Optical gains and interband transitions of CdTe/ZnTe single quantum wells

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Abstract - **The optical gains of the CdTe/ZnTe single quantum wells with various CdTe widths were calculated by using a non-interacting pair Green's function and by an energy space integrated function. The interband transition energies from the ground electronic subband to the ground heavy-hole subband calculated taking into account optical gains were in qualitatively reasonable agreement with those determined from the PL spectra**.

I. INTRODUCTION

The prospect of potential applications of II-VI/II-VI semiconductor nanostructures has led to substantial research and development efforts to grow various kinds of quantum structures [1]. Among the various kinds of quantum structures, wide-gap CdTe/ZnTe quantum wells (QWs) are particularly attractive because of interest in their promising applications in optoelectronic devices operating at a blue-green spectral region [2]. Even though many works concerning the growth and the physical properties of CdTe/ZnTe QW structures have been performed, studies on the optical gain of the CdTe/ZnTe QWs have not yet been performed.

This paper reports data for the dependence of the optical gain on the CdTe well width and temperature for CdTe/ZnTe single QWs (SQWs). The optical gains of the CdTe/ZnTe SQWs with various CdTe widths at various temperatures were calculated by using a non-interacting pair Green's function and by an energy space integrated function. Photoluminescence (PL) measurements were carried out in order to investigate the interband transitions in the CdTe/ZnTe SQWs. The interband transition energies from the ground electronic subband to the ground heavy-hole subband (E_1-HH_1) calculated taking into account optical gains were compared with those determined from the PL spectra.

II. THEORETICAL CONSIDERATION

Several methods have been introduced to calculate the optical gain of the QWs [3]. The optical gains used in this study are calculated by using the non-interacting pair Green's functions and by an energy space integrated function [3]. The first optical gain [$g_U^0(E)$] calculated by using the non-interacting pair Green's functions of the conduction electron and the valence hole in a two-band model is given by

$$g_U^0(E) \propto \frac{I(E)}{(1 - V\,R(E))^2 + (V\,I(E))^2}, \qquad (1)$$

with R and I are the real and imaginary parts of $\sum_k \frac{1 - f_e(\varepsilon_k^e) - f_h(\varepsilon_k^h)}{E - \varepsilon_k^e - \varepsilon_k^h + i\delta}$, respectively, where V is the electron-hole Coulomb interaction, ε_k^e and ε_k^h are the k-th subband energies in the conduction and the valence subband, respectively, f_e and f_h are the electron and the hole Fermi functions, respectively, and δ is the damping constant [3]. Only the conduction band and the heavy-hole band are considered in the calculation. Because the proposed model is too ideal to apply to the real quantum structures, the modified version of optical gain (g_U) taking into account additional effects is necessary to obtain exact gain function adopted by using the other gain function with minor effect in this model. Theoretically pre-defined parameters in the model were determined by comparison with an analytical formulation model.

The second optical gain function (g_M) calculated by using the analytic formulation based on the two-band structures obeys the following equation:

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$$g_M(E) \propto E \sum_k \int_{E_{tr}^k}^{\infty} (f_e - f_h) \frac{\hbar/\tau}{(t-E)^2 + (\hbar/\tau)^2} dt, \quad (3)$$

where E_{tr}^k is the transition energy between the k-th quantized levels in conduction and valence band, $\hbar$ is reduced Planck's constant, and τ is the intraband relaxation time [3].

III. RESULTS AND DISCUSSION

Figure 1 shows PL spectra and optical gains calculated by using a non-interacting pair green's function and an energy space integrated function at 21 K for CdTe/ZnTe SQWs. The detailed growth procedures of the CdTe/ZnTe SQW sample used in this study were published elsewhere [4]. The shapes of the optical gains are asymmetric, which is very similar the non-linear gain of compressive strained QW structure [5]. The peak positions corresponding to the E_1-HH_1 interband transition energy calculated by using non-linear Green's function are closer to the PL peak position.

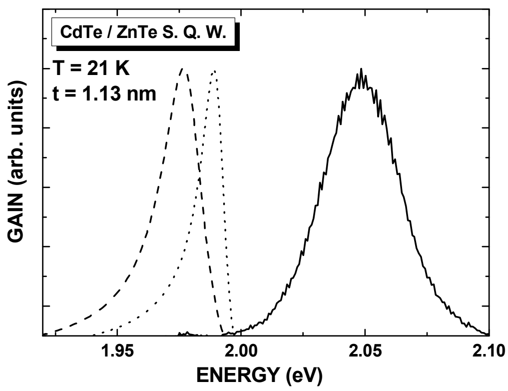

Fig. 1. Photoluminescence spectra and optical gain functions calculated by using a non-interacting pair Green's function or by an energy space integrated function at 21 K for CdTe/ZnTe single quantum wells. Solid, dotted, and dashed lines represent the photoluminescence spectra, the optical gain function calculated by using a non-interacting pair Green's function, and the optical gain function calculated by using an energy space integrated function, respectively.

The E_1-HH_1 interband transitions were calculated as functions of the temperature and the CdTe layer width taking into account the interpolated optical gain function obtained from the g_M and g_U. The E_1-HH_1 interband transition energies are not significantly affected by the interpolated optical gain function. Even though the E_1-HH_1 interband transition energies as functions of the temperature for CdTe/ZnTe quantum wells with a width of 11.34 Å are calculated, there is a significant difference between the E_1-HH_1 interband transition energies determined from the PL spectra and those calculated by using the interpolated optical gain function. The difference between experimental and theoretical E_1-HH_1 interband transition might originate from the exciton binding energy of the CdTe/ZnTe, which is not considered in this calculation. While the E_1-HH_1 interband transition energies calculated by using a interpolated optical gain function decrease linearly with increasing CdTe well width, those obtained from the PL spectra decrease nonlinearly.

IV. SUMMARY AND CONCLUSIONS

The optical gains of the CdTe/ZnTe SQWs with various CdTe widths calculated by using a non-interacting pair Green's function and by an energy space integrated function show that the peak position corresponding to the E_1-HH_1 interband transition energy calculated by using non-linear Green's function is closer to the PL peak position. The E_1-HH_1 interband transition energies are not significantly affected by the interpolated optical gain function. While the E1-HH1 interband transition energies calculated by using a interpolated optical gain function decrease linearly with increasing CdTe well width, those obtained from the PL spectra decrease nonlinearly.

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