SOME ASPECTS OF HYDROGEN PLASMA TREATMENT OF ANTI-MODULATION DOPED NEAR SURFACE GaAs/AlGaAs SINGLE QUANTUM WELL STRUCTURES

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The MBE grown anti-modulation doped GaAs/AlGaAs structures with near surface single quantum wells (QWs) were exposed to a DC hydrogen plasma (~400eV) and investigated using PL, PLE and PR spectroscopy at 5 K. Strong acceptor related free to bound transition (FB) dominates for QW related PL but excitonic features are still observed in PLE spectra. After hydrogen plasma treatment the PL intensity of FB transition from QW was strongly increased for above AlGaAs band gap excitation and was unchanged for below AlGaAs one. These results are consistent with atomic hydrogen passivation of deep defects in AlGaAs barriers. At the same time radiative excitonic recombination was quenched by hydrogenation. PLE and PR spectra indicate on a strong increase of electric field in subsurface region of the structure after hydrogenation. The increase of electric field in anti-modulation doped structure after hydrogen plasma treatment is supposed to be due to passivation by atomic hydrogen of surface states that leads to unpinning of Fermi level from mid gap to carbon acceptor level position in GaAs cap layer. It causes the further band bending and surface electric field increase that strongly suppress excitonic recombination in near surface QWs.

1. Introduction

Hydrogenation of semiconductor materials is one of the methods which allow to improve the optical and electrical properties of the materials due to passivation by atomic hydrogen of most deep defects, interface and surface states. The GaAs/AlGaAs heterostructures with quantum wells (QWs) are widely used for fabrication of optoelectronic devices. For conventional hydrogen passivation of deep defects which strongly decrease radiative recombination yield, low energies of hydrogen ions (<100 eV for GaAs-based structures) are usually preferred to avoid bombardment damage of the structures during plasma exposure and to have only chemical effects of hydrogen-defect interaction [1]. At the same time, the ability of atomic hydrogen to passivate the most deep defects in GaAs and AlGaAs materials and, hence, its own radiation defects [2] makes it possible to use for hydrogenation purposes the ion energies which exceed threshold energy for defect formation in materials. For GaAs/AlGaAs QW structures, the most studies indicate the general improvement in luminescence signal by hydrogen plasma treatment [3-6]. Nevertheless, study of the excitonic spectra of a GaAs epilayer have showed that heavy deuteration or hydrogenation of the material (for doses in the range of 10^{19} cm^{-2}) even at 100eV leads to the accumulation of deuterium at the epilayer-substrate interface and to the strong electric field which causes full quenching of the free exciton [7].

In this work we investigated the effects of hydrogen plasma treatment on low temperature photoluminescence of anti-modulation doped near surface GaAs/AlGaAs single quantum well structures. We demonstrate that for anti-modulation doped structures hydrogen plasma treatment increases the near-surface electric field which quenches the radiative recombination of excitons. These investigations can be useful also for application of simple glow discharge systems for hydrogenation purposes.

2. Experimental details

The two GaAs/AlGaAs SQW structures NU790 and NU791 were grown by MBE on (100) semi-insulating GaAs substrates. They consist of 1 μm thick GaAs buffer, a first $Al_{0.33}Ga_{0.67}As$ barrier 0.5 μm wide, a GaAs well, a second 15 nm $Al_{0.33}Ga_{0.67}As$ barrier and a 20 nm GaAs cap layer. The QW widths (Lz) were 6.3 for the sample NU790 and 3.4 nm for the sample NU791. The central third part of the well of both samples was Si doped (of 1.0×10^{16} cm^{-3}).

The exposures of the samples to a glow discharge DC hydrogen plasma with low power (9.2 mW/cm^2) to reduce plasma irradiation damage have been carried out in a diode type parallel-plate reactor with a plate voltage of 375±25 V and current density of 25 $\mu A/cm^2$ at 260°C for 10 minutes. The hydrogen ion dose (~5×10^{16} cm^{-2}) was estimated to be half a charge passed through the electrodes. The samples were mounted directly on a cathode.

Luminescence was excited by an argon ion laser at 488 nm with powers of 13-100 mW or by Ti: sapphire laser at 720 nm with powers of 100-300 mW and dispersed through a grating monochromator. The laser beam was focused on the sample onto a spot of ~0.2 mm diameter. The photoluminescence excitation (PLE) spectra were obtained using tunable Ti: sapphire laser. Photoreflectance (PR) measurements have been done using 488 nm light for modulation. Both SQW structures were treated by a DC hydrogen plasma and characterized by PL, PLE and PR measurements at 5 K.

3. Results and discussion

The over-all PL spectra at 5 K of the as-grown and plasma treated NU790 samples excited with 720 nm (below AlGaAs band gap) consists of the high enough peak at 1.4945 eV corresponding to the electron-carbon acceptor ($e-A_C$) transition and an envelope of BE and FE transitions from cap and buffer GaAs layers as well as wide QW-related narrower QW except for QW-related peak position is 1.816 eV. It is necessary to note that the luminescence related to carbon acceptor has been observed also in AlGaAs barriers for excitation with 488 nm (above AlGaAs band gap). So the feature of these samples is strong luminescence related to residual carbon which is the usual background impurity of MBE growth. Carbon background doping provides the p-type conductivity of cap GaAs layer and AlGaAs barriers where as QW in the central third is n-type doped.

The QW-related bands for excitation with 720 nm are shown in details in Fig.1 and Fig.2. In Fig.1 one can see the QW-related PL spectrum of as-grown NU790 sample excited with 720 nm. It is characterized by a strong enough and wide PL band (FWHM is of ~20 meV) without visible excitonic features. At the same time PLE spectrum of the structure contains two sharp lines indicating on the exciton transitions corresponding to electronic transitions to the first heavy hole (H11) and light hole energy (L11) states. The same situation is observed in Fig.2 for the narrower QW (NU791 sample) except for ratio between amplitude of H11 and L11 PLE peaks. PLE spectrum of NU791 with reduced amplitude of H11 transition indicates on presence of strong internal fields in QW [8,9]. The wide PL band which dominates in PL spectra of QW corresponds to free to bound (FB) transition that is electronic transition to carbon acceptor confined in QW.

The shape of FB PL band is quite complex taking into account the different energy level positions of acceptor in QW (in the center and near the well interfaces) [10,11]. The total binding energies for acceptor in the well center is of ~34 meV and is of ~18 meV for acceptor at the QW edge [10]. The large difference between both ones (16 meV) correlates with the linewidth of FB transition in SQW spectra. When electric field over QW exists there is a spatial separation of photoelectrons and acceptors occupied by photoholes in QW. The situation is more complicated by donor doping in the center of SQW [12-15].

After hydrogen plasma treatment the PL intensity of FB transition for excitation with 720 nm (in the well) was slightly increased in NU790 (by a factor of ~2.5) and almost unchanged in NU791. At the same time for excitation with 488 nm (in the barriers and in the well) the PL intensity of FB transition was increased both in NU790 (by a factor of ~8) and in NU791 (by a factor of ~2). The additional measurements of PL of AlGaAs barriers with 488 nm excitation have showed the large luminescence intensity increase (more than an order) for NU790 and much lower one (~1.5) for NU791 of electron-carbon acceptor (e-A_C) transition in AlGaAs barriers.

It means that atomic hydrogen passivates the deep defects in the barriers rather than at heteroboundaries so increasing the recombination lifetime. This strongly increases the number of carriers which fall into the QW. Moreover, for our anti-modulation

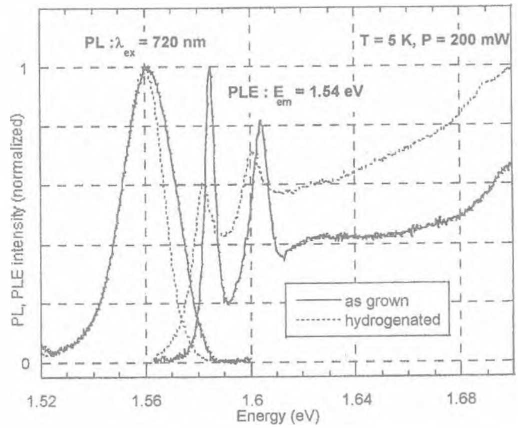

Fig.1. PL spectra for excitation with 720 nm and PLE ones of as-grown and hydrogenated NU790 samples at 5 K.

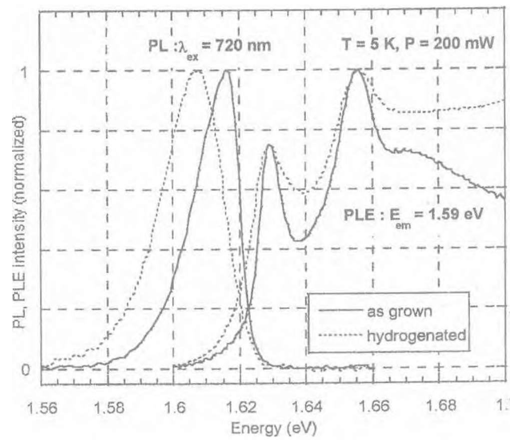

Fig.2. PL spectra for excitation with 720 nm and PLE ones of as-grown and hydrogenated NU791 samples at 5 K.

It is seen in Fig.1,2 that after hydrogenation the FWHMs of FB transitions decreases for NU790 and increases for NU791. For both samples we observe the red shift of the FB transitions, the largest one is for NU791. The PLE spectrum of NU790 exhibits also a strong enough red shift of exciton transition which is an evidence of observation of quantum confinement Stark effect after hydrogen plasma treatment. Moreover, the amplitudes of resonance excitonic absorption in PLE (especially for H11 transition) are strongly reduced by electric field. PLE spectrum of NU791 shows only further reduction of amplitude of the transitions without their sig[illegible]

The measurements of photo[illegible] sensitive to the presence of su[illegible] additional evidence to surface [illegible] hydrogenation. PR spectra of as-grown NU790 ses and becomes wide due to increase of surface electric fields.

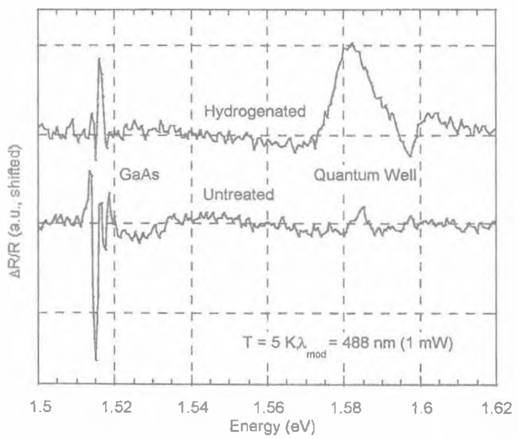

Fig.3. PR spectra of as-grown and hydrogenated NU 790 samples at 5 K.

Thus, the results of the measurements show two effects of hydrogen plasma treatment on the anti-modulation doped AlGaAs/GaAs structures:

-the over-all PL intensity from QW strongly increases only for PL excitation in the barriers,

-the electric field across QWs becomes stronger.

The first effect we can ascribed to observed elsewhere effect of atomic hydrogen passivation of deep defects in barrier epilayers. It leads to an increase of the recombination lifetime and, hence, the number of electrons which come into the QW, so increasing over-all luminescence.

The second effect contradict to most investigations which indicate on positive effect of hydrogenation such as passivation of surface states and related PL enhancement for near surface QWs due to a decrease of surface fields.

It is known that in GaAs the large surface states density pin the Fermi level at approximately in mid gap [16]. It creates the electric field which depletes the near surface region by free carriers. QWs in the near surface region are strongly influenced by these fields mainly due to quantum confinement Stark effect and electric field dissociation of excitons [17].

Nevertheless, we assign the observed increase of near surface fields in our anti-modulation doped structures to passivation of surface states by atomic hydrogen. The decrease of surface states density leads to unpinning of Fermi level from mid gap to energy position of carbon acceptor in GaAs cap layer. It causes an additional band bending and increase of surface electric field.

excitonic features were observed only in PLE spectra.

Strong increase of FB transition intensity in QWs has been observed after hydrogen plasma treatment for above AlGaAs band gap excitation in contrast to below AlGaAs one. This shows that the luminescence from QW was increased mainly due to hydrogen passivation deep defects in AlGaAs epilayers. At the same time the excitonic transition was further

The electric field increased by hydrogenation causes further dissociation of excitons and quenching of exciton luminescence as seen from PLE spectra. For NU791 we did not observe a strong shift of exciton peaks after hydrogenation (as seen from PLE spectra) and amplitudes of H11 and L11 peaks are changed in less extent. It should be noted that the electric field in as-grown NU791 was originally higher than in as-grown NU790 as follows from PLE specta of the samples. Moreover, energy shift of excitonic transition due to Stark effect (which is proportional to Lz^4) must be less pronounced for NU791 sample. The different effect of hydrogen plasma treatment on FB transition in NU790 and NU791 samples is, probably, a result of change in overlapping of complex distributions of free electrons and unoccupied acceptors in QWs which are defined by electric fields in QWs and can be influenced by hydrogen neutralization effect.

In our case we can not say anything about the effect of neutralization of shallow acceptors and donors in the QW and epilayers because the features related to doping were not resolved for these structures. Moreover, the strong increase of recombination lifetime and changes of electric fields don't allow us to compare intensity of carbon related PL bands of as-grown and hydrogenated samples. It should be also noted that hydrogen-shallow impurity complexes are unstable and decays under illumination [18].

We must point out that we have used the plasma with the energies of hydrogen ions (~400 eV) which exceed the threshold energy for point defect production in GaAs for Ga and As atoms (~100 eV). For these ion energies, point defects are produced only in a cap layer [19] and are able to diffuse into the AlGaAs barrier and even into the QW. QW is extremely sensitive to such treatments and is often used as the local probe for such experiments. Usually the distance where the point defects strongly affect the luminescence intensity from QWs at ion etching processes does not exceed 100 nm to QW in [20,21]. Nevertheless, in our case we didn't observe any degradation of PL neither in AlGaAs barriers or QW so we believe that atomic hydrogen fully passivate his own defects. For hydrogenated samples, slight ~1.48 eV transition related probably with slight damage induced by hydrogen plasma in a cap GaAs layer (e-A, A is V_{Ga} [22]) has been observed.

4. Summary

The MBE grown anti-modulation doped GaAs/AlGaAs SQW structures were exposed to a DC hydrogen plasma (~400eV) and investigated using PL, PLE and PR spectroscopy at 5 K. Strong carbon acceptor related free to bound transition dominates for QW related luminescence whereas quenched by plasma treatment. PLE and PR spectra give evidence to strong increase of electric field in subsurface region of the structure.

The increase of electric field in anti-modulation doped structures is explained by the passivation by atomic hydrogen of surface states that lead to unpinning of Fermi level to carbon acceptor level position in p-doped GaAs cap

further band bending and surface electric field increase.

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