Abstract

III-Nitride materials have gathered enormous attention and undergone fast development, due to superior properties such as wide band gap, high stability, high electron motilities, high break down voltage and sensitivity to ultraviolet light. GaN ultraviolet (UV) detector can be used in fire detecting, missile's seeker, combustion process monitoring and other monitoring systems, which require UV detection in harsh environments. Tunability of band gap and the possibility of formation of heterostructures with group III-nitride materials allow the design of complex structures to detect both UV and infra-red (IR) spectral regimes (multi band) on a single chip. By growing AlGaN/GaN quantum well layers, IR detector can also be obtained, which means IR and UV detector can be achieved using same material. GaN based UV/IR detectors can be grown on sapphire, Si or SiC substrate, but sapphire and SiC substrates are more expensive than Si. Moreover, development of such a technology on Si allows lower cost and opens the prospect of integration of III-nitride with Si technology. In this work, plasma assisted molecular beam epitaxy (PA-MBE) is used to grow multi band detector heterostructures on Si substrate.

UV/IR dual band detectors grown on sapphire substrates have been reported. Demonstration of multiband detectors without any optical filter has also been reported. However, growth of such detectors on Si is challenging due to large difference of thermal and lattice mismatch between Si (111) substrate and GaN, which leads to tensile strain and cracking. In this thesis, material properties, parameters for growth optimization and device performance of GaN-based photo detector structures grown on Si will be discussed. The effect of the AlN layer on the surface and crystal quality of GaN is studied. GaN and AlGaN layers with different Si concentration have been studied. Doping concentration is stable throughout the growth as observed in secondary ion mass spectroscopy (SIMS) and the crystal quality does not degrade after doping. Crack free Si doped

GaN with RMS roughness less than 1 nm is successfully grown on Si (111) substrates up to 4 inch. Si doped AlGaN with Al composition of 30% is also obtained on both Si (111) substrate and MOCVD grown AlN/Si template. Highest Si doping of 3×10^{20} cm^{-3} is achieved with RMS roughness less than 1 nm. The achievement of almost crack-free wafers with total epilayer thickness up to 1.3 to 1.4 μm can be attributed to the lower thermal stress from low temperature operation of PA-MBE growth process. Smooth and crack-free multilayer structures for UV and IR photo detector application have been successfully grown on 4 inch Si substrate.

UV photo detectors are fabricated and characterized for electrical and optical properties. During device fabrication, the etching recipe is modified to get uniform and smooth etching surface. Device size may also affect the performance, and hence different mesas namely interdigitated and square detectors are fabricated to understand the effects of device dimensions. Electrodes are fabricated after dry etching by the evaporation of Ti/Al/Ti/Au in that order on both bottom and top layers. The devices are annealed using rapid thermal processing (RTP) to achieve ohmic contacts. UV photo current under different applied bias and different wavelengths of the incident light is measured. UV photo responsivity is calculated from photo current measurements. It is found interdigitated electrodes shows higher responsivity and highest responsivity of 5.7A/W is obtained.

IR photo detectors are also fabricated using similar process and low temperature IR photo responsivity measurements is conducted. Obvious response in middle IR region (4.5 μm) is observed at 50K. Room temperature of similar structure shows response in UV region and highest UV responsivity of 10mA/W is achieved.

Publication List

Conference:

1. Yi Zheng, Manvi Agrawal, K. Radhakrishnan, N. Dharmarasu, G. S. Karthikeyan, A. G. Unil Perera, Annalisa Bruno, Cesare Soci, "AlGaN-based UV-photodetector heterostructure on Si (111) substrate grown by PA-MBE", in 2017 International Workshop on UV Materials and Devices (IWUMD), Nov. 2017.
2. Y. Zheng, M. Agrawal, N. Dharmarasu, and K. Radhakrishnan, "Growth of AlGaN/GaN multiple quantum well structure on 4-inch Si by plasma assisted molecular beam epitaxy for infrared photodetector", in 2017 International Conference on Intersubband Transitions in Quantum Wells (ITQW), Sep. 2017.
3. Yi ZHENG, K. RADHAKRISHNAN, Dharmarasu NETHAJI, Manvi AGRAWAL, "Si Doped $Al_{0.3}Ga_{0.7}N$ Grown on 4-inch Si (111) Substrate by Plasma Assisted Molecular Beam Epitaxy (PA-MBE)", in 2017 International Conference on Materials for Advanced Technologies (ICMAT), Jun. 2017.
4. Yi ZHENG, Ravikiran LINGAPARTHI, K. RADHAKRISHNAN, Dharmarasu NETHAJI, Manvi AGRAWAL, Unil PERERA, "Group III-nitride Heterojunction Based Multi-Band Detector on Si (111) Substrate Grown by Plasma Assisted Molecular Beam Epitaxy (PA-MBE)", in 2016 International Conference on Electronic Materials (ICEM), Jul. 2016.

Journal papers:

1. M. Agrawal, L. Ravikiran, N. Dharmarasu, K. Radhakrishnan, G. S. Karthikeyan, and Y. Zheng, "Stress evolution of GaN/AlN heterostructure grown on 6H-SiC substrate by plasma assisted molecular beam epitaxy", AIP Advances 7, 015022 (2017).

Journal papers under preparation:

1. Ga/Si interfusion blocking during GaN growth on Si (111) substrate by PA-MBE
2. High level Si doping in GaN and $Al_{0.3}Ga_{0.7}N$ grown by PA-MBE
3. Novel designed AlGaN/GaN based photo conductive UV detector grown on Si (111) substrate by PA-MBE
4. AlGaN/GaN multiple quantum wells structure grown for mid-IR photo detector application.