Temperature Dependence Of The Energy Gap In Low Dimensional Semiconductor Heterostructures

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Abstract

The aim of this study is to investigate the temperature dependence of semiconductor band gaps in low dimensional semiconductor heterostructures. Low dimensional semiconductor systems are considered as a foundation of modern quantum devices. In this study, the temperature characterization of $Ga_{1-x}Al_xAs/GaAs$ quantum well systems was determined by using Varshni relation. The band gap of the investigated semiconductors were observed at deffirent temperatures. The energy bandgap of semiconductors tends to decrease as the temperature is increased.

Introduction

In recent years, several theoretical and experimental studies have focused on the electronic properties of II–VI and III–V semiconductor alloys and their multilayer heterostructures, largely motivated by the potential applications of these materials in opto-electronic devices [1].The crystal structure of $Ga_{1-x}Al_xAs/GaAs$ depends both on the alloy composition (x). Growth of $Ga_{1-x}Al_xAs$ on GaAs substrates leads to a zinc blende structure over the entire composition range.Development of multilayered heterojunctions and the possibility of controlled growth of low-dimensional semiconductors are achieved due to the invention of recent nanofabrication techniques such as Molecular Beam Epitaxy, Metal Organic Chemical Vapour Deposition and Electron Lithography [1,2,3].

Significantly important information concerning electron–phonon interactions, excitonic effects, luminescence, and photoconductivity. Could be obtained from the temperature dependence of the electronic interband transitions[1,2,4].
In this research, we have investigated temperature dependence of the fundamental band gap parameters of $Ga_{1-x}Al_xAs$/GaAsby photoconductivity. Most of the experimental results were analysed using the Varshni equation or its modifications and could properly describe the temperature dependence of the band gap in a variety of group, III–V semiconductors.

Results and Discussions

Understanding of the low dimensional structures plays crucial role in designing new optoelectronic devices[3]. The samples studied in the investigation were$GaAs/Al_xGa_{1-x}As$ multiple quantum well samples (MQWs), were grown by the MBE technique on a semiinsulating GaAs substrate, where x is Alconcentraction. The samples are modulation doped defining a constant two-dimensional (2D) electron density in the wells within 10%.Table 1 shows the details of the sample studied. Sample was fabricated in the form of Hall-bars with arm bar=3.5mm and side bar=0.2mm, and ohmic contacts were formed by diffusing Au/Ge/Ni alloy, through all the layers in the sample[4,5].
At room temperature the energy band gap of GaAs is 1.424eV and 1.823eV for GaAlAs. The temperature dependence of the energy bandgap has been experimentally determined yielding the following expression for Eg as a function of the temperature *T* (Varshni equation) [6] .

$$\frac{\alpha T^2}{\beta+T} - E_{g1}(T) = E_{g1}(0) \qquad \textbf{(1)}$$

$$E_{g2}(T) = E_{g1} + 1.55x + 0.37\,x^2 \qquad \textbf{(2)}$$

Here $E_g(0)$ represents the energy bandgap at *T*=0K, while α and β _ are fitting parameters,where $E_g(0)$ =1.519 eV ,

α = 5.405*10^{-4} and β = 204 K [5,6,7]. These parameters are specific for any material, and they can be used to determine the composition of any compound. The temperature dependences of the calculated energy gaps, E_{g1} and E_{g2} are plotted in Figure 2.

The band offsets (ΔE_C and ΔE_V) are controllable, and therefore different offsets can artificially be put at both sides of the GaAs wells through the control of the growth sequence forming the interfaces, which brings unique characteristics on the quantum structures. According to the electron affinity model and the anion element rule. This rule is clearly confirmed in the material system $Al_xGa_{1-x}As$/GaAs where ΔE_C / ΔE_g ≈ 2 / 3 and ΔE_V / ΔE_g ≈ 1 / 3 for direct-gap range of $Al_xGa_{1-x}As$ (x ≤ 0.45). as shown in Table.2 [8] .

Table.1: List of GaAs/$Ga_{1-x}Al_xAs$ Components investigated in .this work with Al concentration and their well width

Resistance Ohm	concentration Al (x)	Well width (dA° ¿	Sample
1055	32	51	C579
696	32	106	C568

The samples were nominally undoped, and have the same structure with differentlayer thicknesses as indicated in Figure1[3,5].

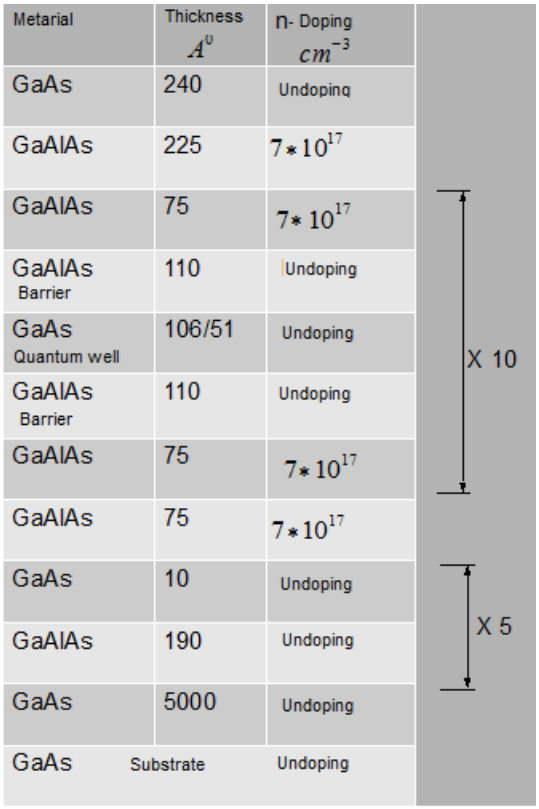

Figure 1. A schematic diagram of the samples[3].

Table.2:Calculated bandgap energies , valence and conduction band offsets of semiconductor heterostructures

T K	E_{g1} (eV)	E_{g2} (eV)	E_C(eV)Δ	E_V(eV)Δ
300	**1.424**	**1.823**	**0.267**	**0.131**
0	**1.519**	**2.052**	**0.357**	**0.175**

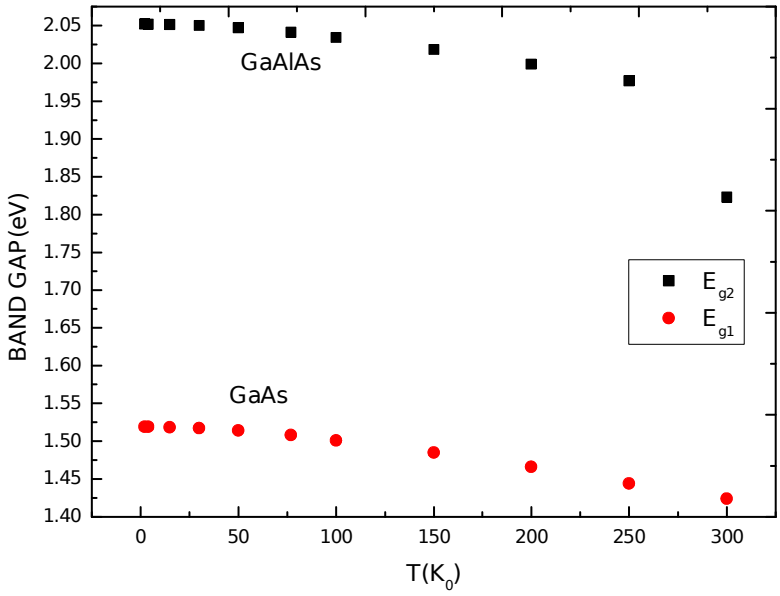

Figure 2. Energy band gaps as a function of temperature ofthese Samples

We have calculated energy band gaps of the GaAs and GaAlAs using Eq(1,2)at different values oftemperature.The energy bandgap of semiconductors tends to decrease as the temperature is increased. This behaviour can be better understood if one considers that the interatomic spacing increases when the amplitude of the atomic vibrations increases due to the increased thermal energy. This effect is quantified by the linear expansion coefficient of a material. An increased interatomic spacing decreases the potential seen by the electrons in the material, which in turn reduces the size of the energy bandgap. A direct modulation of the interatomic distance, such as by applying high. compressive (tensile) stress, also causes an increase (decrease) of the bandgap[9] .

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الخلاصة
الهدف من الدراسة هو دراسة تاثير درجـات الحـرارة علـى طاقـة الفجـوة لاشباة الوصلات ذات التركيب الغير متجانس والـتي تمتلـك ابعـاد صـغيرة. ان انظمة اشـباة الموصـلات ذات الابعـاد الصـغيرة تعتـبر اساسـا للاجهـزة الكمية الحديثة.في هذه الدراسه, حددت الخـواص الحراريـة لسـبيكة $Ga_{1-x}Al_xAs/GaAs$ ذات انظمة بئـر الجهـد الكمـي بواسـطة معادلـة فيرشـن. حيث وجد أن طاقة الفجوة لاشباه الموصلات تقل بزيادة درجة الحرارة .