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Degeneracy Based Tunable Wavelength of Quantum Dot Laser

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Abstract

We have tried to model the effect of degeneracy on the tunability of wavelength in quantum dots lasers (QDLs). Quantum dots undergo 3D confinement. We obtain the energy values from the Energy of a particle in a box model. The transitions taking place between the energy levels led to emission of radiation having a wide range of wavelengths. The quantum dot size was found to have tunable effect on the wavelength of the emitted radiation.

Keywords: Quantum dots lasers, 3D confinement and tunable wavelength.

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Quantum Dot lasers (QDLs) have the advantage of tunable wavelength. The degeneracy occurring in the energy for a quantum well (QW) and quantum dots (QD) is related to the relaxation time during transition of atoms from excited states to ground states. The degeneracy occurs more in quantum dots compared to quantum well making quantum dot lasers more efficient than quantum well lasers. The scope of tuning the wavelength of the emergent radiation is also more in QD lasers. QDLs also have advanced characteristics compared to conventional semiconductor lasers.

Computational Studies: The degeneracy depends upon the quantum numbers n_x, n_y and n_z denoting quantum confinement in x, y and z directions. However by tuning the dimensions L_x, L_y and L_z, we can enhance the degeneracy level. Using computational studies we have been able to show degeneracy occurring in QW and QD structures. We obtained the same energy for different combination of n_x, n_y and n_z. Electron hole pairs act as carriers and are present in the excited and ground states with FD distribution. The relation between carrier escape time and carrier capture time is based upon the degeneracy of the states (D_{GS} and D_{ES})

$$\tau_{GS}^{ES} = \tau_{ES}^{GS}\left(\frac{D_{GS}}{D_{ES}}\right) exp\left(\frac{E_{ES} - E_{GS}}{K_B T}\right)$$

The principle quantum numbers n_x, n_y and n_z in the x, y, z directions from 1 to 5 and the QD dimensions L_x, L_y and L_z from

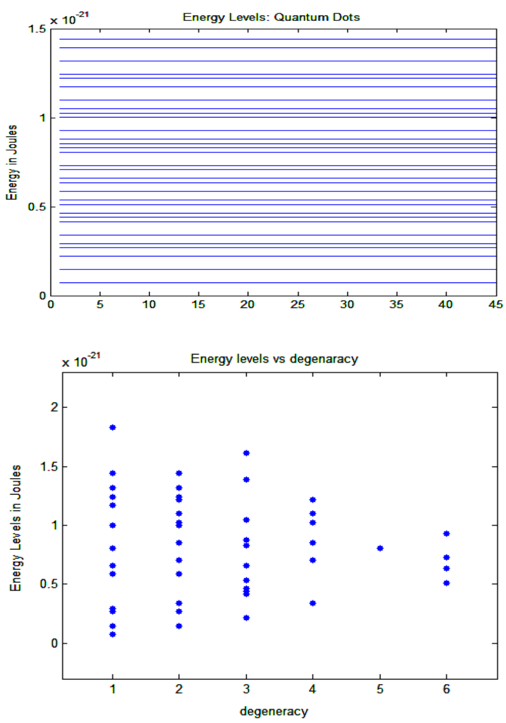

Fig 1: (a) Energy Levels in quantum dots (b) Energy levels vs degeneracy for n = 5

10 to 500 nm were varied. We then calculated the different possible energies based upon the different combinations of n_x, n_y

and n_z. We obtained energy values in a 5 5 5 matrix. The energy levels are shown below (fig 1)

A maximum degeneracy of 6 was obtained. The energy difference between the energy levels was calculated and given as *s (i, j)* which is a 48 × 48 matrix. Emission of radiation will correspond to only the positive values of *s (i, j)* which indicates transition of atoms from higher energy level to lower energy level. The wavelengths of emitted radiation were obtained from the energy difference values. A linear variation of energy difference with increase in energy was obtained . The frequency and wavelength were determined from the energy difference values. A wide range of wavelength emission in QDLs was observed.

If we vary the quantum numbers from 1 to any integer say n, we will get the energy values in a (n × n × n) matrix as E (n: n: n). Changing the dimension however has no effect in the matrix dimensions. The plot showing energy vs. degeneracy value for n_x= n_y= n_z = 3 shown below in Fig 2. The highest degeneracy was obtained to be 4.

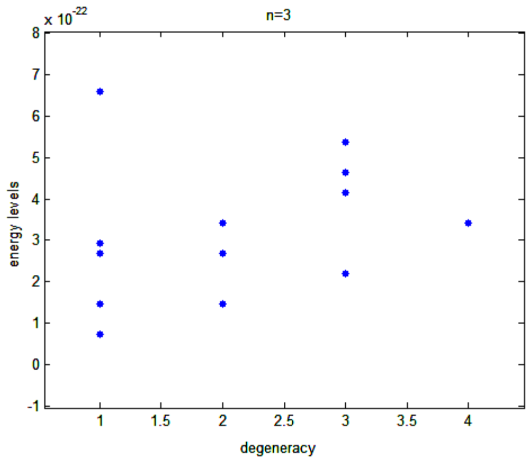

Fig 2: Energy vs. degeneracy for n=3

For setting the limits of the quantum numbers to 10 the plot further changes to the one shown in fig 3. The highest degeneracy obtained in this case was 16.

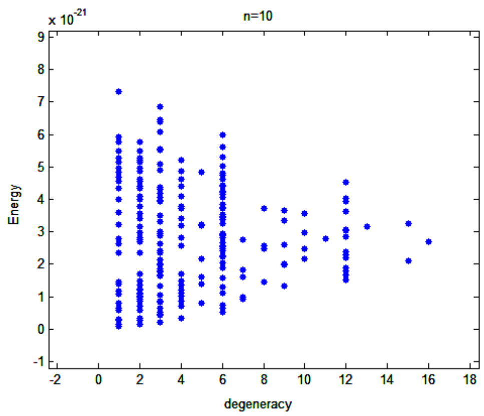

Fig 3: Energy vs. degeneracy for n=10

Table1: The highest degeneracy and highest and lowest energy levels for quantum numbers 1 to 10

n	DH	EH 1.0e-20 (J)	LE 1.0e-24 (J)	ΔEH 1.0e-20 (J)	FH 1.0e+11 (Hz)	λH (nm)	EM Spec.
1	1	0.73	73.2	0	0	0	-
2	3	2.93	73.2	2.20	3.33	1109	UV
3	4	6.59	73.2	5.86	8.87	2958	UV
4	6	11.7	73.2	10.98	16.64	5545	Vis
5	6	18.3	73.2	17.57	26.62	8873	IR
6	7	26.3	73.2	25.62	38.82	12 939	IR
7	12	35.8	73.2	35.14	53.24	17 745	IR
8	12	46.8	73.2	46.12	69.87	23 291	IR
9	15	59.2	73.2	58.56	88.73	29 576	IR
10	16	73.2	73.2	72.47	109.8	36 600	IR

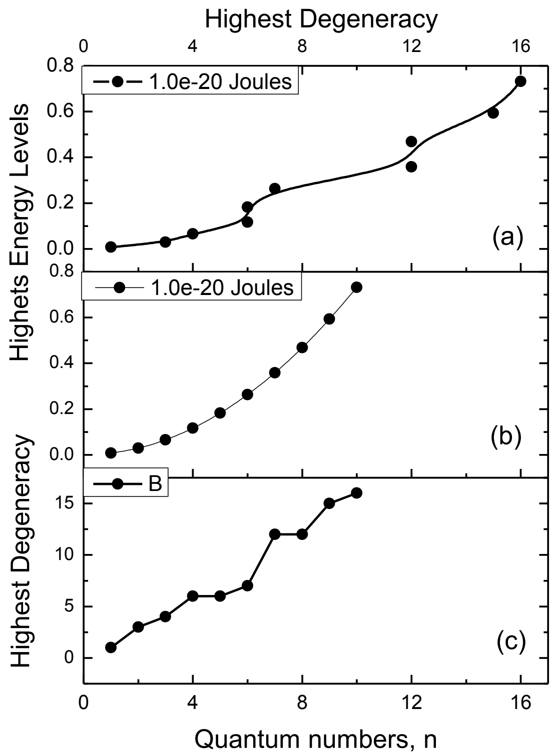

Fig 4: (a) Highest Energy levels vs Highest density and Variation of (b) Highest Energy levels and (c) Highest density with quantum numbers

The degeneracy values were sorted in descending order and the first value was taken as the highest degeneracy value. The energy difference values obtained previously were divided by Planck's constant to get the frequency values which were then used to get the wavelength values from c (speed of light).

The variation of the highest degeneracy (DH), energy (EH), frequency (FH) and wavelength (λH) with increase in quantum numbers is tabulated in the table below. The lowest energy was 0.732 e-22 J for all the cases. The highest energy levels however increase in a parabolic fashion with increase in quantum numbers (fig 4). The wavelengths obtained varied from UV to IR region.

The highest energy difference, frequency and wavelength all vary in a similar parabolic fashion with quantum numbers as shown in fig 5.

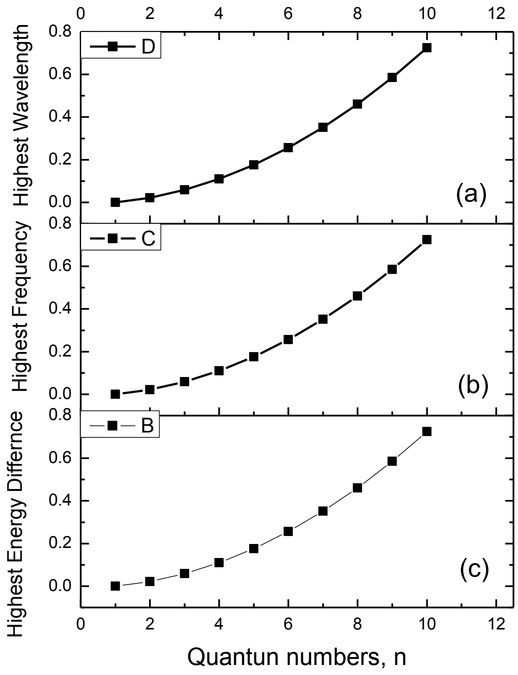

Fig 5: (a) Highest emitted wavelength (b) Highest emitted frequency and (c) Highest energy difference for n between 1 to 10.

Conclusions

A model showing the effect of quantum dot size on the wavelength tunability of quantum dots has been given. The discrete energy levels due to quantum confinement were obtained with degeneracy. The possibility of emission of a wide range of wavelengths is shown with the help of simulation.

Acknowledgements

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