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ELECTRONIC STATES AND OPTICAL TRANSITIONS IN UNDOPED AND MODULATION DOPED GaInAs/AlInAs QUANTUM WELLS AND SUPERLATTICES

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ABSTRACT

We briefly discuss selected fundamental properties of the electronic states and optical transitions in GaInAs/AlInAs quantum wells and superlattices either undoped or modulation doped. The results of different optical investigations are compared and we provide information on the excitonic as well as many-body states under different excitation conditions.

Recent advances in the technique of Molecular Beam Epitaxy (MBE) allow to fabricate high quality superlattices consisting of III-V semiconductors. Owing to the important opto-electronic applications the GaInAs/AlInAs material system is of particular importance. In this communication we briefly survey several recent results concerning the optical properties of MBE grown $Ga_{0.47}In_{0.53}As/Al_{0.48}In_{0.52}As$ superlattices either undoped (QW) or modulation doped (MDQW). It is well known that the perfect lattice matching and the interface roughness are the most critical problems for the succesful fabrication of photonic devices made of this material system. In fig.1 we show the comparison between the absorption spectra measured in narrow QWs and MDQWs. The undoped quantum wells (broken line) clearly exhibit sharp heavy and light hole exciton peaks positioned at the energy calculated with the simple particle in a box model (arrow in fig.1). The excitonic features are quenched in the MDQW heterostructure with a sheet density of $4\cdot10^{11}$ cm^{-2}. This is due to the screening of the Coulomb interaction which reduces the binding energy of the exciton. In addition we observe a blue shift of the absorption edge up to the Burstein-Moss edge, due to the band filling effect, and a red shift of the luminescence due to the band gap renormalization. The quantitative analysis of these data is reported elsewhere [1].

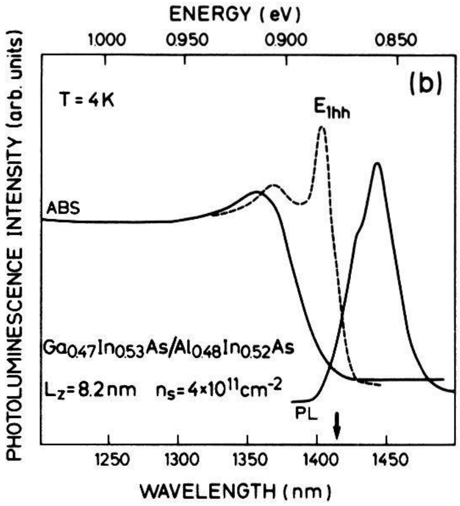

Fig.1 ABS and PL spectra from the MDQW and QW

It is worth noting that the luminescence in the MDQW does not show any singularity at the Fermi edge, indicating that no relaxation of the k-conservation due to localized states or impurities occurs in the investigated superlattices [2]. This is a clear indication of the extremely high quality of the MBE grown superlattices even in the limit of narrow well widths.

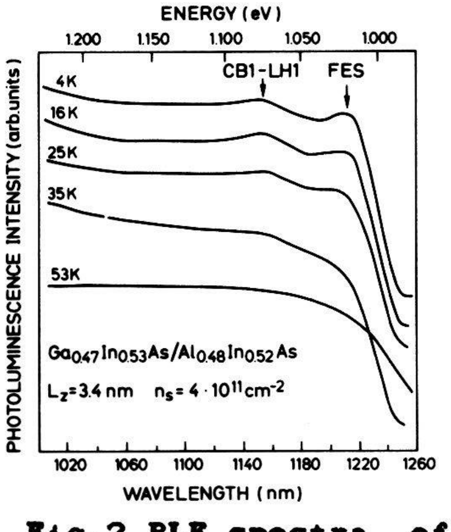

Fig.2 PLE spectra of the MDQW at different temperatures

The existence of a pronounced intrinsic Fermi edge singularity is observed in the photoluminescence excitation (PLE) and absorption spectra of the GaInAs MDQWs. In fig.2 we show the temperature dependence of the PLE spectra of a 3.4 nm MDQW recorded at very low excitation intensity. The peak labeled FES, which is located at the Burstein-Moss edge, originates from the enhanced oscillator strength of the scattered electronic states. The screening of the photogenerated holes by the confined electron gas in the MDQW leads to a charge rearrangement in the modulation doping induced plasma. In doing this, the scattering processes can only have final states above the Fermi level (where empty states are available) causing the enhancement of the electron correlation above the Fermi edge. This results in the FES peak observed in the PLE spectra of fig.2. As expected from the decrease of the electron correlation this spectral feature disappears rapidly with increasing temperature, and the absorption spectrum recovers the density-of-state profile around 50 K.

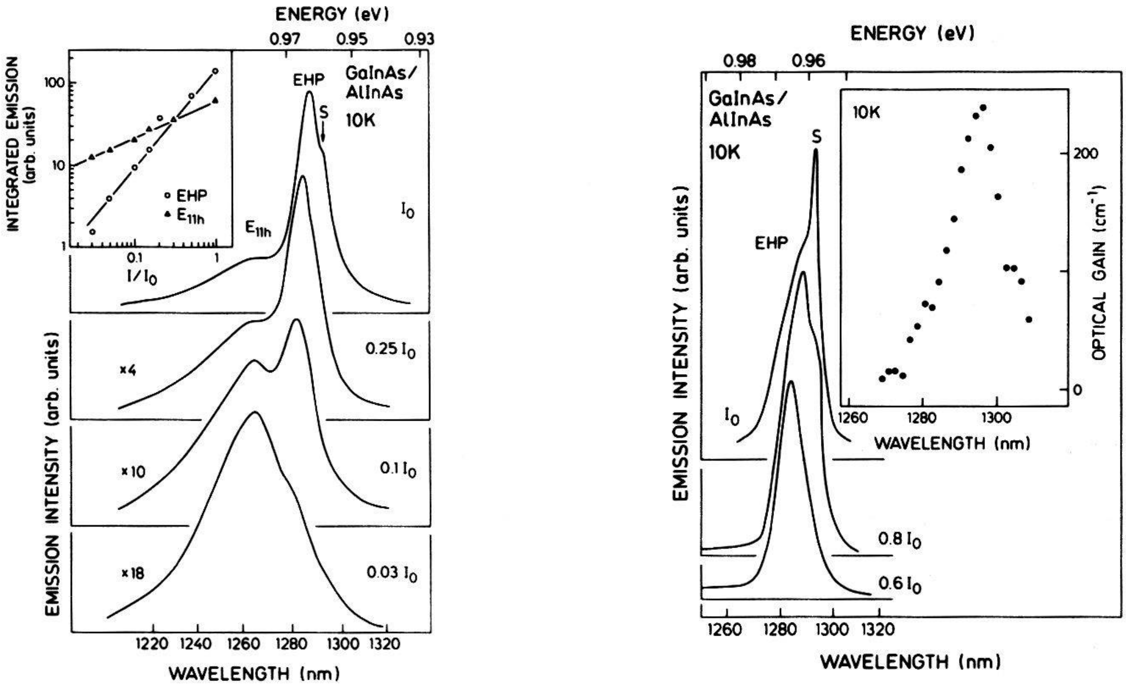

Fig.3 a) Spontaneous emission at different excitation intensities (I =1 MW/cm^2) and b) stimulated emission and optical gain for 3.6 nm QW

We next study the interesting effect of an increase of the density of photogenerated quasi particles in the superlattice, i.e. when we apply a strong optical pumping. In fig.3a we show the luminescence spectra obtained at low temperature and under different excitation conditions from an undoped superlattice. The ordinary excitonic luminescence observed at low excitation rate (E_{11h}) grows linearly and saturates with the excitation intensity. A superlinear emission band (EHP) arises on the low energy side of the E_{11h} band and becomes dominant at the highest excitation intensities. Sharp stimulated emission and optical gain are observed from this band (fig.3b). The main radiative channel is now the electron-hole plasma (EHP band) recombination. A detailed explanation of the emission line-shape will be the subject of another work. The stimulated emission threshold is considerably higher than in GaAs/AlGaAs superlattices under identical excitation conditions, and the optical gain is of the order of 250 cm^{-1} at 10 K.

A strong improvement of the optical amplification performances is achieved in the n-type MDQW heterostructures [2]. In fig.4 we show the stimulated emission and the optical gain spectrum measured in a MDQW of 8.2 nm well width under the same excitation conditions as before. The optical gain increases by about a factor 3 and the stimulated emission arises over more

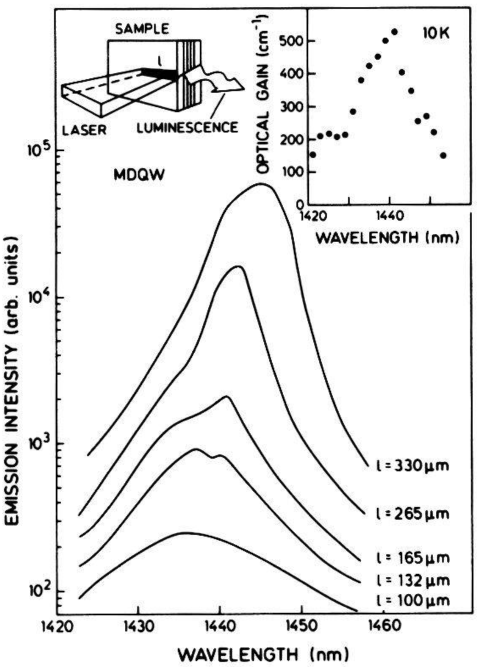

Fig.4 Stimulated emission and optical gain in MDQW

than three decades when the length of the optical cavity in the crystal is ranging from 100 and 330 μm. This effect is ascribed to the presence of the dense electron-plasma which is confined in the conduction well. From the phenomenological point of view this situation allows us to achieve a population inversion state simply by photogeneration of electron-hole pairs in the superlattice [3], thus lowering the stimulated emission threshold and improving the optical amplification performances of the MDQW as compared to the undoped case.

CONCLUSIONS

We have briefly discussed a few fundamental electronic transitions occurring in undoped and modulation doped GaInAs/AlInAs superlattices. The very high quality of the investigated superlattices allowed us to study the effects of the confined electron plasma on the excitonic states and the increasing electron correlation at the Fermi edge. Under high carrier photogeneration rates, the establishment of a dense electron-hole plasma results in an optical amplification which is very promising for opto-electronic devices operating in the 1.3-1.5 μm spectral range. We finally show that n-type modulation doping can be very useful for the improvement of these emission performances, since it allows to obtain a population inversion in the MDQW in stationary conditions.

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