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Quantum wells

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Abstract
An approximate model for the band gap in a quantum well is developed and the limitations in the approximate model are discussed.

Semiconductor quantum well technology lies at the heart of many important opto-electronic devices. For example the Blu-Ray DVD player, with its 405 nm wavelength laser, is based around an InGaN quantum well. An important parameter in this type of device is the band gap and, in a semiconductor quantum well, this is modified by size quantisation: when made from a layer of a small band gap semiconductor (B) sandwiched between layers of a large band gap semiconductor (A), a quantum well can confine both electrons and holes.

Here we calculate the band gap of the quantum well, E_{well}, within a simple infinite 1D quantum box approximation. We find that,

$$E_{well} = E_{g,B} + \frac{\hbar^2 \pi^2}{2 m_o d^2} \left(\frac{1}{m_e} + \frac{1}{m_h} \right), \tag{1}$$

where $E_{g,B}$ is the 'B' material bulk band gap, d is the well width and m_e, m_h are the electron and hole masses in 'B'. With Eq. (1) and the parameters in Ref. [1], we calculate that a 405 nm laser could be produced from a GaAs/InAs/GaAs quantum well of width $d \approx 2.5$ nm.

With this simple model we can easily calculate the parameters of quantum wells made from other semiconductors, A/B/A. In semiconductors where m_h is large, we may even be able to simplify Eq. (1) by dropping the $1/m_h$ term. However, in deriving Eq. (1), we have neglected many effects which may be important and these should be investigated.

First, we have ignored the finite size of the potential barriers between the B and A material. The potential barrier for electrons is $\chi_B - \chi_A$, while that for holes is $\chi_A + E_{g,A} - \chi_B - E_{g,B}$, where χ is the electron affinity of the semiconductor. Second, we might expect that image charge effects at the interfaces will play an important role in cases when the dielectric constants of the A and B materials differ. Third we have neglected the effect of strain and this may change both the band gap and the effective masses. In a quantum well, the x,y and z components of the strain tensor are approximately $\epsilon_{xx} = \epsilon_{yy} = \epsilon$, and $\epsilon_{zz} = -\epsilon$ where ϵ is the relative lattice mismatch between the A and B material. The strained band gap is roughly, $E_g + a_c(\epsilon_{xx} + \epsilon_{yy} + \epsilon_{zz})$, where a_c is the electron deformation potential.

Most semiconductor parameters can be found in on-line databases, for example Ref. [1].

REFERENCES

[1] http://www.ioffe.rssi.ru/SVA/NSM/Semicond/index.html