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Formation of p-type ZnO thin film through cocktail implantation

Department of Physics, National Central University, Zhongli District,Taoyuan City 32001,Taiwan
Fifth-year doctoral student: Yao Teng Chuang(莊曜滕), Advisor: Wei Yen Woon(溫偉源)

Motivation

- Advantage of ZnO: Wide direct band gap, lower exciton binding energy at room temperature, native wafer, and transparent characteristics

=> A good candidate to replace GaN as blue light emitter

- The lower formation energy of donor defects, Zn_I and V_O, result in native N-type ZnO

=> Mono-doped is difficult to form P-type ZnO under equilibrium method

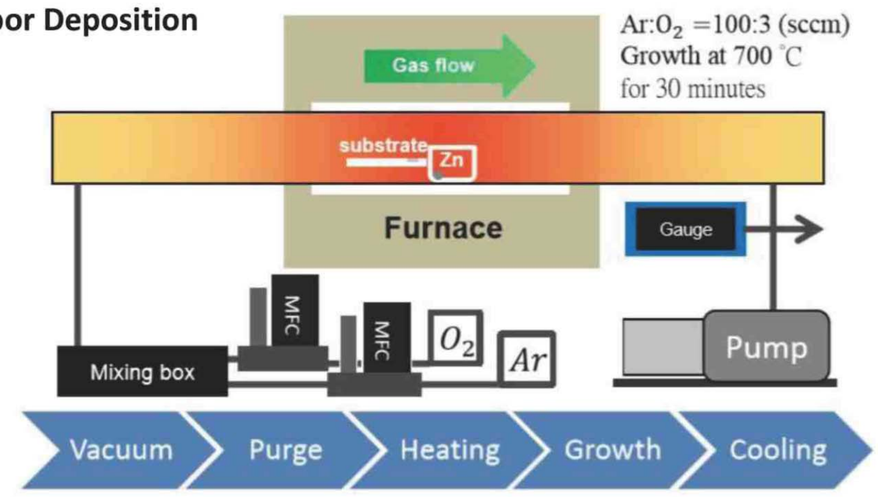
=> Different kinds of dual-doped achieve P-type ZnO with narrow fabricated window

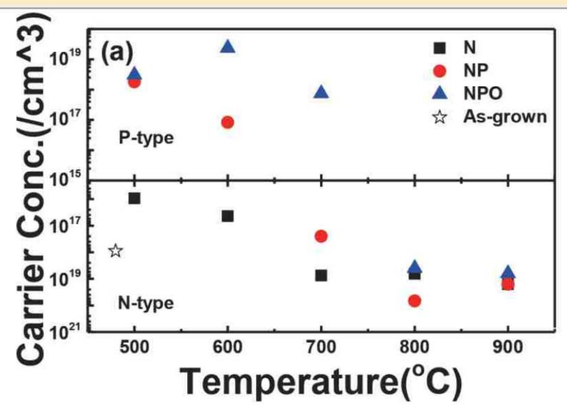
Q:

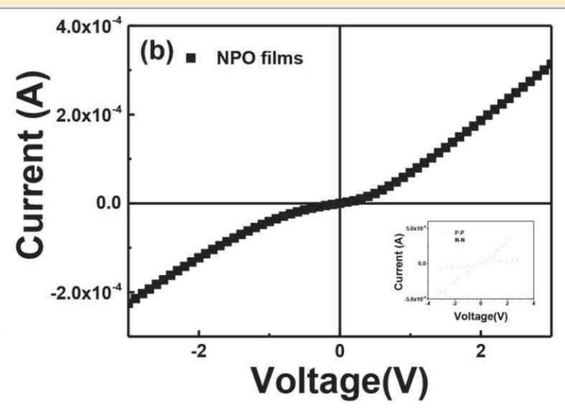
- What kind of defects result in P-type ZnO formation for N and P dual-doped?
- Is any improvement for P-type ZnO via oxygen co-implanted?
- How to fabricate P-type ZnO with broaden activation window?

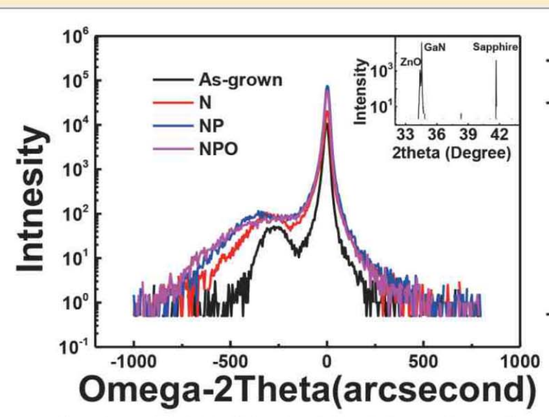
Setup

Chemical Vapor Deposition

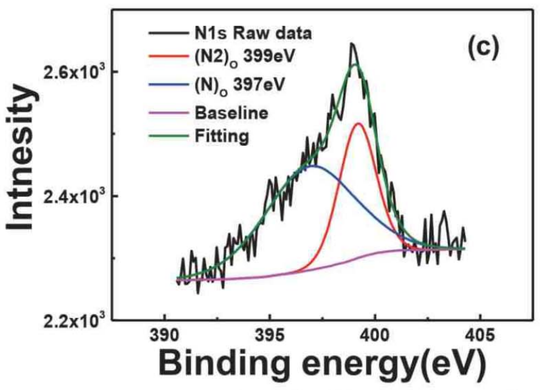








Ion	Ionic radii
Zn^{2+}	0.74Å
P^{3+}	0.44-0.58Å
P^{5+}	0.31-0.34Å
O^{2-}	1.38-1.4Å
P^{3-}	1.8-2.12Å
N^{3-}	1.68Å



- Comparing to the as-grown sample, N only doped sample only become slightly N-type under lower activation temperature

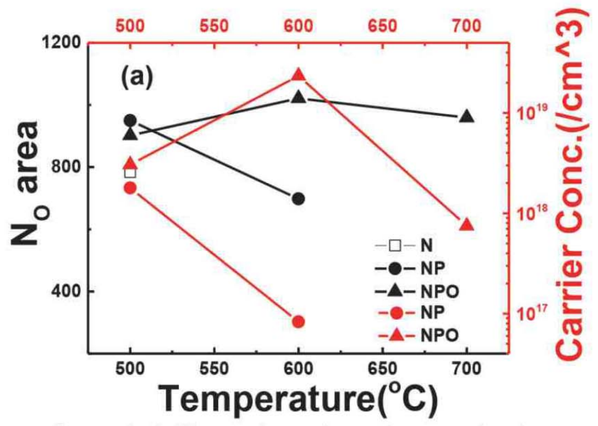
- P-type ZnO are fabricated in co-implanted samples and have 200℃ activation window, which is much broaden activation window than other works

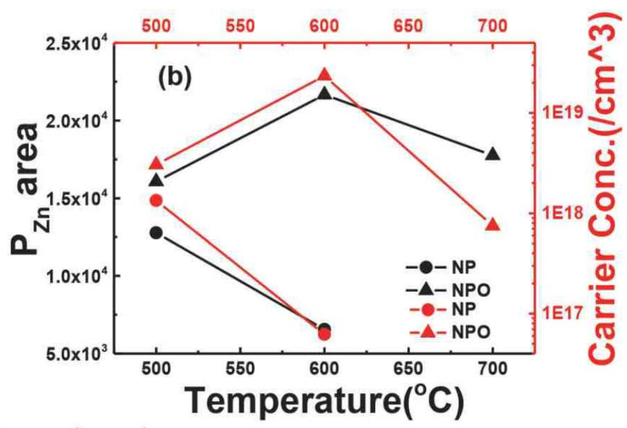
- Rectifying behavior can be observed via P-ZnO:(NPO)/N-ZnO homojunction, which is different to the linear behavior between two P-type or N-type ZnO

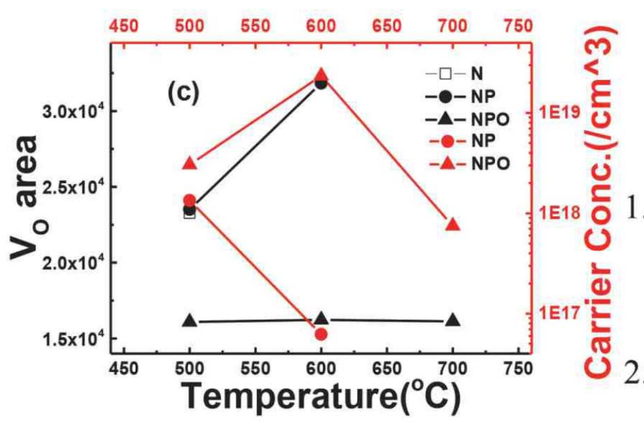
- Only (0002) ZnO thin film signal can be observed in long rang scanning, indicating no other phase exist in CVD growth process

- For all the doped samples, lattice constant getting larger, but it is not in consistence with only acceptor like defect exist, N_O and P_O

- From the XPS O spectrum fitting, the existence of $(N_2)_O$ is the reason why lattice become larger because much larger size dominated in lattice constant







- The solubility of N_O is enhanced when p is co-doped
- Both of trend of integrated peak area of N_O and P_{Zn} exhibit obvious resemblance to carrier concentration, indicating N_O and P_{Zn} are both instrumental to formation of P-type ZnO
- For the additional O co-doped sample, the decrement of peak area of V_O and almost constant value of V_O under P-type ZnO activation window, implying reduction of V_O via additional O implanted facilitates the formation of P-type ZnO and stabilizes the P-type conductivity with broader activation windows

Conclusion:

1. Stable P-type ZnO can be fabricated via co-implanted with a wide thermal activation window
2. N_O and P_{Zn} are regarded as the major defect configuration for P-type ZnO formation through generation of P_{Zn}-$4N_O$ complex defect as theory
3. Reduction of V_O plays the critical role to stabilize and broaden the thermal activation window

研究生活及心得:從設計實驗、架設儀器到實驗量測一切都相當的忙碌與辛苦，不僅要花許多時間在實驗的執行面上，更需要花功夫在找出實驗的癥結點與閱讀文獻資料來舉證輔佐實驗的結果。雖然剛起步時會對實驗有許多的質疑，但隨著時間的前進，慢慢地將問題一一的解決並獲得完整架構的實驗內容時，頓時之間會覺得自己的努力是有所斬獲而感到欣慰。對於這樣的歷練相信不只光在實驗上，往後不管是從事研究員或是研究相關的工作，都將會是未來成功工作的重要基石。希望能藉由博班的歷練，可以在未來台灣半導體相關研究有實質上的貢獻。