A Review on Materials for Optoelectronics Applications

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Abstract - *Unlike other silicon based electronic devices, optoelectronic devices are primarily made from III-V semiconductor compounds such as GaAs, InP, GaN, GaP, GaSb, and their alloys since they are of direct band gap materials. Understanding the properties of these materials in the production of optoelectronic devices has been of critical importance. After the first demonstration in the early 1960s, of a semiconductor laser, optoelectronic devices have been developed in their millions, pervading our everyday lives in communications, computing, entertainment, lighting, and medicine.*

***Key Words*: Optoelectronics, Quantum Wells, LEDs, Photodetectors, Solar cells.**

1. INTRODUCTION

Group III-V compound semiconductors are very important in the development of optoelectronics devices. Important applications of InP, GaAs based III-V compound semiconductors are devices for optical fiber communications. GaN based compounds are very important for short wavelength light emitters used in solid state lighting systems.

1.1 Light emitting diodes and lasers

Laser diodes are used as sources for telecommunications. InGaAsP/InP is currently used for fabricating 1.3μm lasers for telecommunications [3]. However, the major disadvantages of lasers fabricated from this material system arise due to small bandgap offsets between the InGaAsP quantum wells (QW) and InP barriers. The InP based diode lasers require thermoelectric cooling. All these factors result in very high fabrication and operation costs for the lasers. All these disadvantages can be decreased by using GaAs based emitters emitting at 1.31μm. Some of the materials that provide long wavelength emission on GaAs substrate are: In (Ga) As, GaAsSb, InGaAsN.

1.2 Photodetectors

For quantum well infrared photodetectors (QWIPS), the standard III-V semiconductor material used is AlGaAs-GaAs. This material can be tuned between 6-20μm for the spectral response for detectors. Most of the energy gap discontinuity occurs in the conduction band for AlGaAs/GaAs. Using n-doped QWIPs intersubband absorption at a much shorter wavelength can be obtained. The n-doped QWIPs are insensitive to normal incidence radiation. QWIPs based on inter valence band transitions are sensitive to normal incidence radiation because of its band mixing.

1.3 Solar cells

The operating principle of solar cells is photovoltaic effect. When sunlight incident on the semiconductor material it creates electron-hole pairs which are collected in an external circuit. The efficiency of a solar cell is measured by its short circuit current density and open circuit voltage. Both short current density and open circuit voltage are functions of the bandgap energy of the material. The maximum possible short circuit current density increases with decreases in bandgap, since more photons in the solar spectrum are now capable of creating electron hole pairs in the material. But maximum obtainable open circuit voltage decreases with decreasing bandgap energy of the semiconductor. To maximize the solar cell efficiency there exists optimum bandgap energy for the semiconductor material in the range 1.4 to 1.6eV.

The material GaAs has the optimal bandgap energy for solar cell applications, it enables a theoretical maximum possible efficiency of ~25%. Since GaAs has got a direct bandgap, incident light is absorbed very close to the surface of the semiconductor and high surface combination velocities reduce the efficiency of GaAs homojunction cells. The efficiency in the conversion of sunlight into electricity can be achieved by employing multi-junction solar cells, in which different bandgap semiconductors are used for absorption in different energies of the solar spectrum. To obtain highest efficiency the bandgap and the thickness of each junction should be optimized.

1.4 (In)GaAsN

Inclusion of Nitrite and Indium into the GaAs lattice results in lowering the bandgap energy of GaAs, it minimizes the strain as Indium tends to increase and Nitrite tends to decrease the lattice constant of GaAs. Because of this there is a possibility of lattice matching InGaAsN layers to GaAs. For 1.3μm emission, In composition of ~35% and N composition of ~1% are used. In compositions in excess of 35% lead to very high compressive strain and N composition beyond 1% deteriorates the crystal quality due to large miscibility gap between GaAs and GaN and increases the non-radiative recombination in the QWs.

(In)GaAsN lasers were first demonstrated in 1996[3]. InGaAsN QW lasers exhibit higher threshold currents and lower characteristic temperatures, as compared to InGaAs QW lasers. GaAsP or GaAsN larger bandgap barriers was proposed to decrease the hole leakage from the InGaAsN QWs. Calculations show that reduced hole leakage may result in greater than 40% increase in the material gain for the QW laser. GaAsP or GaAsN barriers also act as strain compensating layers, allowing for more QW layers to be stacked together. Lasing at lower threshold currents was demonstrated using strain compensating, larger bandgap GaAsP and GaAsN barriers instead of GaAs.

1.6 GaN

Light emitting devices of shorter wavelength are required for applications like full color displays, laser printers, read-write laser sources for high density information storage and light emitting diodes for solid state lighting. GaN related materials have bandgap energy which can be tuned in the blue-green region of the visible spectrum and UV-region. For demonstration of blue LEDs, InGaN doped with Si and Zi was used as the active region. The longest peak electroluminescence wavelength demonstrated in InGaN/AlGaN double heterostructure LEDs is ~500 nm. Due to carrier escape from the active region, InGaN QW devices shows reduced efficiencies at higher injection currents. This is a noticeable problem with high power lasers that normally operate at high injection densities. An improved slope efficiency and reduces threshold currents in InGaN devices has been resulted by the use of AlGaN/GaN multi quantum well barriers as carrier blocking layers.

AlGaN heterostructures are used for emitters in the UV region. By increasing the Al content the emission wavelength can be relatively blueshifted. Reduced radiative efficiency is resulted due to increase in the strain in the AlGaN layers, when emission is below 360 nm with AlGaN QWs.

GaN wafers are better than GaN pseudomorphic layers grown on sapphire for (InAl)GaN devices because of reduced threading dislocation densities in the former, that are detrimental to the device performance. An alternative approach to reduce the effect of dislocations on the device performance is to grow device structures on GaN layers laterally overgrown on sapphire substrates. These overgrown GaN layers have fewer or no threading dislocations compared to buffer layers directly grown on sapphire and devices grown on laterally overgrown GaN layers show improved performances.

1.7 InGaAs/GaAs

The binary barriers in the InGaAs/GaAs QW system have better carrier transport properties, when compared to the GaAs/AlGaAs system. Also n-type doping of the InGaAs/GaAs long wavelength QWIPs enhances the absorption of TE modes.

1.8 InGa(As)P/GaAs

Growth of lattice matched quaternary barriers is difficult because of the presence of two volatile group V elements in GaInAsP material. n-and p-type detectors have been demonstrated in InGaP/GaAs material system. The devices of p-type operate in 3-5 µm range and n-type detectors have peak detectivities beyond 10 µm. There is a possibility of monolithic integration of two color photodetectors on a single chip.

1.9 Nanostructured Optoelectronics

Due the unique geometry of nanostructure materials they are used for optoelectronic devices like, light emitting diodes (LEDs), laser diodes, photo detectors and solar cells. For the high performance optoelectronic devices nanostructures in small dimensions can be perfectly integrated into a variety of technological platforms, offering novel physical and chemical properties. Recent rapid advances in research involving two-dimensional (2D) layered nanomaterials and nanoplasmonics made the way for developing next-generation optoelectronic and photonic devices. The use of these 2D materials as a buffer layer for the growth of light –emitting III-V compound semiconductors by van der Waals epitaxy method has opened up a new route of heteroepitaxy, mitigating a lot of growth related technological challenges [5].

1.10 Graphene

Graphene has optical transparency and high mobility along with flexibility robustness and environmental stability. Earlier the main focus was on fundamental physics and electronic devices but now a days Graphene is used to produce devices like solar cells and light emitting devices, touch screens, photodetectors and ultrafastlasers.

2. DISCUSSIONS

(Al)InGaN is the material used for fabricating high luminescence blue-green laser diodes and LEDs. Along with GaAs based emitters in red region of the visible spectrum, the (Al)InGaN blue-green emitters have enabled full color displays. The standard material for infrared photodetectors based on inter-subband transitions is AlGaAs-GaAs. Some of the InP based materials used for long wavelength light emission, modulation and amplifications are InGaAsP/InP, InAlGaAs/InP.

3. CONCLUSION

Nowadays, Semiconductor devices have become an integral part of our lives. Although Silicon is an important semiconductor that has revolutionized the microelectronics industry, it has indirect bandgap and thus an inefficient light emitter/absorber. Optoelectronics devices include the photon-electron interaction. For such applications direct bandgap semiconductors which show strong absorption/emission characteristics are best suited. Widely used semiconductors for optoelectronic devices are compounds formed between elements of group III and group V. Bandgap of these compound materials can be engineered by alloying them. Bandgap engineering enables formation of heterojunctions that is critical for design of high performance optoelectronic devices.

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