Chapter 4

Conclusions and Future Prospects

4.1 Conclusions

Recently, the direct growth of CNTs on glass substrate by thermal CVD at low temperature has been researched for the fabrication of field emission displays. Owing to the higher throughput and better uniformity, thermal CVD is still the most attractive method for CNT growth. Although using soda lime glass substrate indeed costs down, the melting point of 570℃ restricts the processing temperature at which CNTs were synthesized by thermal CVD. Therefore, in the field of CNT-FED fabrication, how to grow uniform CNT at low temperature has been one of the most important issues. We successfully investigated the multilayer catalyst films as catalyst to grow CNTs at 550℃ and 500℃ for 30mins by thermal CVD. Especially, the CNTs using 20A Co/30A Cr/100A Al and 20A Co/30A Ti/100A Al have the superior performance no matter how the morphology and field emission properties are. From the SEM, EDS, XPS, and XRD results, the mechanism of CNTs using multilayer catalyst films can be established. The Co film is a catalyst metal to grow CNTs, the Cr film enhances adhesion between CNTs and substrate and Cr carbide can disperse carbon atoms uniformly, and Al_2O_3 which was transformed from Al film in the pretreatment can prevent catalyst particles from merging together. Ti metal can be transferred to TiC, which means the formation carbide lowered the bottom of catalyst carbon solubility, as shown in Fig.3-13 (a-c)

In sum, multilayer catalyst films possess some advantages, including the lower melting point as nanoparticles formation and more activity for low temperature CNT growth. Such excellent field emission properties, especially the 20A Co/30A Cr/100A Al and 20A Co/30A Ti/100A Al were the best candidates for multilayer catalyst film , first at 550℃ including low turn on field (3.71V/um)/(3.5V/um) and high current density (18.24 mA/cm^2)/ (28.6 mA/cm^2). Besides, CNTs using 20A Co/30A Cr/100A Al and 20A Co/30A Ti/100A Al had the superior performance no matter how the reliability and field emission properties were, which exceeded 10mA/cm^2 even after 1 hr stress test. Additionally, we listed some comparison with recently research in Table 4-1. [59-68] and uniform luminescent images and its performance gave a great hope for the CNT-FED in the future.

Table 4-1 Comparison with other recently research.[59-68]

	This work	Ref.1	Ref.2	Ref.3	Ref.4	Ref.5
CVD process	Thermal CVD		PECVD	ECR-CVD	RF-PECVD	MPCVD
catalyst	Co/Ti/Al & Co/Cr/Al	Ni(5 nm)	Ni/Cr (6 nm/70 nm)	Co (10 nm)	Fe (5nm)	Ni/Ti
pretreated gas	H_2		H_2	Ar	H_2	
gas	C_2H_4		C_2H_2/NH_3	CH_4/H_2	C_2H_2	CH_4/H_2
growth Temperature	550℃	650℃	600℃	630℃	650℃	700℃
Turn on Field (V/μm)	3.81	2.3	3.2	7.11	2	10
anode current density (mA/cm^2)	28.6 & 18.24 (E=6 V/μm)	1.5 (E=4 V/μm)	0.1 (E=6 V/μm)	6.73*10^{-2} (E=10V/μm)	1.5 (E=3 V/μm)	1 (E=15 V/μm)

	This work	Ref.10	Ref.9	Ref.6	Ref.7	Ref.8
CVD process	Thermal CVD	Two-zone hot filament Thermal CVD	RF-PECVD	PECVD	Thermal CVD	Two-zone hot filament Thermal CVD
catalyst	Co/Ti/Al & Co/Cr/Al	Co/Ti (5 Å/5 Å)	Ni/Cr (100nm/30 nm)	Ni/Cr(3nm/150nm)	Ni/Ag (200nm/5μm)	Ni/Ti (100 nm/200 nm)
pretreated gas	H_2		H_2	NH3	NH3	NH3
gas	C_2H_4		CH_4	C_2H_2	C_2H_2	C_2H_2
growth Temperature	550℃	700℃/550℃	400℃	550℃	550℃	550℃
Turn on Field (V/μm)	3.8	2.3	2	5	2.8	1.3
anode current density (mA/cm^2)	28.6 & 18.24 (E=6 V/μm)	0.1	1 (E=3.3 V/μm)	0.01 (E=6 V/μm)	10 (E=4 V/μm)	2.5

Moreover, the low temperature triode structure with low driving voltage , high field emission current , and the improvement of gate controlled anode current CNT-triodes was proposed and characterized. The insulated gate structure field emission triodes which can avoid the short circuit problem between cathode and gate has been realized. So far, the Ti 30 A showed anode current (12.38 mA/cm^2) gate current (81.6 mA/cm^2) at 80 V/um and field emission efficiency was 13.17%. Cr 30 A showed anode current (21.6 mA/cm^2) gate current (196.4 mA/cm^2) at 80 V/um and field emission efficiency was 9.91%, many problems still have to be overcome. We believe after some improvements the low temperature CNT triode structure display will be realized.

For practical application of CNT-FED, we utilized glass as the substrate for CNT growth. By using 20A Co/30A Cr/100A Al and 20A Co/30A Cr/100A Al as the catalyst, we have synthesized uniform CNTs on a large area of glass and obtained fine electric properties. Excellent field emission properties could be obtained, which exceeded 20mA/cm^2 even after 1 hr's stress test. It is gratified that we have fabricated CNT-FED on glass substrate by thermal CVD successfully.

We believe that the multilayer catalyst films investigated in this thesis are helpful to the synthesis of CNTs for the application of flat-panel FED.

4.2 Future Prospects

For the synthesis of CNTs for field emission displays, the further research topics are presented as follows:

(1) Grow CNTs at low temperature (below 500℃) by thermal CVD

(2) Reduce density of CNTs to avoid screening effect

(3) Improve the uniformity and stability of CNT-FED

(4) Use co-sputtering to mix catalyst and interlayer with suitable surface energy, try improved the nano-particle uniformity.

(5) Identify the proof by other CVD processes, like ECR-CVD, MP-CVD…

For the filed emission property investigation of CNTs:

(1) The long-term reliability should be researched.

(2) To improve the graphite crystallization of low temperature growth of CNTs

(3) To enhance field emission ability by post-treatment

For the low temperature CNT triode structures:

(1) Optimum CNTs length should be developed to reduce the gate leakage current and gain the best field emission efficiency.

(2) Fabricate CNT-FED on glass substrate with triode structure

(3) To increase the uniformity of luminescent images