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PHOTOLUMINESCENCE STUDIES OF CUBIC PHASE GaN GROWN BY MOLECULAR BEAM EPITAXY ON (001) SILICON COVERED WITH SiC LAYER

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In this work we evaluate optical properties of cubic phase GaN epilayers grown on top of (001) silicon substrate prepared by a new process. Prior to the growth Si substrate was annealed at 1300–1400°C in propane. The so-prepared substrate is covered with a thin ($\approx$ 4 nm) SiC wafer, which allowed a successful growth of good morphological quality cubic phase GaN epilayers. The present results confirm recent suggestion on smaller ionization energies of acceptors in cubic phase GaN epilayers.

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1. Introduction

Cubic phase GaN (c-GaN) epilayers show several interesting properties, which may lead to new applications of GaN-based devices. Two of these properties seem to be especially important. By the first we mean here the recent prediction on a higher optical gain for the c-GaN [1]. The second property was reported very recently by Menninger et al. [2]. These authors claim that the ionization energy of shallow acceptors in c-GaN is of about 100 meV, i.e., it is considerably smaller than for acceptors in wurtzite phase GaN (w-GaN). Smaller acceptors ionization energy may result in a higher free hole concentration at room temperature.

2. Samples

Metastable c-GaN epilayers were grown on Si [3], SiC [4], MgO [5] and GaAs [6] substrates. In this work we describe optical properties of c-GaN epilayers grown by the molecular beam epitaxy (ECR-MBE) on top of (001) Si substrate, which prior to the growth process was annealed at 1300–1400°C in propane. This annealing covered Si substrate with a thin (≈ 4 nm thick) SiC wafer acting as a buffer layer. Even though SiC layer is very thin, the so-obtained c-GaN epilayers are of a good morphological quality [7].

3. Experimental results

In Fig. 1 we show the photoluminescence (PL) spectrum of the GaN/SiC/Si epilayer measured at 12 K under uv line excitation of Ar^+ laser. In addition to the band-edge emission a weak "orange" PL was observed (inset), which is an analog of a known "yellow" PL of w-GaN samples, shown for the comparison. The band-edge part of the PL can be decomposed to four PL subbands with the maxima at 3.251 eV, 3.191 eV, 3.116 eV and 3.034 eV. Two latter PL bands are noticeably broader than the first two.

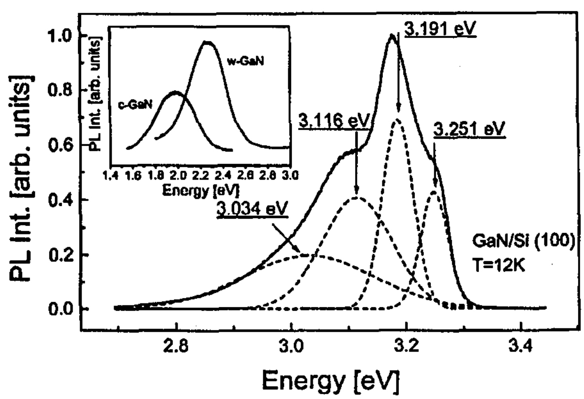

Fig. 1. Photoluminescence spectrum of the cubic phase GaN/SiC/Si (100) epilayer measured at 12 K. In the inset we show a weak orange emission.

Intensity and temperature dependencies of PL and PL kinetics were measured to identify the PL subbands. PL bands, with the maxima at 3.034 eV and 3.191 eV, increase linearly with the increasing excitation intensity. Two other PLs saturate at the increased excitation intensity. Spectral position of the 3.251 eV and 3.191 eV PLs does not change with an increase in the excitation intensity. For the 3.116 eV PL a weak up in the energy shift was observed, which is more pronounced for the 3.034 eV PL. Such up in the energy shift of the PL spectral position is expected for donor–acceptor pair (DAP) transitions, since for distant DAPs recombination rate is small and their contribution to the PL can be saturated at the increased light intensity.

The 3.191 eV PL and 3.034 eV PL increase in the intensity up to 20–30 K. For higher temperatures all PL subbands decrease in the intensity. For the temperature above 50 K this decrease is a single exponential and is characterized by the deactivation energies of about 30 meV for the 3.191 eV PL, 20 meV for the 3.116 eV and 3.034 eV PLs and of about 12 meV for the 3.251 eV PL. The decrease in the PL intensity is accompanied by a small shift of the spectral position of the

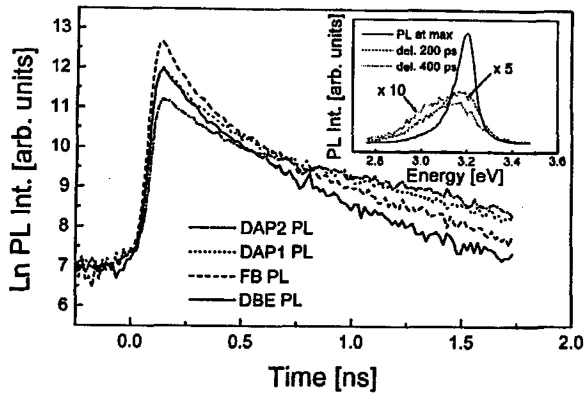

Fig. 2. PL kinetics and time-resolved PL spectrum (inset) of the cubic phase GaN/SiC/Si (100) epilayer measured at 2 K under nonresonant excitation conditions.

PL emissions. Whereas three other PLs shift down in the energy, which reflects the decrease in the band gap energy, the 3.191 eV PL shifts up in the energy at increased temperature.

Picosecond dynamics of the edge-band PLs of c-GaN (GaN/GaAs) was first studied by Klann et al. in 1995 [8]. A biexponential decay of the free exciton (FE) PL was observed with an initial fast decay of about 15–40 ps, which was related to FE relaxation to donor bound exciton (DBE). For DBEs a longer PL decay time was observed of about 100–400 ps. In Fig. 2 we show PL kinetics measured for the GaN/SiC/Si structure studied. Figure 2 indicates quite different PL decay times for four PL subbands. A biexponential PL decay is observed for all four emissions. All of them show a fast component of the decay ($\approx$ 200 ps for the 3.251 eV PL and $\approx$ 125 ps for the 3.191 eV PL) and a slow component (600–950 ps depending on the detection energy) observed at longer delay times. We relate the slow component of the decay of two higher energy PLs to their spectral overlap with the two low energy PL subbands showing longer PL decay times.

Due to different PL decay times, the PL changes its spectral shape at longer delay times in the time-resolved experiment shown in the inset of Fig. 2. At longer delay times, after the 3 ps long laser pulse, the contribution of the two lower energy PL subbands increases and dominates at 400 ps delay.

4. Discussion

Identity of the PL emissions in c-GaN is still disputed. Only recently it was agreed that the band gap of cubic phase GaN is of about 3.300 eV at 2 K [9]. The energies of PL transitions may differ from sample to sample, which reflects presence of strain in relatively thin GaN epilayers studied. The shift of PL position may be as large as about 10 meV [10] and can be either up or down in the energy. This is why identification of PL transitions in GaN epilayers is often tentative.

The present experimental results indicate a bound exciton (DBE) origin of the 3.251 eV PL. Its intensity saturates at increased excitation intensity. This PL decreases fast with increasing temperature and shows a fast PL decay. We observed such properties for the DBE transition in w-GaN [11]. The 3.191 eV PL is likely of the free-to-bound nature (hole–donor?). This identification explains most of the present experimental results.

Two low energy emissions with the maxima at 3.116 eV and 3.034 eV are of the same origin. They are considerably broader than two other emissions and show much longer PL decay times. We exclude here that the 3.034 eV PL is a LO-phonon replica of the first DAP band. The two PLs show several slightly different properties excluding such their identification. For example, a different temperature dependence of the PL intensity is observed.

The present results indicate the DAP origin of the 3.116 eV and 3.034 eV PLs with the same shallow donor center active in the recombination transitions, being about 20–40 meV deep. Thus, two DAPs emissions are observed due to the presence of the two types of shallow acceptors with their ionization energies of about 100 meV and 200 meV. These energies are estimated from the comparison of the spectral positions of the two PLs with the energy of relevant shallow DAP emission in w-GaN, taking into account the difference of band gaps of two phases of GaN.

Concluding, the present results confirm the recent suggestion on a smaller ionization energy of shallow acceptors in c-GaN as compared to acceptors in w-GaN. This, as already mentioned in the introduction, is a very important property of cubic phase GaN epilayers.

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