表 4-2 碳奈米結構試片之形貌與特性表 (以 Co 為觸媒)

Specimen designation	Catalyst thickness (nm)	Features of Co catalyst via H-plasma pretreatment		Deposition condition	Features of as-deposited CN s				
		Average particle size(nm)	Number density of particle (G particles/in^2)	Working pressure (Torr)	Diameter (nm)	Length (nm)	Tube number density (G tubes/in^2)	Morphology	I_G/I_D ratio
A1	5	~35	~294	8	-	-	-	-	-
A3				32	-	-	-	-	-
A2	10	~125	~17	8	-	-	-	-	-
A4				32	-	-	-	-	-
B1	5	~35	~115	8	~30	77-310	~115	worm-like	0.4
B3				32	-	-	-	-	-
B2	10	~47	~270	8	~40	77-310	~86	worm-like	0.4
B4				32	-	-	-	-	-
C1	5	~62	~46	8	-	-	-	particle-like	-
C3				32	~7 & ~30	30-260	~31	root-growth CNTs (network) and catalyst-split nanotubes	8.5
C2	10	~177	~10	8	~5	30-153	~6	root-growth CNTs	4.2
C4				32	~10	45-153	~11	root-growth CNTs	0.9
D1	5	~46	~109	8	-	-	-	particle-like	-
D3				32	-	-	-		-
D2	10	~157	~8	8	-	-			-
D4				32	-	-	-		-
E1	5	~60	~66	8	-	-	-	particle-like	-
E3				32	~7 & ~30	30-275	~30	root-growth CNTs (network) and catalyst-split nanotubes	15.7
E2	10	~180	~7	8	~5	30-153	~6	root-growth CNTs	2.2
E4				32	~10	45-153	~9	root-growth CNTs	1.0

表 4-3 碳奈米結構試片之形貌與特性表 (以 Co 為觸媒)(續)

Specimen designation	Buffer layer materials and its thickness (nm)	Catalyst thickness (nm)	Features of Co catalyst via H-plasma pretreatment		Deposition condition	Features of as-deposited CNTs				
			Average particle size(nm)	Number density of particle (G particles/in^2)	Working pressure (Torr)	Diameter (nm)	Length (nm)	Tube number density (G tubes/in^2)	Morphology	I_G/I_D ratio
E5	AlON (5)	5	~60	~64	32	~7 &~30	25-80	~8	root-growth CNTs (network) and catalyst-split nanotubes	6.5
E6		10	~160	~7		-	-	-	particle-like	-
E7	AlON (20)	5	~60	~69		~7 &~30	31-350	~20	root-growth CNTs (network) and catalyst-split nanotubes	3.3
E8		10	~184	~7		~7	38-90	~9	root-growth CNTs	0.9
E9	AlON (10)	5	~60	~59	23	~ 7-10 &~20	30-360	~187	root-growth CNTs (network) and catalyst-split nanotubes	27.4
E10					16	-	-	-	particle-like	-
D5	AlN (15)	10	~150	~9	32	~6	27-250	~18	root-growth CNTs	2.1

表 4-4 碳奈米結構試片之形貌與特性表 (以 Fe 為觸媒)

Specimen designation	Catalyst Thickness (nm)	Features of Fe catalyst via H-plasma pretreatment		Deposition condition	Features of as-deposited CNTs				
		Average particle size(nm)	Number density of particle (G particles/in^2)	CH_4/H_2 ratio (sccm/sccm)	Diameter (nm)	Growth rate (μm/min)	I_G/I_D ratio	Morphology	CNTs orientation
FB1	5	-	-	5/50	-	-	-	particle-like	-
FC1	5	-	-	5/50	~15-32	-	0.7	MWNTs	random
FA1	5	~30	~605	5/50	~9-13	-	0.9	trace MWNTs	random
FA2				1.5/50	~9-15	-	0.9	trace MWNTs	random
FA3				1.5/100	~9-13	-	1.0	trace MWNTs	random
FA4	10	~108	~11	5/50	-	-	-	particle-like	-
FA5				1.5/50	-	-	-	particle-like	-
FA6				1.5/100	-	-	-	particle-like	-
FD1	5	~23	~1985	5/50	~10-26	13.16	0.7	MWNTs	aligned
FD2				1.5/50	~9-24	4.91	1.1	MWNTs	aligned
FD3				1.5/100	~6-25 & 0.9-1.3	0.06	10	MWNTs and trace SWNTs	random
FD4	10	~28	~774	5/50	~13-30	3.90	0.8	MWNTs	aligned
FD5				1.5/50	~13-29	1.32	0.9	MWNTs	aligned
FD6				1.5/100	~13-31	0.07	1.3	MWNTs	random
FE1	5	~15	~1855	5/50	~10-20	5.10	0.7	MWNTs	aligned
FE2				1.5/50	~8-21	2.63	1.7	MWNTs	aligned
FE3				1.5/100	~6-22 & ~ 0.9-1.3	0.11	10.5	MWNTs and trace SWNTs	random
FE4	10	~25	~738	5/50	~13-27	0.57	0.7	MWNTs	aligned
FE5				1.5/50	~14-28	0.47	1.7	MWNTs	aligned
FE6				1.5/100	~7-26 & ~0.9-1.3	0.33	2.9	MWNTs and trace SWNTs	random

表 4-5 碳奈米結構試片之形貌與特性表 (以 Fe 為觸媒)(續)

Specimen designation	Buffer layer materials and its thickness (nm)	Catalyst Thickness (nm)	Features of Fe catalyst via H-plasma pretreatment		Deposition condition	Features of as-deposited CNTs			
			Average particle size(nm)	Number density of particle (G particles/in^2)	CH_4/H_2 ratio (sccm/sccm)	Diameter (nm)	I_G/I_D ratio	Morphology	CNTs orientation
FD7	Al_2O_3 (5)	5	~21	~1473	1.5/200	~10-19 & 0.9-1.3	3.2	MWNTs and trace SWNTs	random
FD8	Al_2O_3 (10)		~23	~1985		~10-15 & ~1.3	1.7	MWNTs and trace SWNTs	random
FD9	Al_2O_3 (15)		~25	~1511		~ 10-15 & ~1.3	2.2	MWNTs and trace SWNTs	random
FE7	AlN (5)		~17	~1548		~9-15 & 0.9-1.3	19.7	MWNTs and SWNTs	random
FE8	AlN (10)		~15	~1855		~9-15 & 0.9-1.3	31.5	MWNTs and SWNTs	random
FE9	AlN (15)		~25	~1360		~9-15 & 0.9-1.3	27.3	MWNTs and SWNTs	random

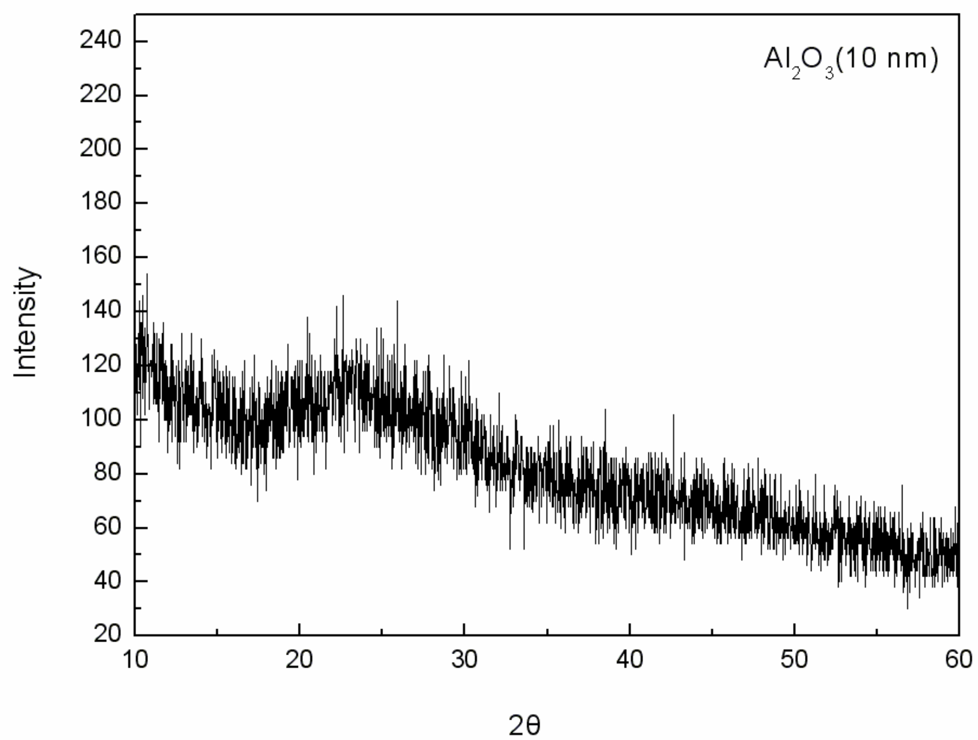
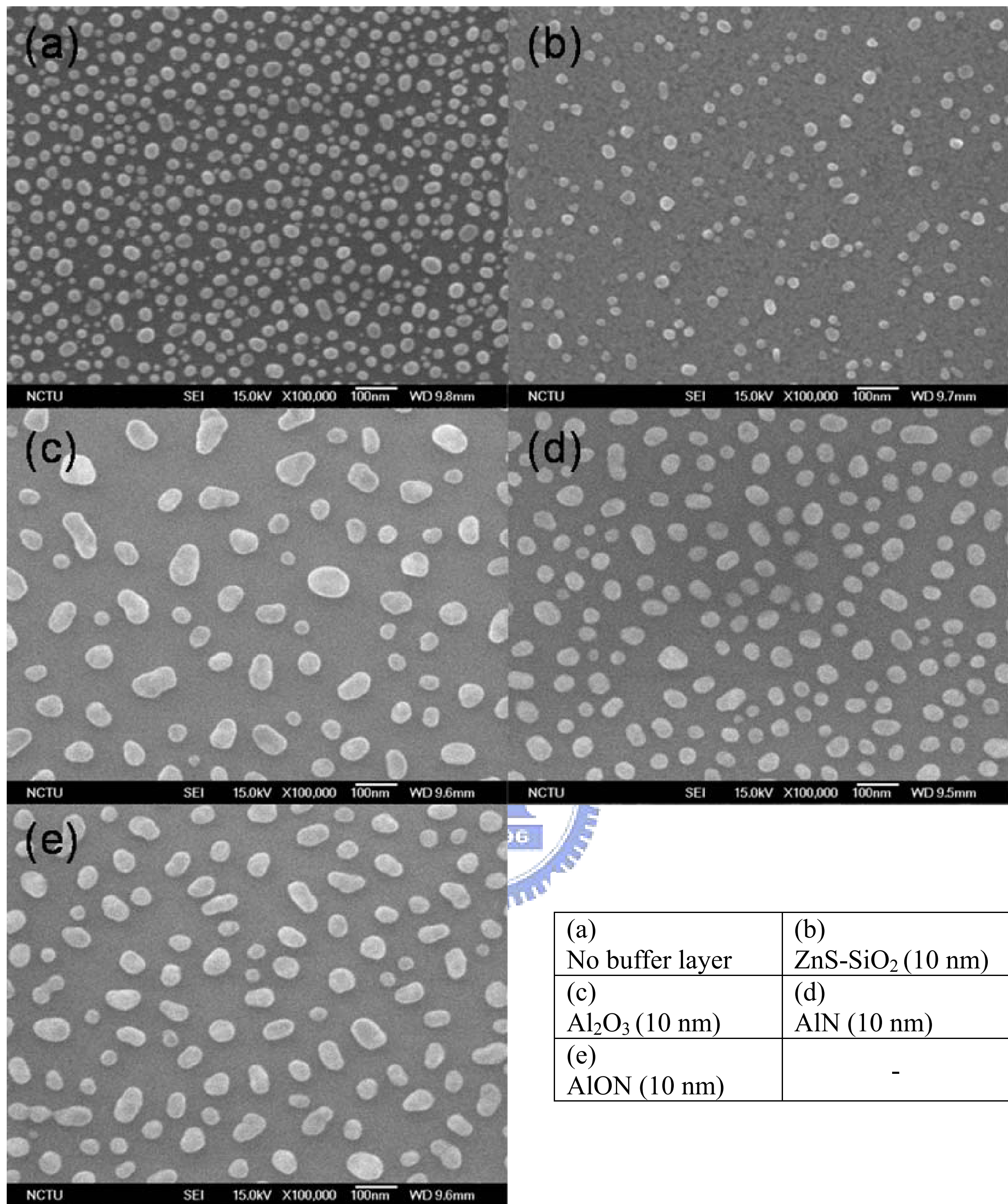
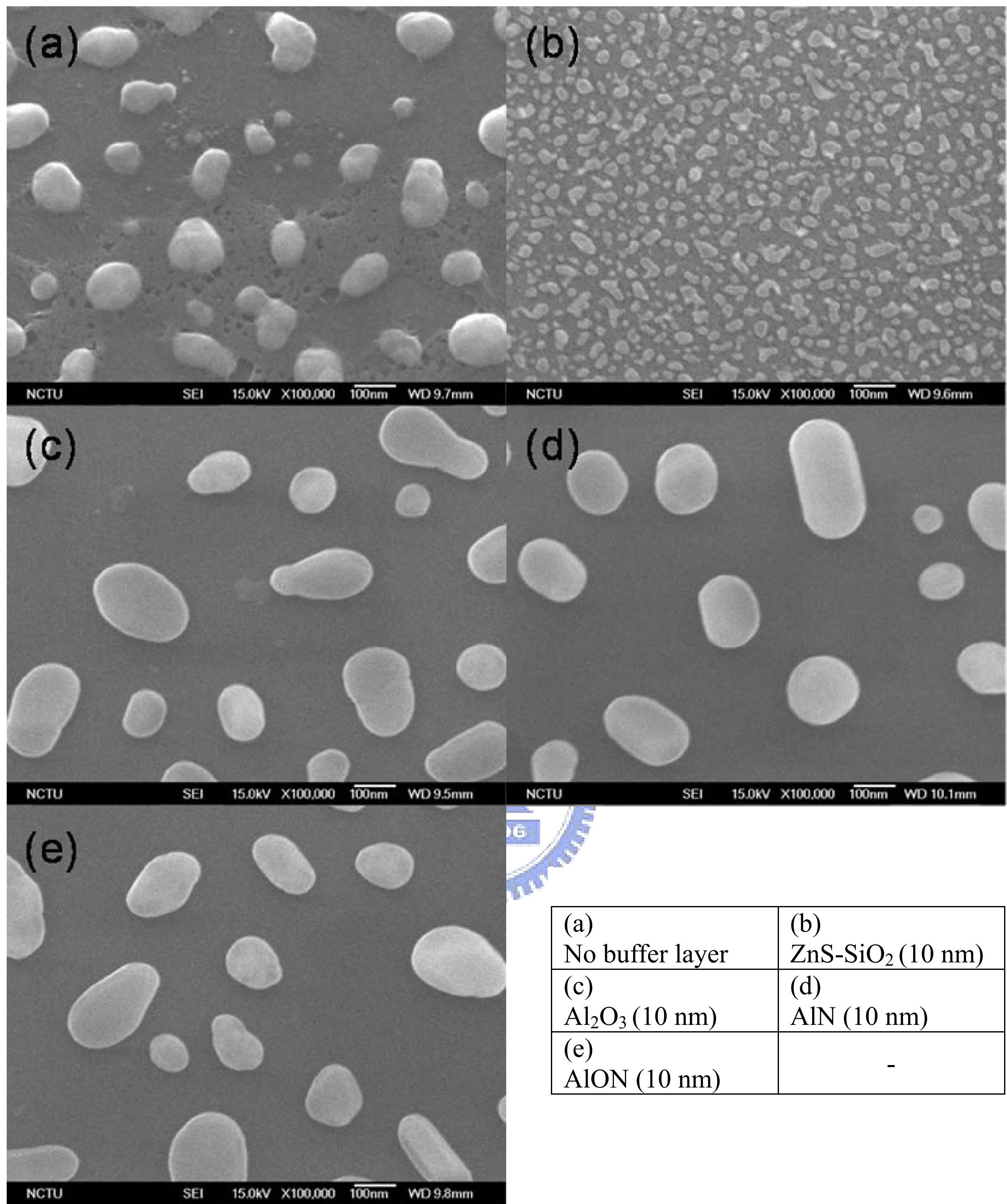


圖 4-1　Al_2O_3初鍍膜(10 nm)之XRD分析圖



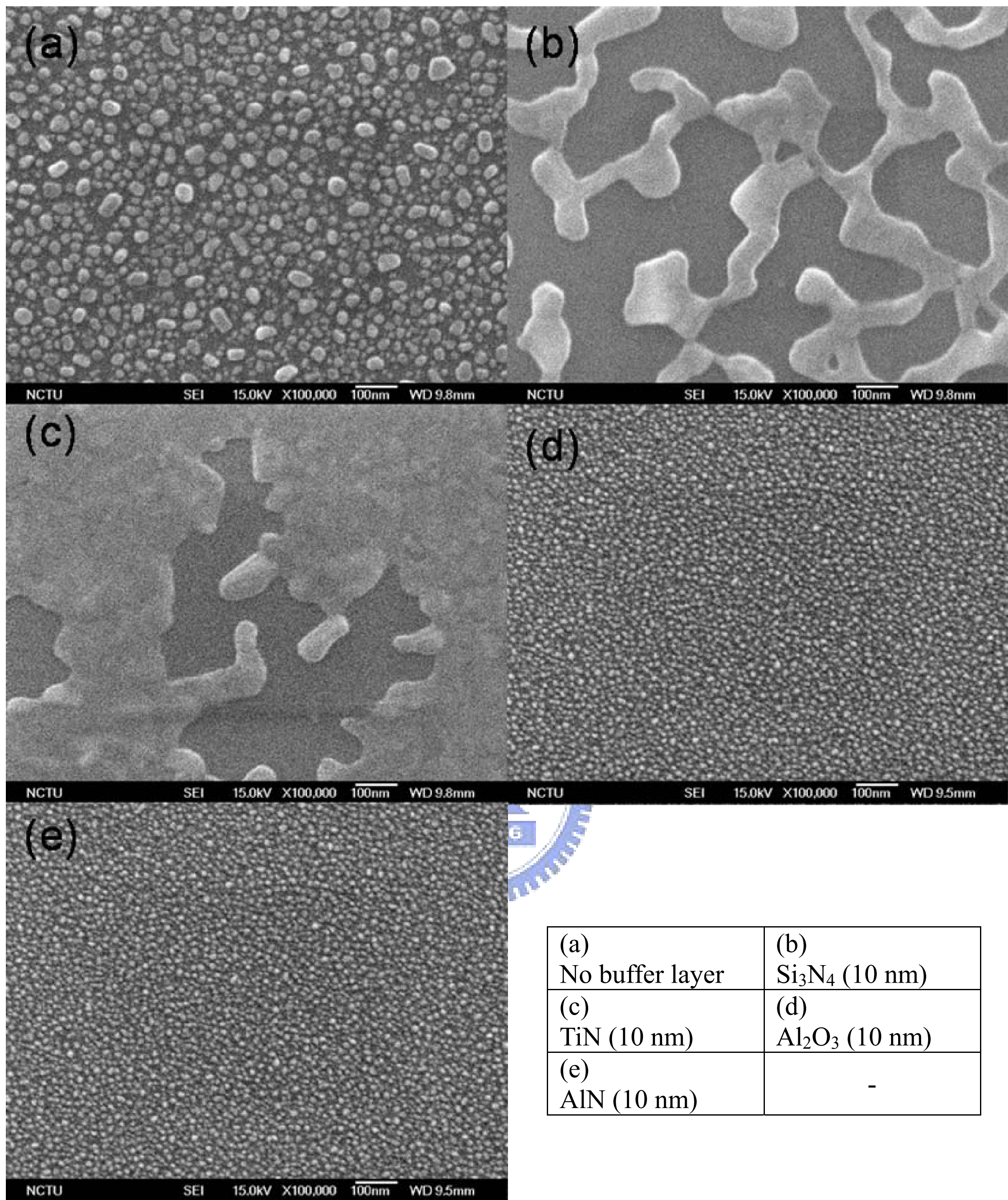
(a) No buffer layer	(b) ZnS-SiO_2 (10 nm)
(c) Al_2O_3 (10 nm)	(d) AlN (10 nm)
(e) AlON (10 nm)	-

圖 4-2　Co(5 nm)於不同緩衝層材料上經氫電漿前處理後之形貌 ：(a)No buffer layer; (b) ZnS-SiO_2; (c) Al_2O_3; (d) AlN; (e) AlON



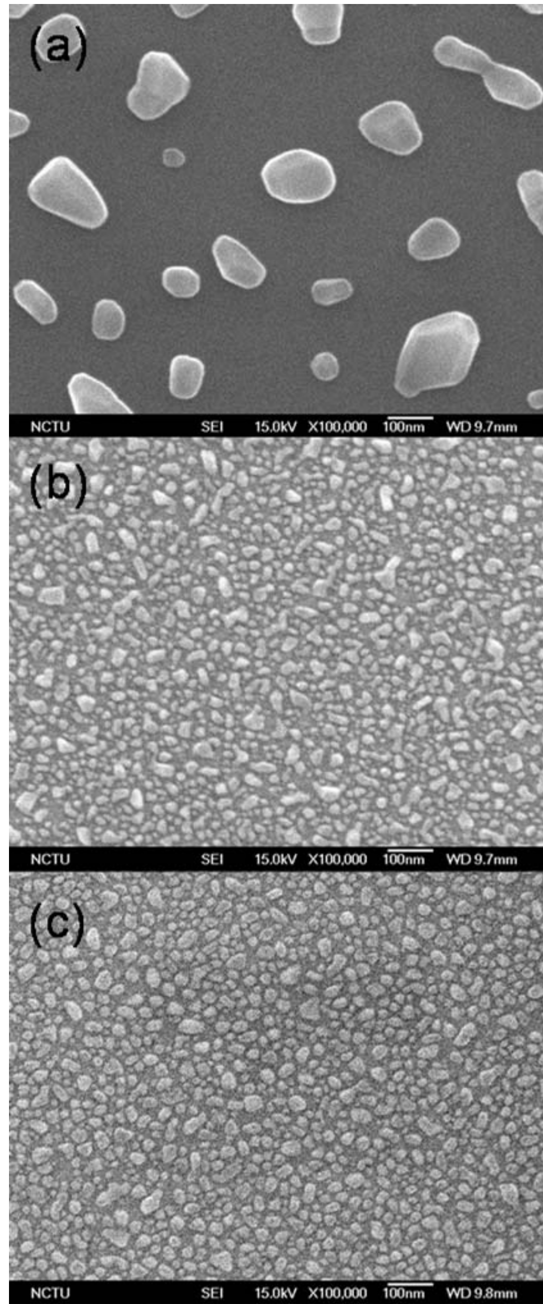
(a) No buffer layer	(b) $ZnS\text{-}SiO_2$ (10 nm)
(c) Al_2O_3 (10 nm)	(d) AlN (10 nm)
(e) AlON (10 nm)	-

圖 4-3　Co(10 nm)於不同緩衝層材料上經氫電漿前處理後之形貌：(a)No buffer layer; (b) $ZnS\text{-}SiO_2$; (c) Al_2O_3; (d) AlN; (e) AlON



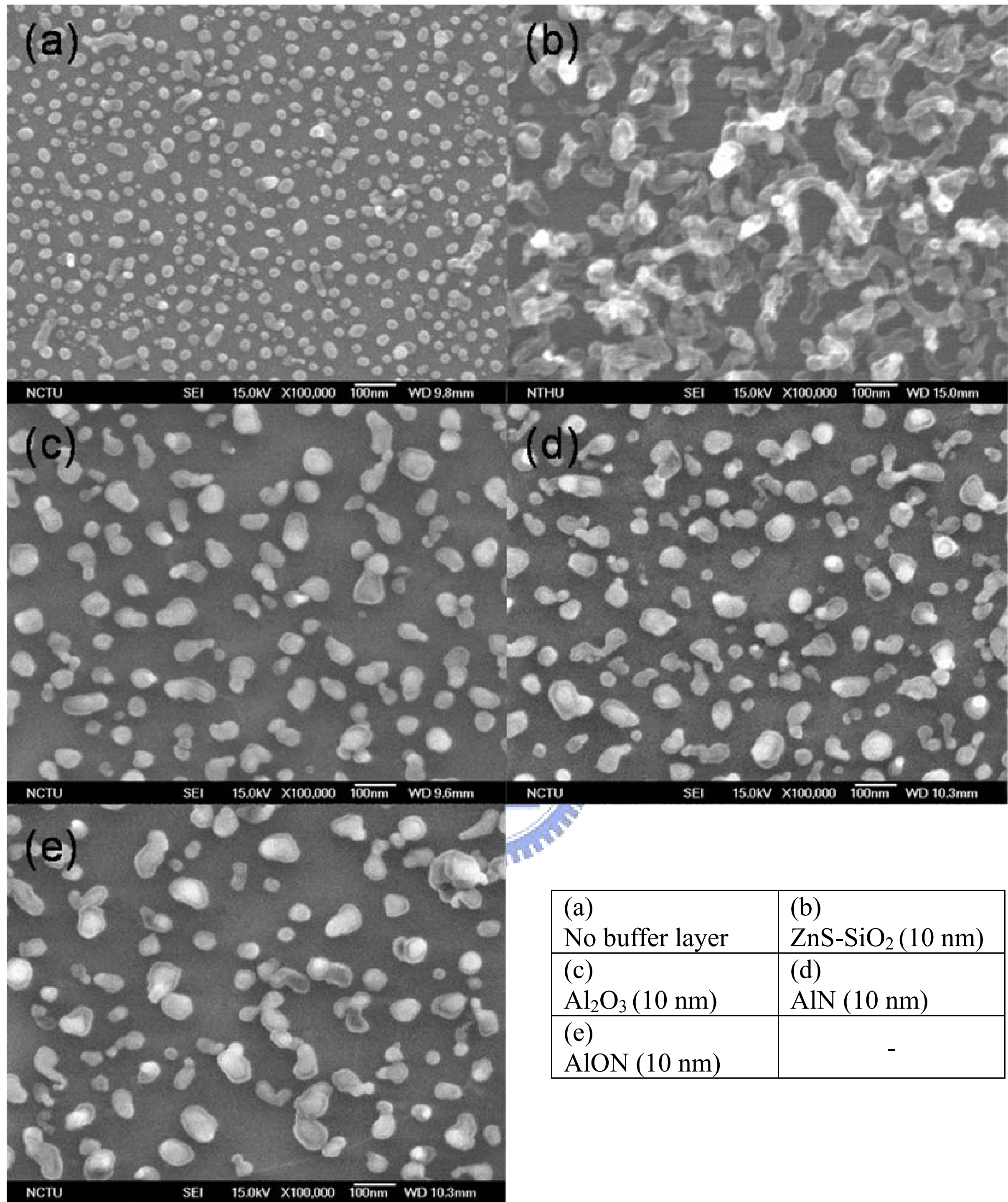
(a) No buffer layer	(b) Si_3N_4 (10 nm)
(c) TiN (10 nm)	(d) Al_2O_3 (10 nm)
(e) AlN (10 nm)	-

圖 4-4　Fe(5 nm) 於不同緩衝層材料上經氫電漿前處理後之形貌：(a)No buffer layer; (b) Si_3N_4; (c)TiN; (d) Al_2O_3; (e) AlN



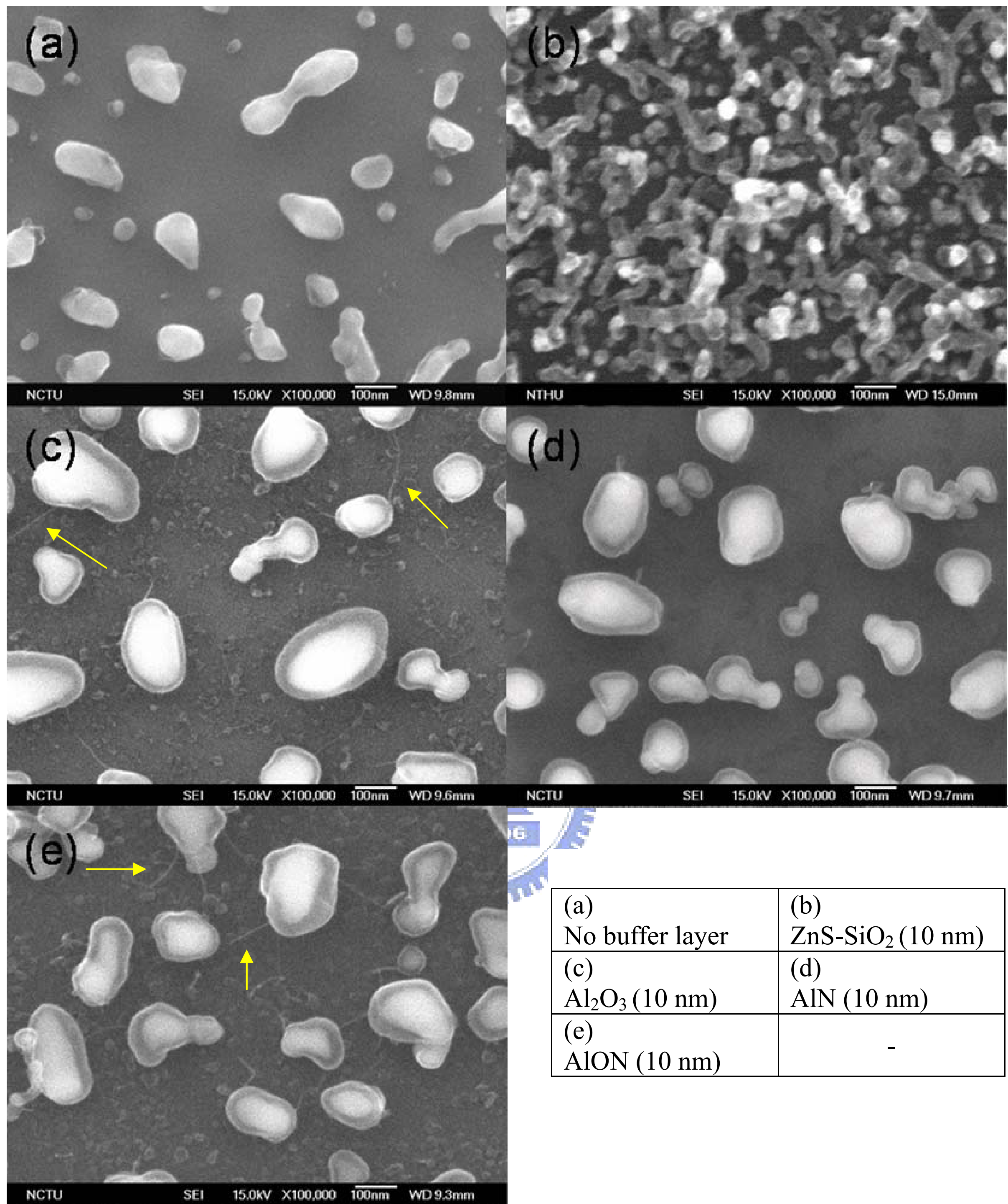
(a) No buffer layer
(b) Al_2O_3 (10 nm)
(c) AlN (10 nm)

圖 4-5 Fe(10nm) 於不同緩衝層材料上經氫電漿前處理後之形貌：(a)No buffer layer; (b) Al_2O_3; (c) AlN



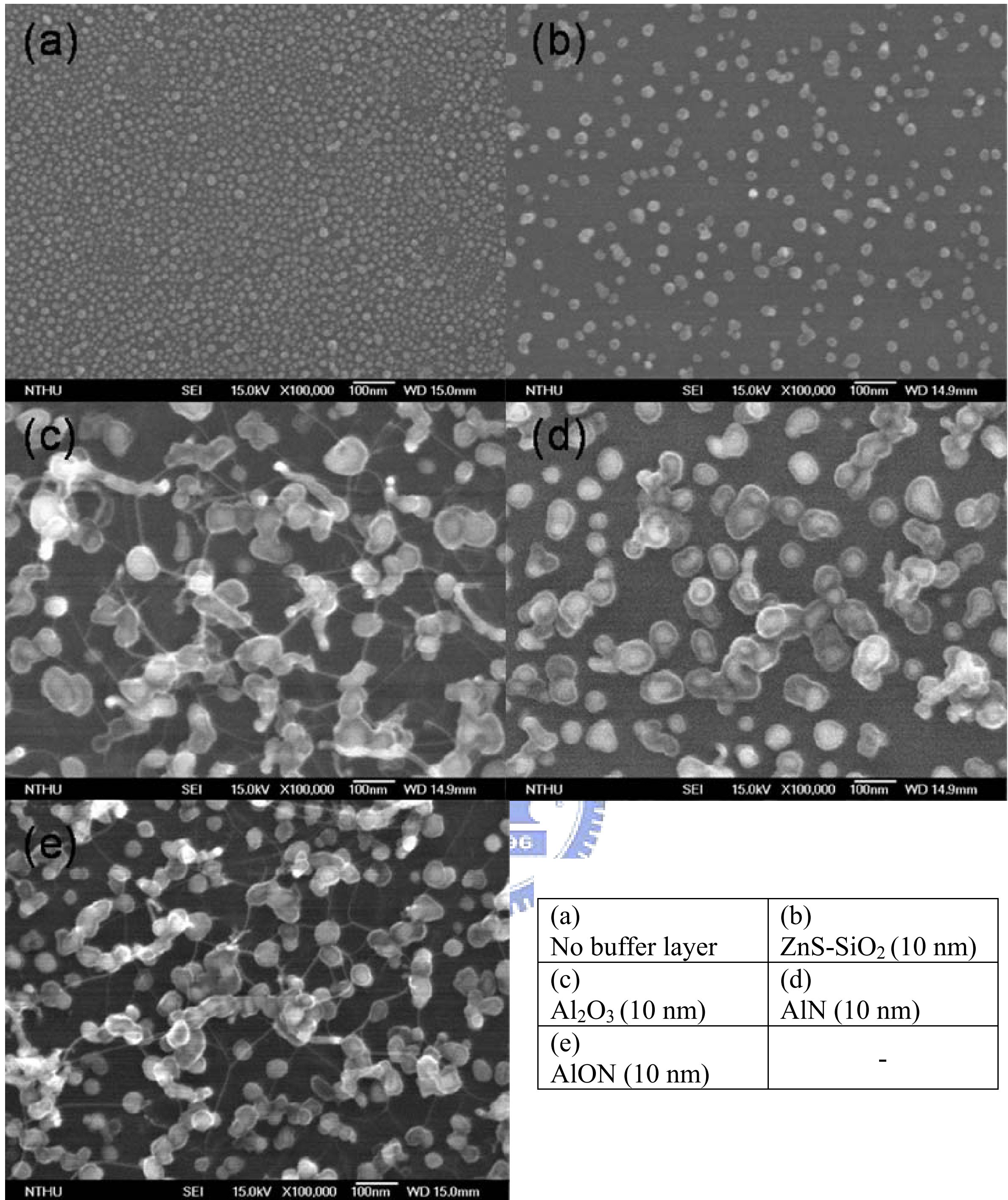
(a) No buffer layer	(b) ZnS-SiO_2 (10 nm)
(c) Al_2O_3 (10 nm)	(d) AlN (10 nm)
(e) AlON (10 nm)	-

圖 4-6 不同緩衝層材料對碳奈米結構形貌之影響於 8 Torr成長壓力(以 5 nm 厚的Co為觸媒), (a)No buffer layer; (b) ZnS-SiO_2; (c) Al_2O_3; (d) AlN; (e) AlON(試片編號分別為A1, B1, C1, D1 和E1)



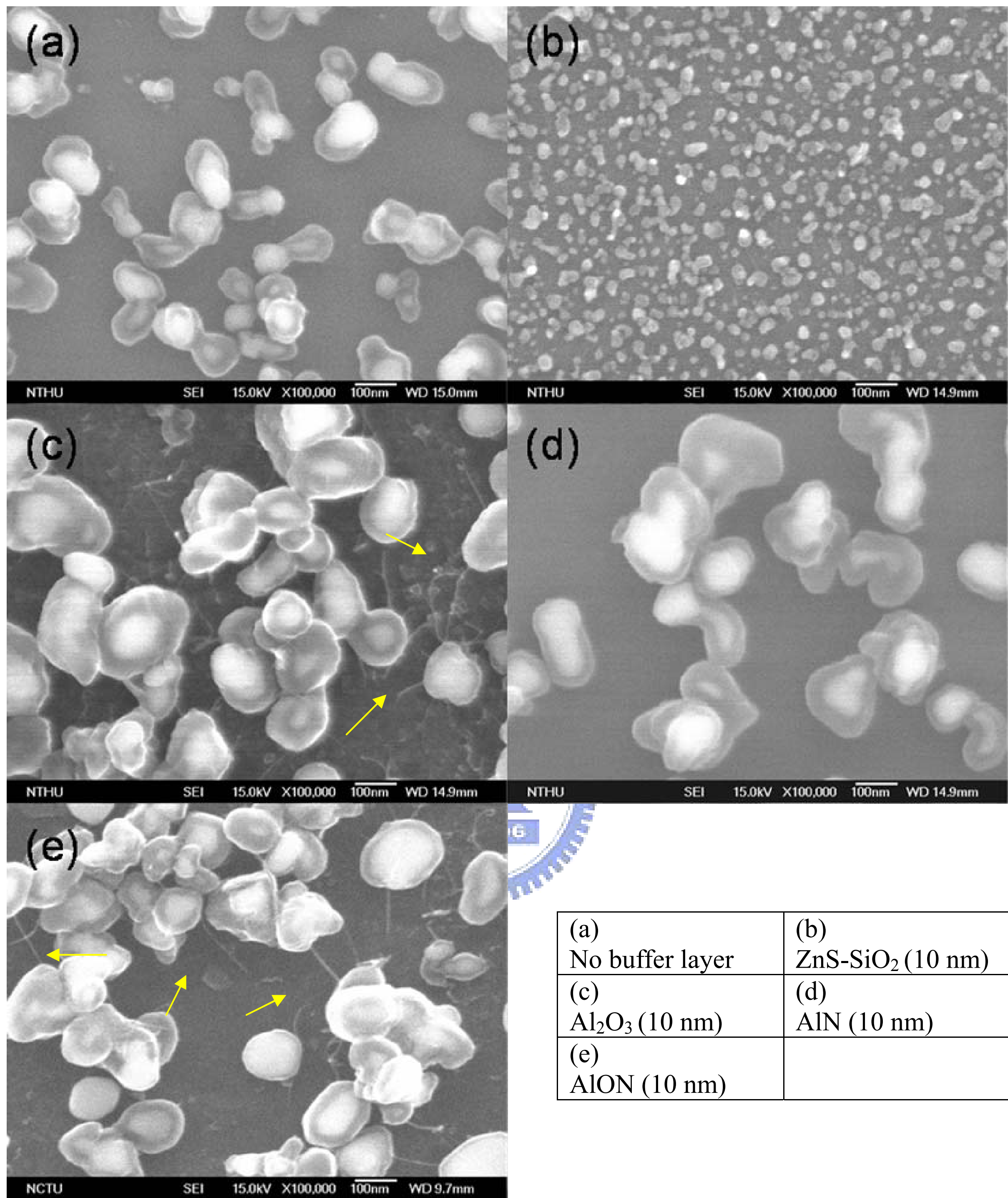
(a) No buffer layer	(b) ZnS-SiO_2 (10 nm)
(c) Al_2O_3 (10 nm)	(d) AlN (10 nm)
(e) AlON (10 nm)	-

圖 4-7 不同緩衝層材料對碳奈米結構形貌之影響於 8 Torr成長壓力(以 10 nm厚的Co為觸媒), (a)No buffer layer; (b) ZnS-SiO_2; (c) Al_2O_3; (d) AlN; (e) AlON(試片編號分別為A2, B2, C2, D2 和E2)



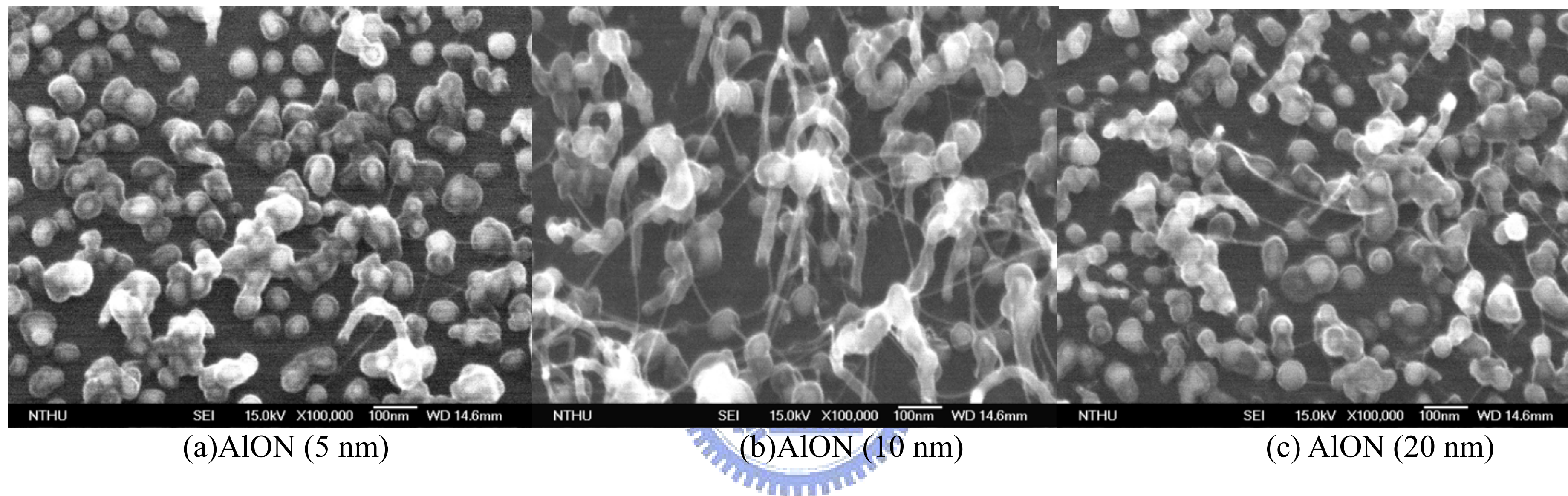
(a) No buffer layer	(b) ZnS-SiO_2 (10 nm)
(c) Al_2O_3 (10 nm)	(d) AlN (10 nm)
(e) AlON (10 nm)	-

圖 4-8 不同緩衝層材料對碳奈米結構形貌之影響於 32 Torr 成長壓力(以 5 nm厚的Co為觸媒), (a)No buffer layer; (b) ZnS-SiO_2; (c) Al_2O_3; (d) AlN; (e) AlON(試片編號分別為 A3, B3, C3, D3 和 E3)



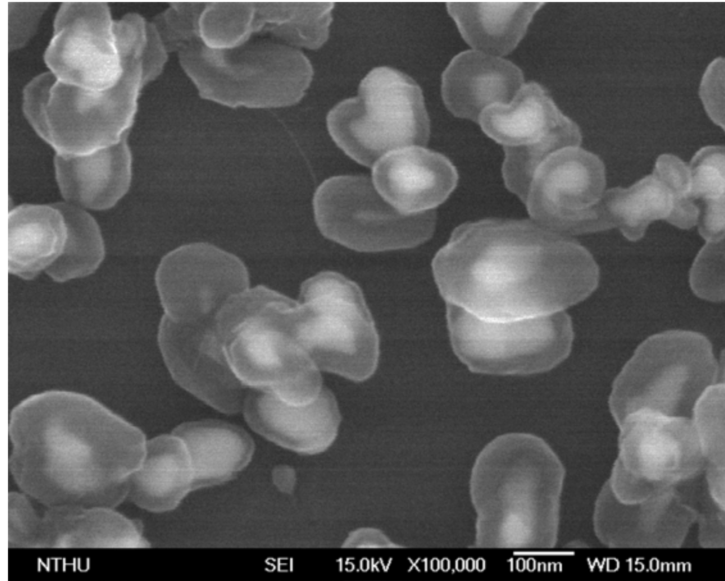
(a) No buffer layer	(b) $ZnS-SiO_2$ (10 nm)
(c) Al_2O_3 (10 nm)	(d) AlN (10 nm)
(e) AlON (10 nm)	

圖 4-9 不同緩衝層材料對碳奈米結構形貌之影響於 8 Torr成長壓力(以 10 nm厚的Co為觸媒), (a)No buffer layer; (b) $ZnS-SiO_2$; (c) Al_2O_3; (d) AlN; (e) AlON(試片編號分別為A4, B4, C4, D4 和E4)

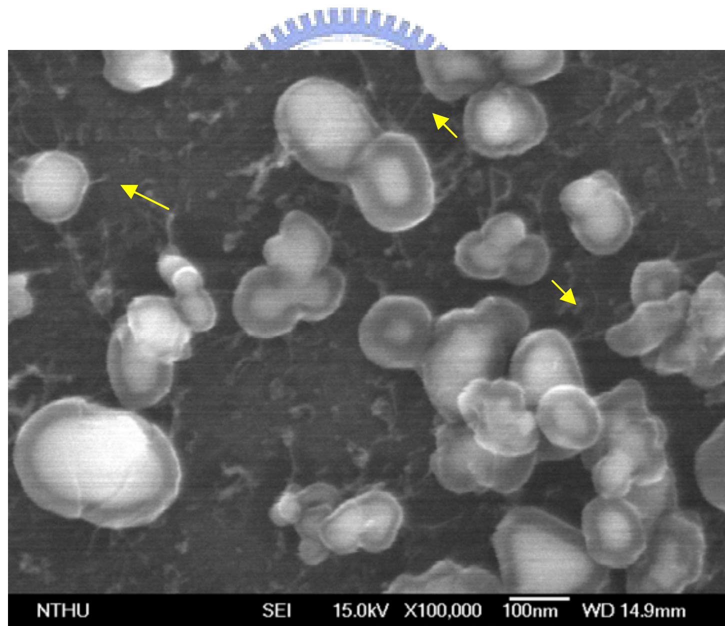


(a)AlON (5 nm) (b)AlON (10 nm) (c) AlON (20 nm)

圖 4-10 不同 AlON 緩衝層厚度對碳奈米結構形貌之影響(以 5 nm 厚的 Co 為觸媒), (a) 5 nm; (b) 10 nm; (c) 20 nm (試片編號分別為 E5,E3 和 E7)

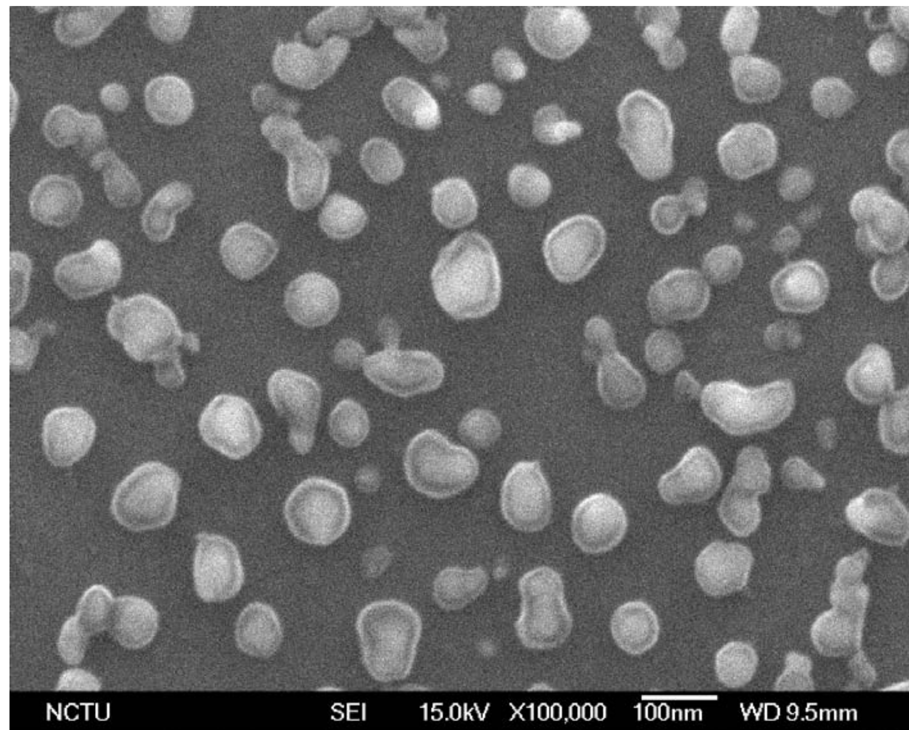


(a) AlON (5 nm)

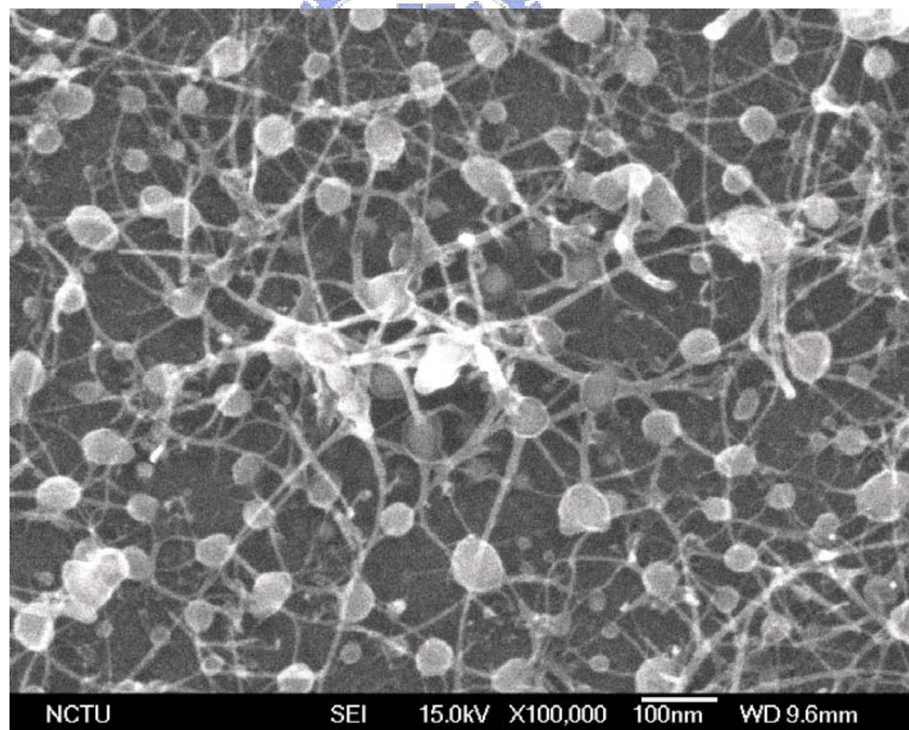


(b)AlON (20 nm)

圖 4-11 不同 AlON 緩衝層厚度對碳奈米結構形貌之影響(以 10nm 厚的 Co 為觸媒),(a) 5 nm; (b) 20 nm (試片編號為 E6 和 E8)



(a) 16 Torr



(b) 23 Torr

圖 4-12 不同成長壓力對碳奈米結構形貌之影響(以 5 nm 厚的 Co 為觸媒於 AlON 緩衝層上),(a) 16 Torr; (b) 23 Torr (試片編號為 E10 和 E9)

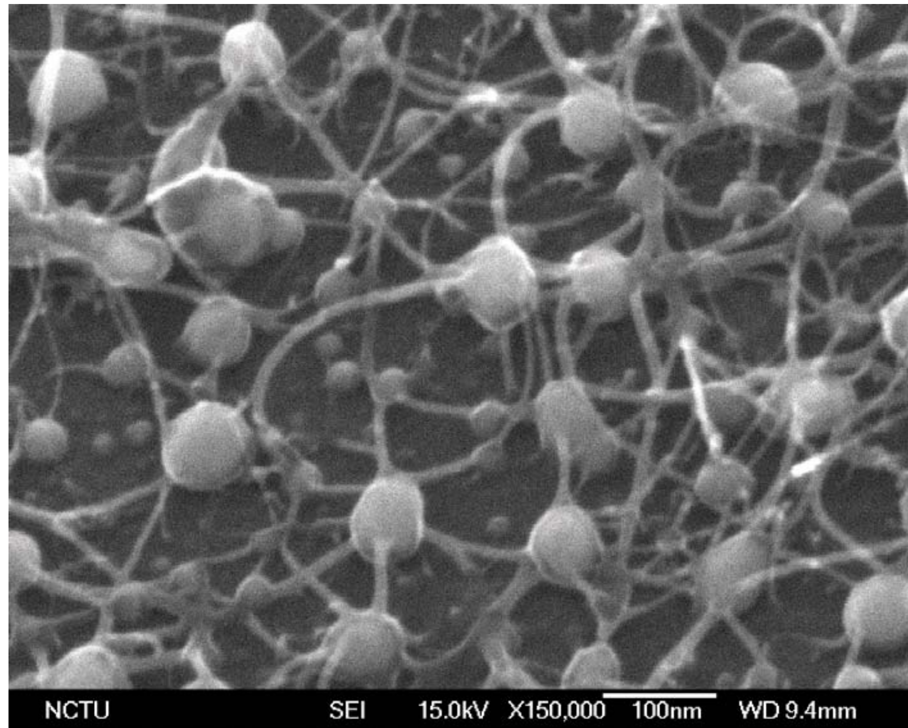


圖 4-13 為試片編號 E9,在試片傾斜 30 度及觀測倍率為 150k 所得之 SEM 圖

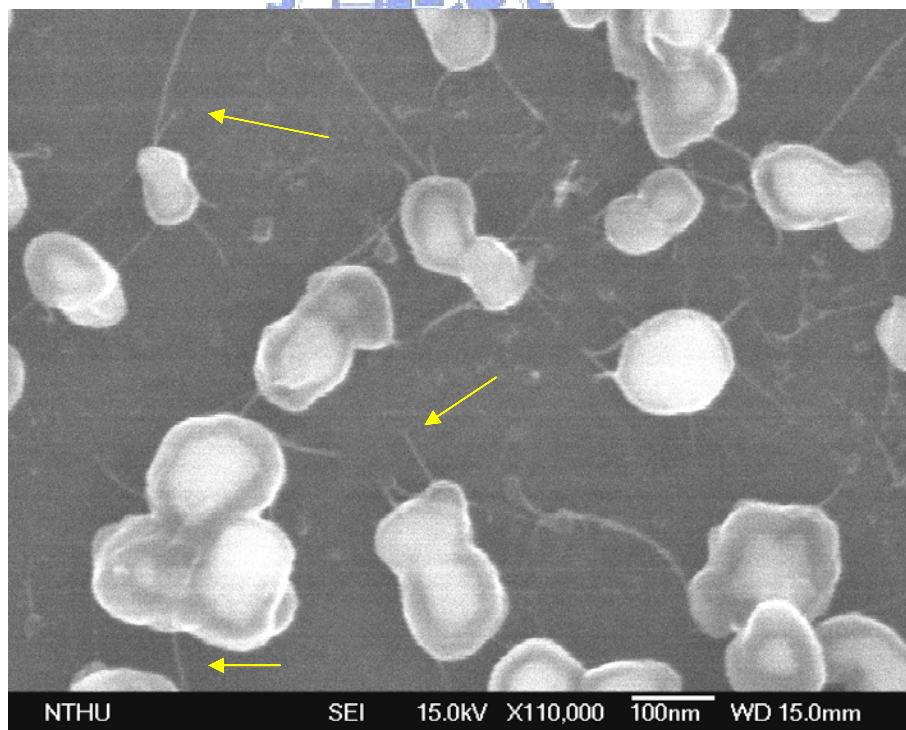
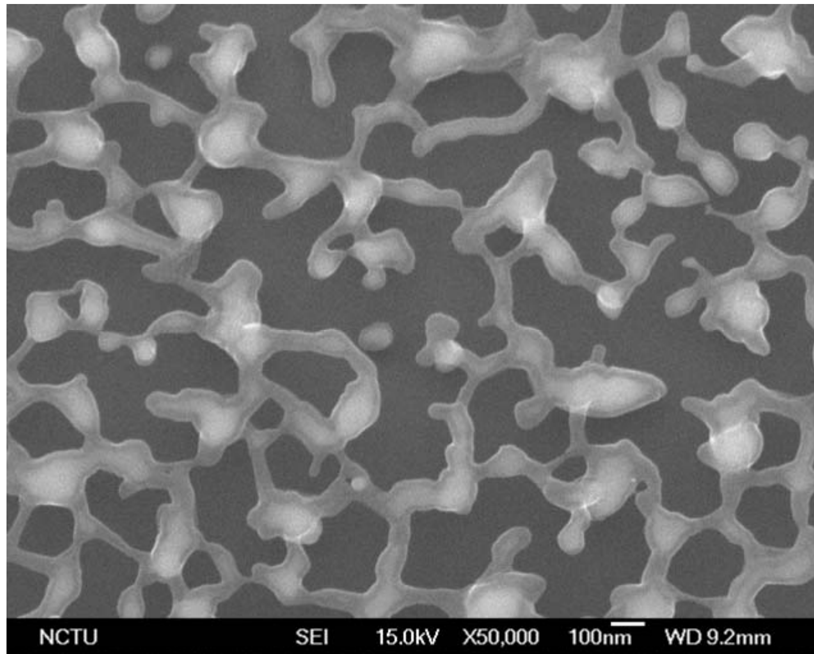
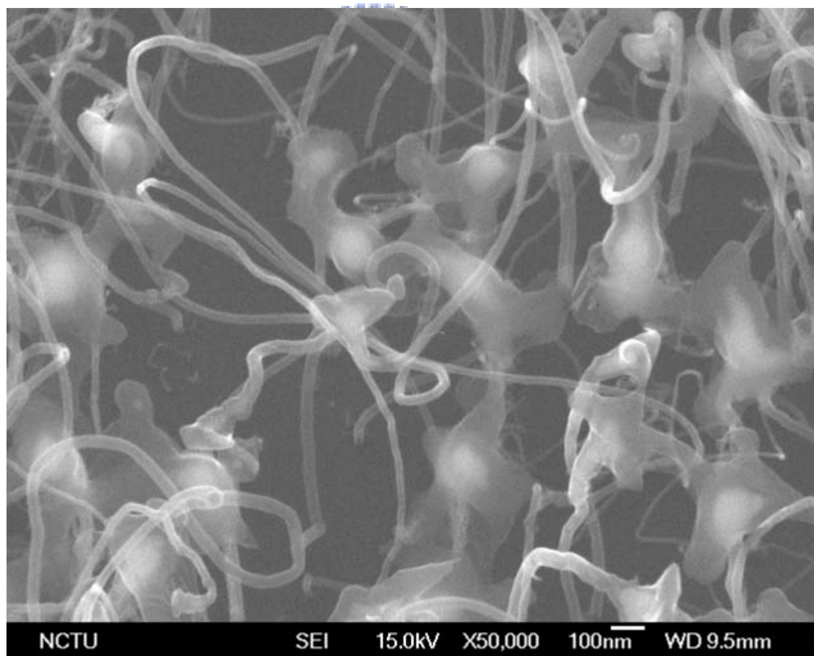


圖 4-14 為 AlN(15 nm)/Co(10 nm)在 32 Torr 成長壓力之碳結構形貌,
試片編號為 D5

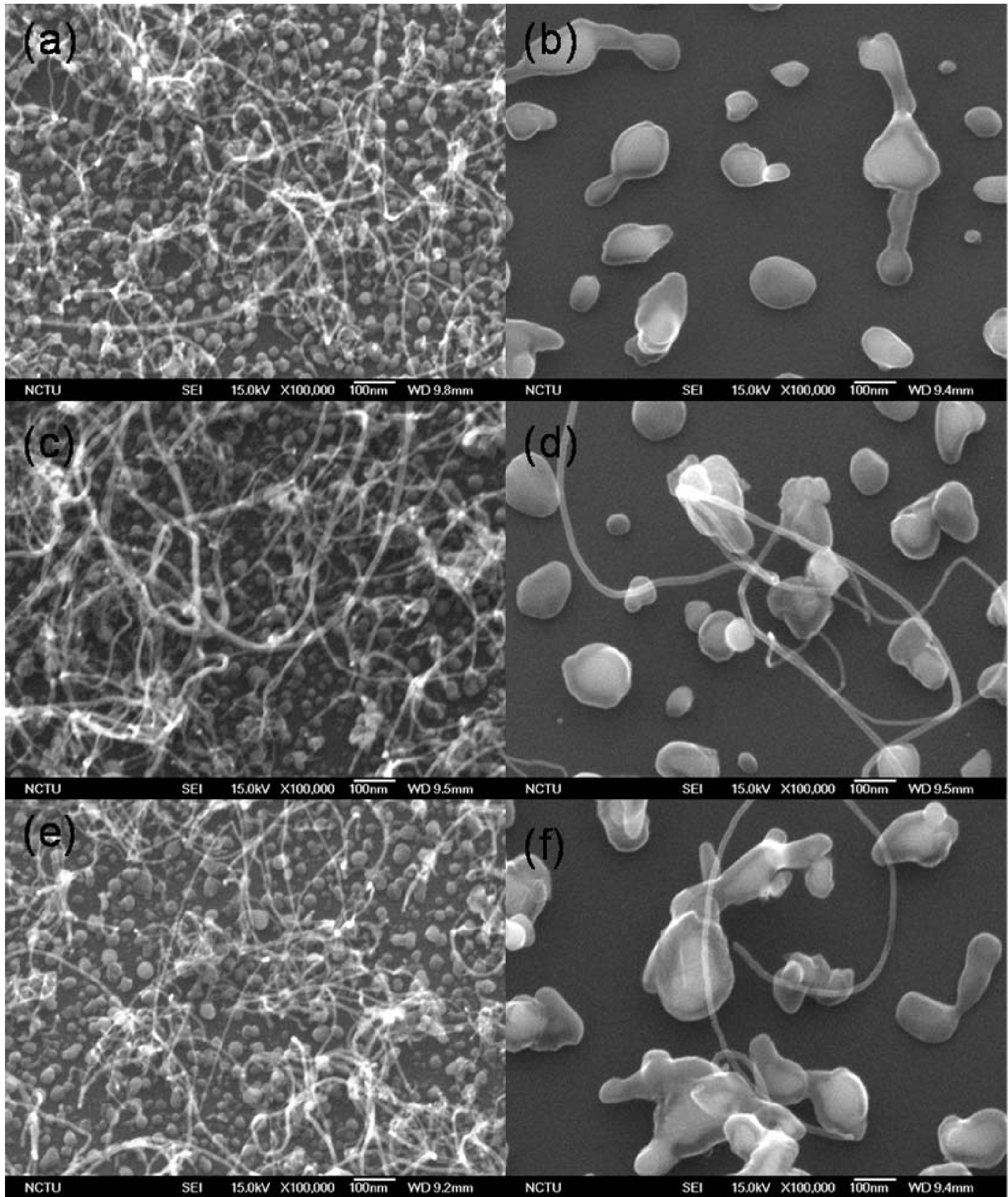


(a) Si_3N_4 (10 nm)



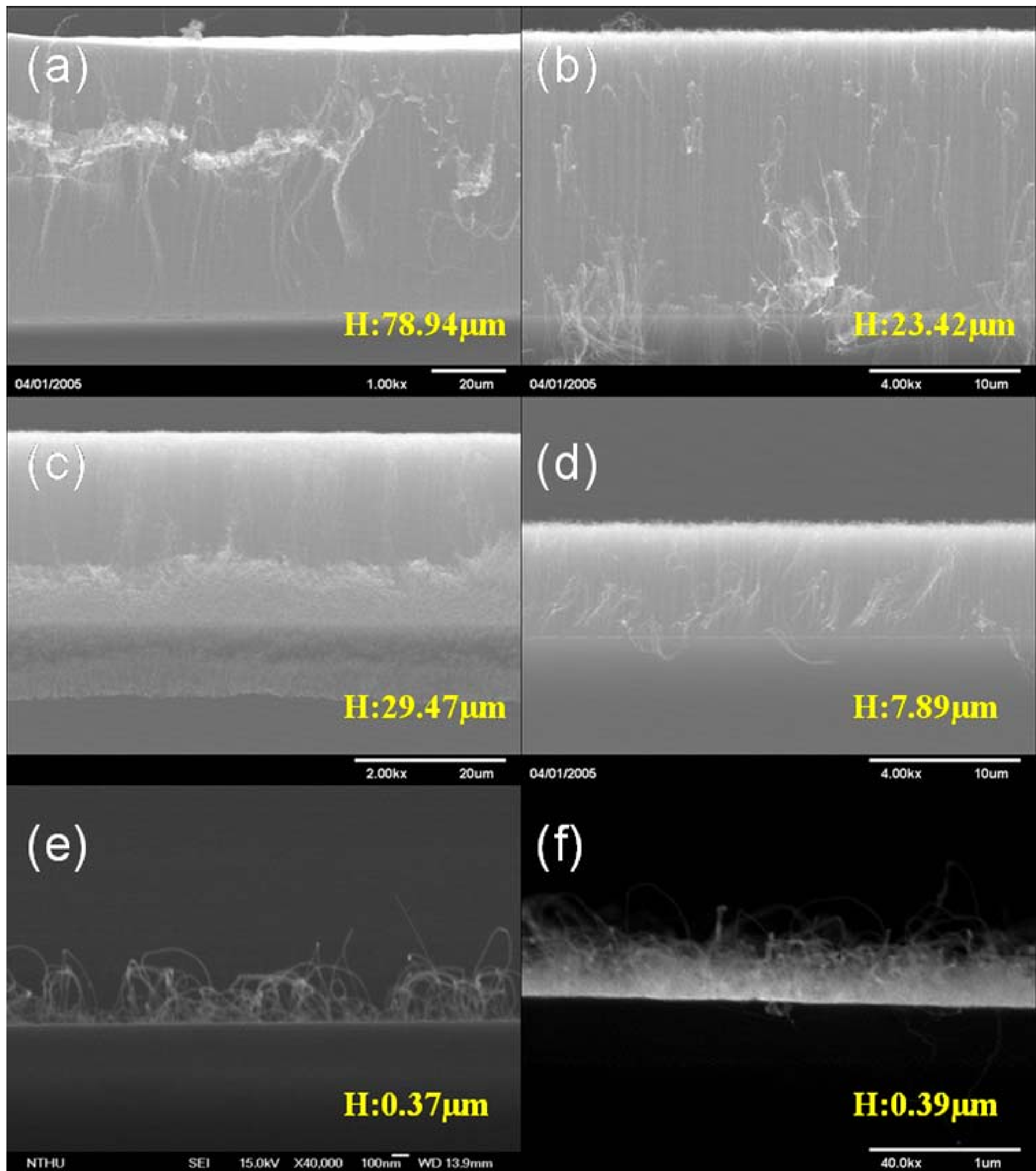
(b) TiN (10 nm)

圖 4-15 Fe(5nm)分別在 Si_3N_4 和TiN緩衝層上所成長之碳奈米結構,試片編號分別為 FB1 和 FC1



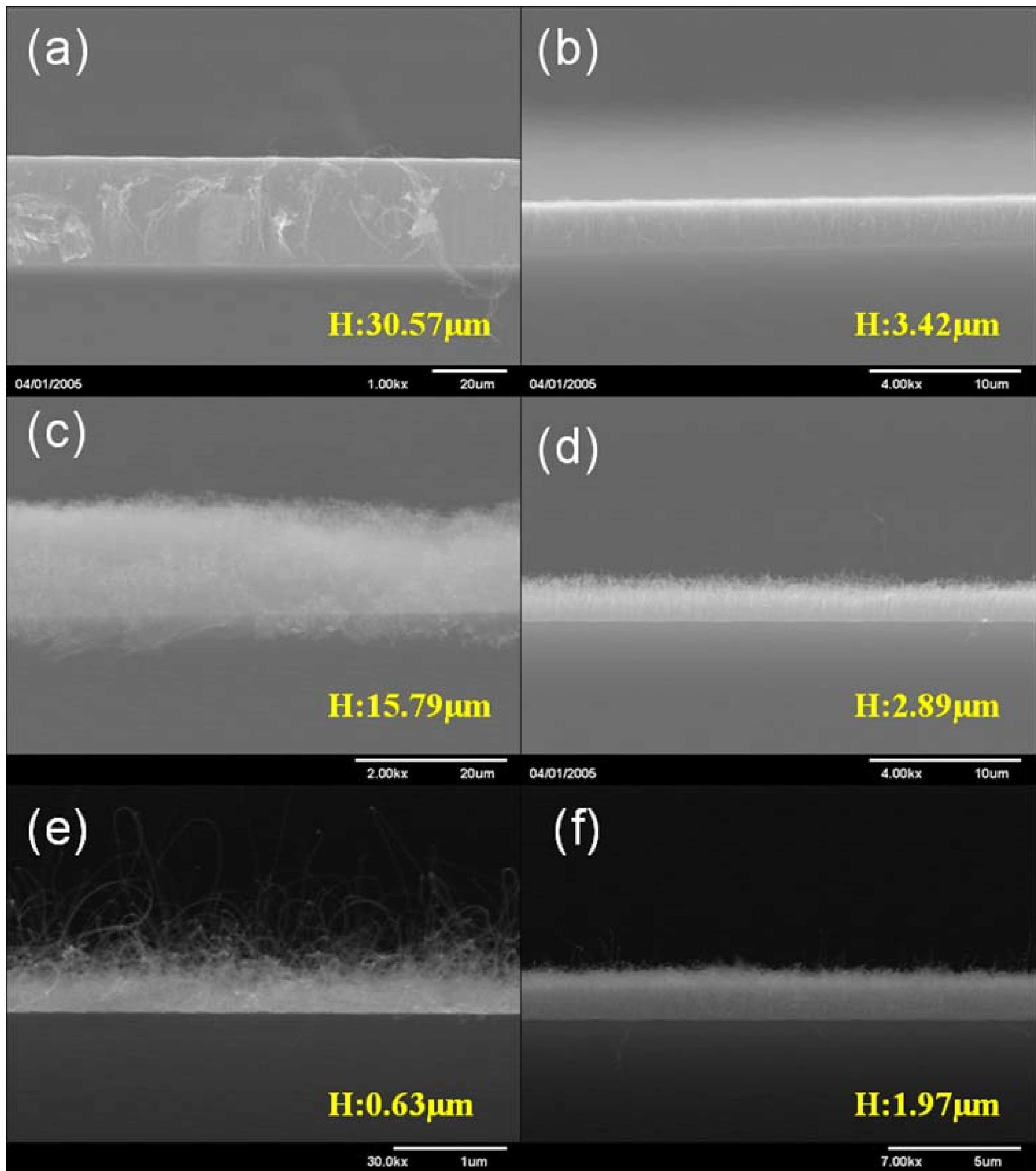
(a) CH_4/ H_2 (5/50 sccm/sccm), [SP.FA1]	(b) CH_4/ H_2 (5/50 sccm/sccm), [SP.FA4]
(c) CH_4/ H_2 (1.5/50 sccm/sccm), [SP.FA2]	(d) CH_4/ H_2 (1.5/50 sccm/sccm), [SP.FA5]
(e) CH_4/ H_2 (1.5/100 sccm/sccm), [SP.FA3]	(f) CH_4/ H_2 (1.5/100 sccm/sccm), [SP.FA6]

圖 4-16 Fe觸媒厚度與CH_4/ H_2流量比對碳管成長速率之影響(no buffer layer),左半圖(a,c,e)與右半圖(b,d,f)分別為觸媒厚度 5 及 10nm,隨不同CH_4/ H_2流量比所成長之碳管形貌俯視圖



(a) CH_4/ H_2 (5/50 sccm/sccm), [SP. FD1]	(b) CH_4/ H_2 (5/50 sccm/sccm), [SP. FD4]
(c) CH_4/ H_2 (1.5/50 sccm/sccm), [SP. FD2]	(d) CH_4/ H_2 (1.5/50sccm/sccm), [SP. FD5]
(e) CH_4/ H_2 (1.5/100 sccm/sccm),[SP. FD3]	(f) CH_4/ H_2 (1.5/100sccm/sccm),[SP. FD6]

圖 4-17　Fe觸媒厚度與CH_4/ H_2流量比對碳管成長速率之影響(Al_2O_3 buffer layer),左半圖(a,c,e)與右半圖(b,d,f)分別為觸媒厚度 5 及 10nm,隨不同CH_4/ H_2流量比所成長之碳管形貌側視圖



(a) CH_4/ H_2 (5/50 sccm/sccm), [SP. FE1]	(b) CH_4/ H_2 (5/50 sccm/sccm), [SP. FE4]
(c) CH_4/ H_2 (1.5/50 sccm/sccm) , [SP. FE2]	(d) CH_4/ H_2 (1.5/50sccm/sccm), [SP. FE5]
(e) CH_4/ H_2 (1.5/100 sccm/sccm), [SP. FE3]	(f) CH_4/ H_2 (1.5/100sccm/sccm), [SP. FE6]

圖 4-18 Fe觸媒厚度與CH_4/ H_2流量比對碳管成長速率之影響(AlN buffer layer),左半圖(a,c,e)與右半圖(b,d,f)分別為觸媒厚度 5 及 10 nm,隨不同CH_4/ H_2流量比所成長之碳管形貌側視圖