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Improvement in Electroabsorption and the Effect of the Electric Field in the Tuneable Wavelength Converter

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Abstract

The numerical results of the study of a novel wavelength converter which can be tuned with the application of an external field are presented. For this device, exciton binding energies, radiuses and the absorption coefficient are numerically analysed as a function of electric field. We showed that the interband transition energy and the overlap function between electron and hole changes abruptly when an electric field is applied. This phenomenon can be used the increase the change in the absorption coefficient and reduce the on-state transmission loss in electroabsorption modulators.

1. Introduction

The study of light emitting devices has always been an interesting field in solid state semiconductor physics. Such devices are especially useful for new developments in display technology or for the creation of optical computers. A device that can be used for these kinds of applications is the semiconductor laser. For a light emitter it is important to tailor the wavelength of the light emission to the one optimal for its use in optical communication or optical storage technology(CD). The structures most studied for tuneable wavelength emission, normally contain low dimensional carrier confinement where the carriers can only occupy some sharply defined energy levels and not some broad energy regions as they are defined by the bulk band structure in a semiconductor. The energy levels in these quantum structures can be tune by changing physical parameters of the QW structure (L, V, x).

The aim of this study is to develop a theoretical model for light emission of hot electrons in semiconductor heterostructures in order to explain the HELLISH device.

This device recently suggested and demonstrated experimentally by Balkan et al [1,2]. The device consist basically of an $Ga_{1-x}Al_xAs$ p-n junction with a GaAs QW on the n-side of this diode (see Figure 1). When the carriers in the sample heated by an electric field the device emits light. The energy spectrum of the emitted photons shows that nearly all the photons are generated at energies consistent with electron-hole recombination in the GaAs QW. This effect is planned to obtain a new type semiconductor laser. In some recent experiments this new possibility was examined in greater detail [3,7].

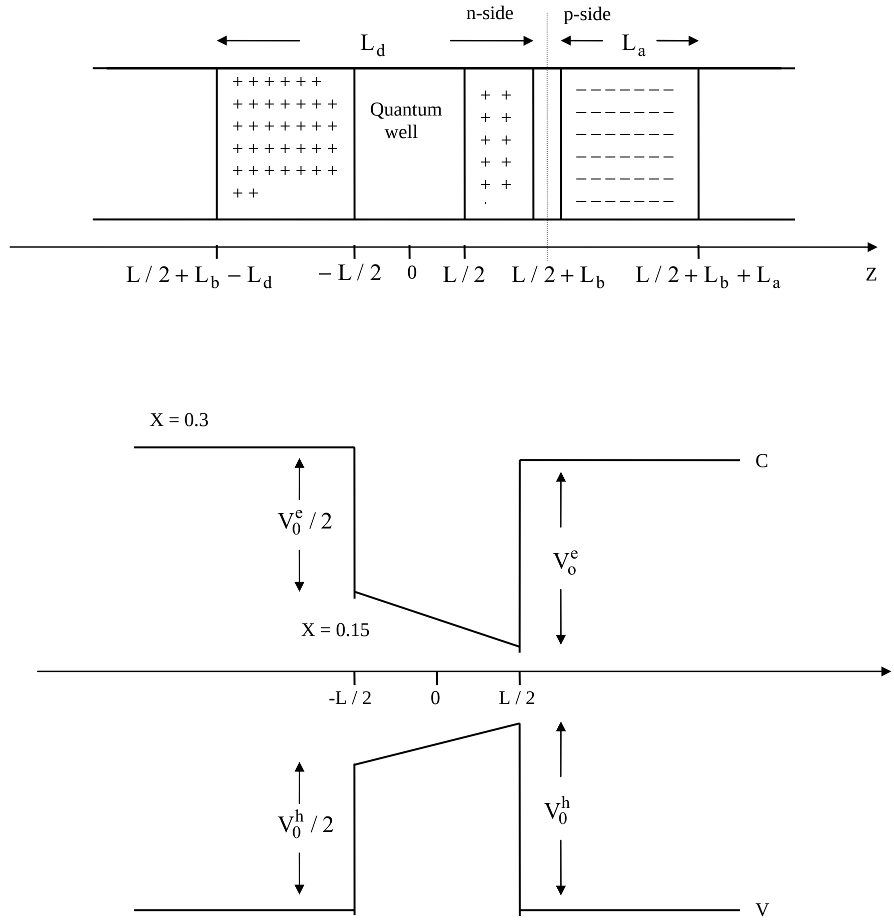

Figure 1. Schematic diagram of the HELLISH-1 device with a graded quantum well on the n-side of the depletion region.

2. Theoretical Model

The sample considered is a single $Ga_{1-x}Al_xAs$ p-n diode with an intrinsic 130 Åwide graded quantum well placed on the n-side, separated from the junction by 60 Åof n-GaAlAs. To calculate the potential profile of this structure we use a one-dimensional approach based on the depletion approximation [4], which leads to a simple distribution for the space charge density $\rho(z)$ in the sample:

$$\rho(z) = \begin{cases} 0 & \text{for } z \leq L/2 + L_b - L_d \\ eN_D & \text{for } L/2 + L_b - L_d < z \leq -L/2 \\ -eN(z) & \text{for } -L/2 < z \leq L/2 \\ eN_D & \text{for } L/2 < z \leq L/2 + L_b \\ -eN_A & \text{for } L/2 + L_b < z \leq L/2 + L_b + L_a \\ 0 & \text{for } L/2 + L_b + L_a < z \end{cases} \tag{1}$$

Here, N_D is the concentration of donors; N_A is the concentration of acceptors on the respective sides of the sample; L_d is the n-side depletion length; L_a is the p-side depletion length; e is the elementary charge and $n(z) = N_{well}|\Psi(z)|^2$ is the concentration of the free carriers in the graded quantum well, which contains the total concentration per unit area oved N_{well} of carriers; and $\Psi(z)$ is the quantum mechanical wave function inside the quantum well. N_{well} is calculated from the charge neutrality condition

$$N_{well} = N_D(L_d - L) - N_A L_a. \tag{2}$$

We have calculated the potential profile by self-consistently solving the Schrödinger equation and Poisson's equation for the electrostatic potential ϕ

$$\frac{\partial^2 \phi}{\partial z^2} = -\frac{1}{\in_0 \in_r}\rho(z), \tag{3}$$

where $\in_0$ are $\in_r$ the absolute and relative dielectric constants, respectively.

3. Results and Discussion

For numerical calculations we have employed the following values: $N_A = N_D = 7 \times 10^{17}\text{cm}^2$, $m_e = 0.067m_0$, $m_e = 0.45m_0$, $L = 130$ Å, $L_b = 60$ Å, L_b Å, $V_0^e = 225$ meV, $V_0^h = 147$ meV and the relative dielectric constant $\in_r = 13$. The calculated conduction and valance band profile of the system is given in Figure 2 (a) as a function of the forward bias. Forward biasing the junction reduces the built-in field, thus the field associated with the grading becomes effective as shown in Figure 2 (a). The tuning of the operation wavelength is based on the Quantum Confined Stark Effect and is achieved during the forward biasing of the device. The results of the tuneable wavelength converter with the application of an external field are presented. The interband transition energy as a function of the forward bias is shown in Figure 2 (b). The tuning range is $\Delta\Lambda = 500$ Åabout the operation wavelength, $\Lambda = 8700$ Å. In the present model the calculated physical parameters are: $L_d = 540.51$ Å, $L_a = 354.271$ Å, $N_w = 3.936 \times 10^{11}\text{cm}^{-2}$, and $F_{built-in} = 2.87 \times 10^5$ V/cm.

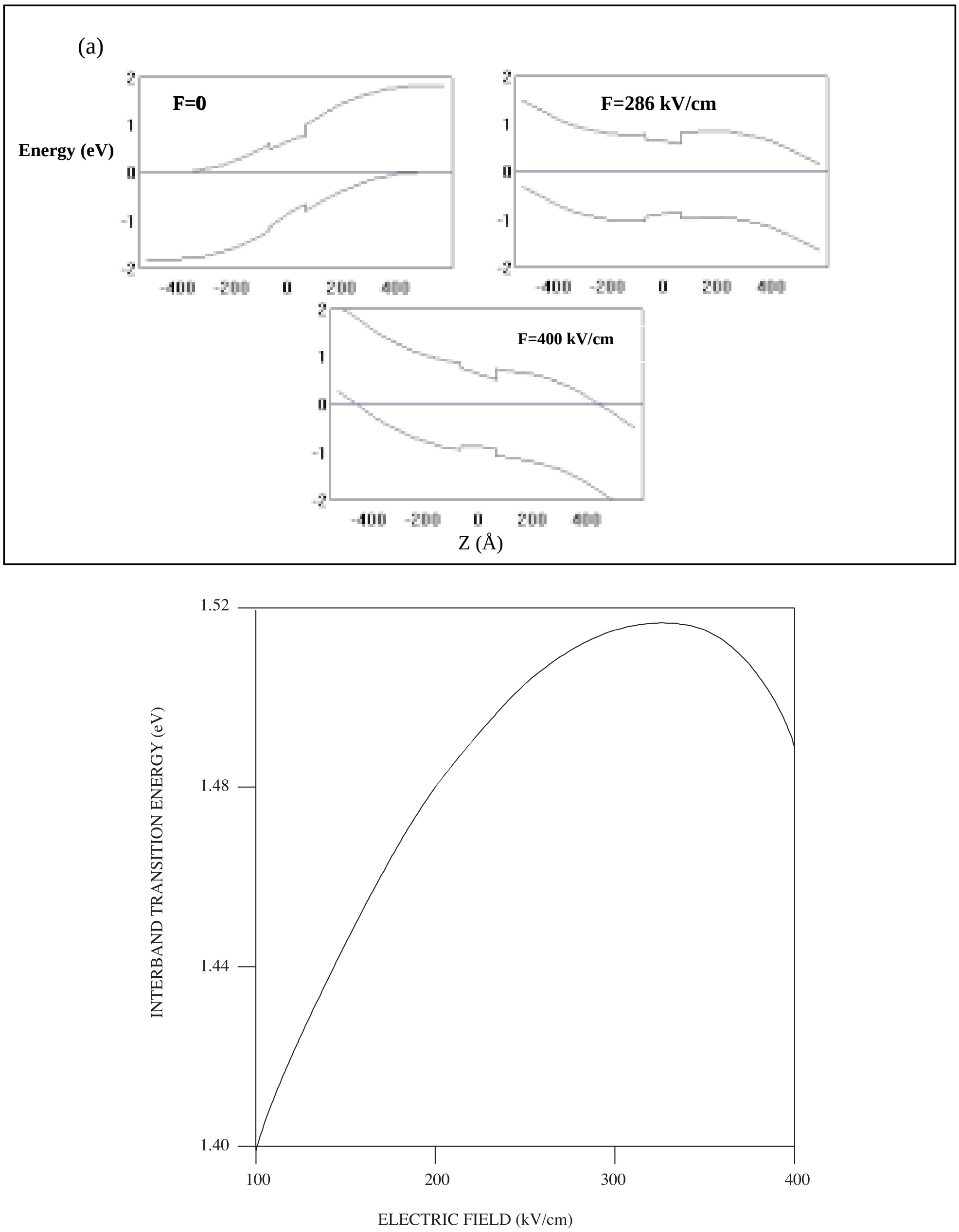

Figure 2. (a) Electric field dependence of the built-in potential profile, and (b) the interband (el-hh1) transitions

Also, we have calculated the intersubband resonance absorption as a function of the forward bias. As seen in Figure 3, due to the increment of the overlap of the electron wave functions, forward biasing the junction gives a higher, and sharp absorption coefficient. The figure clearlry indicates the tunability of the excitonic interband transitions and the intersubband transitions by the applied field. The tuning range is from 13-26 μm, and this capability is achieved with an applied electric field in the 200-400 kV/cm range. This double tunability makes the structure an ideal candidate for electro absorption detectors and converters.

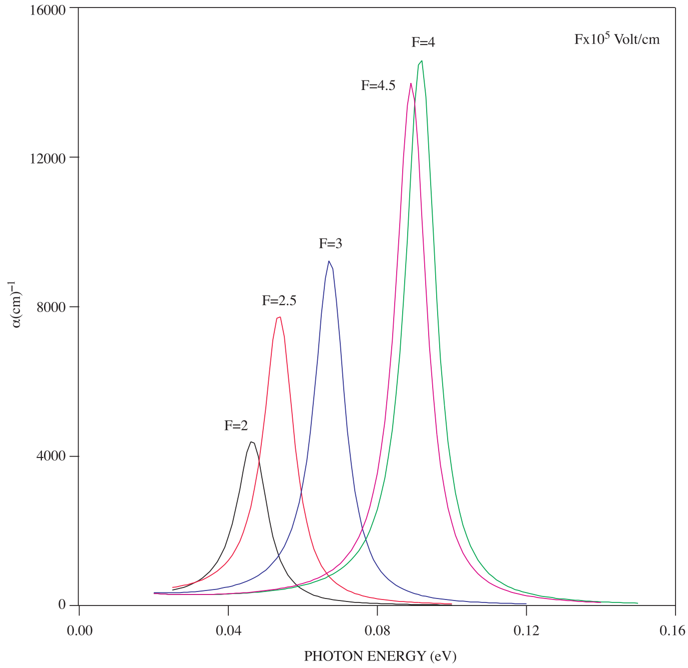

Figure 3. Calculated linear intersubband (ΔE_{1-2}) absorption coefficient as a function of the forward bias

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