Ground and excited excitonic resonances in heteroepitaxial GaN layers: A magnetooptical study

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It is well known that the biaxial stress modifies the energies of free exciton transitions (*A, B, C*) observed in GaN layers. It is less known, however, that at the same time the Zeman splitting pattern of these exciton transitions may be also completely changed. Both effects are the consequence of the strain-induced modifications of the valence band energy structure. In this paper, it is shown that changes in the energy position of excitons A, B and C as well as the modification of the Zeeman splitting pattern in heteroepitaxial layers can be consistently explained by single exciton model implying only one strain parameter. We further report on the observation of a series of the excited excitonic states which are clearly resolved in high magnetic fields.

We have studied the reflectivity spectra of high quality heteroepitaxial GaN layers grown on sapphire in magnetic fields up to 23T. The experiments have been performed at low temperatures (4.2K) in the configuration of the magnetic field B applied along (B||c) and perpendicular (B⊥c) to the c-axis of the GaN lattice. The representative spectra obtained for the B⊥c configuration, in the range from B = 0 to 23 T, are presented in Fig. 1. In the absence of magnetic field, the reflectivity spectra of these layers show pronounced structures associated with ground (1*s*) states of free excitons *A*, *B* and *C,* which arise from the crystal-field and spin orbit effects in the valence band (Fig. 1). Less intense but still visible are resonances associated with first exited (2s) states of excitons *A* and *B* (Fig. 1).

Application of magnetic fields modifies the reflectance spectra. The observed splitting pattern is quite different from the one observed for homoepitaxial layers grown on bulk GaN substrates [1]. In the B||c configuration, the lines $1s_A$ and $1s_B$ show practically no splitting up to 23 T (Fig. 3) whereas in the case of homoepitaxial layers the pronounced splitting of the $1s_B$ line has been observed [1]. In the B⊥c configuration, both $1s_A$ and $1s_B$ lines split (Fig. 4), however the splitting values as well as the number of observed components are different from this what has been observed for homoepitaxial GaN [1]. At sufficiently high fields, several new reflectivity lines are observed (Fig. 1). These new lines we attribute to higher excited excitonic states which become resolved only under the application of the magnetic field.

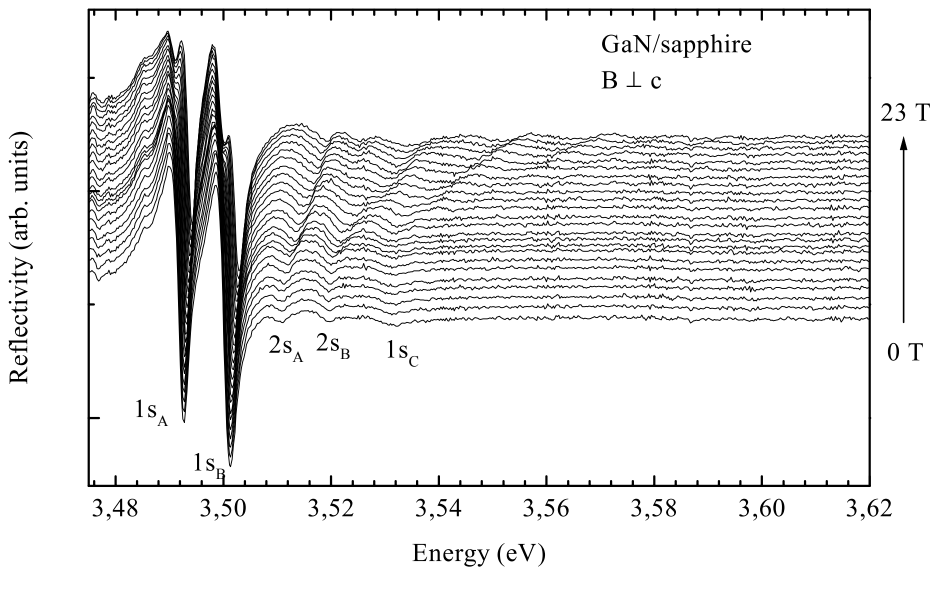

Fig. 1 Magnetoreflectance spectra of heteroepitaxial GaN measured for **B⊥c**

The Zeeman splitting pattern of the ground exciton states observed in the investigates structures can be well described using the model which has been previously invoked for homoepitaxial (strain free) layers [1]. We apply this model to our strained layers by modifying only one parameter, which is the crystal field parameter. As a matter of fact, this parameter can be almost directly red from the spectra, i.e., it can be easily determined by analysing the energy positions of the ground state excitons A, B and C at zero magnetic field. In this way we have found the crystal field parameter of 29 meV, which is more than three times larger than the corresponding value for homoepitaxial layers. As shown in Fig. 2, our calculations reproduce very well the experimental data for both B||c and B⊥c configurations of the magnetic field.

The analysis of the excited states has been performed within the frame of the model of the (renormalised) hydrogen atom subjected to magnetic fields [2, 3]. Using formulas derived for excitons in CdS and taking into account the observed energy difference between the 1s and 2s states, the effective Rydberg of 23.8meV and the reduced exciton mass of μ=0.171m_0 have been obtained, both values being common for excitons *A* and *B.* Using these later parameters we have been able to adopt the hydrogen-like model to magneto-excitons in GaN. Although it is difficult as yet, to firmly assign each excited state, our calculations specify some possible candidates among highly excited hydrogen-like excitonic states which could be optically active at high magnetic fields.

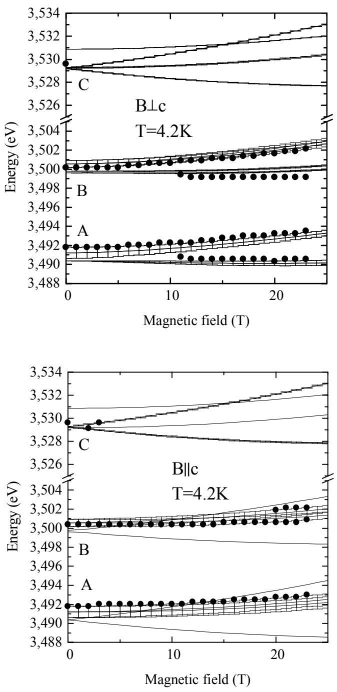

Fig. 2 The splitting of exciton ground states in the heteroepitaxial GaN layer. Symbols represent experimental data. Solid lines account for the theory (see text). Error bars represent the calculated oscillator strengths.

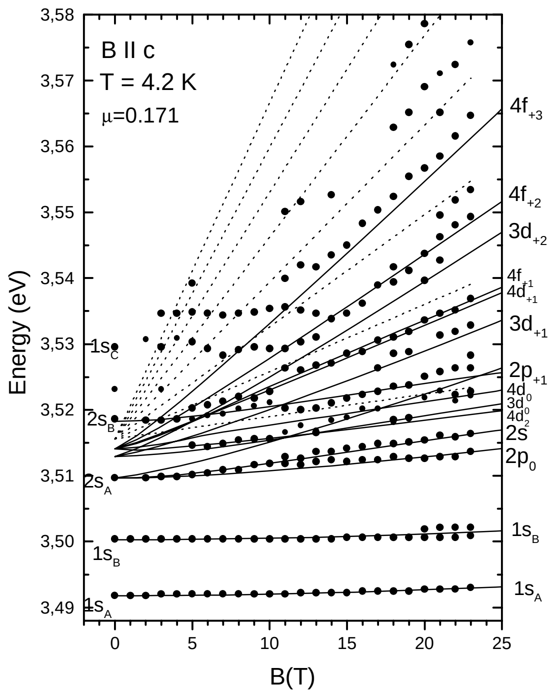

Fig. 3 Magnetic field dependence of excited states of free excitons. Circles – experimental data, solid lines – the calculation of the energy levels of hydrogen like atom in magnetic field , dotted lines- "Landau levels" corresponding to the exciton reduced mass.

In summary, we believe to have shown that the presence of the biaxial stress in heteroepitaxial GaN layers modifies not only the energy positions but also the Zeeman splitting pattern of the ground state excitons A, B, and C. Both effects can be consistently understood vie strain-induced changes in the valence band structure. Highly excited excitonic states have been resolved under the application of the magnetic field and tentatively described within a simple hydrogen-like model.

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