Chapter 10 Conclusion

10.0 Conclusions

Single crystalline (0002)-oriented ZnO NWs are grown for the first time by copper-catalyzed VLS growth process on p-type Si(100) substrate. The diameters of ZnO NWs within 80-150 nm are controlled by the thickness of the copper thin film. Besides, the ZnO NWs are almost vertically grown on Si substrates by turning the thermal treatment contribution. The XRD and XPS studies determine that the composition of ZnO NWs is stoichiometric and their structures are hexagonal. Room temperature PL spectrum of the NWs shows a strong near band-edge UV emission at 381 nm and a weak and broad deep-level green light emission at 520 nm. We believe that the ZnO NWs grown by the method discussed in this study could be used as semiconducting or optical light-emitting devices in nano-scale electronics and electro-optical applications at much lower production costs.

In summary, the enhanced VLS growth ZnO nanowires in N_2 compared to in Ar was observed. Such enhancement is due to the lower viscosity of N_2 used in ZnO nanowires growth, which was supported by mass transfer control growth mechanism derived in the present study. The ZnO nanowires grown in different carrier gases, N_2 and Ar exhibits hexagonal structure with <0002> orientation. The photoluminescence analysis demonstrated that the nanowires grown in N_2 have stronger ultraviolet emission peak near at 380 nm in comparison with in Ar, which is attributed to larger number of density of nanowires grown in N_2.

The new nanostructure ZnO nanowires/ZnO(002) thin film/Si(100) has been successfully fabricated in a single vertical growth direction. The compositional studies, including EDS, XPS and AES, supported the theory that the ZnO nanowires have stoichiometric composition. TEM characterization confirmed the ZnO nanowires have hexagonal crystal structure. Room temperature PL spectrum of the nanowires on ZnO(002)/Si showed a much stronger near band-edge UV emission at 380 nm compared to those on Si. In summary, well-aligned and vertically grown Cu catalyzed ZnO nanowires, which have an excellent wurtzite structure, less contamination and precise chemical composition, were successfully grown at 750~950 ^{o}C by adopting a CGFP method. The ZnO nanowires emitted strong UV at ~381 nm at room temperature by using Xe-lamp (320 nm) as the excitation source. The field emission measurements indicated high emission current density of 1.5 mA/cm^2 under the field of 8.5 V/μm and low turn-on field of 0.83 V/μm at current density of 25 μA/cm. The Cu catalyzed ZnO nanowires exhibited higher field emission area factor of about 7.18×10^3 and larger field adjustment factor of 1.21×10^{-5} than those values of Au catalyzed nanowires, which is due to the vertical direction growth of Cu catalyzed nanowires. Such vertically grown ZnO nanowire_array is a good candidate for the future flat panel display applications.

In summary, the single crystalline SZO nanowires are fabricated at 800 ^{o}C under the conditions of a vapor-liquid-solid (VLS) growth process. The morphologies of SZO nanowires is quite different from the undoped ZnO nanowires due to the occupancy of Sn atom at the Zn site. This Sn addition also affects the ultra-violet (UV) emission of SZO nanowires. Furthermore, the 0.3 SZO nanowires exhibit good field emission characteristic of 0.05 V/μm as the turn−on electric field and 0.5 mA/cm^2 as the current density. The lower work function of the SZO nanowires is due to the higher carrier concentration and the smaller diameters that result in the higher field enhancement factor. Therefore, the SZO nanowires could be used for fabricating optoelectronic and field emission devices.

In summary, the SIO NWs is successfully fabricated by VLS process while the added Sn dopant that effectively decreases the synthesis temperature from ~1100 ^{o}C to ~770 ^{o}C. The geometry and morphology (80 nm diameter and ~10 μm length) of the SIO NWs are very perfect without much contamination. On the basis of the fabricated process, these nanowires have well-defined cubic crystal structure and less defect or dislocation. On the other hand, the SIO NWs emitted a strong blue light band at ~445 nm at room temperature by using a Xe-lamp (275 nm) as the excitation source. Furthermore, the doped Sn also could shift the main emission to shorter wavelength of the SIO NWs. Therefore, the synthesis of SIO NWs would possess technological promise for manipulating the nano optical properties, which is important in nanoscale optoelectronic applications. The field emission measurements indicated the low turn-on electric field of 0.66 V/μm at a current density of 1.0 mA/cm^2. The low temperature fabricated (~770 ^{o}C) SIO NWs exhibited higher field emission area factor of about 1.48×10^5 and larger field adjustment factor of 2.34×10^{-4} than those values of 900 ^{o}C fabricated nanowires, which is due to the Sn dopant that remained more into the nanowires when fabricated at 770 ^{o}C. The Sn dopant added in the in SIO NWs is ~2.45 a.t.% which lower the resistance and increase the conductivity, respectively. Using these structurally controlled Sn doped SIO NWs, a more interesting physical and chemical properties can be studied. Therefore, the vertically and selectively grown SIO NWs array is a good candidate for the future flat panel display applications.

In summary, the gate controlled ZnO NWs field emission devices have been successfully fabricated by a simple lift-off process. About the physical and chemical properties of the VLS process fabricated ZnO NWs which have well crystalline and composition that can investigate by TEM, XRD and EDS analysis. The field emission characteristics are improved while applied the gate voltage (V_g). Under the V_g is equal to ~35 V, the turn-on electric field is at ~0.6 V/μm that is the best controlled condition we have. Furthermore, the β value has been promoted by the sweep of V_g because of the lower band energy level when V_g is applied that offer a easily tunneling environment for a number of electrons emitted from the tips of ZnO NWs. The more electrons emitted, the higher β value can achieved. While the V_g is equal to 40 V, the β value is become ~17800 which is larger than that β is ~7073 when V_g is equal to 0 V. The transconducance, g_m is also an important data to judge the ability of the gate controlled ZnO NWs field emission devices. In our study, the g_m value is about 4.0×10^{-4} S that means the better controlled V_g locates at beyond ~35V and the anode to emitter electric field is fixed on ~1.5 V/μm which can using the focusing electric field from V_g applied to converge the emission electrons approaching to the stability current density. The side gate controlled ZnO NWs field emission devices have more potential to apply in field emission display (FED) in the future.

10.1 Future Works and Suggestions

The metal oxide NWs, especially ZnO NWs have potentials for much field application such as field emission display arrays or optical emission. Furthermore, the studies of the ZnO NWs are still narrow focus on the electric and optical applications. In the future, there are many kinds of subjects could be study which will increase the speed of commercialize. About the metal oxide nanowires, there are some suggestions to study in the future as follow:

(1). Improveing the synthesized process which could focus on the convenient and easily to mass product. Convenient mass product is the merit to integrate the semiconductor industry.

(2). Offering some whole new growth mechanism to explain the nanowires growth no matter what VLS process or other. In the same time, the new model also could explain the dopant effects.

(3). Establishing new controlled methods to control the turn-on electric field effectively for the ZnO NWs field emission devices. This way will offer more and more possible to improve the prototype for the ZnO NWs field emission devices.

(4). Studying other metal oxide nanowries that could find many new application in each field of the nano technology.

(5). Attempting the hybrid or many of new architecture of the nanowires which will offer any kinds of potentials for the application in the future.