

# FIGURE CAPTIONS

## Chapter 1

Fig. 1-1 Energy diagrams of vacuum-metal boundary: (a) without external electric field; and (b) with an external electric field.

Fig. 1-2 The schematic diagram of (a) conventional CRT, (b) FED.

Fig. 1-3 The SEM micrograph of (a) Spindt type triodes array, (b) Spindt type field emission triode, and the schematic image of (c) Spindt type triode diagram [27-29]

Fig. 1-4 The FED products based on Spindt type field emitters, (a) motorola 5.6" color FED, (b) Pixtech 5.6" color FED, (c) Futaba 7" color FED and (d) Sony/Candescent 13.2" color FED. [30]

Fig. 1-5 (a) Si tip formed by isotropic etching and (b) Si tip field emission triodes array formed by CMP. [31]

Fig. 1-6 (a) SEM image of CNT cathode from Samsung's FED. (b) Demonstration of a 4.5-inch FED from Samsung. The emitting image of fully sealed SWNT-FED at color mode with red, green, and blue phosphor columns. [35]

Fig. 1-7 Lindemann criterion [41]

Fig. 1-8 the relationship between melting point and (a) particle sizes, (b) bulk metal ...., Co metal for example [42].

Fig. 1-9 the calculated surface energy for (a) the fcc (111) surfaces of the 3d metals. (b) period table elements. [43]

Fig. 1-10 The growth rate variation with temperature for thermal CVD and PECVD. The data points for thermal CVD and high temperature PECVD are from previous data by Ducati *et al.*. The values for the activation energies were calculated from a linear interpolation of the slopes. [44]

## Chapter 2

Fig. 2-1 Schematic experimental procedures

Fig. 2-2 (a) photo and (b) schematic picture of thermal CVD

Fig. 2-3 Heat of formation of various hydrocarbon gases. [46]

Fig. 2-4 Diode structure fabrication flow diagrams

(a) 2000Å Cr cathode deposition by Egun, (b) Lithography procedure (c) Multilayer catalysts deposition, (d) Lift photoresist off, (e) Pretreatment, and (f) CNT growth.

Fig. 2-5 Surface Energy with catalyst interface reaction diagrams[this work]

Fig. 2-6 Heat of Formation Carbides diagrams[this work]

Fig. 2-7 Experiments A-D diagrams (a) thickness increased to 50 Å (b) thickness from 10 Å to 30 Å (c) Cr : thickness added to 100 Å ,and Ti : added to 150 Å (d) growth temperature lowed down to 500°C , repeat the experiment.

Fig. 2-8 Triode structure fabrication flow diagrams

(a) 2000Å Cr cathode, 1µm SiO<sub>2</sub>, and 2000Å Cr gate deposition by Egun, PECVD, and Egun, respectively. (b) Lithography procedure, (c) Define the gate and spacer by wet etching, (d) Multilayer catalysts deposition, (e) Lift photoresist off, (f) Pretreatment, and (g) CNT growth.

Fig. 2-9 Diode structure of CNT-FED on glass substrate

(a) 2000Å Cr cathode deposition by Egun, (b) Lithography procedure (c) Multilayer catalysts deposition, (d) Lift photoresist off, (e) Pretreatment, and (f) CNT growth.

Fig. 2-10 High vacuum measurement system

### Chapter 3

Fig. 3-1 The Surface energy of interlayer Diagram.

Fig. 3-2 (a) The SEM cross-section images of CNT growth without interlayer and image represents the top view image of, (b) which growth condition.

Fig. 3-3 The SEM cross-section images of CNT growth with interlayer of (a) W 20 A, Mo 20 A, Pt 20 A, Cr 20 A, Hf 20 A, Pd 20 A and image represents the top view image of, (b) which Ta 20 A, Ti 20 A, and Cu 20 A.

Fig. 3-4 (a) I-V plot in the Exp. A and (b) F-N plot in the Exp. A (Effect of interlayer)

Fig. 3-5 (a) The field emission current versus gate voltage, the anode was set at 450 volt, (b) The F-N plot of the fabricated device, the linearity clarifies the field emission phenomenon.

Fig. 3-6 The field emission current versus anode voltage with different gate bias.

Fig. 3-7 (a) I-V plot in the Exp. A and (b) F-N plot in the Exp. A (Effect of interlayer)

Fig. 3-8 Emission current stability of the insulated gate structure CNTs triode over a period of 1500 seconds.

Fig. 3-8 Raman analysis in Exp. A ; (a) G peak at  $1590\text{ cm}^{-1}$  and D peak at  $1330\text{ cm}^{-1}$ , (b) IG/ID ration vs. anode current density .

Fig. 3-9 The SEM cross-section images of CNT growth with interlayer of (a) Cr 100 A , (b) Ti 100 A, and Ti 150 A .by which image represents the top view .

Fig. 3-10 (a), (c) I-V plot in the Exp. B and (b),(d) F-N plot in the Exp. B (Effect of heat from formation carbide)

Fig. 3-11 (a), (c) XPS analysis from Handbook of X-ray Photoelectron Spectroscopy, Perkin-Elmer, Eden Prairie, MN, 1979 (b) in using 20Co/30Ti/100Al in Exp.B , (d)20Co/30Cr/100Al in Exp.B[48-49]

Fig. 3-12 XRD analysis for CNTs using 20Co/20Cr/100Al in the Exp. A

Fig. 3-13 (a) Heat of interlayer formation carbides ,(b)CNTs tip growth model, (c) interlayer below the catalyst diagram.

Fig. 3-14 (a) TEM analysis of CNTs growth in Exp.A using 20Co/30Ti/100Al (b) EDS analysis.

Fig. 3-15 (a) TEM analysis of CNTs growth in Exp.A using 20Co/30Cr/100Al (b) EDS analysis.

Fig. 3-16 (a) The SEM images of CNT before growth without interlayer, (b) which growth condition.

Fig. 3-17 (a) The SEM images of CNT before growth using Ti , Cr interlayer, (b)Ta, Hf interlayer

Fig. 3-18 (a) The SEM cross-section images of CNT growth without interlayer and image represents the top view image of, (b) which growth condition.

Fig. 3-19 The SEM cross-section images of CNT growth at 500°C with interlayer of (a) Cr 100 A , (b) Ti 100 A, and Ti 150 A .by which image represents the top view .

Fig. 3-20 (a) I-V plot in the Exp. D and (b) F-N plot in the Exp. D (Effect of Growth Temperature)

Fig. 3-21 Raman analysis in Exp. D ; (a) G peak at 1590 cm<sup>-1</sup> and D peak at 1330 cm<sup>-1</sup>, (b) IG/ID ration vs. anode current density .

Fig. 3-22 stress tess in Exp. E at 550°C; (a) Ti interlayer : 20 A, 30 A, and 50 A. (b) Cr interlayer : 20 A, 30 A, and 50 A .

Fig. 3-23 stress tess in Exp. E at 500°C; (a) Ti interlayer : 20 A, 30 A, and 50 A. (b) Cr interlayer : 20 A, 30 A, and 50 A .

Fig. 3-24 Stress test in 10 Hours with Ti 30 A and Cr 30 A

Fig. 3-25 Luminescent image in Exp. E .( Stress test )

Fig. 3-26 The SEM top views and cross-section images of CNT grow with Triode structure using (a) Cr 30 A (b) Ti 30 A , at 550 °C for 30 min.

Fig. 3-27 The SEM top views and cross-section images of CNT grow with Triode structure using (a) Cr 30 A (b)and Ti 30 A , at 550 °C for 45 min.

Fig. 3-28 The SEM top views and cross-section images of CNT grow with Triode structure using (a) Cr 30 A (b) and Ti 30 A , at 550 °C for 60 min.

Fig. 3-29 The SEM top views and cross-section images of CNT grow with Triode structure using (a) Cr 30 A (b) Ti 30 A , at 500°C for 30 min.

Fig. 3-30 The SEM top views and cross-section images of CNT grow with Triode structure using (a) Cr 30 A (b) Ti 30 A , at 500°C for 45 min.

Fig. 3-31 The SEM top views and cross-section images of CNT grow with Triode structure using (a) Cr 30 A (b) Ti 30 A , at 500°C for 60 min.

Fig. 3-32 Luminescent image in Exp. E at 550°C for 45 min growth time.

Fig. 3-33 The pattern with 25 dies, which dimension was 100 μ m<sup>2</sup>.in 1mm x 1mm.

Fig. 3-34 Growth condition in Exp.G [CNT-FED on Glass Substrate for Diode Structure]

Fig. 3-35 The SEM top views and cross-section images of CNT grow in Exp.G

Fig. 3-36 The stress test of Exp.G,(a)at 550°C ,(b)at 500°C

Fig. 3-37 The Luminescent image in Exp. G .

