MOVPE GROWTH OF III-NITRIDE BASED ADVANCED HETEROSTRUCTURES

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JANUARY 2023

MOVPE Growth of III-Nitride based Advanced Heterostructures

by

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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the

Indian Institute of Technology Delhi

January 2023

Dedicated to Readers & Researchers

Certificate

This is to certify that the research work presented in this thesis entitled "**MOVPE Growth of III-Nitride based Advanced Heterostructures**", being submitted by **Mr. Kapil Narang** for the award of the degree of **Doctor of Philosophy** to the Indian Institute of Technology Delhi is a record of bonafide research carried out by him under our guidance and supervision. He has fulfilled the requirements, which to our knowledge have reached the requisite standard for the submission of the thesis.

To the best of our knowledge, this thesis does not contain any results which have been submitted in part or full at any other Institute or University for the award of any degree or diploma.

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ACKNOWLEDGEMENTS

Recollecting the contributions of everyone who had played an important role in the work mentioned in this dissertation is as challenging as III-N epitaxial growth. Before I proceed further, I would like to apologize to everyone whom I may miss to acknowledge here. They are also wonderful human beings who are helping me to improve my research ability with their critical/praising comments and support.

First of all, I would like to express my greatest regard to Thee who has created this amazing creation. We pronounce Thee by different names. But, for me, Thee is **CREATOR**. Creation requires CREATOR. A BIG THANK to the highly Intellectual, Wise, Omnipresent, and Merciful CREATOR for always providing me with A RAY OF HOPE to proceed further.

The first and foremost person, I would like to express my deepest gratitude to is my supervisor Prof. Rajendra Singh, who always provided great support, encouragement, and interest in my research journey. I would like to thank him for providing me the opportunity to do a Ph.D. under his supervision. Despite his busy schedule, he always makes time and shows interest in my research struggles. This work would not have been possible without you Sir. It was an honour and a remarkable experience to work under his invaluable guidance.

Now, I would like to extend my sincere thanks to my awesome co-supervisor, Dr. Rajesh Kumar Bag, who spent un-tirelessly many hours, days, and weeks working with me on scientific discussion and execution of various epitaxial growth runs. The results of which are presented here in this dissertation. His support is unmatchable.

I am grateful to Prof. Neeraj Khare, Prof. Pankaj Srivastava and Prof. Pushparaj Singh from IIT Delhi for being my SRC members and for providing valuable inputs throughout this research journey.

I would like to acknowledge both organizations SSPL, DRDO and IIT Delhi. Being a part of esteem research institutes is one I always cherish.

I would like to thank Dr. Seema Vinayak (Director, SSPL), Dr. R. K. Sharma and Dr. R. Muralidharan (Former Directors, SSPL) for their support and encouragement.

I am also very grateful to Prof. Vikram Kumar (Former Director, SSPL & NPL) for his advice and inspiration to find the path for this research journey.

I would like to express great respect to Dr. MVG Padmavati and Dr. Renu Tyagi for their un-tirelessly, constant support and guidance for this research and my entire professional journey

in SSPL till today. Their invaluable advice and continuously supportive attitude helped to provide directions and at the same time gave me an opportunity and freedom to explore my ideas too.

Dr. Akhilesh Pandey deserves a really special thanks for his insightful support and motivation. He is like a BB (Big Brother) to me who always motivated me to pursue higher and higher on both technical and personal levels.

This dissertation would not have been possible without the assistance and support of persons from MOVPE growth, characterization and device teams. Among them, I would like to acknowledge Mr. Sachin Kumar Saini, Mr. Partha Sarthi Chakraborty, Mr. Sandeep Dalal, Ms. Sunita Singh, and Ms. Garima Upadhyay. They have provided ample time and support during epitaxial runs and characterizations.

My seniors and friends at SSPL and IIT Delhi for making an enjoyable and educational experiences to work and for helping me now and then. Special thanks to Dr. D.S. Rawal, Dr. Shankar Dutta, Mr. Robert Laishram, Dr. Jaya Lohani, Dr. Janesh Kaushik, Dr. Vikash K. Singh, Mr. Aman Arora, Ms. Yashoda Parmar, Ms. Isha Yadav (soon to be Dr.) from SSPL and Dr. Ashok Kapoor, Dr. Uday Dadwal, Dr. Manjari Garg, Dr. B.R. Tak, Dr. Aditya Singh, Dr. Shuchi Kaushik, Mr. Sahin and Mr. Hardhyan from IIT Delhi.

Lastly and very importantly, I would like to give sincere and warm thanks to my beautiful family i.e. parents (Mrs. Rajni and Mr. Ashok Narang, Mrs. Janak and Mr. Ved Prakash Dhamija), siblings (Mohit, Amit, Sumit), wife (Vandna) and kids (Sanyam and Chaitanya) for their important and supportive role in my life. I know they will be very happy to see my name on the cover page of this thesis. Without their help, patience, understanding and support I could not have achieved this.

Kapil Narang
New Delhi, India
January 2023

ABSTRACT

III (Al, Ga, In)-Nitride (N) family material hetero-structures have emerged as an important building block for the next generation opto-electronics and electronics applications. Among many devices, AlGaN/GaN HEMT (High Electron Mobility Transistor) has been widely used for high frequency, high power RF applications. It is the inherent material properties such as large energy bandgap, high breakdown field, high peak electron velocity and very high 2DEG concentration ~1×10^{13} cm^{-2} even without intentional doping which make it superior to its other technological counterparts such as Si and III-As. However, there are various unsolved challenges in the epitaxial growth of crack-free, high-quality III-N based epi-layers and HEMT structures. Hence, to utilize the full potential of III-N, a systematic strategy is adopted to address several challenges related to III-N hetero-epitaxy on SiC substrate in this dissertation. The strategy involved in-depth research on III-N hetero-epitaxy followed by fine-tuning of different growth parameters at different layers/stages of HEMT structure. This leads to repeatable and sustainable material development and growth processes.

The brief details about the growth technique to grow III-Nitride hetero-epitaxy on SiC substrate i.e. MOVPE (Metal Organic Vapour Phase Epitaxy) and characterization tools to characterize structures are also discussed.

The work reported in this dissertation is focused on the improvement of quality (crystalline, surface and interface) of AlN nucleation layer, AlGaN and InAlN barrier layers of HEMT structures. Hence, the work reported in this dissertation highlights the importance of growth parameters to achieve high quality (crystalline, interface and surface) epi-layers of III-Nitride based HEMT structure.

The work reported in this dissertation has resulted an optimized AlGaN/GaN and InAlN/GaN HEMT structures with step-flow surface morphology with excellent electrical and structural characteristics. The achieved 2DEG mobility is 2050 $cm^2/V\cdot s$ with 1×10^{13} cm^{-2} 2DEG concentration in AlGaN/GaN while 1500 $cm^2/V\cdot s$ with 2.4×10^{13} cm^{-2} in lattice matched InAlN/GaN HEMT structures respectively

This dissertation also focuses on the growth of AlGaN/GaN HEMT structure with thin-GaN (~200 nm) buffer and compared its material and device characteristics with conventional-GaN (~2 μm) based HEMT structure.

The work reported in this dissertation has resulted a similar material and device characteristics of conventional-GaN and thin-GaN based AlGaN/GaN HEMT structure.

सारांश

III (Al, Ga, In)-नाइट्राइड (N) पारिवारिक सामग्री हेटेरो-स्ट्रक्चर अगली पीढ़ी के ऑप्टो-इलेक्ट्रॉनिक्स और इलेक्ट्रॉनिक्स अनुप्रयोगों के लिए एक महत्वपूर्ण बिल्डिंग ब्लॉक के रूप में उभरा है। कई उपकरणों में, AlGaN/GaN HEMT (उच्च इलेक्ट्रॉन गतिशीलता ट्रांजिस्टर) का व्यापक रूप से उच्च आवृत्ति, उच्च शक्ति RF अनुप्रयोगों के लिए उपयोग किया गया है। यह अंतर्निहित सामग्री गुण हैं जैसे कि बड़ी ऊर्जा बैंडगैप, उच्च ब्रेकडाउन फील्ड, उच्च शिखर इलेक्ट्रॉन वेग और बहुत उच्च 2DEG सांद्रता $\sim 1\times10^{13}$ cm^{-2} डोपिंग के बिना भी जो इसे अपने अन्य तकनीकी समकक्षों जैसे Si और III-As से बेहतर बनाती है। हालांकि, दरार-मुक्त, उच्च-गुणवत्ता वाले III-N आधारित एपि-लेयर्स और HEMT संरचनाओं के एपिटैक्सियल विकास में विभिन्न अनसुलझी चुनौतियाँ हैं। इसलिए, III-N की पूरी क्षमता का उपयोग करने के लिए, इस शोध-कार्य में SiC सब्सट्रेट पर III-N हेटेरो-एपिटैक्सी से संबंधित कई चुनौतियों का समाधान करने के लिए एक व्यवस्थित रणनीति अपनाई गई है। HEMT संरचना की विभिन्न परतों/चरणों पर विभिन्न विकास मापदंडों के फाइन-ट्यूनिंग के बाद III-N हेटेरो-एपिटाक्सी पर गहन शोध में शामिल रणनीति है। यह दोहराने योग्य और टिकाऊ भौतिक विकास और विकास प्रक्रियाओं की ओर जाता है।

MOVPE (मेटल ऑर्गेनिक वेपर फेज एपिटाक्सी) से SiC सब्सट्रेट पर III-नाइट्राइड हेटेरो-एपिटाक्सी को विकसित करने के लिए विकास तकनीक के बारे में संक्षिप्त विवरण और संरचनाओं की विशेषताओं को निरूपित करने के लिए लक्षण वर्णन उपकरण पर भी चर्चा की गई है।

इस शोध-कार्य में बताया गया तरीके HEMT संरचना की विभिन्न परतों (AlN न्यूक्लिएशन परत, AlGaN और InAlN बाधा परतों) की गुणवत्ता (क्रिस्टलीय, सतह और इंटरफ़ेस) के सुधार पर केंद्रित है। इसलिए, इस शोध-कार्य में बताए गए तरीके III-नाइट्राइड आधारित HEMT संरचना की उच्च गुणवत्ता (क्रिस्टलीय, इंटरफ़ेस और सतह) एपि-लेयर प्राप्त करने के लिए विकास मापदंडों के महत्व पर प्रकाश डालते हैं।

इस शोध-कार्य में रिपोर्ट किए गए कार्य के परिणामस्वरूप उत्कृष्ट विद्युत और संरचनात्मक विशेषताओं के साथ कदम-प्रवाह सतह आकृति-विज्ञान के साथ एक अनुकूलित AlGaN/GaN और InAlN/GaN HEMT संरचनाएं हुई हैं। AlGaN/GaN में 1×10^{13} cm^{-2} 2DEG सांद्रता के साथ प्राप्त 2DEG गतिशीलता 2050 cm^{2}/V·s है जबकि लैटिस कॉन्सटेंट मिलान InAlN/GaN में 2.4×10^{13} cm^{-2} 2DEG सांद्रता के साथ प्राप्त 2DEG गतिशीलता 1500 cm^{2}/V·s है

यह शोध-कार्य थिन-GaN (~200 nm) बफर के साथ AlGaN/GaN HEMT संरचना के विकास पर भी केंद्रित है और पारंपरिक-GaN (~2 μm) आधारित HEMT संरचना के साथ इसकी सामग्री और उपकरण विशेषताओं की तुलना करता है। इस शोध-कार्य में रिपोर्ट किए गए कार्य के परिणामस्वरूप पारंपरिक-GaN और थिन-GaN आधारित AlGaN/GaN HEMT संरचना की समान सामग्री और उपकरण विशेषताएँ सामने आई हैं।

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Abbreviations

MOCVD	Metal Organic Chemical Vapour Deposition
MOVPE	Metal Organic Vapour Phase Epitaxy
MBE	Molecular Beam Epitaxy
CCS	Close-Coupled Showerhead
NL	Nucleation Layer
TMG	Trimethyl Gallium
TMA	Trimethyl Aluminium
TMI	Trimethyl Indium
III-N	Three Nitride
NH3	Ammonia
V/III	Mole fraction ratio of Group-V to Group-III precursors
HEMT	High Electron Mobility Transistor
2DEG	Two-Dimensional Electron Gas
HRXRD	High Resolution X-Ray Diffraction
XRC	X-Ray Rocking Curve
XRR	X-Ray Reflectivity
FWHM	Full Width at Half Maximum
TDD	Threading Dislocation Density
AFM	Atomic Force Microscopy
RMS	Root Mean Square
Rq	RMS Roughness
SEM	Scanning Electron Microscopy
CL	Cathodo-Luminescence
X-CL	Cross-sectional Cathado-Luminescence
SIMS	Secondary Ion Mass Spectroscopy