Magnetic field induced excitons in photoluminescence from the heavily modulation doped 
\textit{p-type Ga}_{1-x}\text{Al}_x\text{As/GaAs single heterojunction}

L. Bryja, M. Kubisa, K. Ryczko, J. Misiewicz
Institute of Physics, WUT, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław,
M. Byszewski, R. Stepniewski, M. Potemski
Grenoble High Magnetic Field Laboratory, 25 av. Martrys, F-38042 Grenoble Cedex 9

We have studied polarisation resolved photoluminescence from \textit{p-type} modulation doped 
\textit{Ga}_{1-x}\text{Al}_x\text{As/GaAs} single junctions in temperature \( T=2\text{K} \) as a function of magnetic field up to 23T 
in Faraday configuration. We investigated the PL from five samples, two of Al mole content \( x=0.5 \) with two dimensional hole gas (2DHG) concentrations \( p_1=7.6\cdot10^{11}\text{cm}^{-2} \) and \( p_2=9.8\cdot10^{11}\text{cm}^{-2} \) and the hole mobility \( \mu=10^4\text{cm}^2/\text{Vs} \). Three samples had Al content \( x=0.3 \), the 2DHG concentration \( p_3=4.0\cdot10^{11}\text{cm}^{-2} \), \( p_4=3.1\cdot10^{11}\text{cm}^{-2} \), \( p_5=2.2\cdot10^{11}\text{cm}^{-2} \) and a very high hole mobility from \( \mu=1.25\cdot10^5\text{cm}^2/\text{Vs} \) to \( \mu=7.99\cdot10^5\text{cm}^2/\text{Vs} \). In photoluminescence spectra from all samples 
we observed three groups of interface related transitions. Two transitions we observed previously. 
The lowest energy one are the radiative recombination of photoexcited GaAs conduction band 
electrons trapped on donors with 2D holes confined at the interface. We named it D-line [1]. The 
second transition we attributed to the radiative recombination of photoexcited electrons with 2D 
holes. It is known in the literature as H-band. In this transitions the photoexcited electrons are not 
bound with 2D holes which manifests as its linear energy shift vs. magnetic field. Therefore we 
could determined experimentally 2D holes Landau levels energy dispersion [2]. The third group 
of lines exhibit a clear diamagnetic shift under the magnetic field and cannot be attributed, 
according to our theoretical calculations, to any recombination of unbound photoexcited 
electrons with 2D holes. In samples with very high 2DHG concentrations they appear in PL 
spectra in both, \( \sigma^+ \) and \( \sigma^- \) polarisations when appropriate H lines disappear from the spectra. 
This exchange take place at filling factors for which 2D holes Landau levels attributed to 
appropriate H transitions cross the Fermi level and start to fill with electrons. We accessed these 
lines to the radiative recombination of interface excitons. The nature of interface excitons is not 
quite clear. They can substitute free (X) or positively charged (X\textsuperscript{+}) excitons. In the first 
theoretical papers concerning charged excitons in 2D structures its observation in PL spectra 
from strongly anisotropy structures such as modulation doped single junctions were excluded. 
Nevertheless the observation of negatively charged excitons has been reported in \textit{n-type} modulation doped \textit{Ga}_{1-x}\text{Al}_x\text{As/GaAs} heterostructures. In the paper we analyse carefully all 
arguments concerning charged or neutral character of excitons in both heavily and modest doped 
\textit{p-type} single junctions.

References