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BAND GAP IN NANO-LASERS

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ABSTRACT: A **nano-laser** is a laser that has nano-scale dimensions and it refers to a micro-/nano- device which can emit light with light or electric excitation of nano-wires or other nano-materials that serve as resonators. A standard feature of nanolasers includes their light confinement on a scale approaching or suppressing the diffraction limit of light. These tiny lasers can be modulated quickly and, combined with their small footprint, this makes them ideal candidates for on-chip optical computing. Due to its exceptional features, quantum well and quantum dot laser technology has recently received a lot of interest. Gain materials for semiconductor lasers are frequently made of quantum well and quantum dot architectures. In comparison to Gallium arsenide and Indium phosphaide quantum well lasers, the Indium Arsenide laser exhibits a very high level of variation. Indium Arsenide active layers exhibit greater fluctuation at low energies than Gallium arsenide and Indium phosphaide active layers. Variation is incredibly little in medium bandgap materials. Indium Arsenide laser variation is also found to be much higher than that of Gallium arsenide and Indium phosphaide quantum dot lasers. Indium arsenide exhibits greater fluctuation at low energies than Gallium arsenide. Because of this, quantum dot nano-structured laser is more suited for device applications.

***IndexTerms* -** Nano-scale, Quantum Dot Laser, Band Gap, Quantum Well Laser, Quantum Confinement, Nano-stuctured laser.

INTRODUCTON

A **quantum well laser** is a laser diode in which the active region of the device is so narrow that quantum confinement occurs. Laser diodes are formed in compound semiconductor materials that (quite unlike silicon) are able to emit light efficiently. The wavelength of the light emitted by a quantum well laser is determined by the width of the active region rather than just the bandgap of the materials from which it is constructed.[1] This means that much shorter wavelengths can be obtained from quantum well lasers than from conventional laser diodes using a particular semiconductor material. The efficiency of a quantum well laser is also greater than a conventional laser diode due to the stepwise form of its density of states function.

A **quantum dot laser** is a semiconductor laser that uses quantum dots as the active laser medium in its light emitting region. Due to the tight confinement of charge carriers in quantum dots, they exhibit an electronic structure similar to atoms. Lasers fabricated from such an active media exhibit device performance that is closer to gas lasers, and avoid some of the negative aspects of device performance associated with traditional semiconductor lasers based on bulk or quantum well active media. Improvements in modulation bandwidth, lasing threshold, relative intensity noise, linewidth enhancement factor and temperature insensitivity have all been observed. The quantum dot active region may also be engineered to operate at different wavelengths by varying dot size and composition. This allows quantum dot lasers to be fabricated to operate at wavelengths previously not possible using semiconductor laser technology.[2] One challenge in the further advances with quantum dot lasers is the presence of multicarrier Auger processes which increases the nonradiative rate upon population inversion.[3] Auger processes are intrinsic to the material but, in contrast to bulk semiconductors, they can be engineered to some degree in quantum dots at the cost of reducing the radiative rate. Another obstacle to the specific goal of electrically-pumped quantum dot lasing is the generally weak conductivity of quantum dot films.

Gain materials for semiconductor lasers are frequently made of quantum well and quantum dot architectures. Low band gap material is sandwiched between materials with wider band gaps in quantum well lasers. In a double hetero-structure, the potential well for electrons and holes varies depending on the material. Recent years have seen a lot of research into quantum-confined semiconductor structures such quantum dots, quantum rods, and quantum wells. The size-dependent band gap is one of the most intriguing effects of low-dimensional semiconductor devices. [4-6] A laser diode with a quantum well is one whose active region is so small that quantum confinement takes place. Compound semiconductor materials that are effective at emitting light are used to make laser diodes. The breadth of the active zone, rather than solely the band gap of the constituent material, governs the wavelength of the light emitted by a quantum well laser. [7] This means that compared to ordinary laser diodes, quantum well lasers may emit light at significantly shorter wavelengths. QDs are highly sought-after, notably for use in laser diodes. The development of a new generation of optical light sources, including injection lasers, is thought to be made possible by quantum dot. It is anticipated that quantum dot lasers will possess better qualities than traditional quantum well lasers.

The effective band gap of the active material affects the laser's output wavelength. If the active layer thickness or quantum dot particle size is reduced to nanoscale size, the quantum confinement effect occurs, increasing effective bandgap. In general, the band gap energy increases with crystal size; the higher the energy difference between the highest valence band and lowest conduction band, the more energy is required to excite the dot, and the crystal returns to its original state.

FOR QUANTUM WELL LASER

The energy levels in the conduction band and valence band are discrete, and the effective band gap grows, as the thickness of the active layer is made similar to the de-Broglie wavelength of the electron. The calculation of the expression for band gap in the QW laser is

$$E_g^{QW}(eV) = E_g(eV) + \frac{\pi^2 \hbar^2}{2d^2 e}\left(\frac{1}{m_e^*} + \frac{1}{m_h^*}\right) eV \quad \dots (1)$$

After substituting the value of each element's unique band gap, we discovered equations for Gallium arsenide, Indium Arsenide, and Indium phosphaide, which were also presented in Figure 1.

FOR QUANTUM DOT LASER

The relationship between effective band gap and quantum dot radius is stated as

$$E_g^{QD} = E_g(bulk) + \frac{\hbar^2 \pi^2}{2d^2}\left(\frac{1}{m_e^*} + \frac{1}{m_h^*}\right) - \frac{1.80e^2}{4\pi\varepsilon\varepsilon_0 r} \quad \dots (2)$$

Three quantum dot laser systems' variations in effective band gap with dot radius have been calculated and are shown below. After substituting the value of each material's specific bandgap, we have now discovered the equations for Gallium arsenide, Indium Arsenide, and Indium phosphaide, which are also represented in Figure 2 against the dot's diameter (d =2r).

FOR VARIOUS MATERIALS

Utilizing the properties of three different materials with small, medium, and large band gaps, the variation of effective band gap with active layer thickness and variation of effective band gap with dot diameter have been calculated. In a quantum well laser, the effective band gap varies with the thickness of the active layer for three distinct materials: Gallium arsenide, Indium Arsenide, and Indium phosphaide shown in figure 1. Figure 2 depicts how the effective band gap varies with dot diameter in a quantum dot laser.

In contrast to large Eg material, it has been discovered that changes in small Eg material are significantly higher, as seen in Figure 1. In comparison to Gallium arsenide and Indium phosphaide quantum lasers, the Indium Arsenide laser exhibits a very high level of variation. InAs active layers exhibit greater fluctuation at low energies than do Gallium arsenide and Indium phosphaide active layers. Variation is incredibly little in medium bandgap materials. Figure 2 makes it obvious that the variation of the InAs laser is much higher than that of the Gallium arsenide and Indium phosphaide quantum dot laser. InAs active layers exhibit greater fluctuation at low energies than do Gallium arsenide and Indium phosphaide active layers. Variation is incredibly little in medium bandgap materials. Thus, based on Figures 1 and 2, we deduce that both quantum well and quantum dot lasers exhibit a similar type of change in the effective band gap. However, it is evident from Figures 1 and 2 that effective band gap values for quantum dots are significantly higher than for quantum wells of the same thickness. Because of this, quantum dot laser is more suited for device applications.

Effective band gap has been plotted against the well thickness/diameter of the quantum dot for Gallium arsenide, Indium Arsenide material systems, and characteristics of QW and QD lasers in relation to the above parameter have been compared.

GALLIUM ARSENIDE

In Figure 3, we have plotted the effective band gap behaviour for quantum well and quantum dot lasers against the well thickness/dot diameter for the GaAs quantum well and quantum dot system. For the whole range of the dot's diameter used in our theoretical calculations, the greater effective band gap values can be observed in quantum dot lasers. Additionally, the quantum dot laser has a wider range of fluctuations in effective band gap.

INDIUM PHOSPHIDE

For this system, a comparably extremely high effective band gap value is attained at lower values of dot diameter. Additionally, the quantum dot laser has a wider range of fluctuations in effective band gap. Additionally, it is observed that Indium phosphide exhibits a wider variational range than GaAs shown in figure 4.

CONCLUSIONS

The effective band gap reduces abruptly when the thickness of the active layer in the quantum well rises, then it starts to decrease very slowly for all semiconductors before becoming constant. In the case of quantum dots, the effective band gap first reduces abruptly and then slowly decreases with dot diameter. When compared to big band gap materials, small band gap materials (InAs) show the greatest variation in effective band gap in both quantum well & quantum dot lasers (GaAs and InP).

It has been discovered that little Eg material experiences far higher Eg changes than large Eg material. Compared to Gallium arsenide and Indium phosphaide quantum well lasers, the variation of quantum well band gap in the InAs laser is extremely great. InAs quantum well band gap fluctuation at low energies is greater than that of the active layers made of Gallium arsenide and Indium phosphaide. The fluctuation of quantum well band gap in medium Eg materials is incredibly tiny. Additionally, it is evident that the InAs laser's quantum well band gap variation is far higher than that of the Gallium arsenide and Indium phosphaide quantum dot lasers. quantum dot band gap variation in InAs is greater than in Gallium arsenide and Indium phosphaide active layers at low energies. The fluctuation of quantum dot band gap in middle band gap materials is really tiny. There is good agreement amongst our projections.

REFERENCES

1. "Fujitsu, University of Tokyo Develop World's First 10Gbps Quantum Dot Laser Featuring Breakthrough Temperature-Independent Output - Fujitsu Global
2. The Origin of Quantum Wells and the Quantum Well Laser, by Charles H. Henry, in "Quantum Well Lasers," ed. by Peter S. Zory, Jr., Academic Press, 1993, pp. 1-13.
3. Melnychuk, C.; Guyot-Sionnest, P.;"Multicarrier Dynamics in Quantum Dots". Chemical Reviews, 121 , 4, 2021, p 2325.
4. E.O. Chukwuocha, M.C. Onyeaju and T. T. Harry, World Journal of Condensed Matter Physics, **2**, 96-100, (2012).
5. H. Yu, J. Li, R. A. Loomis, P. C. Gibbons, L. W. Wang and W. E. Buhro, J. Am. Chem. Soc., **125**, 16168, (2003).
6. L. L. Li, J. Hu, W. Yang and A. P. Alivisatos, Nano Lett., **1**, 349, (2001).
7. Charles H. Henry and Peter S. Zory, Jr., Academic Press, 1-13, (1993).

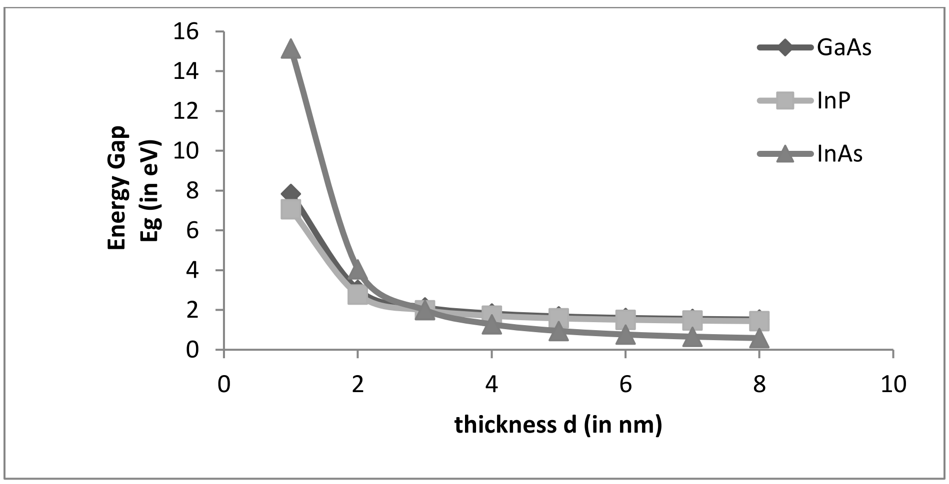

Figure 1: Variation of Effective Band Gap (QW)

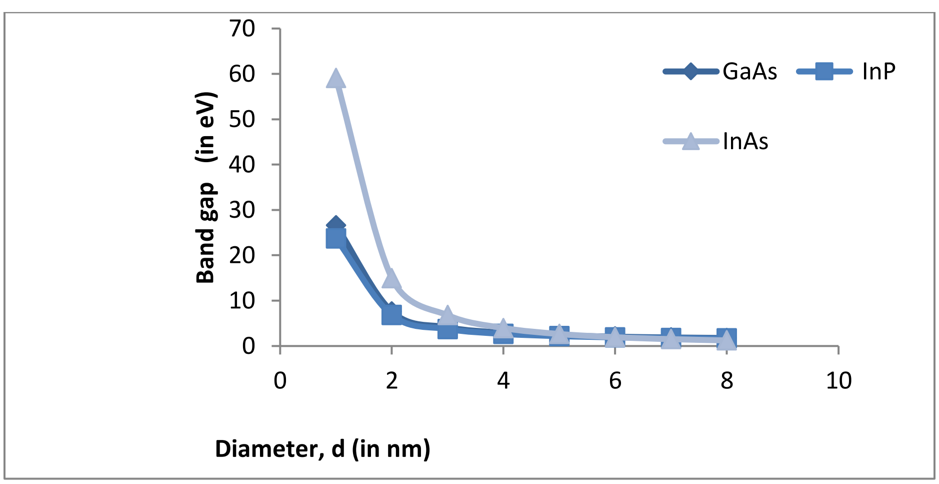

Figure 2: Variation of Effective Band Gap (QD)

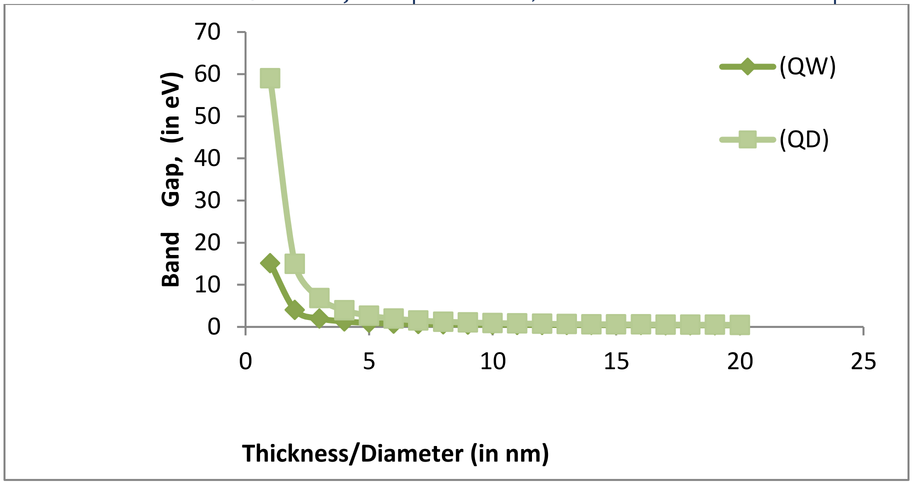

Figure 3: Variation of Effective Band Gap (GaAs)

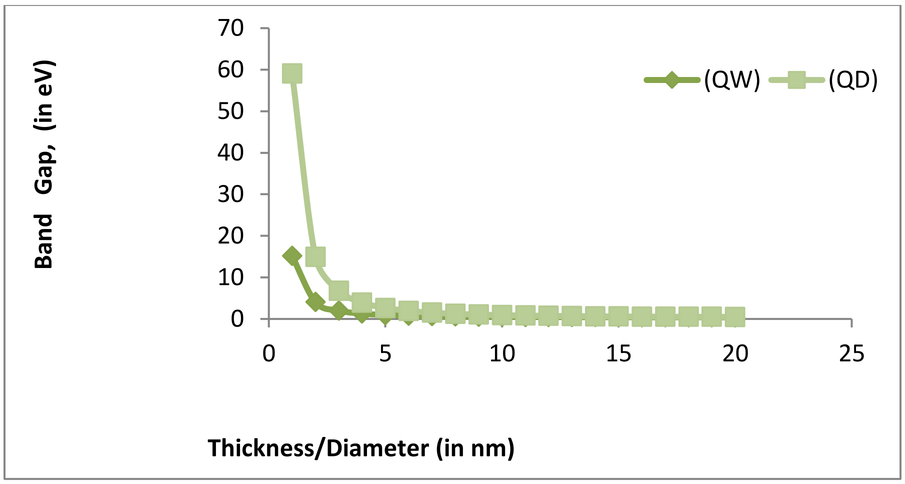

Figure 4: Variation of Effective Band Gap (InP)