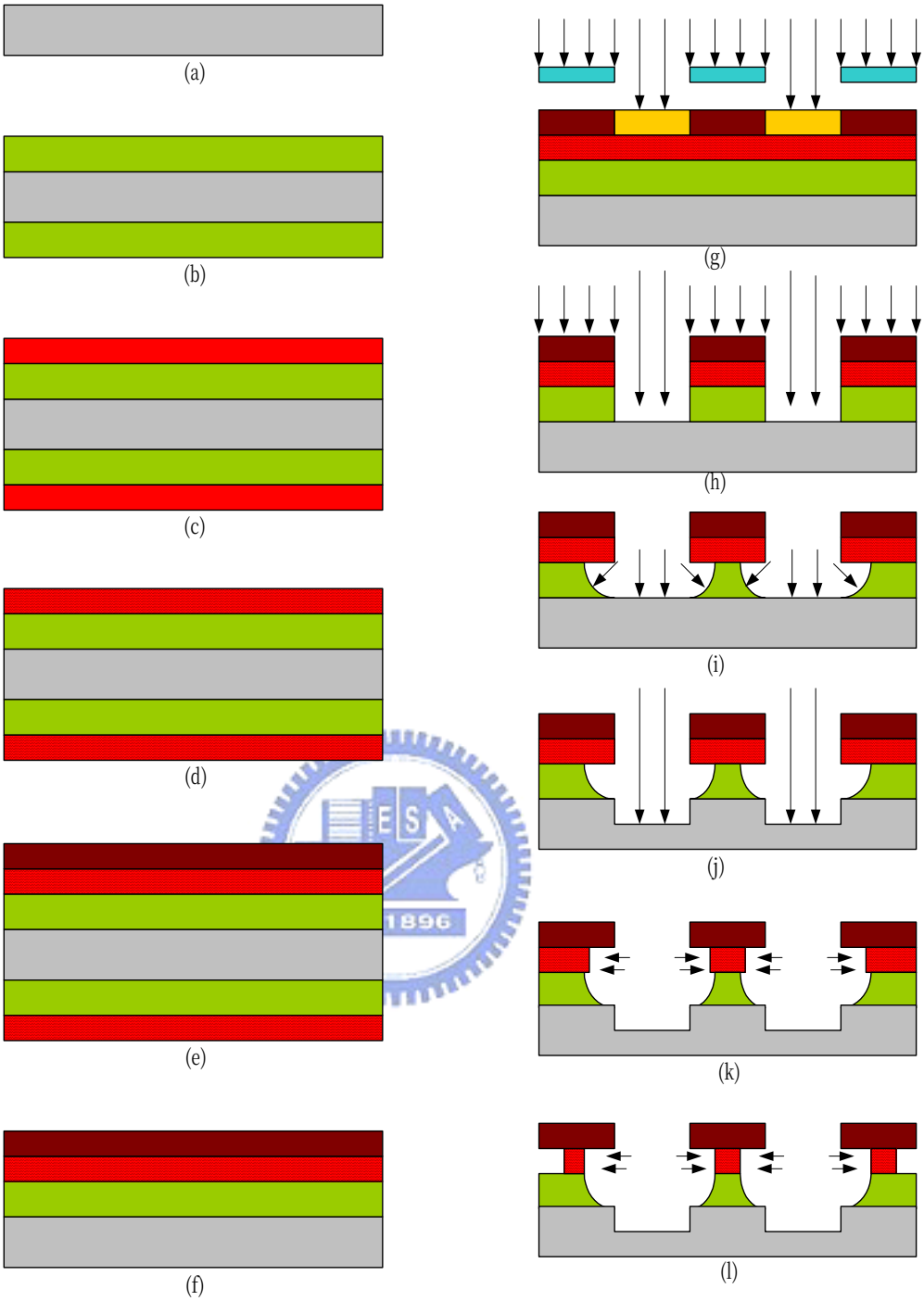


Fig. 3.3 (a)~(c) High density plasma post treatment for diode device


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)

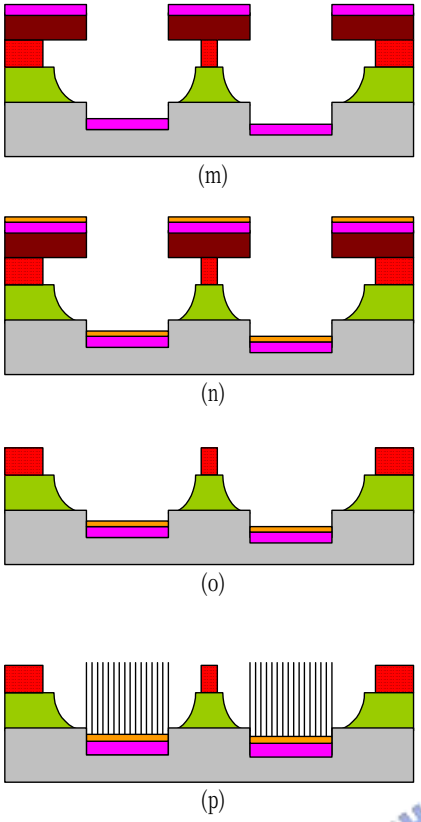


Fig. 3.4 Fabrication procedure of the carbon nanotubes insulated gate structure field emission device (a)~(p).

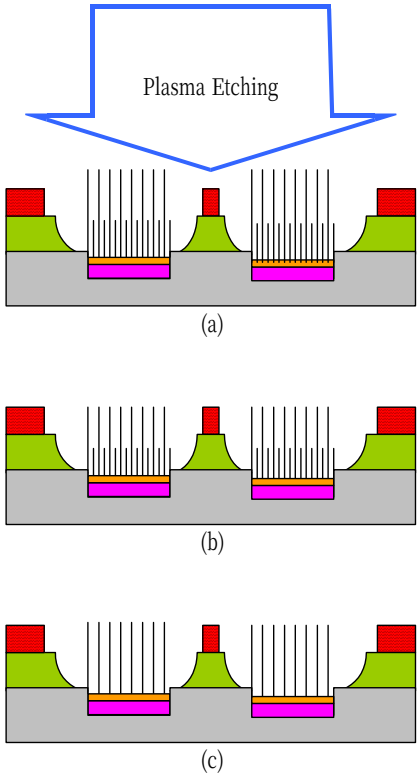
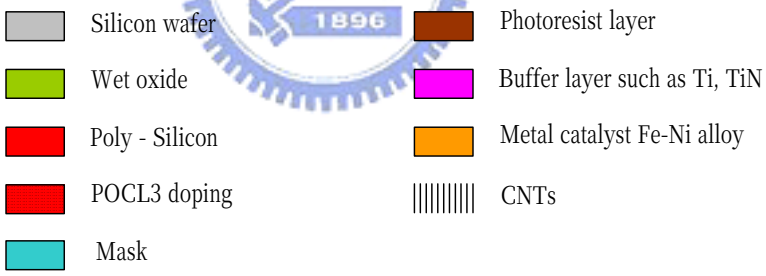


Fig. 3.5 High density plasma post treatment for triode device (a)~(c)



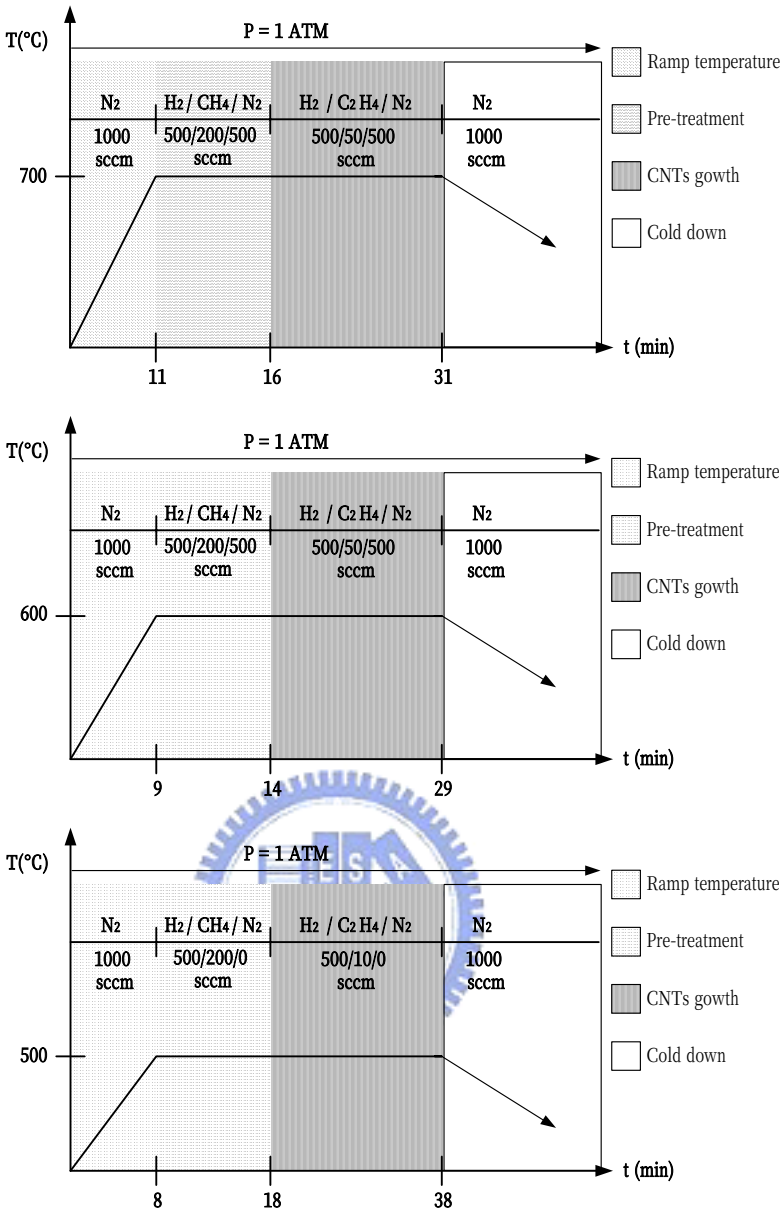
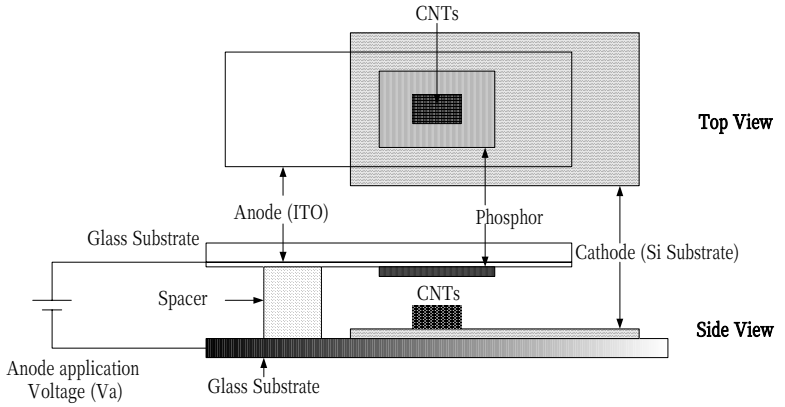
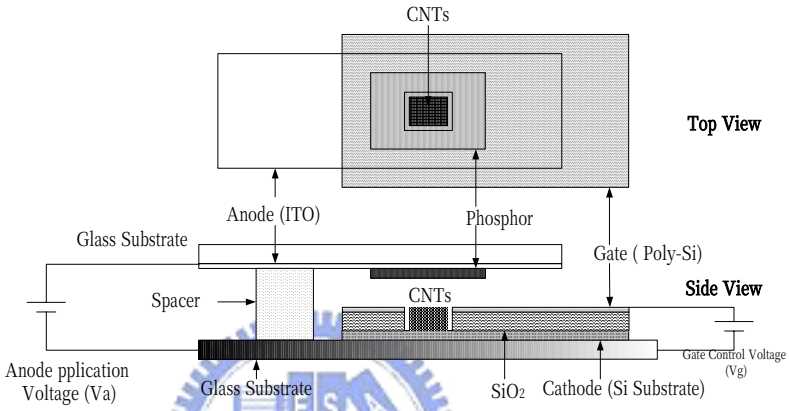


Fig. 3.6 Experimental procedure by Thermal CVD process



(a)



(b)

Fig. 3.7 Schematic of emission measurement for (a) diode type and (b) triode type

Pre-treatment conditions	Temperatures : 700℃ H_2 : 500 sccm CH_4 : 200sccm N_2 : 500sccm Pressures : 1ATM

Growth conditions	Temperatures : 700℃ H_2 : 500 sccm N_2 : 500sccm Pressures : 1ATM

Table 3-1 Conditions of different pretreatment time and catalyst layer thickness.

thickness / time		Catalyst Thickness (Å)			
		50	75	100	150
Pretreatment time (minutes)	5	A1	B1	C1	D1
	10	A2	B2	C2	D2
	15	A3	B3	C3	D3
	20	A4	B4	C4	D4

Table 3-2 Conditions of C_2H_4 flow rate for CNTs growth lengths (700℃).

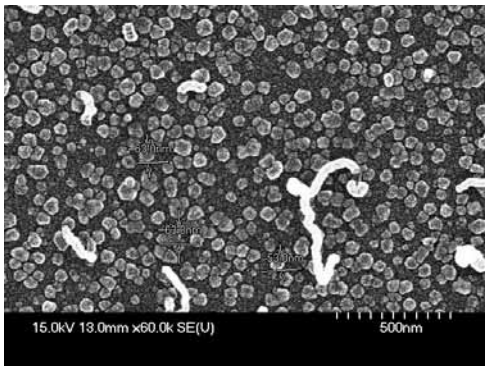
temperature / gas		Growth Temperature 700℃
C_2H_4 (sccm)	10	E1
	20	E2
	30	E3
	40	E4
	50	E5
	70	E6
	100	E7
	138	E8

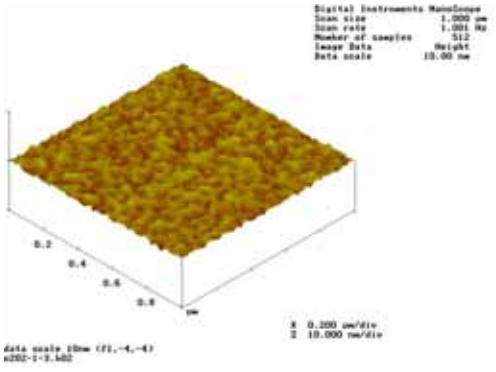
Table 3-3 Conditions of Ar or/and mixture O_2 gas HDPPT for diode (without Bias power).

power / gas		ICP power			
		250W	300W	400W	500W
Ar gas	10sccm	F1	F2	F3	F4
	20sccm	G1	G2	G3	G4
	30sccm	H1	H2	H3	H4
	40sccm	I1	I2	I3	I4
O_2 gas	5sccm	J1	J2	J3	J4
	10sccm	K1	K2	K3	K4
	15sccm	L1	L2	L3	L4
Ar and O_2 mixture gas	Ar (20sccm) + O_2(10sccm)	M1	M2	M3	M4

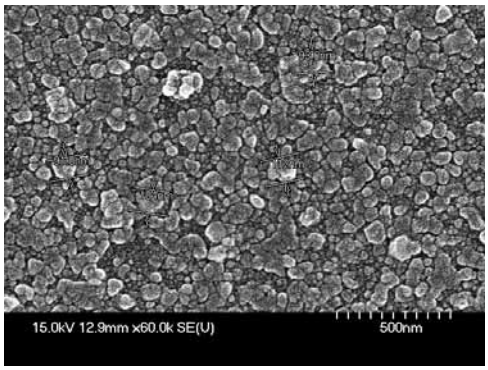
Table 3-4 Conditions of Ar or/and O_2 mixture gas HDPPT for diode with Bias power (fixed ICP power 300W).

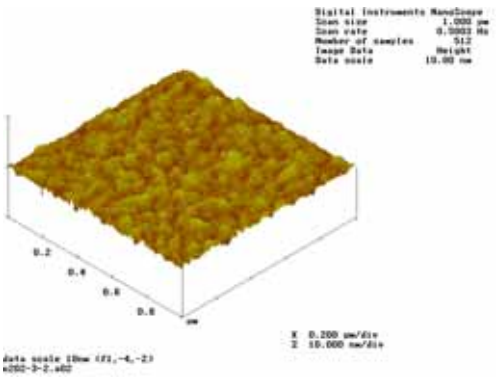
power / gas		Bias power			
		50W	100W	150W	
Ar gas	20sccm	N1	N2	N3	
O_2 gas	10sccm	O1	O2	O3	
Ar and O_2 mixture gas	Ar (20sccm) + O_2 (10sccm)	P1	P2	P3	


15.0kV 13.0mm x60.0k SE(U)
500nm

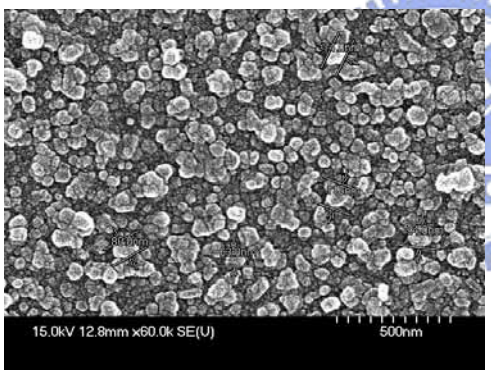


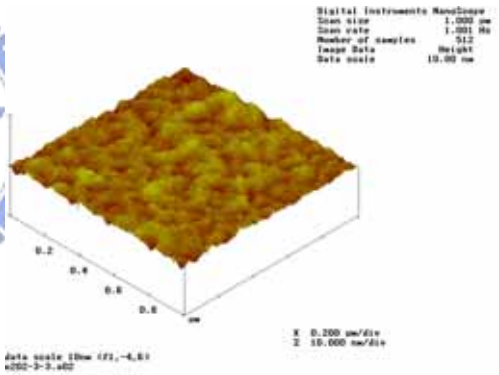
(a)


15.0kV 12.9mm x60.0k SE(U)
500nm

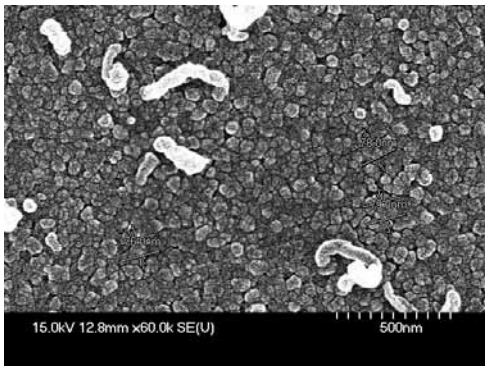


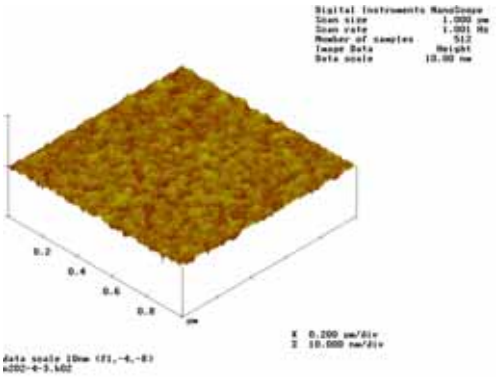
(b)


15.0kV 12.8mm x60.0k SE(U)
500nm

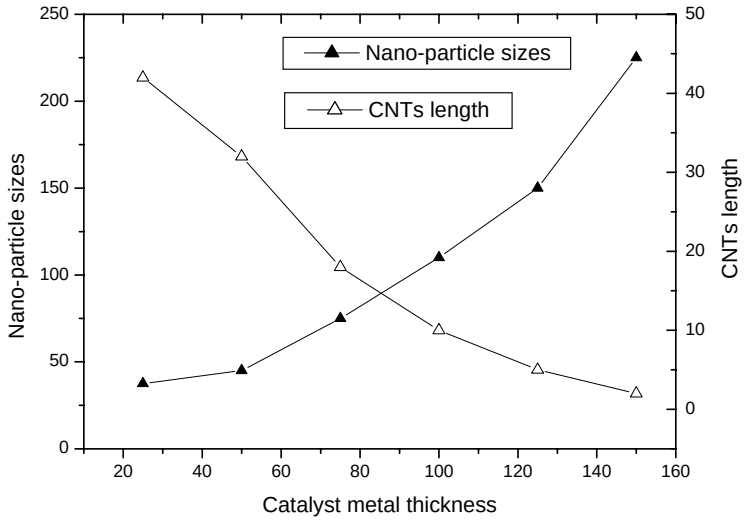


(c)


15.0kV 12.8mm x60.0k SE(U)
500nm



(d)

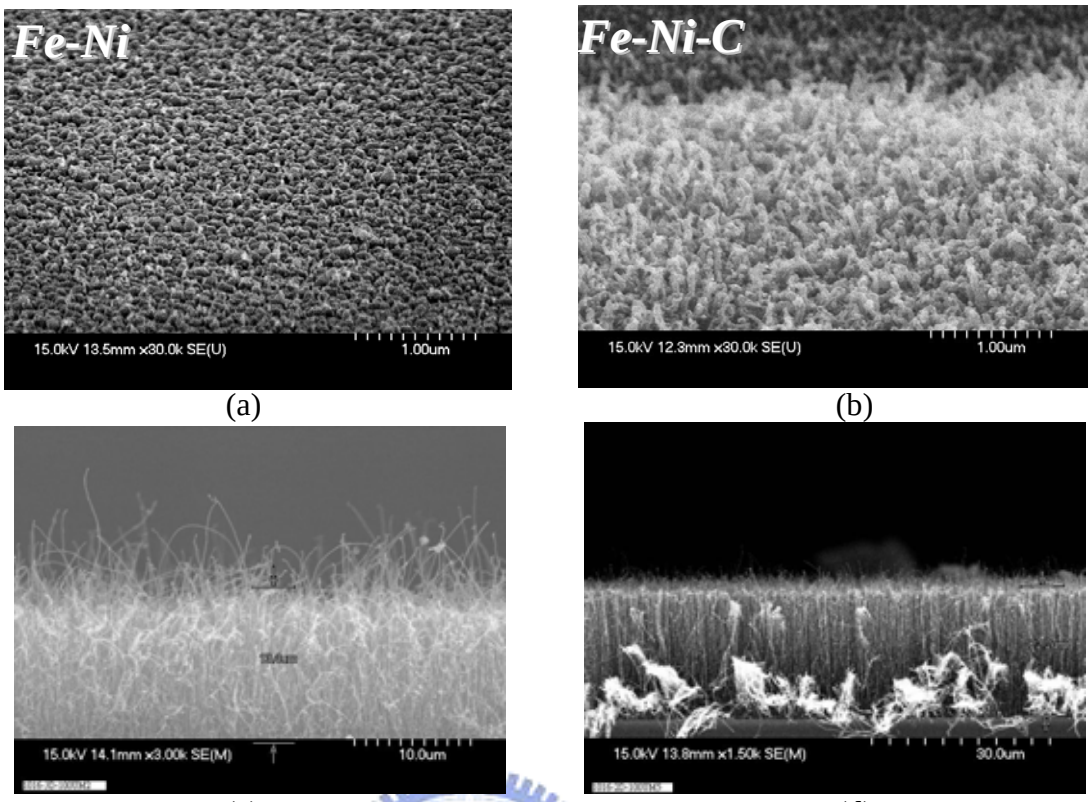


(e)

Catalyst metal thickness	Nano-particle sizes	CNTs length
25	37.5	42
50	45	32
75	75	18
100	110	10
125	150	5
150	225	2

(f)

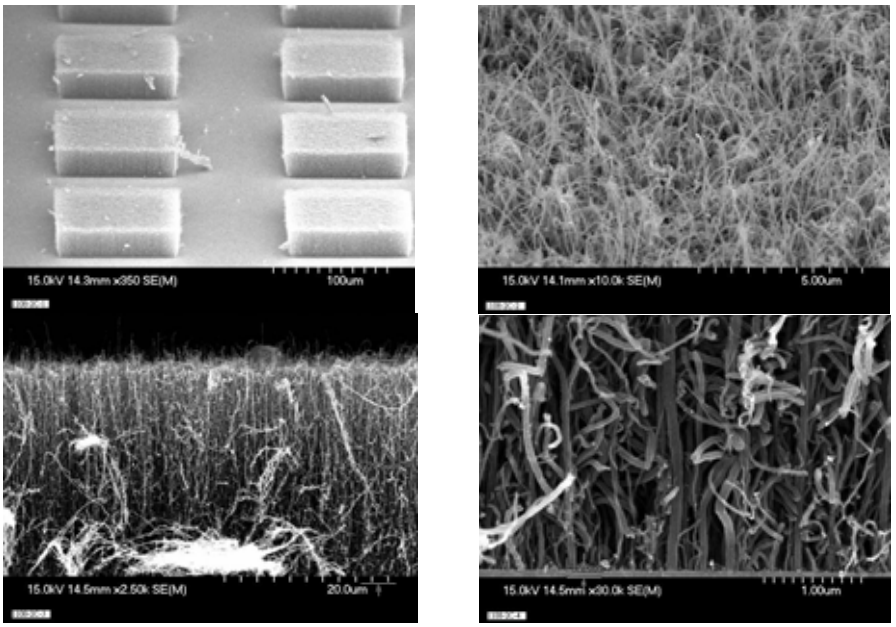
Fig. 4.1 Effects of pretreatment 15min for different catalyst layer thickness (a) 50Å, (b) 75Å, (c) 100Å, (d) 150Å, (e) plot of average nanoparticle size and CNT length as a function the Fe-Ni thickness (pretreatment temperature 700℃), and (f) catalyst metal thickness versus nanoparticle size and CNT lengths.



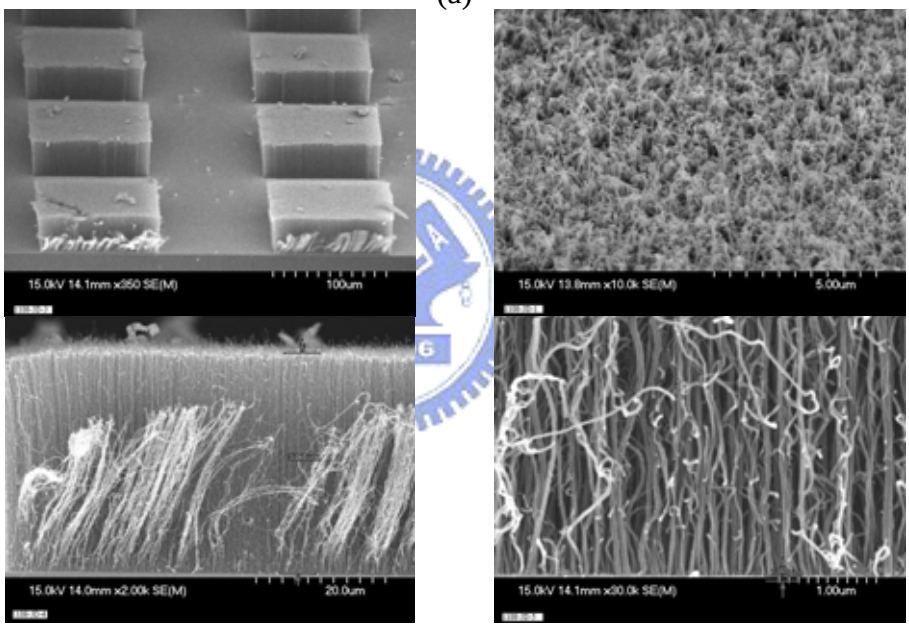
(a) (b)

(c) (d)

Fig. 4.2 Effects of CH_4 on pre-treatment for CNT growth (a) without CH_4, (b) with CH_4 (200sccm)(C_2H_4 =20sccm , 500 ℃, 15minutes), (c) without CH_4, (d) with CH_4 (200sccm)(C_2H_4 =20sccm , 700 ℃, 15minutes).

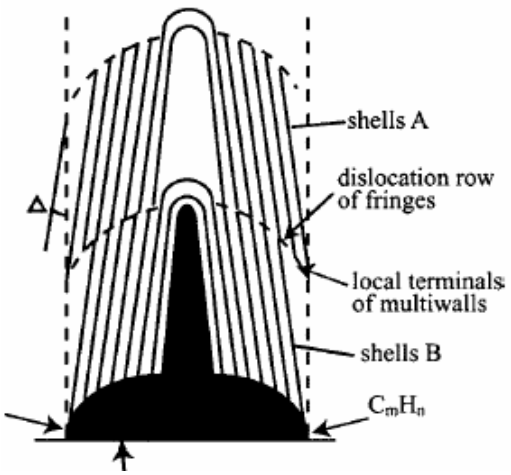

15.0kV 14.3mm x350 SE(M)
100um
15.0kV 14.1mm x10.0k SE(M)
5.00um
15.0kV 14.5mm x2.50k SE(M)
20.0um
15.0kV 14.5mm x30.0k SE(M)
1.00um

(a)


15.0kV 14.1mm x350 SE(M)
100um
15.0kV 13.8mm x10.0k SE(M)
5.00um
15.0kV 14.0mm x2.00k SE(M)
20.0um
15.0kV 14.1mm x30.0k SE(M)
1.00um

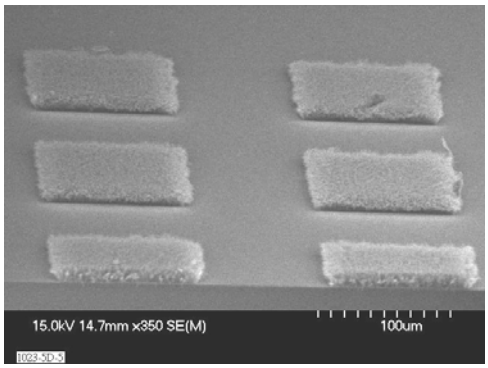
(b)

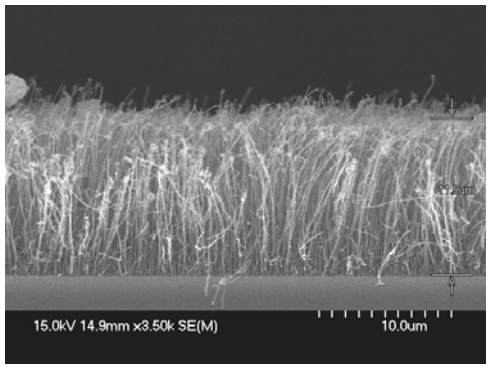
(c)



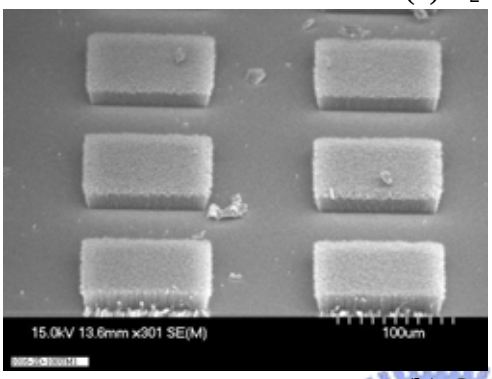
(d)

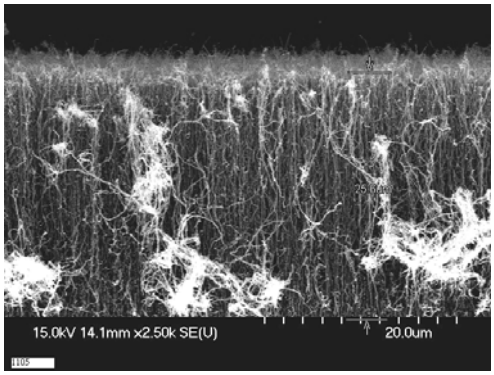
Fig. 4.3 Effects of CNTs growth (a) without N_2, (b) with N_2, (c) TEM image for bamboo-like CNTs, and (d) bamboo-like CNTs mechanism [74].



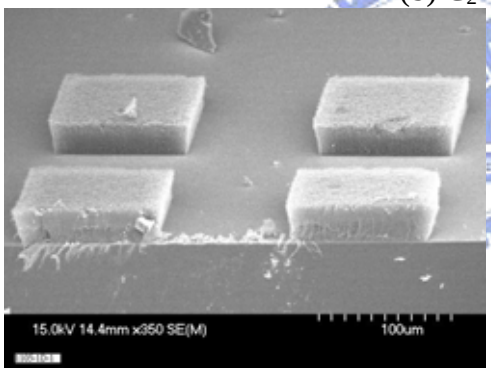


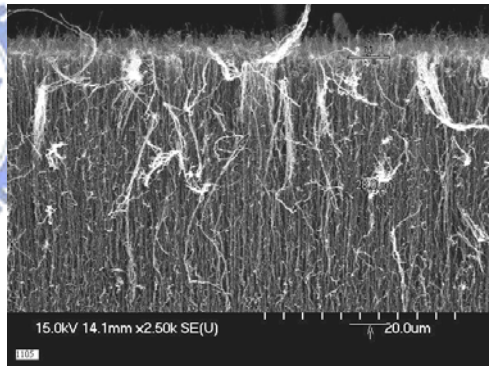
(a) C_2H_4 : 20sccm



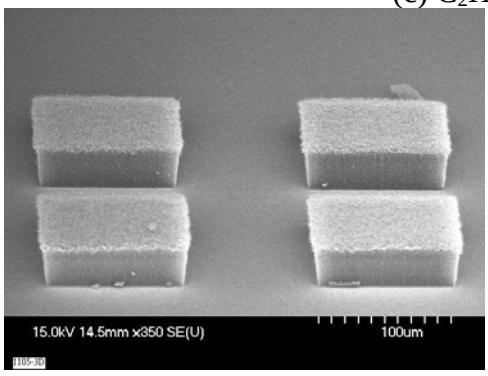


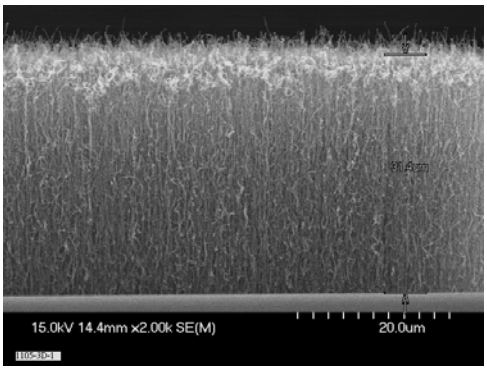
(b) C_2H_4 : 50sccm



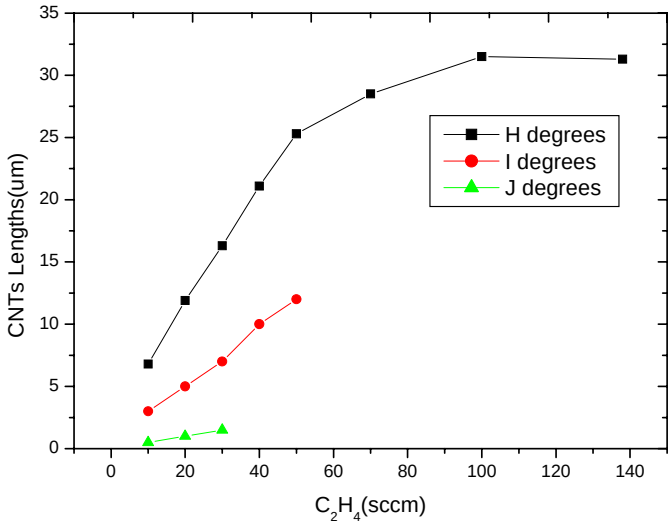


(c) C_2H_4 : 70sccm





(d) C_2H_4 : 138sccm



(e)

C_2H_4 flows	Growth Temperature		
	700℃	600℃	500℃
10	6.8	3.1	0.2
20	11.9	5.6	0.5
30	16.3	7.2	1
40	21.1	10.3	
50	25.3	12.1	
70	28.5		
100	31.5		
138	31.3		

(f)

Fig. 4.4 SEM images for different C_2H_4 flow rate (a) 20sccm, (b) 50sccm, (c) 70sccm, (d) 138sccm, (e) effects of different growth temperature versus C_2H_4 flow rate and (f) summary experimental results for CNT lengths and different growth temperature.

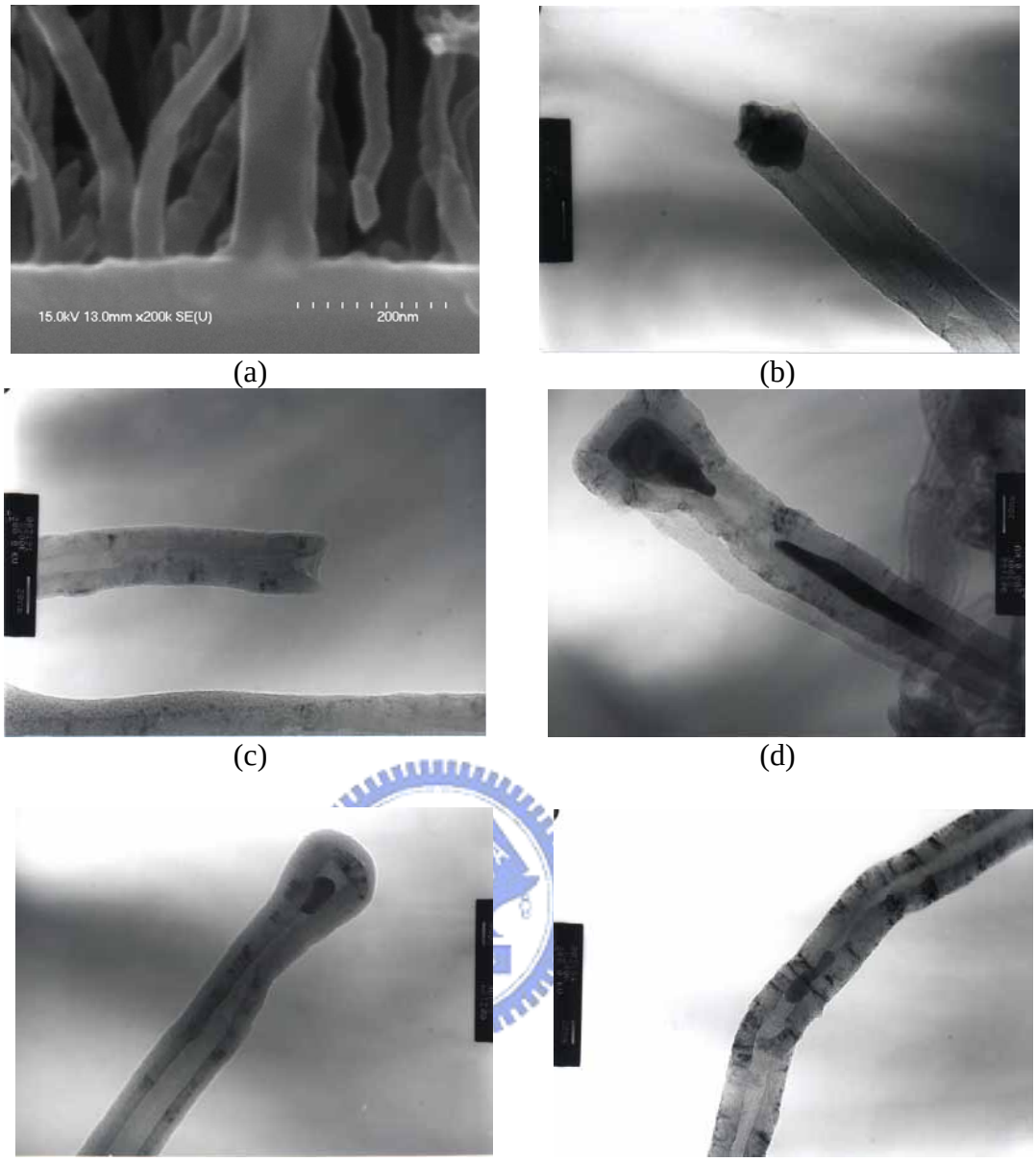


Fig. 4.5 TEM images for growth mechanism on thermal CVD (a) base growth, (b)(c) with/without the catalyst on base growth, (d)(e) tip growth, and (f) catalyst metal inside.

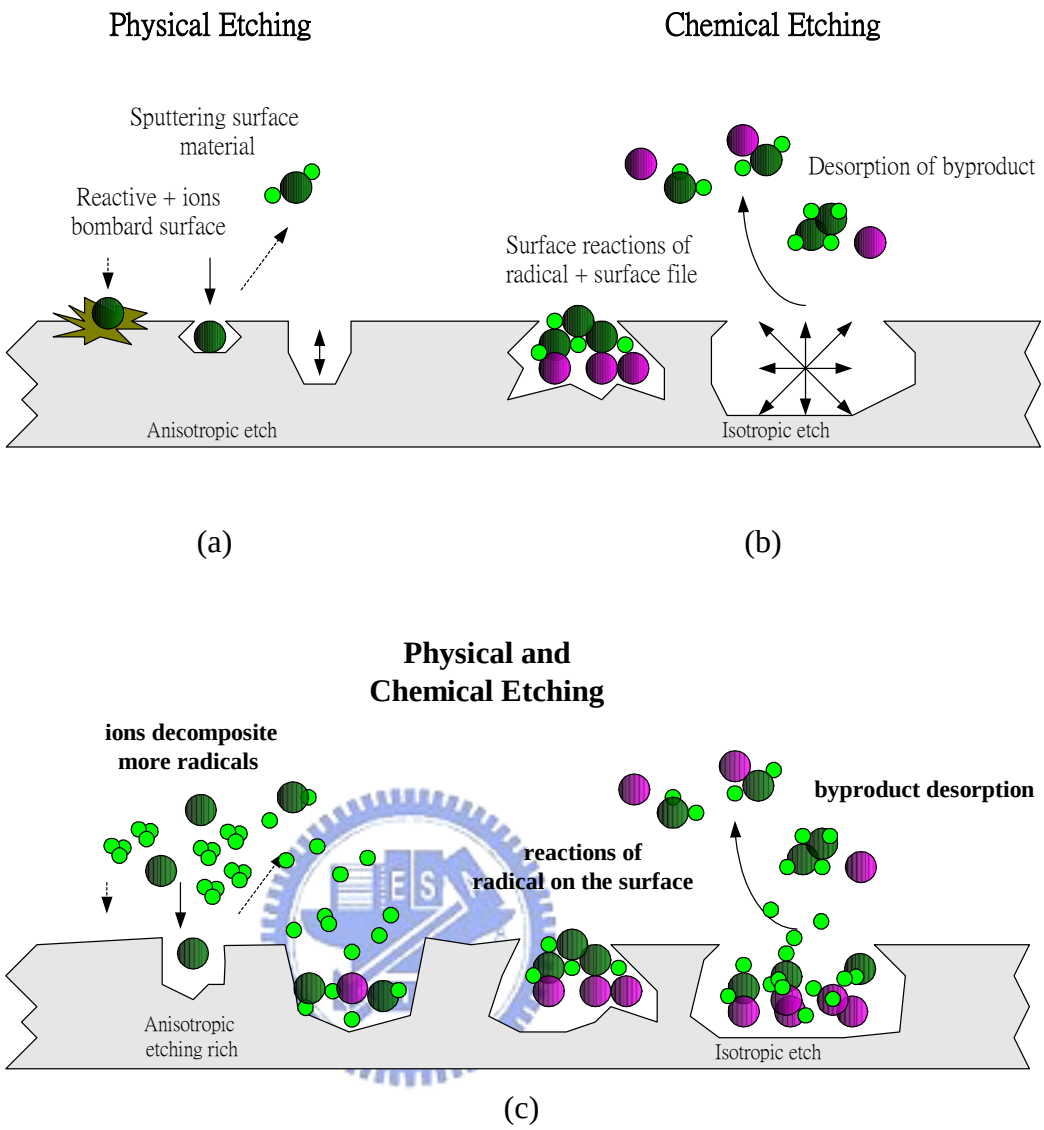
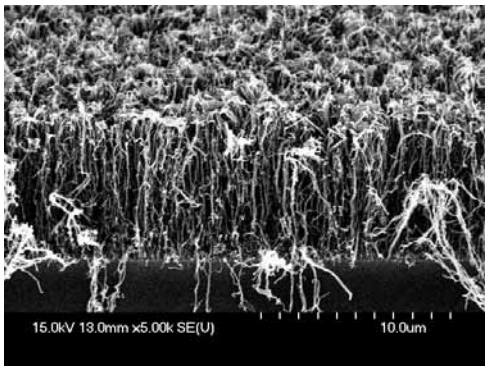
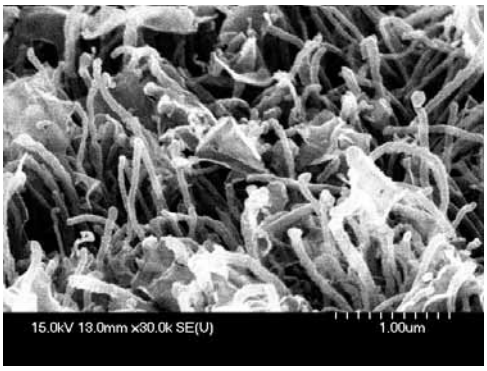
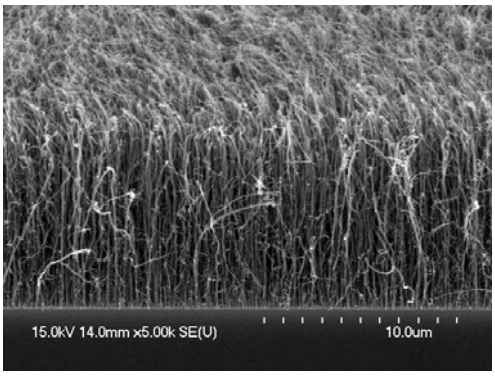


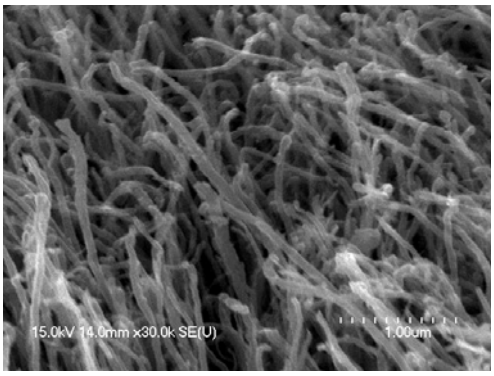
Fig. 4.6 (a) Physical mechanism, (b) chemical mechanism, and (c) combined physical and chemical mechanism.


15.0kV 13.0mm x5.00k SE(U)
10.0um

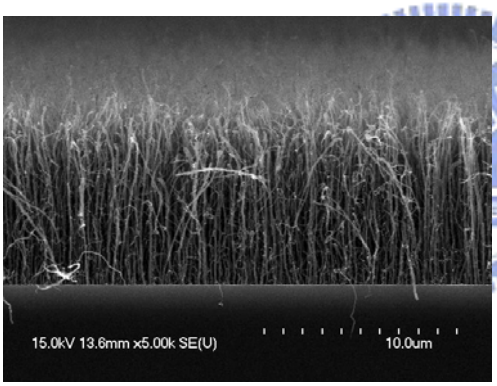

15.0kV 13.0mm x30.0k SE(U)
1.00um

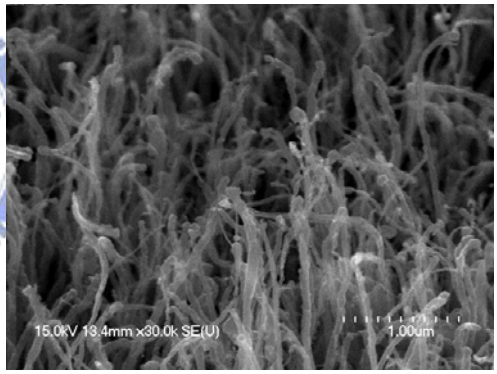
(a)


15.0kV 14.0mm x5.00k SE(U)
10.0um

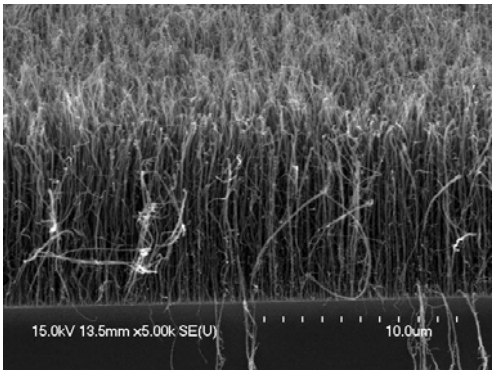

15.0kV 14.0mm x30.0k SE(U)
1.00um

(b)


15.0kV 13.6mm x5.00k SE(U)
10.0um


15.0kV 13.4mm x30.0k SE(U)
1.00um

(c)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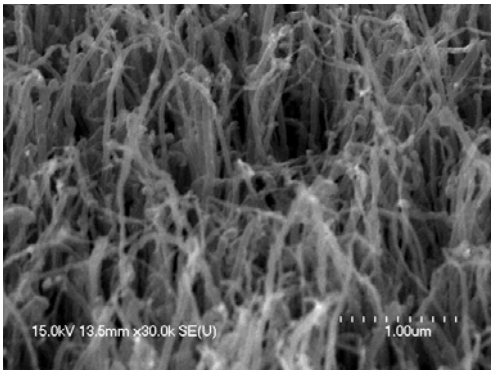
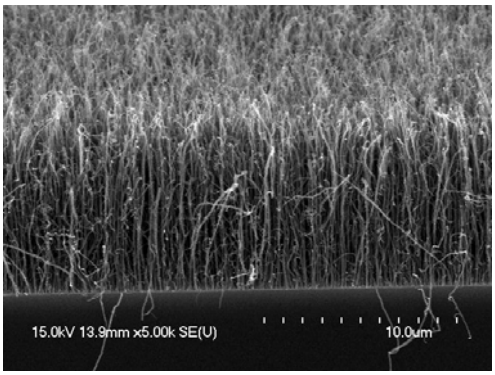
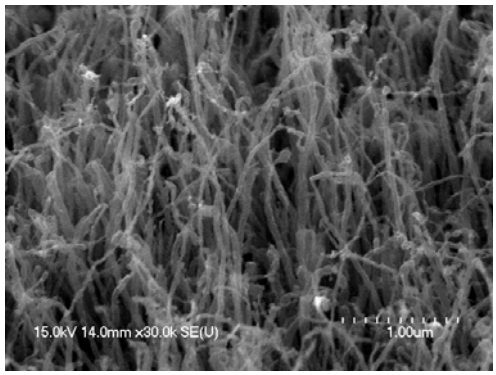
10.0um

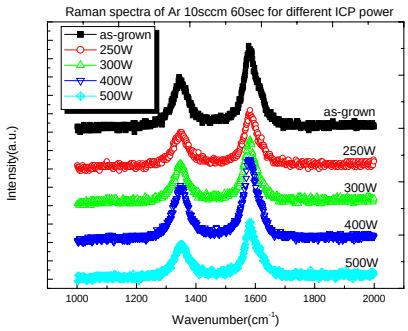

15.0kV 13.5mm x30.0k SE(U)
1.00um

(d)



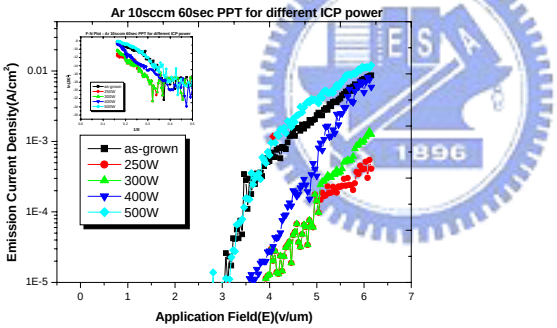


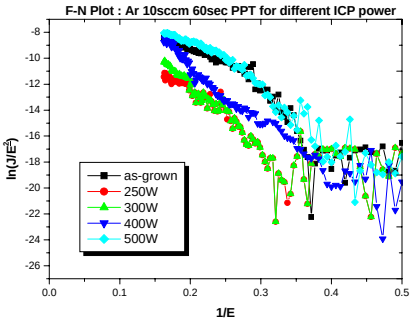
(e)



Sample number	Condition	ID/IG ratio
a.	0W	0.73077
b.	250W	0.75
c.	300W	0.742
d.	400W	0.745
e.	500W	0.73676

(f)



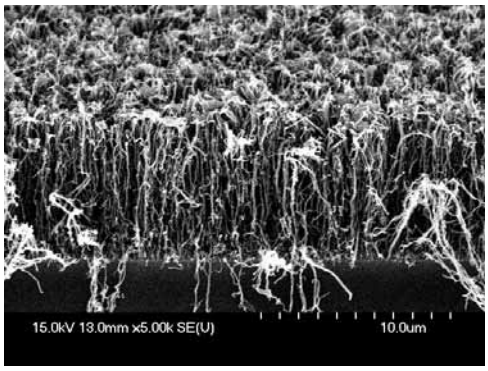


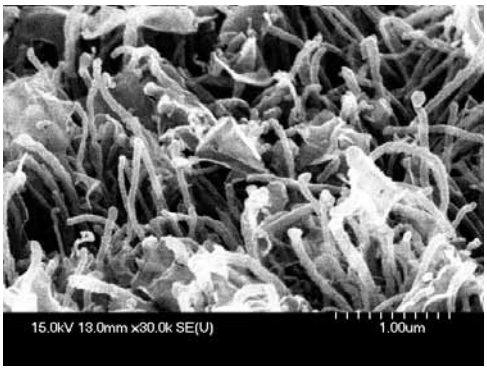
(g) (h)

Sample number	Condition	Turn on field E (V/um) (@J=10uA/cm^2)	Current density J (mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	As-grown	3.1	2.35	**1869**
b.	250W	3.92	0.143	**1616**
c.	300W	3.9	0.193	**1656**
d.	400W	3.6	0.787	**1750**
e.	500W	3.1	3.77	**1890**

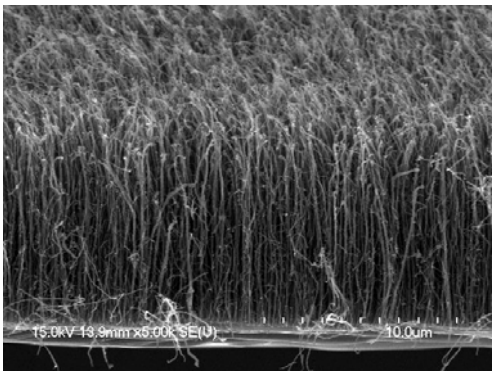
(i)

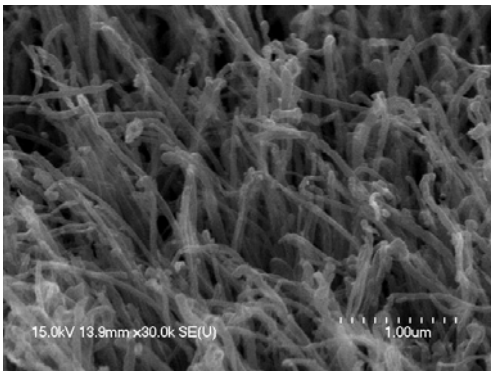
Fig. 4.7 SEM images of CNTs post-treatment by Ar 10sccm 60sec for different ICP power of (a) as-grown, (b) 250W, (c) 300W, (d) 400W, (e) 500W, (f) Raman spectra of CNTs, (g) field emission curve J-E, (h) F-N plot, and (i) summary experimental results.


15.0kV 13.0mm x5.00k SE(U)
10.0um

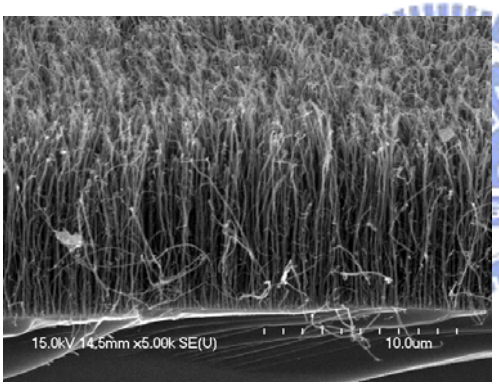

15.0kV 13.0mm x30.0k SE(U)
1.00um

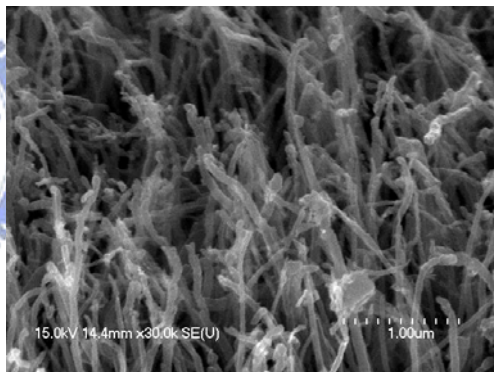
(a)


15.0kV 13.9mm x5.00k SE(U)
10.0um

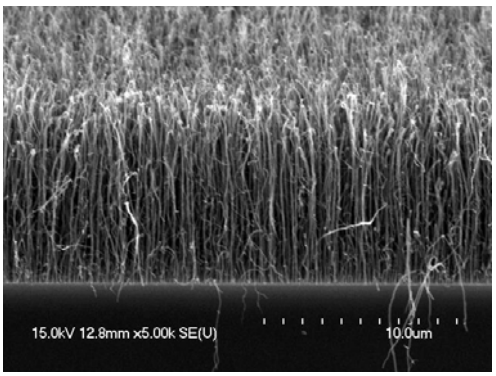

15.0kV 13.9mm x30.0k SE(U)
1.00um

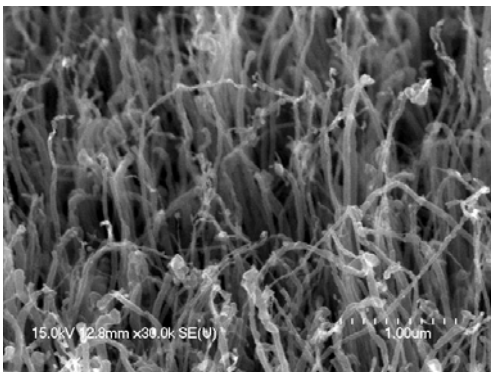
(b)


15.0kV 14.5mm x5.00k SE(U)
10.0um

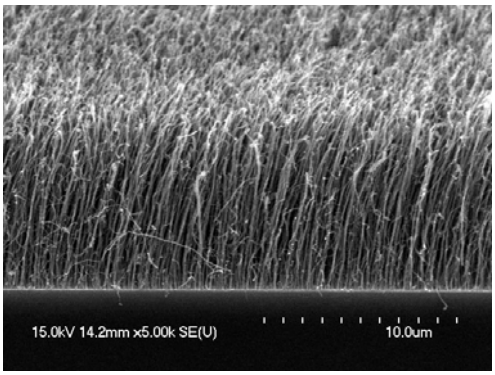

15.0kV 14.4mm x30.0k SE(U)
1.00um

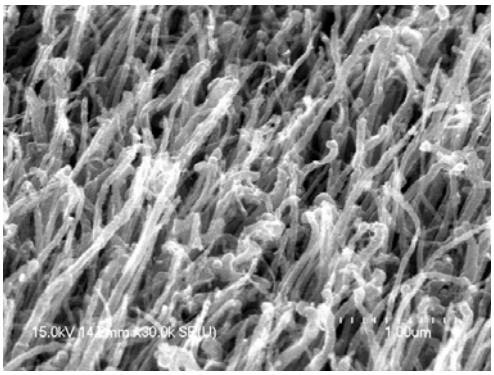
(c)


15.0kV 12.8mm x5.00k SE(U)
10.0um

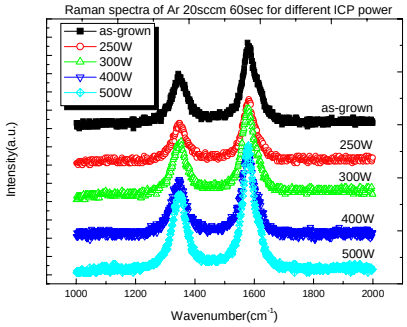

15.0kV 12.8mm x30.0k SE(U)
1.00um

(d)



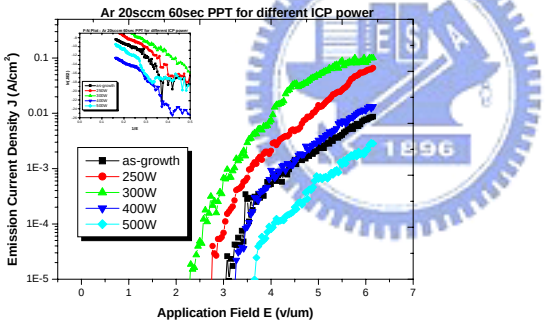


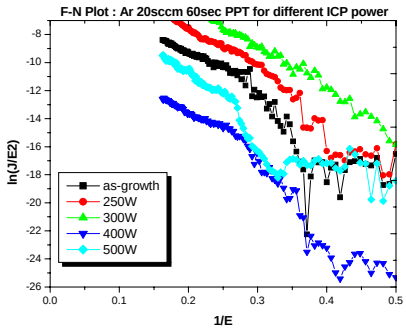
(e)



Sample number	Condition	ID/IG ratio
a.	As-grown	0.73077
b.	250W	0.68889
c.	300W	0.68333
d.	400W	0.78788
e.	500W	0.7941

(f)



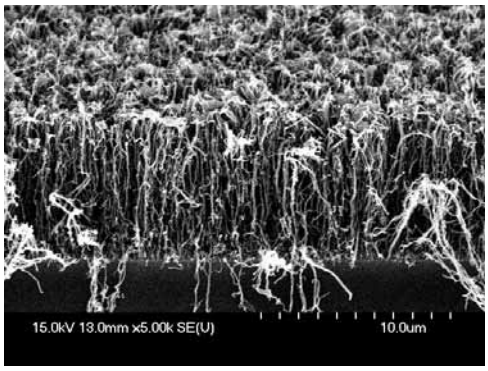


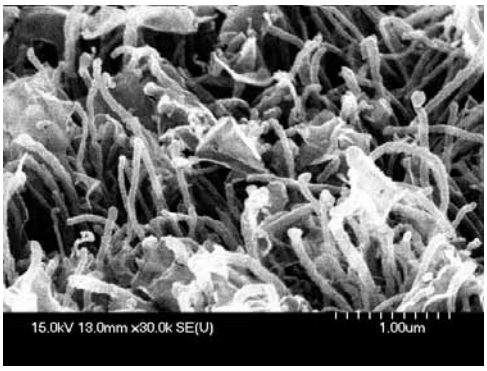
(g) (h)

Sample number	Condition	Turn on field E (V/um) (@J=10uA/cm^2)	Current density J (mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	As-grown	3.1	2.35	**1869**
b.	250W	2.7	12	**3108**
c.	300W	2.2	48	**3463**
d.	400W	3.2	3.18	**1956**
e.	500W	3.6	0.65	**1631**

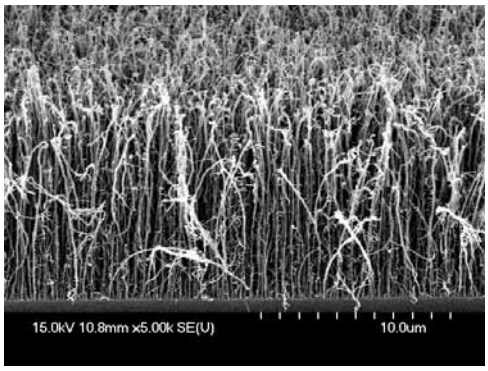
(i)

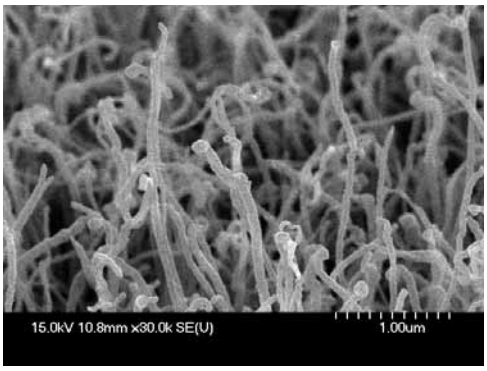
Fig. 4.8 SEM images of CNTs post-treatment by Ar 20sccm 60sec for different ICP power of (a) as-grown, (b) 250W, (c) 300W, (d) 400W, (e) 500W, (f) Raman spectra of CNTs, (g) field emission curve J-E, (h) F-N plot, and (i) summary experimental results.


15.0kV 13.0mm x5.00k SE(U)
10.0um

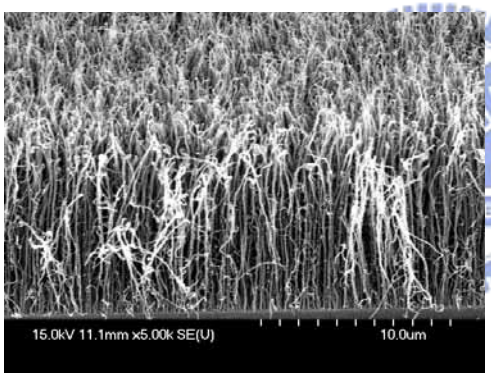

15.0kV 13.0mm x30.0k SE(U)
1.00um

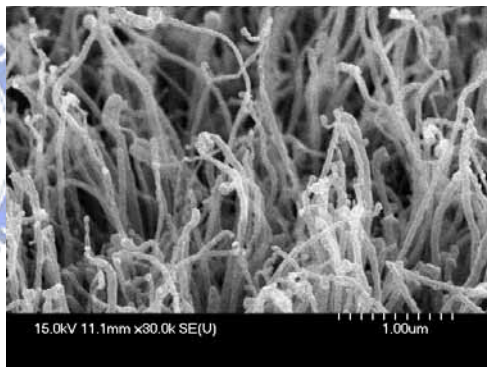
(a)


15.0kV 10.8mm x5.00k SE(U)
10.0um

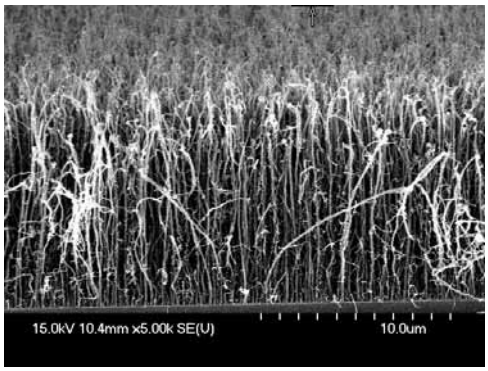

15.0kV 10.8mm x30.0k SE(U)
1.00um

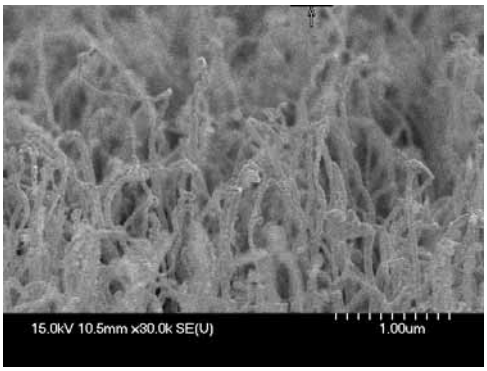
(b)


15.0kV 11.1mm x5.00k SE(U)
10.0um

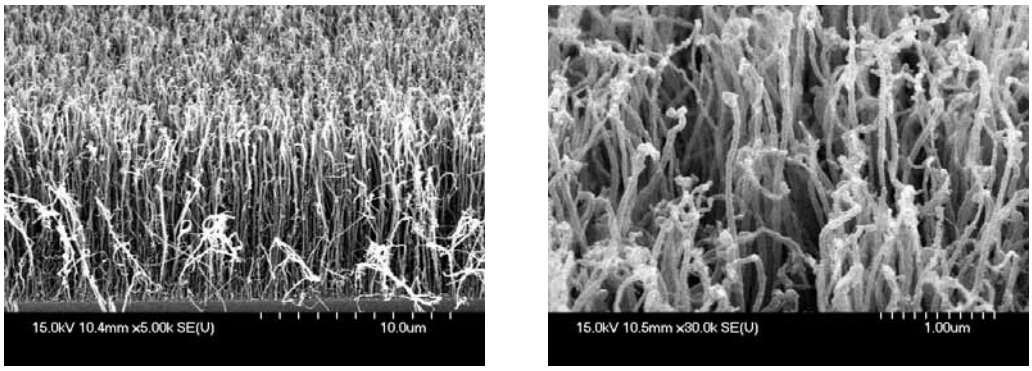

15.0kV 11.1mm x30.0k SE(U)
1.00um

(c)

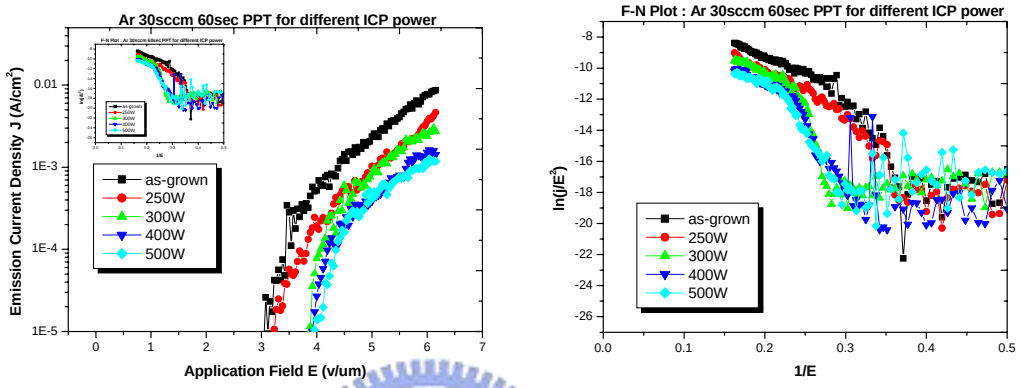

15.0kV 10.4mm x5.00k SE(U)
10.0um


15.0kV 10.5mm x30.0k SE(U)
1.00um

(d)



(e)

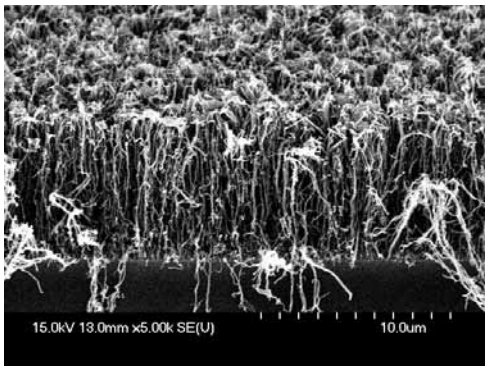


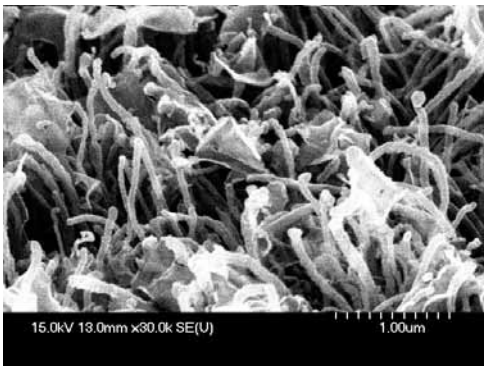
(f) (g)

Sample number	Condition	Turn on field E (V/um) (@J=10uA/cm^2)	Current density J (mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	As-grown	3.1	2.35	**1869**
b.	250W	3.23	1.02	**2246**
c.	300W	3.85	0.814	**1435**
d.	400W	3.9	0.437	**1427**
e.	500W	3.9	0.435	**1427**

(h)

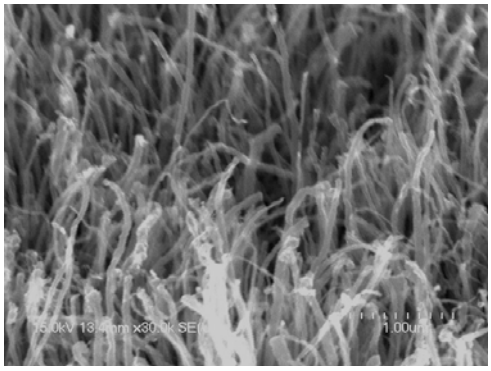
Fig. 4.9 SEM images of CNTs post-treatment by Ar 30sccm 60sec for different ICP power of (a) as-grown, (b) 250W, (c) 300W, (d) 400W, (e) 500W, (f) field emission curve J-E, (g) F-N plot, and (h) summary experimental results.


15.0kV 13.0mm x5.00k SE(U)
10.0um

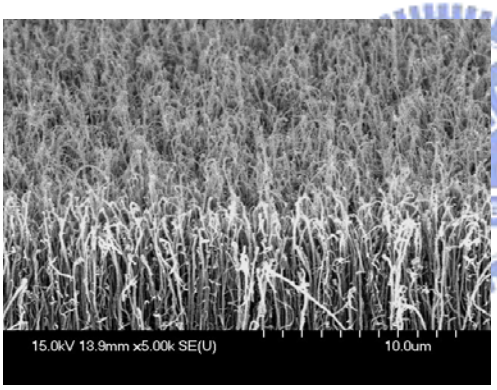

15.0kV 13.0mm x30.0k SE(U)
1.00um

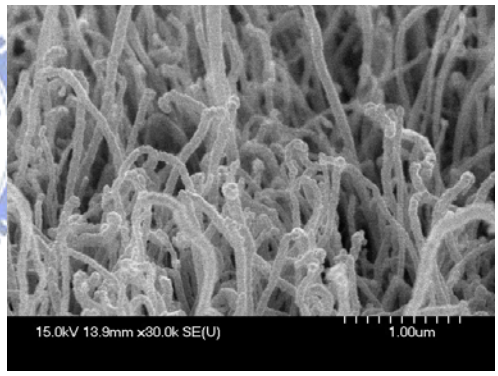
(a)


15.0kV 13.4mm x5.00k SE(U)
10.0um



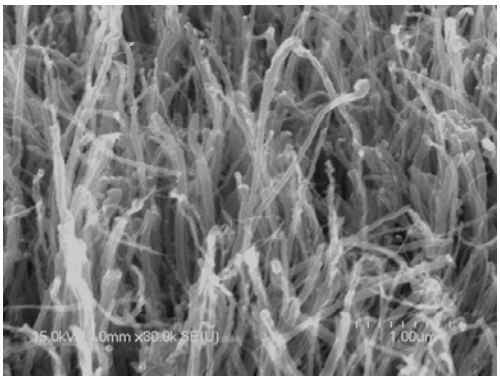
(b)


15.0kV 13.9mm x5.00k SE(U)
10.0um

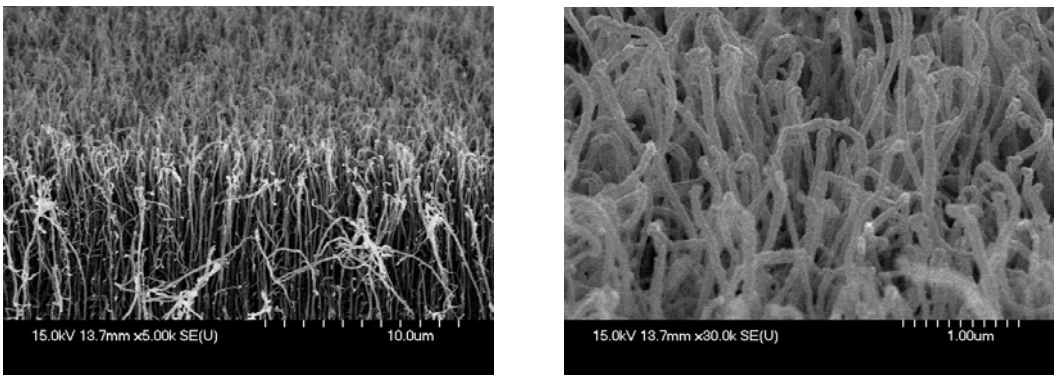

15.0kV 13.9mm x30.0k SE(U)
1.00um

(c)

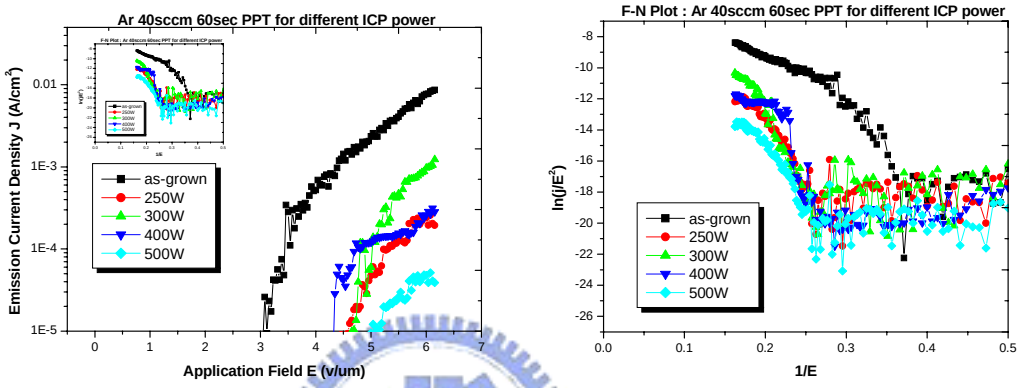

15.0kV 13.0mm x5.00k SE(U)
10.0um



(d)



(e)

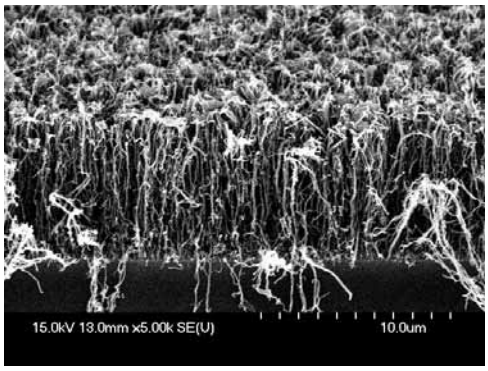


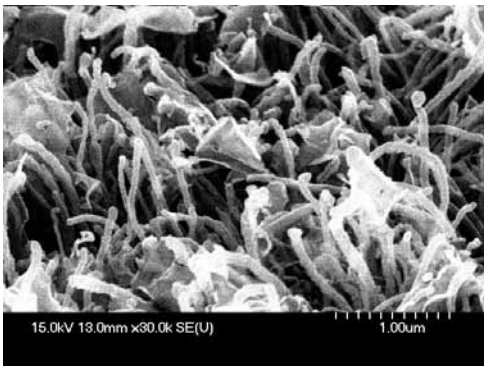
(f) (g)

Sample number	Condition	Turn on field E (V/um) (@J=10uA/cm^2)	Current density J (mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	As-grown	3.1	2.35	**1869**
b.	250W	4.35	0.125	**780**
c.	300W	4.6	0.123	**745**
d.	400W	4.67	0.051	**712**
e.	500W	5.1	0.01	**712**

(h)

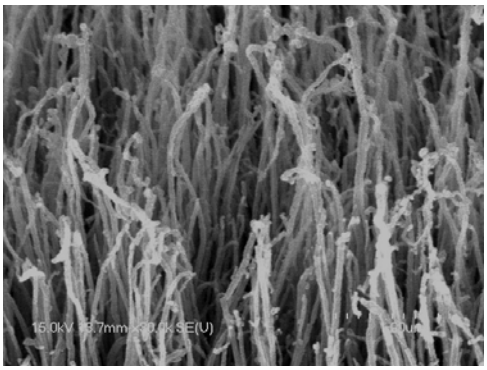
Fig. 4.10 SEM images of CNTs post-treatment by Ar 40sccm 60sec for different ICP power of (a) as-grown, (b) 250W, (c) 300W, (d) 400W, (e) 500W, (f) field emission curve J-E, (g) F-N plot, and (h) summary experimental results.


15.0kV 13.0mm x5.00k SE(U)
10.0um


15.0kV 13.0mm x30.0k SE(U)
1.00um

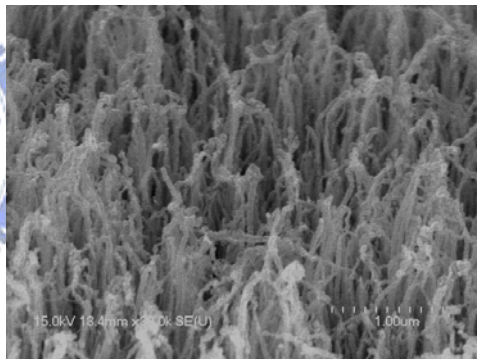
(a)


15.0kV 13.7mm x5.00k SE(U)
10.0um



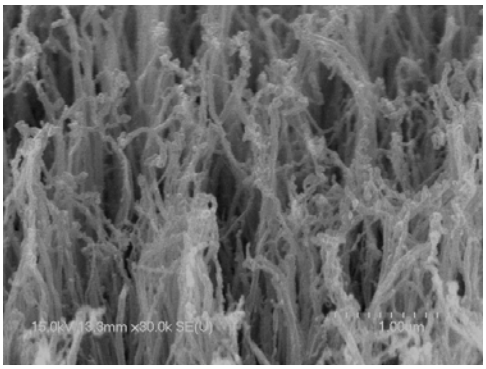
(b)


15.0kV 13.4mm x5.00k SE(U)
10.0um

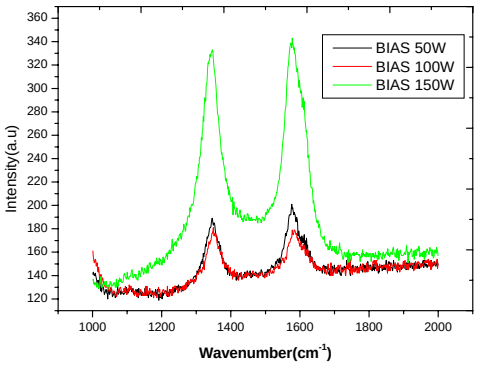

15.0kV 13.4mm x30.0k SE(U)
1.00um

(c)


15.0kV 13.3mm x5.00k SE(U)
10.0um

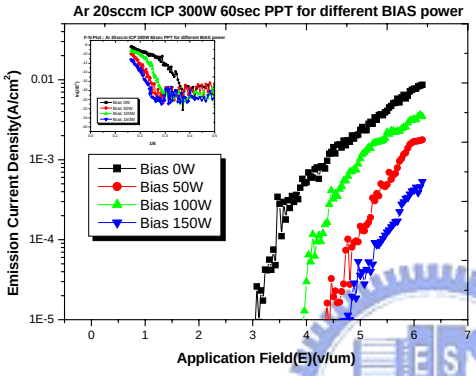

15.0kV 13.3mm x30.0k SE(U)
1.00um

(d)

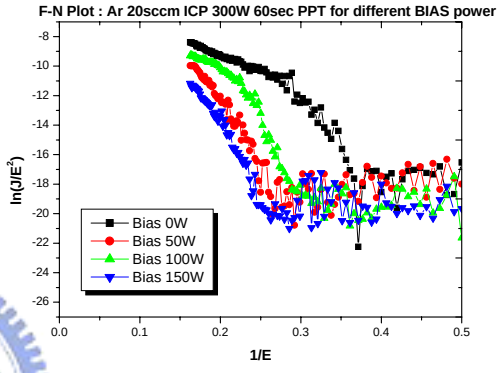


Sample number	Condition	ID/IG ratio
a.	0W	0.73077
b.	50W	0.94
c.	100W	1.08
d.	150W	0.95

(e)



(f)

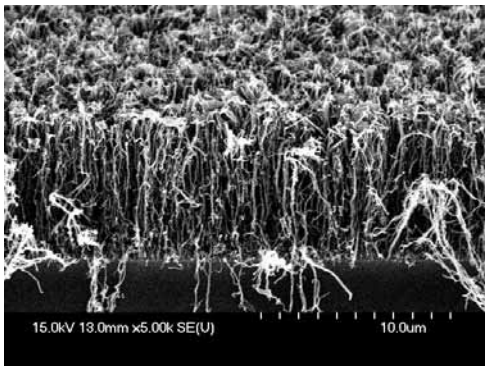


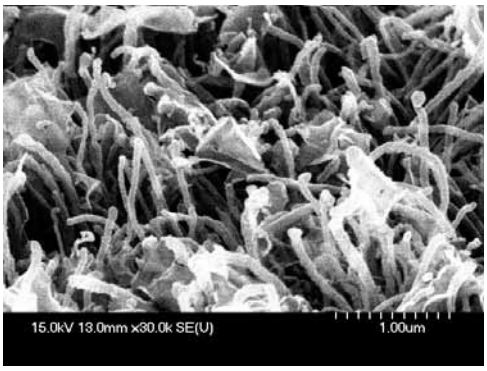
(g)

Sample number	BIAS Condition	Turn on field E (V/um) (@J=10uA/cm^2)	Current density J (mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	0W	3.1	2.35	2500
b.	50W	4.43	0.137	1072
c.	100W	3.96	1	1470
d.	150W	4.8	0.038	860

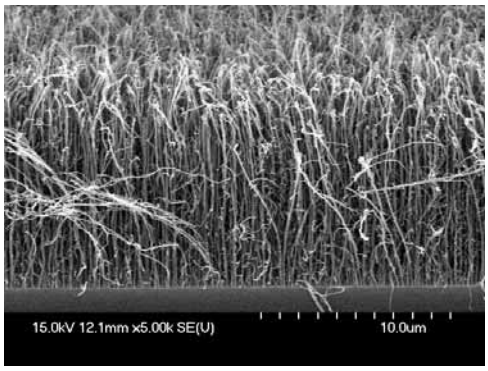
(h)

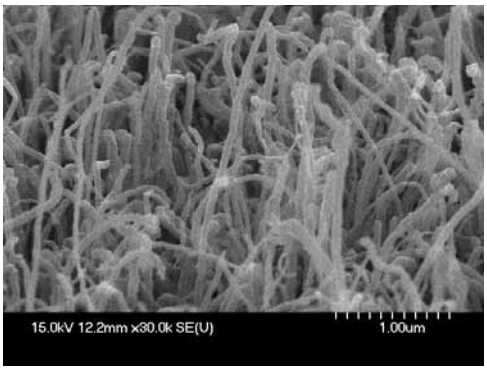
Fig. 4.11 SEM images of CNTs post-treatment by Ar 20sccm ICP power 300W 60sec for different BIAS power of (a) 0W, (b) 50W, (c) 100W, (d) 150W, (e) Raman spectra of CNTs, (f) field emission curve J-E, (g) F-N plot, and (h) summary experimental results.


15.0kV 13.0mm x5.00k SE(U)
10.0um

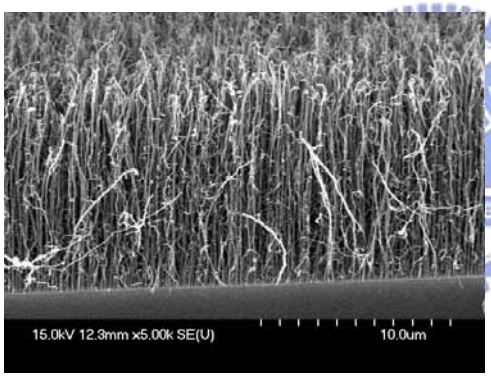

15.0kV 13.0mm x30.0k SE(U)
1.00um

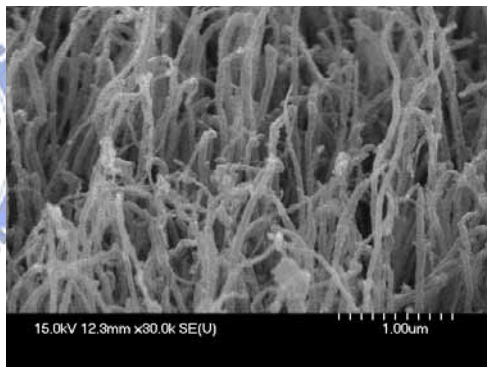
(a)


15.0kV 12.1mm x5.00k SE(U)
10.0um

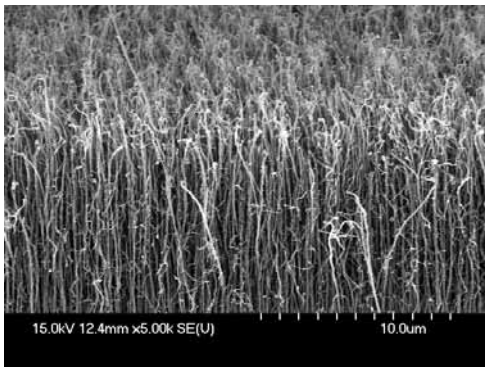

15.0kV 12.2mm x30.0k SE(U)
1.00um

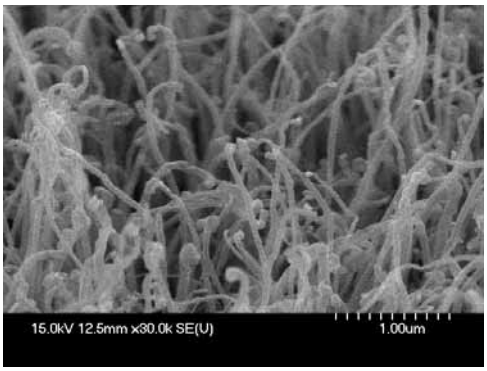
(b)


15.0kV 12.3mm x5.00k SE(U)
10.0um

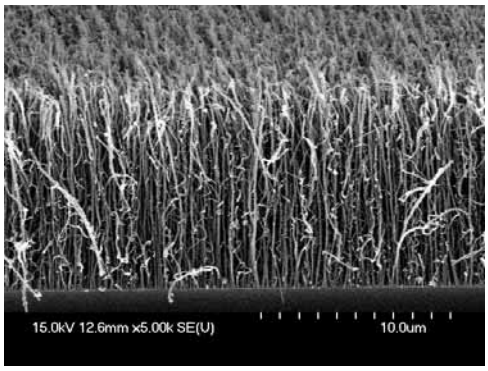

15.0kV 12.3mm x30.0k SE(U)
1.00um

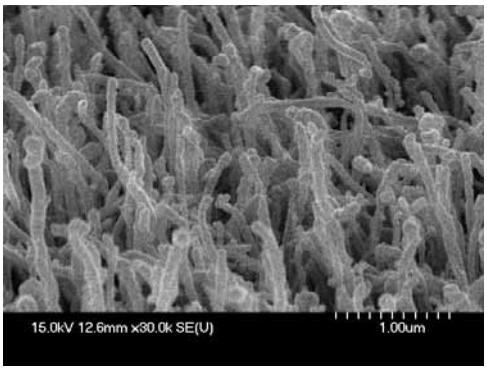
(c)


15.0kV 12.4mm x5.00k SE(U)
10.0um

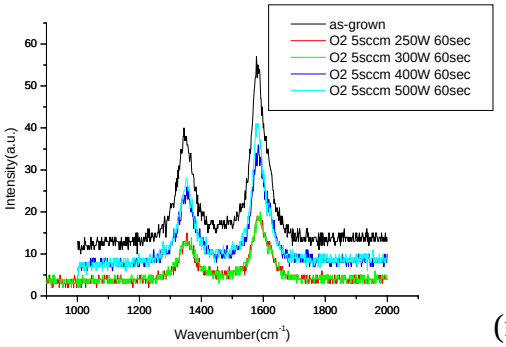

15.0kV 12.5mm x30.0k SE(U)
1.00um

(d)



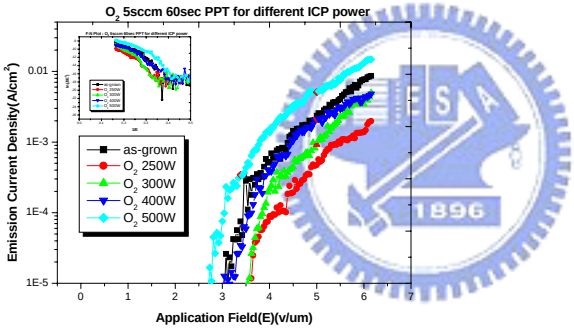


(e)

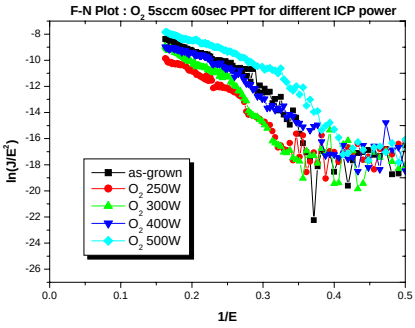


(f)

Sample number	Condition	ID/IG ratio
a.	As-grown	0.73077
b.	250W	0.78947
c.	300W	0.68421
d.	400W	0.72222
e.	500W	0.68293



(g)

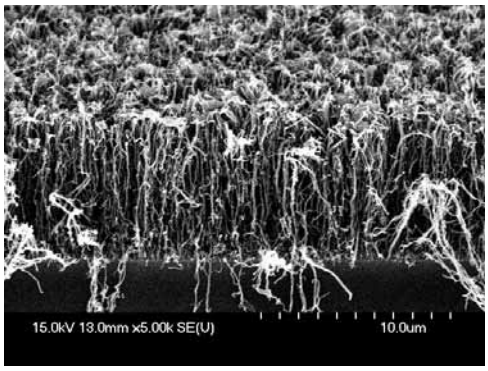


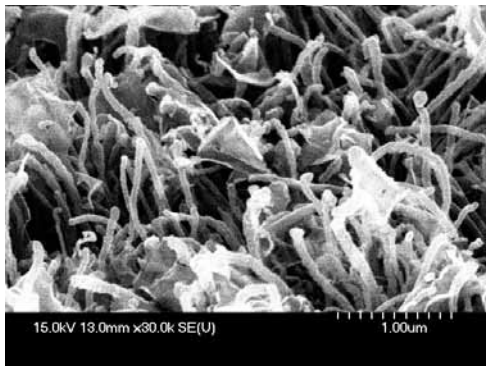
(h)

Sample number	Condition	Turn on field E (V/um) (@J=10uA/cm^2)	Current density J (mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	As-grown	3.1	2.35	**1869**
b.	250W	3.59	0.05	**1893**
c.	300W	3.55	1	**2041**
d.	400W	3.19	2	**2239**
e.	500W	2.75	5	**3096**

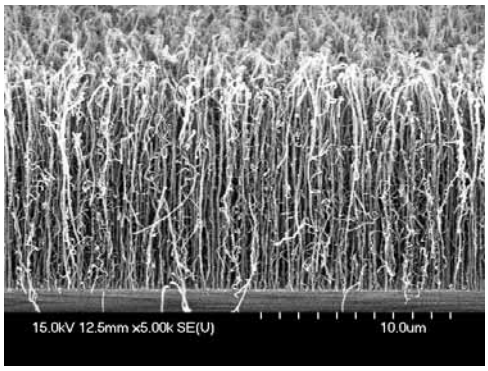
(i)

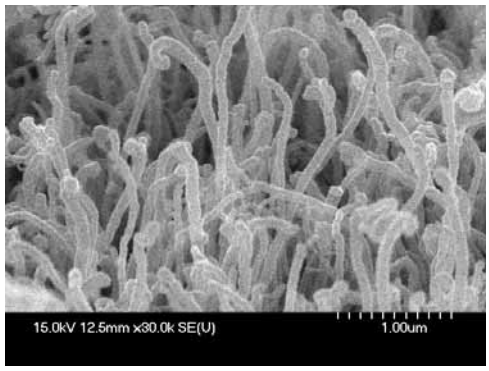
Fig. 4.12 SEM images of CNTs post-treatment by O_2 5sccm 60sec for different ICP power of (a) as-grown, (b) 250W, (c) 300W, (d) 400W, (e) 500W, (f) Raman spectra of CNTs, (g)field emission curve J-E, (h) F-N plot, and (i) summary experimental results.


15.0kV 13.0mm x5.00k SE(U)
10.0um

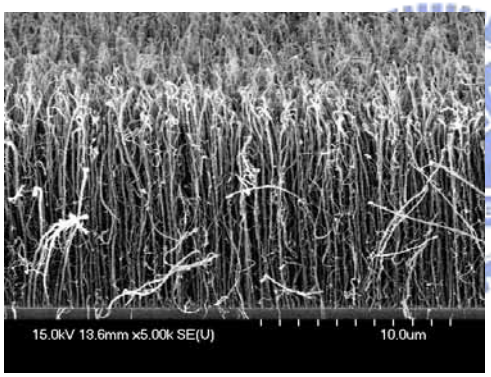

15.0kV 13.0mm x30.0k SE(U)
1.00um

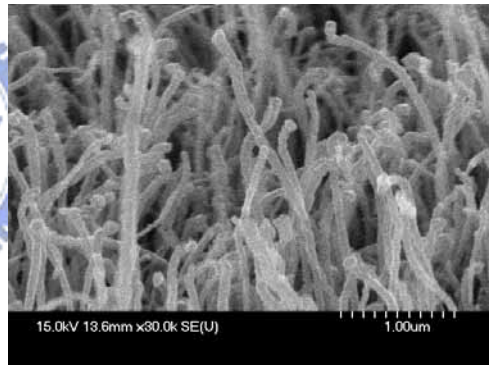
(a)


15.0kV 12.5mm x5.00k SE(U)
10.0um

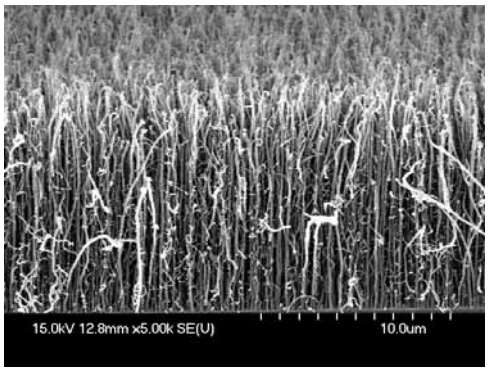

15.0kV 12.5mm x30.0k SE(U)
1.00um

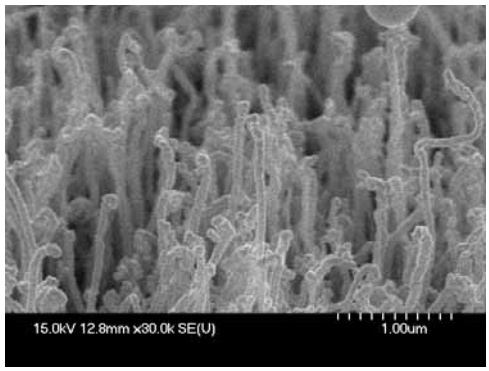
(b)


15.0kV 13.6mm x5.00k SE(U)
10.0um

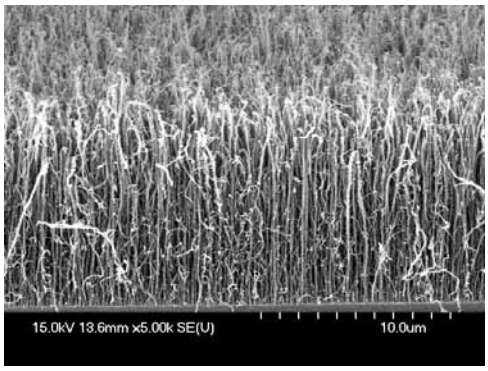

15.0kV 13.6mm x30.0k SE(U)
1.00um

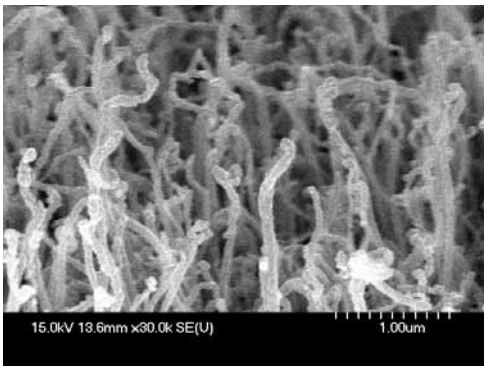
(c)


15.0kV 12.8mm x5.00k SE(U)
10.0um

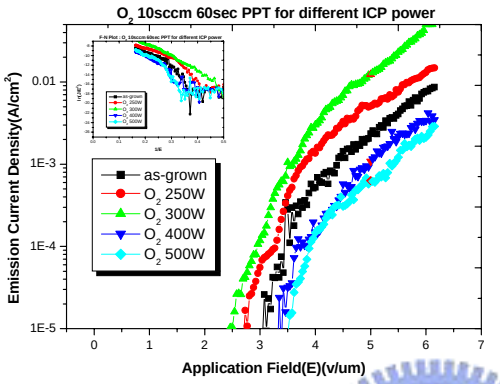

15.0kV 12.8mm x30.0k SE(U)
1.00um

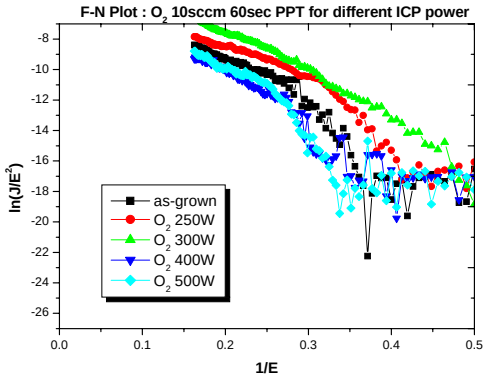
(d)





(e)



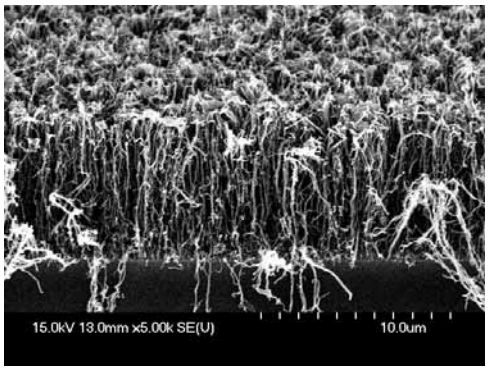


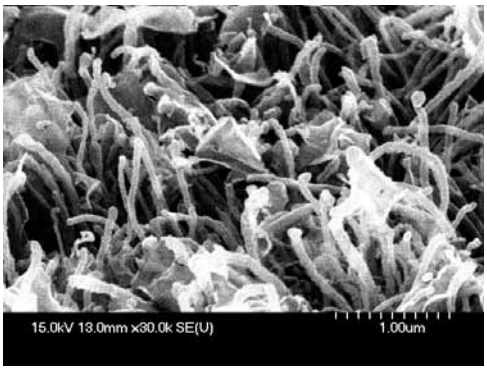
(f) (g)

Sample number	Condition	Turn on field E (V/um) (@J=10uA/cm^2)	Current density J (mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	As-grown	3.1	2.53	1869
b.	250W	2.76	5.2	2976
c.	300W	2.47	12.5	3130
d.	400W	3.35	1.09	2031
e.	500W	3.52	0.624	1708

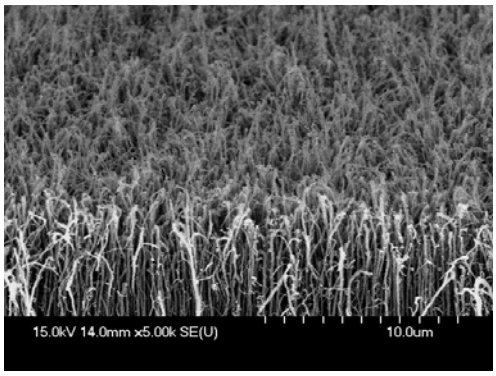
(h)

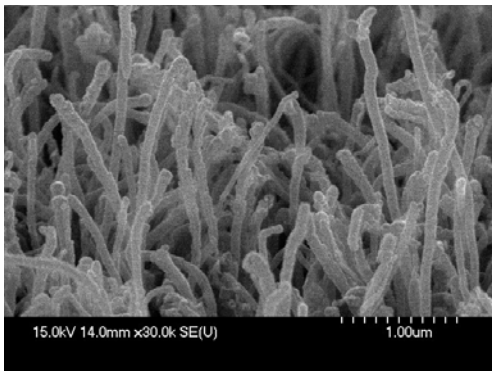
Fig. 4.13 SEM images of CNTs post-treatment by O_2 10sccm 60sec for different ICP power of (a) as-grown, (b) 250W, (c) 300W, (d) 400W, (e) 500W, (f) field emission curve J-E, (g) F-N plot, and (h) summary experimental results.


15.0kV 13.0mm x5.00k SE(U)
10.0um

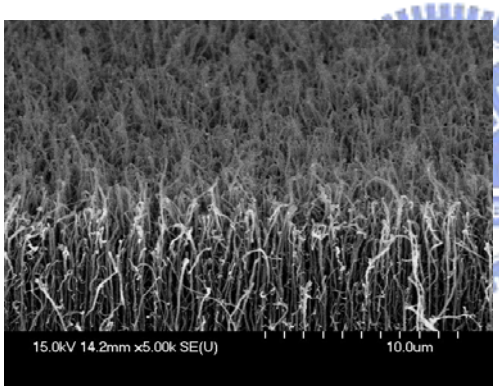

15.0kV 13.0mm x30.0k SE(U)
1.00um

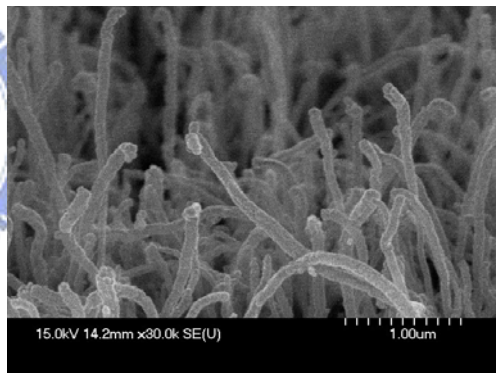
(a)


15.0kV 14.0mm x5.00k SE(U)
10.0um

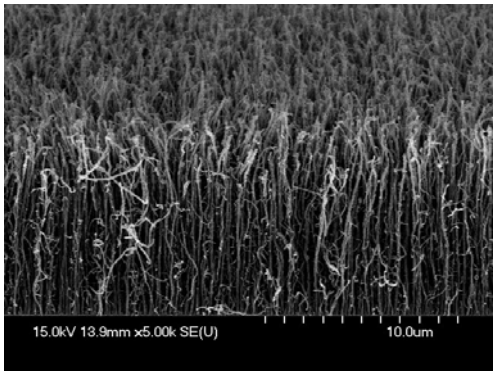

15.0kV 14.0mm x30.0k SE(U)
1.00um

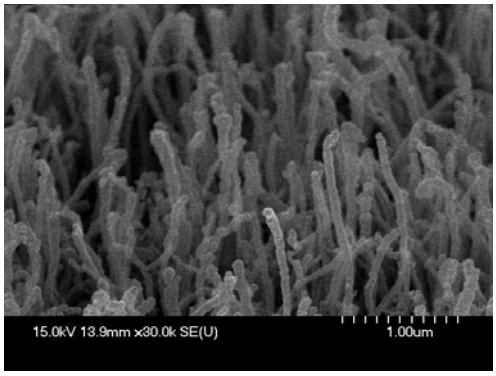
(b)


15.0kV 14.2mm x5.00k SE(U)
10.0um

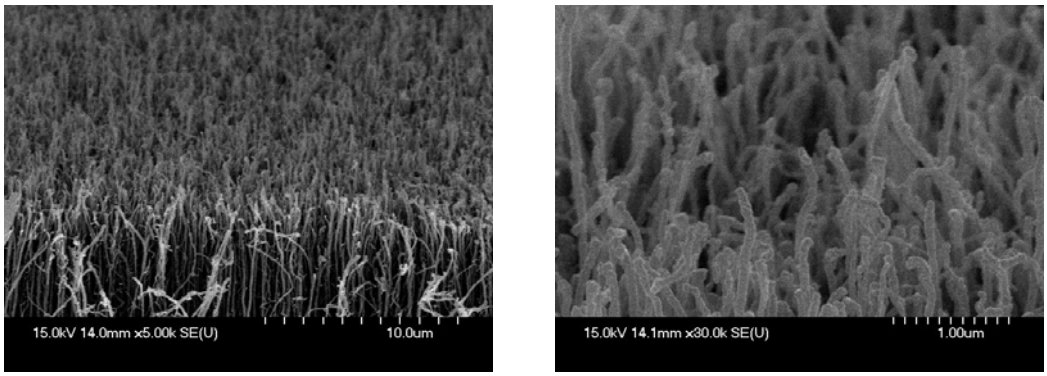

15.0kV 14.2mm x30.0k SE(U)
1.00um

(c)

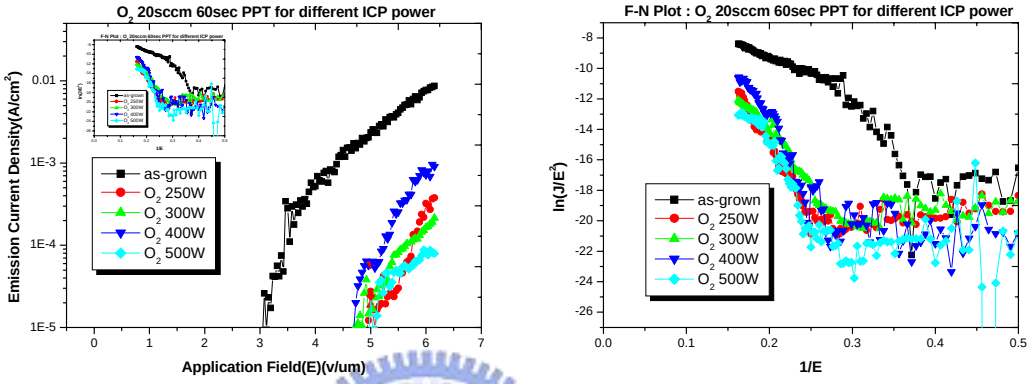

15.0kV 13.9mm x5.00k SE(U)
10.0um


15.0kV 13.9mm x30.0k SE(U)
1.00um

(d)



(e)

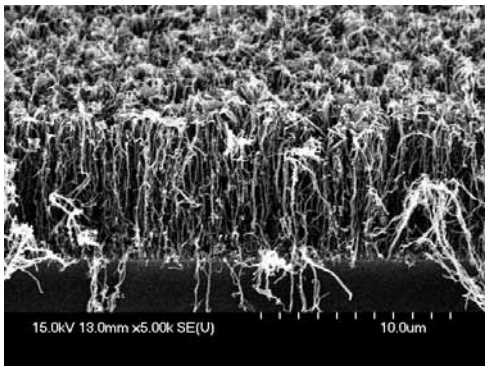


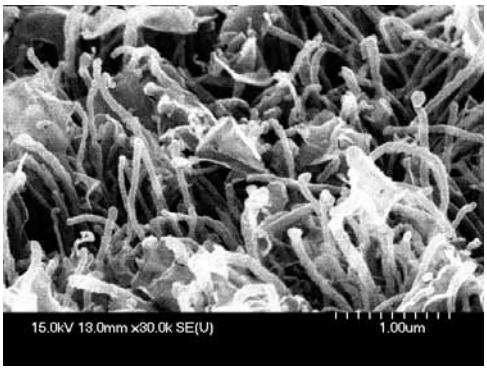
(f) (g)

Sample number	Condition	Turn on field E (V/um) (@J=10uA/cm^2)	Current density J (mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	As-grown	3.1	2.53	1869
b.	250W	5	0.0015	638
c.	300W	4.8	0.0024	614
d.	400W	4.698	0.0015	628
e.	500W	5	0.00578	669

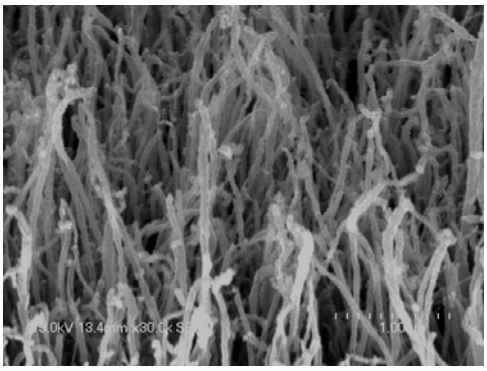
(h)

Fig. 4.14 SEM images of CNTs post-treatment by O_2 20sccm 60sec for different ICP power of (a) as-grown, (b) 250W, (c) 300W, (d) 400W, (e) 500W, (f) field emission curve J-E, (g) F-N plot, (h) summary experimental results.


15.0kV 13.0mm x5.00k SE(U)
10.0um

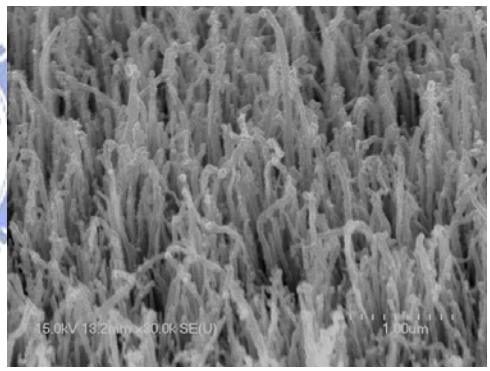

15.0kV 13.0mm x30.0k SE(U)
1.00um

(a)

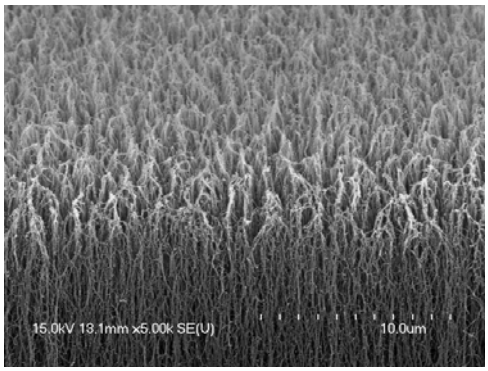


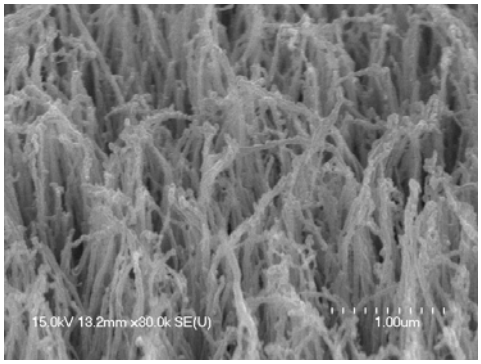
(b)


10.0um

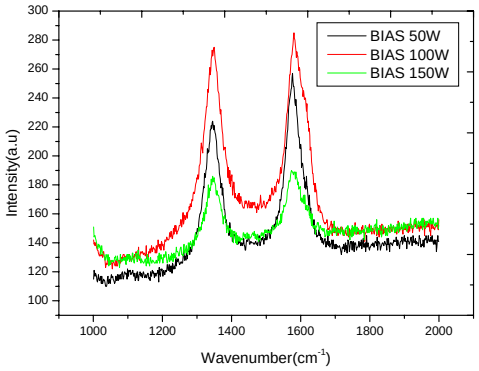

1.00um

(c)


15.0kV 13.1mm x5.00k SE(U)
10.0um

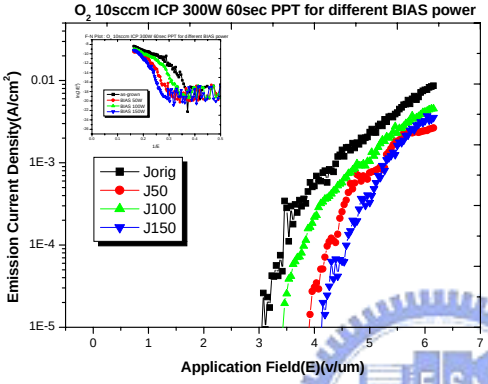

15.0kV 13.2mm x30.0k SE(U)
1.00um

(d)

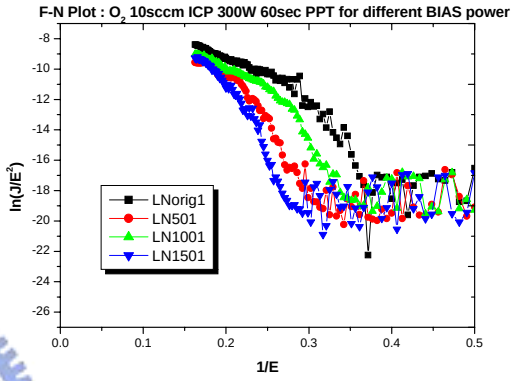


Sample number	Condition	ID	IG	ID/IG ratio
a.	0W	38	52	0.73077
b.	50W	221	248	0.891
c.	100W	275	285	0.964
d.	150W	185	189	0.8788

(e)



(f)

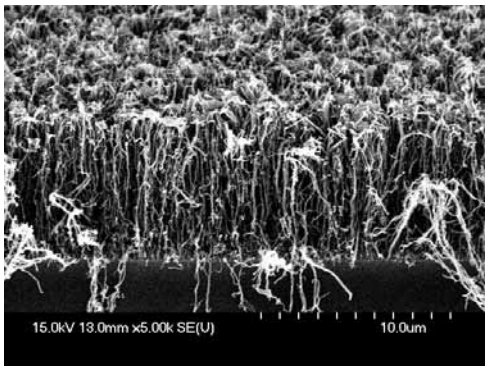


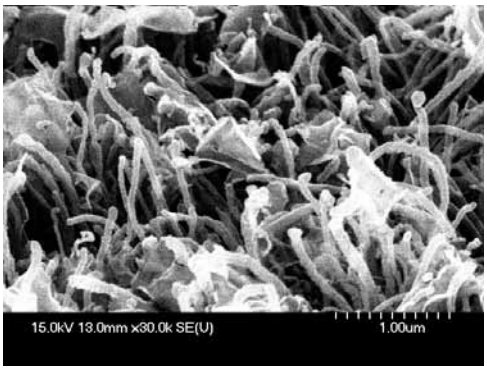
(g)

Sample number	BIAS Condition	Turn on field E (V/um) (@J=10uA/cm^2)	Current density J (mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	0W	3.1	2.35	**2500**
b.	50W	3.9	0.076	**1173**
c.	100W	3.4	1.17	**1684**
d.	150W	4.1	0.035	**848**

(h)

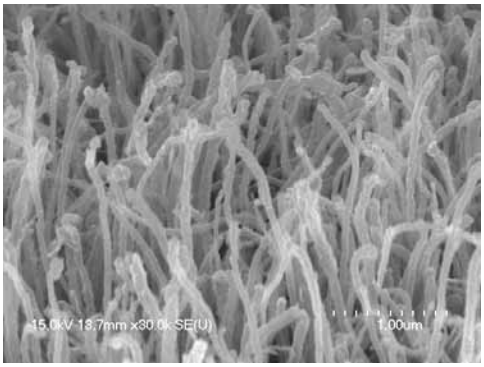
Fig. 4.15 SEM images of CNTs post-treatment by O_2 10sccm ICP power 300W 60sec for different BIAS power of (a) 0W, (b) 50W, (c) 100W, (d) 150W, (e) Raman spectra of CNTs, (f) field emission curve J-E, (g) F-N plot, and (h) summary experimental results.


15.0kV 13.0mm x5.00k SE(U)
10.0um


15.0kV 13.0mm x30.0k SE(U)
1.00um

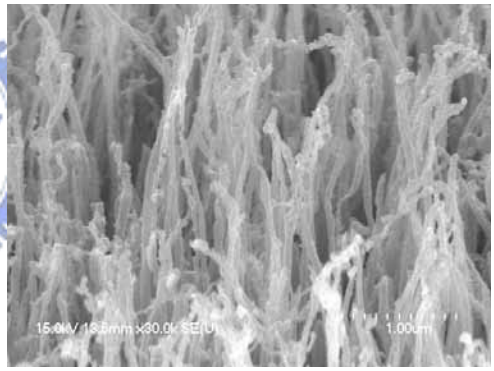
(a)


15.0kV 13.6mm x5.00k SE(U)
10.0um

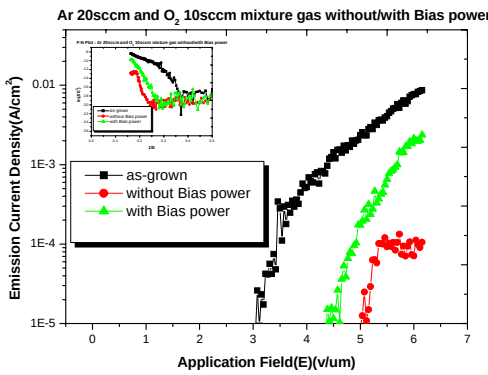

15.0kV 13.7mm x30.0k SE(U)
1.00um

(b)

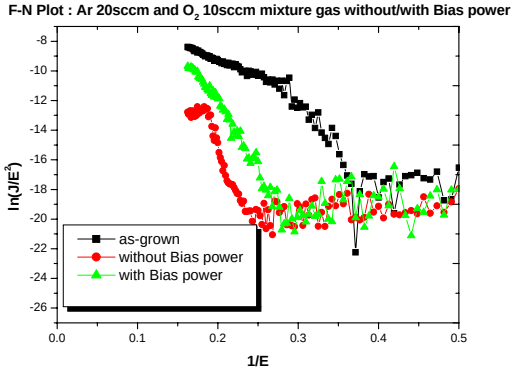

15.0kV 13.6mm x5.00k SE(U)
10.0um


15.0kV 13.6mm x30.0k SE(U)
1.00um

(c)



(d)

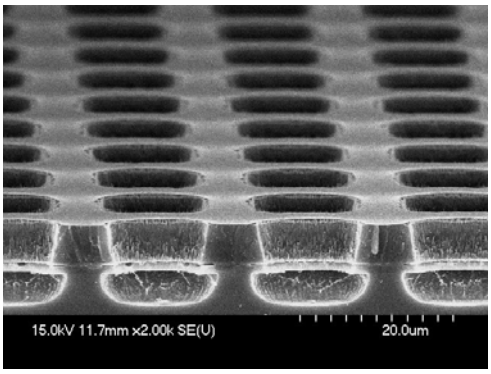


(e)

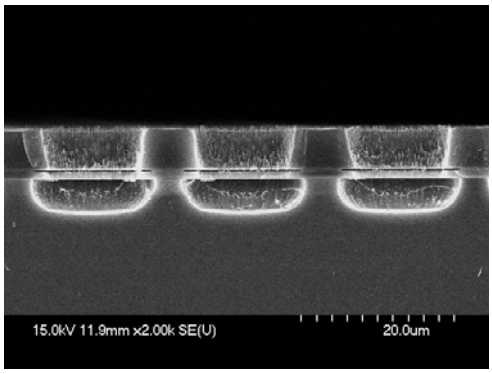
Sample number	BIAS Condition	Turn on field E(V/um) (@J=10uA/cm^2)	Current density J(mA/cm^2) (@E=5 v/um)	Field enhancement factor (ß)
a.	No PPT	3.1	2.35	**1869**
b.	without Bias	4.5	0.165	**872**
c.	With Bias	5.08	0.00176	**504**

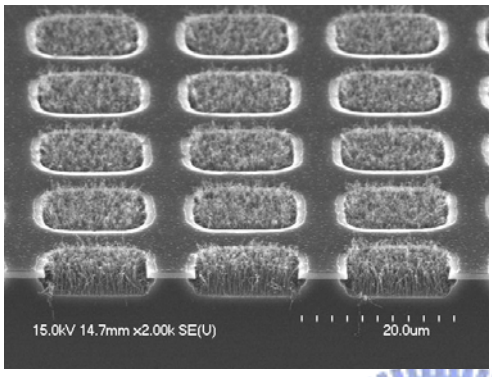
(f)

Fig. 4.16 SEM images of CNTs post-treatment by Ar 20sccm and O_2 10sccm mixture gas ICP power 300W 60sec for BIAS power of (a) no PPT, (b) without Bias power , (c) with Bias power 100W, (d)field emission curve J-E, (e) F-N plot, and (f) summary experimental results.

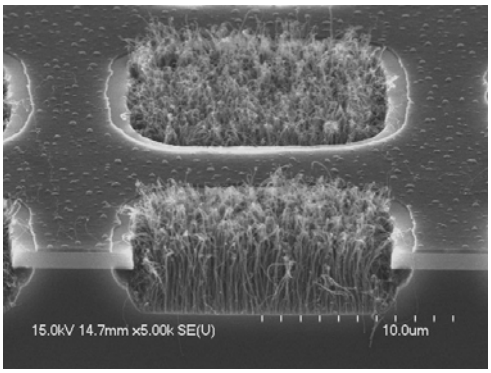

15.0kV 11.7mm x2.00k SE(U)
20.0um

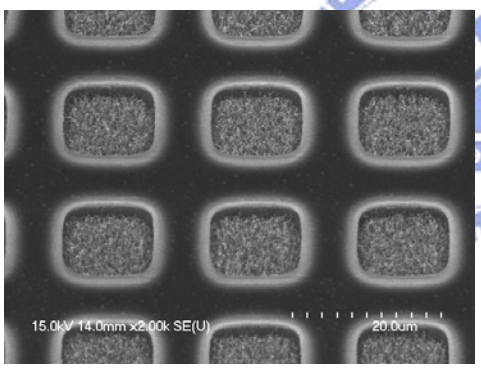
(a)


15.0kV 11.9mm x2.00k SE(U)
20.0um

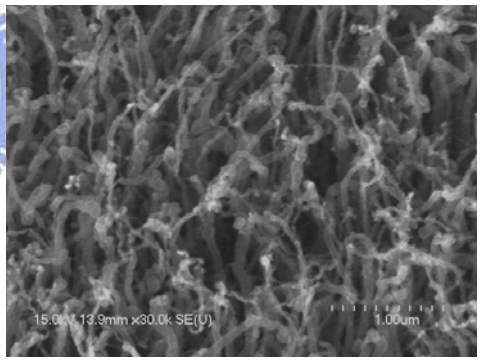

15.0kV 14.7mm x2.00k SE(U)
20.0um

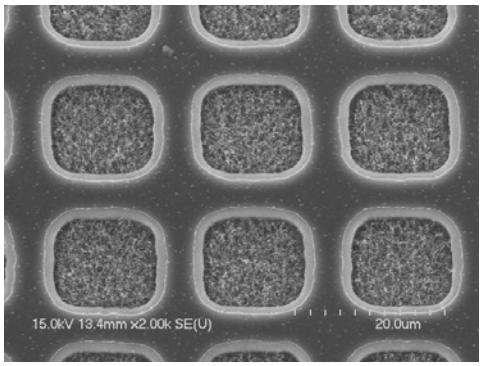
(b)


15.0kV 14.7mm x5.00k SE(U)
10.0um

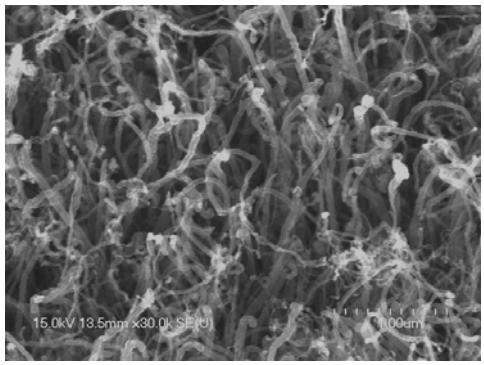

15.0kV 14.0mm x2.00k SE(U)
20.0um

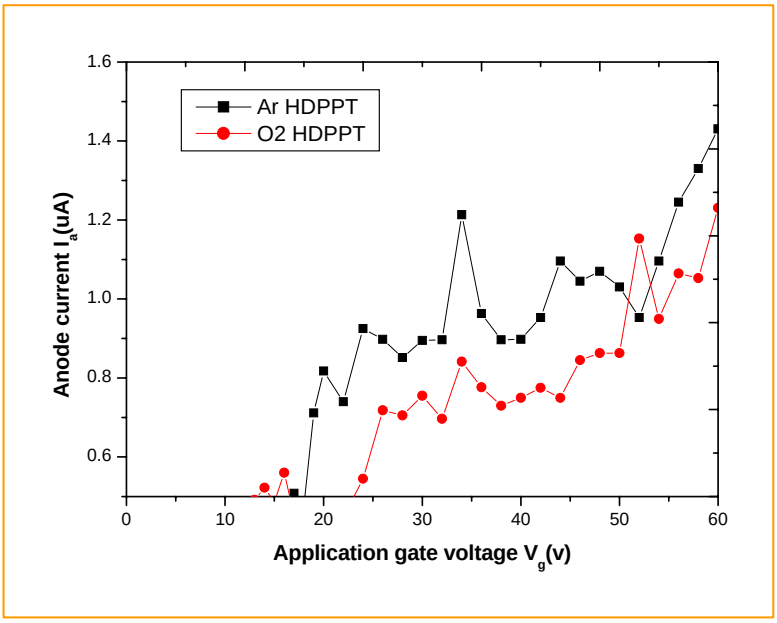
(c)


15.0kV 13.9mm x30.0k SE(U)
1.00um


15.0kV 13.4mm x2.00k SE(U)
20.0um

(d)


15.0kV 13.5mm x30.0k SE(U)
1.00um



(e)

Sample number	Condition	Turn on voltage	Emission Current (uA) (@V=50 v)
a.	Ar (20sccm)	18	1
b.	O_2 (10sccm)	23	0.86

(f)

Fig. 4.17 SEM images of CNTs post-treatment for PPT (a) triode structure, (b) as-grown, (c) Ar 20sccm for ICP power 300W 60sec, (d) O_2 10sccm for ICP power 300W 60sec, (e) field emission curve I-V, and (f) summary field emission results.

Table 4-1 Comparison physical versus chemical plasma etching.

Etch Parameter	Physical etch (RF field perpendicular to wafer surface)	Physical etch (RF field parallel to wafer surface)	Chemical etch	Combined Physical and Chemical
Etch Mechanism	Physical ion sputtering	Radicals in plasma reacting with wafer surface	Radical in liquid reacting with wafer surface	In dry etch, etching includes ion sputtering and radicals reacting with wafer surface
Sidewall Profile	Anisotropic	Isotropic	Isotropic	Anisotropic to isotropic
Selectivity	Poor/difficult to increase	Fair/good	Good/excellent	Fair/good
Etch Rate	High	Moderate	Low	Moderate

Table 4-2 Shows effects of changing plasma etch parameters.

Increased(↑) or Decrease(↓) in Etch Control Parameters		Ion Energy	DC BIAS	Etch Rate	Selectivity	Physical Etch
RF Frequency	↑	↓	↓	↓	↑	↓
	↓	↑	↑	↑	↓	↑
RF Power	↑	↑	↑	↑	↓	↑
	↓	↓	↓	↓	↑	↓
DC BIAS	↑	↑	↑	↑	↓	↑
	↓	↓	↓	↓	↑	↓
Electrode Size	↑	↓	↓	↓	↑	↓
	↓	↑	↑	↑	↓	↑

Table 4-3 Summary Ar and O_2 HDPPT for different flow rates VS different ICP Powers on turn-on field, emission current density, and field enhancement factor.

gas \ ICP power Condition	Turn on field E(V/um) (@J=10uA/cm^2)	Current density J(mA/cm^2) (@E=5 v/um)	Field enhancement factor(ß)
As-grown	3.1	2.35	1869
Ar 10sccm 250W	3.92	0.143	1616
Ar 10sccm 300W	3.9	0.193	1656
Ar 10sccm 400W	3.6	0.787	1750
Ar 10sccm 500W	3.1	3.77	1890
Ar 20sccm 250W	2.7	12	3108
Ar 20sccm 300W	**2.2**	**48**	**3463**
Ar 20sccm 400W	3.2	3.18	1956
Ar 20sccm 500W	3.6	0.65	1631
Ar 30sccm 250W	3.23	1.02	2246
Ar 30sccm 300W	3.85	0.814	1435
Ar 30sccm 400W	3.9	0.437	1427
Ar 30sccm 500W	3.9	0.435	1427
Ar 40sccm 250W	4.35	0.125	780
Ar 40sccm 300W	4.6	0.123	745
Ar 40sccm 400W	4.67	0.051	712
Ar 40sccm 500W	5.1	0.01	712
O_2 5sccm 250W	3.59	0.05	1893
O_2 5sccm 300W	3.55	1	2041
O_2 5sccm 400W	3.19	2	2239
O_2 5sccm 500W	2.75	5	3096
O_2 10sccm 250W	2.76	5.2	2976
O_2 10sccm 300W	**2.47**	**12.5**	**3130**
O_2 10sccm 400W	3.35	1.09	2031
O_2 10sccm 500W	3.52	0.624	1708
O_2 20sccm 250W	5	0.0015	638
O_2 20sccm 300W	4.8	0.0024	614
O_2 20sccm 400W	4.698	0.0015	628
O_2 20sccm 500W	5	0.00578	669

Table 4-4 Summary Ar and O_2 HDPPT for different BIAS Powers on turn-on field, emission current density, and field enhancement factor

Sample number	BIAS Condition	Turn on field E(V/um) (@J=10uA/cm^2)	Current density J(mA/cm^2) (@E=5 v/um)	Field enhancement factor(ß)
	No HDPPT	3.1	2.35	2500
Ar 20sccm With BIAS	50W	4.43	0.137	1072
	100W	3.96	1	1470
	150W	4.8	0.038	860
O_2 10sccm With BIAS	50W	3.9	0.076	1173
	100W	3.4	1.17	1684
	150W	4.1	0.035	848
Ar + O_2 (20/10sccm) Without BIAS	0W	4.5	0.165	872
Ar + O_2 (20/10sccm) With BIAS	100W	5.08	0.00176	504