THE APPLICATIONS OF NITRIDE SEMICONDUCTOR MATERIALS

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Overview

Recently, the surge of research activities in wide band gap semiconductors, such as GaN, SiC, ZnSe and ZnO have arisen from the need for electronic devices which are capable of operating at high temperatures, high power/frequency and in caustic environments, as well as the demand for optoelectronic applications, especially emitters and photodetectors, which are active in the blue and ultraviolet (UV) spectral region. Presently, Si and GaAs are the two most widely used materials in the semiconductor industries. Electronics devices based on current Si and GaAs semiconductor technologies are not able to operate at elevated temperatures or chemically hostile environments due to the uncontrolled generation of intrinsic carriers and their low resistance to the caustic chemicals. Si and GaAs also cannot be employed to produce optoelectronic devices capable of operating in the blue and UV regions, which are technologically important in both military and commercial applications. The wide band gap III-V nitrides have long been viewed as promising semiconductors, and are the choice of the materials for these applications. The III-V nitrides posses a number of unique and excellent properties compared to Si or GaAs, such as:-

- Large energy bandgap; which could have a low current leakage from temperature - induced intrinsic conduction.
- Higher breakdown electric field; which sustains larger voltage gradient, enabling thinner active regions, lower on resistances and high voltage operation.
- High electron drift velocity; which leads to faster operating speed.
- High bonding energy; giving high mechanical strength, chemical inertness and radiation resistance.

Due to the superior properties of the nitrides, intense research activities have been focused on this material. The rapid development on nitride semiconductors has great impact on current modern technologies, especially the high-brightness blue light emitting devices, which have dramatically changed the world of lighting, information storage, and optical communication. AlGaN-based photodetectors are useful for solar-blind UV detection and have a wide range of applications such as flame sensors for control of gas turbines or detection of missiles. This material is also showing promise for microwave and high power electronics intended for radar, satellite, wireless base stations and other advanced technologies. Moreover, nitride materials are non-toxic, environmentally friendly materials compared to other conventional III-V compounds such as GaAs and GaP which contain arsenic and phosphorous, and therefore are toxic for human. Among all of the nitride materials GaN is by far the most heavily studied.

Despite these excellent features and exciting applications, some fundamental questions about the nitride growth are still being raised. One of the main problems rests with the absence of well-suited substrates, which leads to the formation of high density of threading dislocation in the material. Therefore the reduction of dislocation density is highly desired in order to improve the performance and reliability of the devices.

The Applications

The wide band gap nitride semiconductors have attracted enormous attention due to their great potential applications in short wavelength optoelectronic devices and in electronic devices such as high temperature, high power and high frequency transistors [1, 2]. These optoelectronic devices, especially by combining high power blue InGaN single quantum well (SQW) light emitting diodes (LEDs), green InGaN SQW LEDs and red AlInGaP could have many potential applications, such as LED full color displays, and LED white lamps, which have the possibility of replacing the light bulbs or fluorescent lamps with the characteristics of high reliability, high durability and low energy consumption [3].

The nitrides form a continuous alloy system with direct band gaps, ranging from 1.9 eV (InN) to 6.2 eV (AlN) with 3.4 eV for GaN. Band gaps adjustable from 1.9 eV to 6.2 eV can be achieved by suitable alloy combinations in the InGaN and AlGaN systems from which heterojunctions can be fabricated. AlGaN is an attractive nitride system; it appears to be ideal for the fabrication of solar-blind UV detectors. These detectors operating in the solar blind UV spectral range (260 to 290 nm) have many useful applications i.e., flame sensing, ozone monitors, laser detectors pollution monitoring, and also the ability to detect and track extremely weak signals from rapid moving threats, such as the missile. The superior physical and chemical stability of GaN based materials also allow them to operate in harsh environments for example in aircraft where heat tolerant electronics, activators and sensors would replace the hydraulic mechanical control.

The shorter wavelength means blue laser can get into much tighter spaces. Digital versatile disks which rely on red semiconductor lasers have a data storage capacity of 4.7 Gbyte. By moving to blue laser, the capacity could be increased to 15 Gbyte. These materials also show great potentials for optical underwater communications. The blue lasers can travel further without losing their brightness and coherency. In the ocean, the intensity of red light is reduced to half, after a distance of 2 meters, however, blue light can travel 35 meters before it experiences the same effect. In addition, the GaN-based laser with shorter wavelength will allow more data to be squeezed together. The existing printing technology bases on infrared lasers, has a standard resolution of 300 dots per inch (dpi). The switch to the shorter wavelength will tremendously enhance the resolution to 2,400 dpi, which would be able to produce an ultra-fine printing.

The rapid development of wireless access as a form of broadband internet and wireless communication are looking for better technology which could improve the speed and capacity. The nitride semiconductor power transistor could be the answer for the speed and capacity enhancement. It features watt-grade power amplification in the 30 GHz band with no need for power divider. In addition, the new transistor can have two- to three-fold increase in transmission power, leading to ultra-small higher power devices.

Substrates and quality of the GaN films

To produce such novel devices, it is important to grow high quality single crystals. Nevertheless, there are still some difficulties in obtaining high quality GaN films. The main problem is the absence of suitable substrate materials, since bulk GaN wafer sufficiently large in size is not available. Sapphire has become the most commonly used substrate because of its wide availability, hexagonal symmetry and ease of handling and pre-growth cleaning. Si is another potential alternative to sapphire as a substrate due to the low price, high quality and wide availability as well as easy integration with the current technology. However, both sapphire and Si possess large lattice and thermal expansion coefficient compared to GaN which may lead to the formation of high density of threading dislocation (typically ~1010cm-2) in the films. Other substrates, i.e. SiC, MgO, ZnO and LiGaO2 which have better thermal and lattice matches to nitrides are being explored. In addition, many novel growth techniques have been developed to improve the quality of the nitrides films, such as lateral epitaxial overgrowth (LEO), and pendeoepitaxy which are able to reduce the threading dislocations significantly [4].

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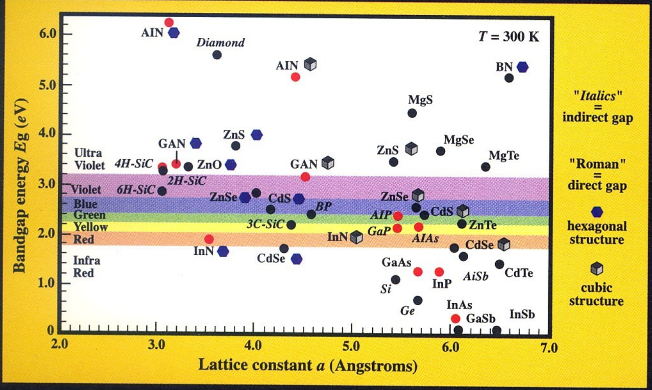
Research on amorphous and microcrystalline GaN

Most of the research activities are focused on epitaxial GaN films grown by MOCVD at high temperatures (above 1273K) for the application of short wavelength optoelectronic devices. However, GaN films grown at low temperatures (below 873K) may have promise as novel electronic materials [5, 6]. The special attribute of these materials is the ability to deposit inexpensively over large area at low temperatures. Development of device films grown at low temperatures widens the range of possible substrates that can be used, and eventually will reduce the cost of technology. The development of amorphous and microcrystalline GaN could open up opportunities for large-area devices such as UV detector arrays, high temperature transistors and large area LED arrays at low cost.

Summary

Group III nitrides are considered as the most promising wide band gap semiconductor materials for optoelectronic applications, electronic devices and other advanced technologies. The crystalline quality of the GaN-based semiconductors could be improved significantly by the adoption of new substrates and novel growth techniques. On the other hand, amorphous and microcrystalline GaN are also currently being investigated for their potential as novel electronic materials which could open up opportunities for large area devices such as UV detector arrays, high temperature transistors and large area LED arrays at low cost. Crystalline/epitaxial GaN is the material of choice at present for short wavelength emitters and detectors.



Room temperature bandgap energy versus lattice constant of common elemental and binary compound semiconductors 7

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