MAGNETO-OPTICS IN MODULATION-DOPED QUANTUM WELLS

T. Rötger, J. Maan, P. Wyder, F. Meseguer, K. Ploog

To cite this version:


HAL Id: jpa-00226787
https://hal.archives-ouvertes.fr/jpa-00226787
Submitted on 1 Jan 1987

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
MAGNETO-OPTICS IN MODULATION-DOPED QUANTUM WELLS

T. Rötger, J.C. Maan, P. Wyder, F. Meseguer* and K. Ploog**

Max-Planck-Institut für Festkörperforschung, Hochfeld-Magnetlabor, BP 166X, F-38042 Grenoble Cedex, France
*Instituto de Física de Materiales (CSIC) and Departamento de Física Aplicada C-4, Universidad Autónoma, E-28049 Madrid, Spain
**Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-7000 Stuttgart 80, F.R.G.

Les spectres de photoluminescence et d’excitation de puits quantiques à modula-
tion de dopage type n dans des champs magnétiques jusqu’à 22 T montrent que les
distances inter-sous-bandes changent de manière périodique avec le champ. Nous
montrons que ce comportement est dû au transfert d’électrons entre des sous-bandes
à extension spatiale différente, qui modifie le potentiel de charge d’espace. La
variation d’intensité de luminescence observée en fonction du champ est également
expliquée par ce modèle.

Photoluminescence and excitation spectra in n-modulation-doped quantum wells
with 3 occupied subbands in magnetic fields up to 22 T show that the intersubband
distances change with field in a periodic manner. This behaviour is shown to be
due to the transfer of electrons between subbands with different spatial extension,
thereby modifying the space charge potential. The observed variation of the
luminescence intensity with field is also explained by this model.

In modulation-doped quantum wells (MDQW’s) [1] both properties of undoped
quantum wells (size quantization) as well as that of modulation-doped single hetero-
junctions (transport properties) are combined. In relatively thick GaAs layers
between doped GaAlAs layers a two-dimensional electron gas is formed at the inter-
faces, like in single heterojunctions, which allows magnetotransport experiments [2].
On the other hand, in the same samples one can perform photoluminescence measure-
ments [3-7], because contrary to heterojunctions the electron and hole wavefunctions
overlap sufficiently to have a substantial optical absorption [8].

Our measurements were done on n-modulation-doped GaAs/GaAlAs multiple quantum
wells [9] with a large GaAs well width (500 Å), and a carrier concentration of
1.6*10^{12} cm^{-2}. In these wide wells, at these densities the subband energies for the
lowest two subbands are mainly determined by the strong band bending and are
localized at the two interfaces as in a double heterojunction.

To avoid the usually poor quality of the "inverted" GaAs/GaAlAs interface [2],
the actual samples used were slightly asymmetric as can be seen in the inset of
Fig. 1. Nevertheless, since the potential is mainly determined by the electrosta-
tics, the actual bandstructure is very similar to a symmetric well [6,10] with two
almost degenerate subbands localized at the interfaces and a third subband centered
in the well.

We performed luminescence and excitation measurements at 1.7 K in a magnetic
field perpendicular to the sample surface (z-direction) between 0 and 22 T. For
the luminescence, we used excitation wavelengths around 1.60 eV (slightly above the
bandgap of GaAs) to avoid electron heating. As shown in Fig. 1, the luminescence
shows two main peaks: a sharper one (A) situated at 1521 meV at B=0, and a broader
one (B) at 1506 meV. We assign peak A to a transition between the electron subband
E_{2} and the highest hole level H_{0}, which is the only one occupied at low temperatures,
and peak B to one between the quasi-degenerate E_{0} and E_{1}, and H_{0}. The hole level,
being common for all electron-hole transitions allows us to determine directly
intersubband distances.
With increasing magnetic field, luminescence peak energy increases, and one sees a clear splitting of peak A into several Landau levels (LL's) up to about 2.7 T; at higher fields the luminescence comes only from the lowest LL, due to thermalization. Furthermore the peak energies do not increase any more as the cyclotron energy, as expected ($E_{\text{Lum}}(B) = E_{\text{Lum}}(B=0) + \hbar \omega_c / 2$), but deviate from it in a step-like manner, the steps becoming more pronounced with increasing field, as shown in Fig. 2. The most striking feature, however, is that the separation between the peaks A and B decreases from 15 meV at $B=0$ to 10 meV at about 17 T. In addition above this field, the intensity of peak B, which had been much less than A at all lower magnetic fields, increases strongly and becomes 3x the intensity of A at 20 T. The magneto-luminescence intensities for peak A and B, both in $\sigma^+$ and $\sigma^-$ circular polarization, are shown in Fig. 3 and compared to the measured two-point magneto-resistance. Except for $B=11$ to 14 T, where a spin splitting seems to manifest more strongly in the dc electrical measurement, the luminescence intensities closely follow the same behaviour as the electrical measurement.

We furthermore measured excitation spectra (Fig. 2, open circles) by detecting both luminescence of peak A and peak B as a function of the exciting radiation energy. Transitions from $E_0$ to all LL's of $E_2$ as well as those involving light holes (situates ~4 meV above the corresponding heavy hole transition) are observed. As absorption can only occur above $E_F$, the electron LL involved must be totally empty or at most partially filled. In the latter case, where $E_F$ is inside the LL in question, luminescence is also possible from the same level, and the luminescence and excitation peaks should overlap within the LL width, i.e. 1 to 2 meV. This is the case for the lowest excitation peak and the luminescence from $E_{2,0}$ (lowest LL, $N=0$, of $E_2$) in the whole magnetic field range above 2.7 T, the field at which luminescence from higher LL's has totally disappeared, and for $N=1$ between 1.4 and 2.2 T. This pinning of $E_F$ to $E_{2,0}$ for a long B interval is in contrast with the usual picture of a Fermi energy making a more or less abrupt jump between levels at each integer filling factor. This usual picture implicitly assumes that the intersubband separation does not depend on the occupation of the subbands [11].
In order to interpret these results, we calculated the band bending and the energy levels by a simple self-consistent calculation by satisfying simultaneously Poisson's and Schrödinger's equation. We obtain two almost degenerate lower subband levels $E_0$ and $E_1$, the corresponding charge distributions being concentrated on each of the triangular wells. The wave function of the next subband, $E_2$, spreads over the whole width of the QW.

With increasing magnetic field, the filling factor $v = nh/eB$ diminishes, and as the LL's of the different subbands cross each other, this causes an oscillatory change in the relative occupation of each subband. As the charge distribution in $z$-direction for each subband is different, this changes the total charge distribution and thus the band bending, and consequently also the energy eigenvalues. As the charge passes from $E_2$ (extended distribution) to $E_0$ and $E_1$ (concentration on the edges), the triangular well becomes sharper, and the stronger confinement raises $E_0$ and $E_1$ with respect to $E_2$, which remains essentially pinned to the band edge maximum. This diminution of intersubband distance is observed above $17$ T ($v=4$, i.e. 2 LL's occupied), where $E_2$ is totally emptied. At lower fields, however, the higher LL's of $E_0$ and $E_1$ are also occupied. At the points where they cross $E_2$, charge passes from the lower subband to $E_2$ with increasing field. As explained above, this charge transfer increases the subband distance, in a way as to counter-balance the moving away of the crossing LL's, and both levels overlap over a finite field range, causing $E_2$ to be pinned to $E_{2,0}$. This is experimentally indeed observed by the coincidence of the highest luminescence and the lowest excitation peaks. As the electrons are easily transferred between these overlapping levels, all of them can contribute to peak A luminescence as well as to electrical conduction. Under these circumstances the minimum in the density of states at $E_F$ corresponds to filling factors 4, 8, etc. (two spin levels and the two almost degenerate lower subbands). This explains the period of magnetoresistance oscillations to be $\Delta(1/B) = 0.060$ T$^{-1}$, which is just the double of the expected value for $n = 1.6 \times 10^{12}$ cm$^{-2}$ given by low-field Hall measurement and corresponding well to $v=4$ at 17 T, where emptying of $E_2$ is observed. As the peak A luminescence intensity depends on the density of occupied states in the highest level, the same oscillation period is observed.

In conclusion, we have determined the subband energies of modulation-doped quantum wells with 3 occupied subbands by luminescence spectroscopy, and have shown that the intersubband distance changes with a magnetic field, depending on the relative occupation of the subbands. In the range between $3$ and $17$ T, $E_2$ is pinned to $E_{2,0}$, which would not be possible if intersubband distances were constant. The same effect in principle also occurs in single heterostructures, although less pronounced.

We thank H. Krath for the excellent technical assistance.