## *Chapter 7 Conclusion*

Supercapacitor characteristics of manganese oxide/nickel ($MnO_x$/Ni) and manganese oxide/carbon nanotubes/nickel ($MnO_x$/CNTs/Ni) nanocomposite electrodes were investigated in this study. The CNTs were deposited on the Ni substrate by electrophoresis in the 0.5 mg CNT/ 1 mL dimethylformamide solution, while the $MnO_x$ were synthesized by anodic deposition in the 0.16 M manganese sulfate pentahydrate aqueous solution on substrates. The specific capacitances of $MnO_x$/CNT/Ni nanocomposite electrode were 415 and 388 F/g with scan rates of 5 and 100 mV/s, respectively. After 1000 cycles of operation, this electrode can maintain 79 % of its original capacitance. These $MnO_x$/CNT/Ni nanocomposite electrodes with good electrochemical reversibility and high capacitance may be applied to supercapacitors in the future.

Single crystalline ZnO NWs are grown on the flexible PET polymer substrates by hydrothermal route. The optical properties and field emission characteristics significantly depend on the surface morphologies of ZnO NWs deposited on the different substrates. The photoenhanced field emission properties are also observed in the ZnO NWs/ITO/PET device since the carriers are excited by photons. Thus, the hydrothermally grown ZnO NWs on the polymer substrate provide a low temperature synthesis process that may be appropriate for fabricating flexible optoelectronic and field emission devices.

Single crystalline $Mg_xZn_{1-x}O$ ($0 \leq x \leq 0.25$) nanowires (MZO NWs) were synthesized on glass substrates by hydrothermal method using a mixture of aqueous solution of zinc nitrate hexahydrate, magnesium nitrate hexahydrate and hexamethylenetetramine at temperature that ranged from 75 to 105 $^{o}$C. These nanowires with direct band gap ranging from 3.21 to 3.95 eV emitted ultraviolet photoluminescence from 406 to 397 nm at room temperature as Mg content increased. Field emission measurements revealed that the turn on electric field and threshold electric field (current density of 1 mA/cm$^2$) of ZnO NWs are 1.6 and 2.1 V/μm with the $\beta$ value of 3340. Therefore, the low temperature synthesized MZO NWs ($0 \leq x \leq 0.25$) with modulated band gap may be applied to solar cells, light emission, and other nano–heterojunction devices.

The photoluminescence and field emission properties of $Mg_{0.1}Zn_{0.9}O$ nanowires (MZO NWs) hydrothermally grown on the *p*-type silicon (100) substrates with and without phosphorus dopant were investigated. The MZO and PMZO are wurtzite single crystals, and the surface morphologies of MZO NWs are identical to those of PMZO NWs with an average diameter of 50 nm and length of 500 nm. The direct band gaps and emitted ultraviolet photoluminescences of the MZO and PMZO NWs are 3.41 eV, 403.8 nm and 3.56 eV, 385.4 nm, respectively. The MZO NWs grown on Si substrates have an emission threshold electric field of 1.8 V/μm (current density of 1.0 mA/cm$^2$) and a field enhancement factor, $\beta$, of 3048 while the PMZO NWs show enhanced properties with threshold electric field of 1.5 V/μm and $\beta$ value of 3054. These field emission properties are also enhanced by illumination, which reveals that the emission behavior is affected by the surface charge state. Therefore, it is suggested that the band structure of MZO NWs has been modulated by phosphorus incorporation.

Two field emission devices based on low temperature hydrothermally grown ZnO NWs was fabricated and characterized. Fabrication and field emission properties of ZnO NWs planar gate field emission triode were carrying out in this study. The ZnO NWs have a single crystalline wurtzite structure, with ~50 nm in diameter and $3.4\times10^{10}$ cm$^{-2}$ in number of density. The ZnO NWs triode shows a good and controllable emission property with the turn on anode electric field ($E_{on}$,current density of 1 μA/cm$^2$), the threshold anode electric field ($E_{th}$,current density of 1 mA/cm$^2$) and field enhancement factor, $\beta$, of 1.6, 2.1 V/μm and 3340, respectively. The ZnO NW triode exhibits the controllable characteristics with gate leakage region, linear region and saturation region. The ZnO NWs based triode emitter was designed exhibits the gate controllable behavior and emits electrons at a threshold gate bias of 14 V with saturation current density of 12 mA/cm$^2$, $g_m$ of 2.2 μS at a low operating $E_a$ of 2.2 V/μm, and on-off ratio of up to $10^2$. Furthermore, the controllable field emission performance of the ZnO NWs triode can be enhanced by the illumination and argon ion bombardment. A low temperature Si-based microelectronic compatible fabrication process was provided to successfully make ZnO NWs based triode with good field emission properties.

Under gate field emission device based on the low-temperature hydrothermally synthesized single crystalline zinc oxide nanowires (ZnO NWs) was also fabricated on Si substrate for the controllable under gate field emission triode application. Field emission measurements reveal that the under-gate field emission with ZnO NWs exhibit a good emission property with the low turn on electric field, low threshold electric field, high current density, high transconductance and wide controllable field emission properties as a function of gate and anode voltages. The ZnO NW based under-gate emitter was design with a 10 μm cathode active region in width. This device exhibits the gate controllable behavior and emits electrons with the $V_{gth}$ of 7 V and the $J$ up to 27 mA/cm$^2$ under the $V_g$ of 7.5 V and $E_a$ of 2.2 V/μm. The triode also displays a high $g_m$ of 0.38 mS at a low operating $E_a$ of 2.2 V/μm and $V_g$ of 7.5 V.Therefore, the present study provides a low temperature fabrication process being compatible with the Si-based microelectronic integration, and the field emission measurements also show that the emission behavior can be well controlled by adopting the under-gate triode structure.