Electric field dependence of the exciton binding energy in GaAs/$Al_xGa_{1-x}As$ quantum wells

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Exciton binding energies in GaAs/$Al_xGa_{1-x}As$ quantum wells are calculated as a function of the external electric field applied perpendicular to the heterointerface, using the equations which are free from errors in the paper of D. A. B. Miller *et al.* [Phys. Rev. B **32**, 1043 (1985)]. The calculated results agree well with other more elaborate calculations.

The binding energy of excitons in a quantum well is a good measure of the stability of their existence. The stability of excitons under an external electric field is particularly important for designing devices which exploit the excitonic electrooptic effects. So far, several authors have calculated the electric field dependence of the exciton binding energy [$E_b(F)$].[1-4] Among these calculations, Miller *et al.*[1] have developed a simple method in which effective quantum-well widths for electrons and holes were introduced instead of taking the finite band discontinuity into account. This approximation greatly reduced the complexity of the calculation. Hence this method is certain to be adopted as a useful method because of its simplicity, provided that it correctly describes the excitonic behavior under an external electric field.

However, the deviation of the binding energy from the value at zero field [$\Delta E_b(F)=E_b(F)-E_b(0)$] calculated by them (Fig. 8 in Ref. 1) is too large compared with the other calculations:[2-4] Sanders and Bajaj[3] pointed this out, ascribing the difference to the different variational wave functions. My check of their formulation[1] showed that this discrepancy results instead from errors in the equation of Bastard *et al.*[5] [Eq. (7) in Ref. 5] which Miller *et al.*, have quoted in their paper.[1] This equation must be replaced by

$$E(\beta)=E_1^{(0)}\left[1+\frac{\beta^2}{\pi^2}+\phi\left[\frac{1}{2\beta}+\frac{\beta}{\pi^2+\beta^2}-\tfrac{1}{2}\coth\beta\right]\right],$$

in their notation. This equation has been used to determine the extent of the separation due to the applied electric field of electrons and holes in the direction perpendicular to the heterointerface. They seem to have overestimated the extent of the separation of electrons and holes. The use of their incorrect equation in our program reproduced exactly the same incorrect results as Fig. 8 in Ref. 1.

Figure 1 shows the numerical results of the electric field dependence of the binding energy for (a) heavy-hole excitons and (b) light-hole excitons, which have been calculated using the revised equation (indicated by thick solid lines), for several quantum-well widths (L_z). The results for other calculations are also shown for comparison (indicated by thin solid lines[2-4] and a dashed line[1]), although the parameter values used are slightly different among the authors (see Table I). As Fig. 1 clearly shows, the present results agree well with other calculations.[2-4] In particular, the deviation of the binding energy from the value at zero field [$\Delta E_b(F)$] nearly coincides with the results of other authors.[2-4] The difference in the $E_b(F)$ values among the authors appears to come from the difference in the parameter values used. For example, I have obtained $E_b(0)=9.944$ meV for heavy-hole excitons when $L_z=50$ Å, while Brum and Bastard[2] reported about 8.3 meV. This discrepancy seems to result from two factors: (1) The larger dielectric constant they used reduced the contribution of the expectation value of attractive potential to the exciton binding energy, and (2) the 85:15 rule for the band discontinuity they used tends to decrease the exciton binding energy, as compared with the 60:40 rule. In this way, the results of Fig. 1 confirm the conclusion more clearly than the somewhat pessimistic

TABLE I. Parameter values used in the calculations of Fig. 1. The parameter values used in the present revised calculation are the same as those in Ref. 1, with $L_z=50$, 95, 100, 150, 200 Å.

	x (Al)	L_z (Å)	Band discontinuity ΔE_c:ΔE_v	Luttinger parameters γ_1	γ_2	Dielectric constant
Miller *et al.* (Ref. 1)	0.32	95	57:43	6.79	1.92	12.15
Brum and Bastard (Ref. 2	0.32	200	85:15	7.36	2.57	13.1
Sanders and Bajaj (Ref. 3)	0.25	200	60:40	6.93	2.15	a
Hong and Singh (Ref. 4)	a	100	60:40	7.68	2.41	a

[a]Unknown.

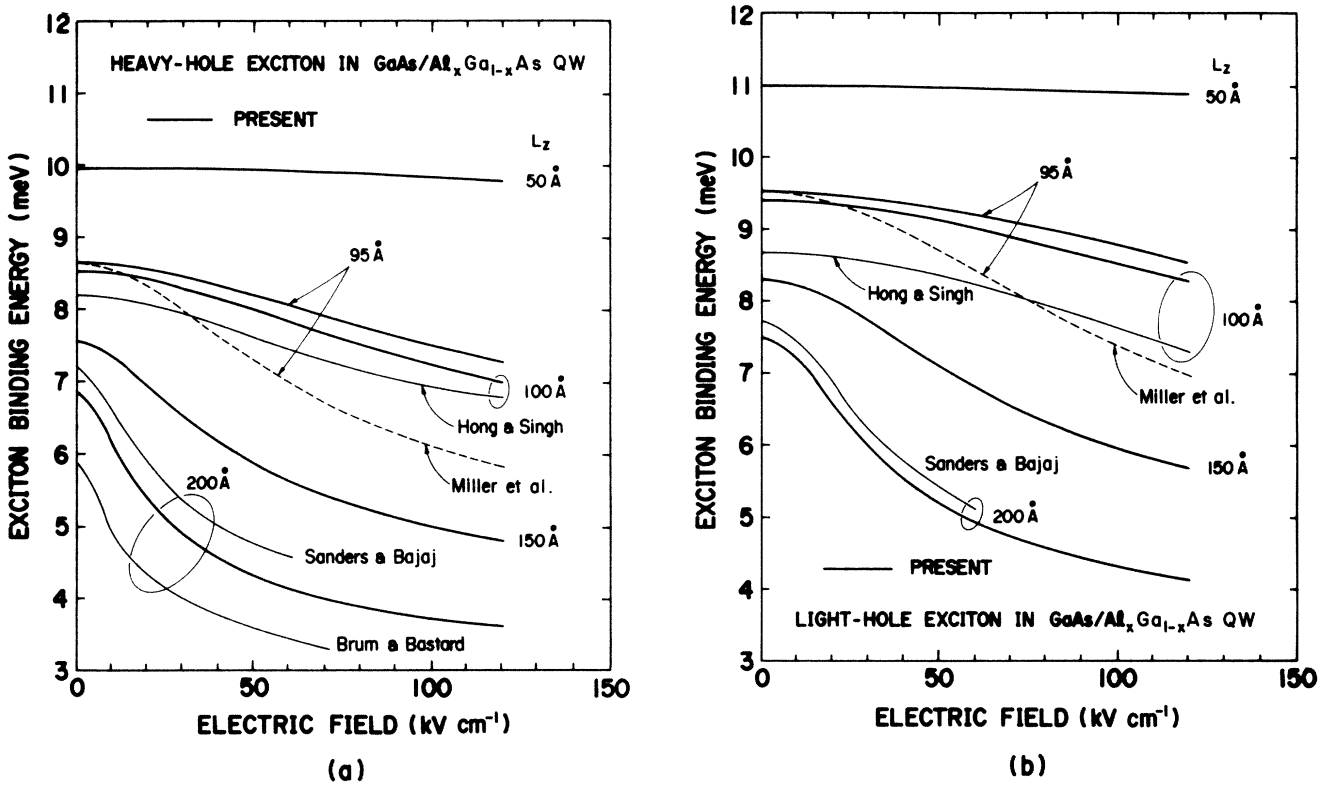

FIG. 1. Binding energy of (a) heavy-hole excitons and (b) light-hole excitons in a GaAs/$Al_xGa_{1-x}As$ quantum well as a function of external electric field for several quantum well widths (L_z). The main parameter values used for calculations in this figure are listed in Table I.

results of Miller *et al.*[1] that the exciton is indeed very stable even in the presence of high electric fields.

Finally, I would like to comment on the paper published recently[6] in which the electric field dependence of the exciton binding energy was calculated using the formulation of Ref. 1 for $In_{0.47}Ga_{0.53}As/InP$ multiple-quantum-well structures grown by metal-organic chemical-vapor deposition. They reported the heavy-hole-exciton binding-energy deviation $[\Delta E_b(F)]$ of, for example, about 1.9 meV at $F = 150$ kV cm^{-1}. This value nearly coincides with 1.866 meV, the value calculated in our program using the incorrect equation and the material constants quoted in their paper.[6] In contrast, I have obtained 0.966 meV at this electric field using the revised equation and the same material constants.

It is thus verified that the present revised calculation describes the excitonic behavior under an external electric field to the same degree of accuracy as the other more elaborate calculations, despite its simplicity.

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