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Short Communication

Control of yellow photoluminescence in AlGaN/GaN heterostructures

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Abstract

Photoluminescence with the peak corresponding to yellow color of the visible spectrum (so-called yellow luminescence) originates from deep levels in the GaN buffer layers of heterostructures and depends on heterostructure growth conditions. In turn deep levels affect the resistance of Ohmic contacts of microwave transistors fabricated from these heterostructures. This determines the reliability of GaN microwave transistor operation.

Two types of units for control of photoluminescence with the peak in the yellow visible spectral region have been designed with the aim to control the quality of AlGaN/GaN/SiC and AlGaN/GaN/Al_2O_3 heterostructures. One of the units is used for fast control of yellow photoluminescence and the other for photoluminescence mapping on heterostructure wafer surfaces. Examples of photoluminescence maps for structures grown on different substrates have been given.

Keywords

yellow photoluminescence in AlGaN/GaN heterostructures, fast control of photoluminescence, photoluminescence mapping, AlGaN/GaN/SiC and AlGaN/GaN/Al_2O_3 heterostructures

1. Introduction

The quality of wide band gap materials and structures can be effectively controlled by photoluminescence methods [1–3].

Photoluminescence (PL) with the peak corresponding to yellow color of the visible spectrum (so-called yellow luminescence) occurs in the 2.0–2.5 eV ($\Delta\lambda$ = 496÷620 nm) region.

Shallow background impurities were identified and relative concentrations of defects in grown films were determined by low-temperature PL method [1]. The PL spectra were taken from GaN layers grown by molecular beam epitaxy without liquid nitrogen or with liquid nitrogen in cryopanels. The PL spectra contained bands produced by two types of recombination:

- with impurities (group of bands peaking at 3.29 eV);
- through defect levels (band peaking at 2.3 eV).

Manganese impurity in GaN can be an acceptor that produces deep levels. It was noted [1] that the lower intensity of edge and defect bands in GaN film PL spectrum can be used for evaluating GaN film quality. Other conditions being the same the intensity of the defect bands (and hence the defect concentration) in the PL spectrum of the layer grown without liquid nitrogen in cryopanels was at least by one order of magnitude higher than in the spectrum of the layer grown with liquid nitrogen in cryopanels.

It was shown [2] that GaN–HEMT epitaxial layers have strong yellow luminescence. It concentrates in the GaN buffer layer of the GaN–HEMT epitaxial layers and is caused by Ga vacancies and carbon impurity which favor the formation of deep electron traps.

Below we analyze results for specimens obtained by varying epitaxial layer growth conditions. As a result yellow PL decreased and hence GaN–HEMT device performance increased.

As reported earlier [3] yellow PL is directly responsible for reliability degradation of GaN microwave transistors.

Therefore tools for yellow PL control are required.

2. Yellow photoluminescence control equipment

2.1. Equipment for fast control of yellow photoluminescence signal in heterostructures.

Schematic of unit for input control of yellow PL in heterostructures is shown in Fig. 1.

PL studies with excitation by 280 nm LED pulses showed that the signal intensity drops with an increase in excitation frequency. Therefore we used DC input PL control. PL intensity decreased dramatically upon specimen heating and was almost absent at 200 °C.

The yellow PL signal changed largely over the specimen surface areas. By way of example Table 1 shows PL

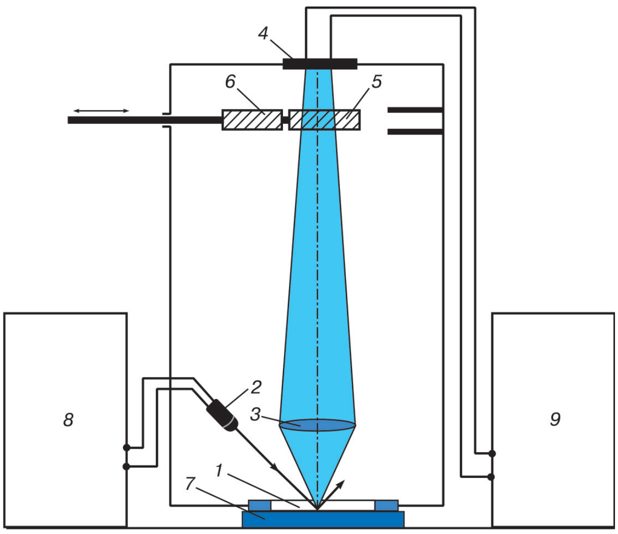

Figure 1. Schematic of equipment for input control of yellow PL in heterostructures: (*1*) test heterostructure specimen, (*2*) UV LED with focusing system, (*3*) glass lens for PL focusing onto photodiode, (*4*) silicon photodiode, (*5* and *6*) two interchangeable PL filters for 530–550 and 340–360 nm, respectively, (*7*) mirror behind back side of test specimen for reflecting PL radiation from back side of test specimen to lens *3* and photodiode *4*, (*8*) UV photodiode power system, (*9*) system for recording signal of PL receiver *4*.

Table 1. Scatter of yellow photoluminescence signal level over heterostructure area.

Batch #	Substrate	Photoluminescence, arb.u		$(V_{max} - V_{min})/ / V_{av}$, %
		Center	Edges	
V–1983–3	C 2850–11*	58	68, 75, 49, 58	12,8
V–1913–3	A 3317–12*	50	16, 75, 62, 42	120
V–1913–6	C 2769–15*	43	18, 72, 45, 29	130
V–1913–5	C 2776–14*	40	17, 65, 32, 24	134
V– 2196–3	C–3092–12*	67	36, 42, 56, 90	93
V–2225–3	A–3512–15*	57	38, 74, 40, 47	70
V–2226–2	C–3028–12*	56	57, 38, 38, 72	65
V–2226–5	C–3058–12*	58	53, 45, 56, 63	34
HT2Z00679	Al_2O_3	43	51, 51, 53, 59	31
HT2Z00690	Al_2O_3	42	47, 52, 51, 47	21
HT2Z00678	Al_2O_3	43	50, 53, 54, 59	32

* SiC substrate; *V* – photoluminescence

signal data for AlGaN/GaN/SiC and AlGaN/GaN/Al_2O_3 specimens. The diameter of the ultraviolet (UV) LED beam that excited luminescence was 4 mm.

Table 1 shows that the specimens on silicon carbide substrates had less uniform PL level distribution across the surface than the heterostructures on sapphire substrates. Furthermore the PL intensity at the edges of heterostructure specimens on silicon carbide substrates was in most cases lower than in the centers. It is not yet clear why PL is nonuniform. However this nonuniformity suggests that the properties of the heterostructures are nonuniform across the surface.

The yellow PL intensity in heterostructures on sapphire substrates was reduced by two times by specimen processing since the UV beams that excited luminescence passed through the sapphire substrate, reflected from mirror 7 (Fig. 1) and excited PL again in the nitride heterostructure. In heterostructures on SiC substrates UV beams were completely absorbed by the silicon carbide layer and double UV excitation did not occur.

2.2. Equipment for photoluminescence mapping on specimen surface.

Block diagram of equipment for photoluminescence mapping is shown in Fig. 2.

The unit is designed for measurements with programmable scanning in the following modes: 10 × 10, 25 × 25, 50 × 50 and 100 × 100 points. Furthermore when measuring each next point the wafer holder moved rapidly and then stopped for approx. 100 ms. This allowed time for measurement of the photodiode current at which the PL signal reached a steady state mode.

Figure 3 shows yellow PL maps for two specimens grown on sapphire and silicon carbide substrates. The maps are plotted for 2500 points.

Figure 3 shows that for the heterostructure on a sapphire substrate the PL signal in the center is sufficiently uniform and lower than at the wafer edge. However for the heterostructure on a silicon carbide substrate the PL signal intensity is higher in the left half of the specimen (the base cut is in the bottom, Fig. 3*a*).

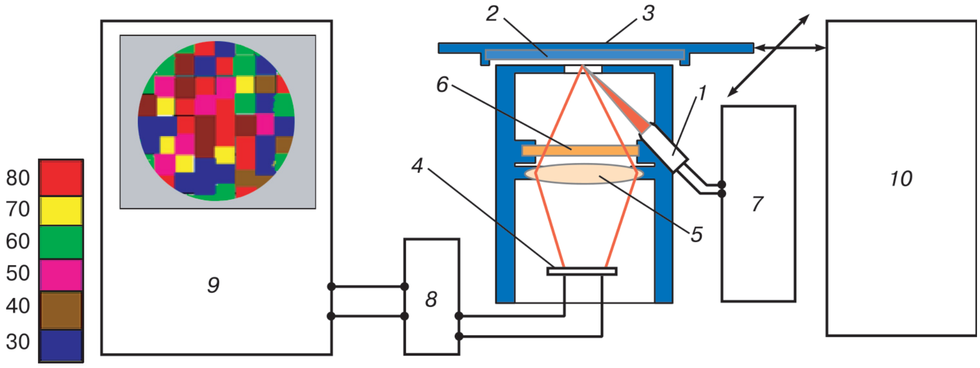

Figure 2. Block diagram of equipment for yellow photoluminescence mapping in AlGaN/GaN heterostructures: (*1*) UV photodiode, (*2*) test wafer with AlGaN/GaN heterostructure, (*3*) mirror, (*4*) silicon photodiode, (*5*) glass lens, (*6*) filter for wavelength of yellow PL, (*7*) UV photodiode power system, (*8*) photodiode current amplifier, (*9*) computer, (*10*) *X–Y* scanning unit.

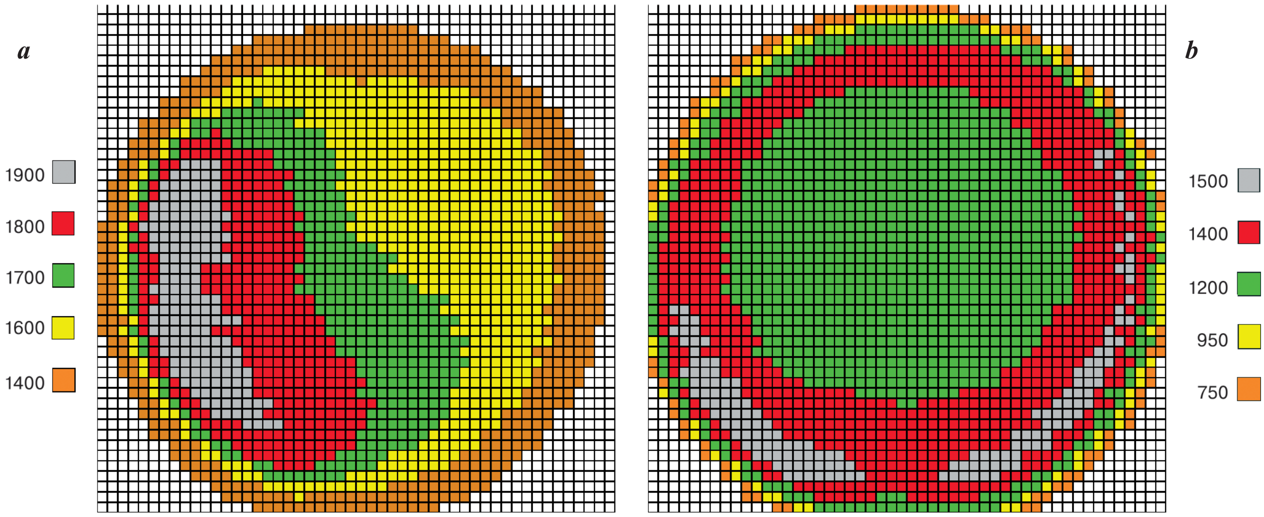

Figure 3. Yellow photoluminescence maps for 50 mm diameter AlGaN/GaN heterostructures grown on (*a*) silicon carbide and (*b*) sapphire substrates.

3. Conclusion

Two types of equipment were designed for input control of AlGaN/GaN/SiC and AlGaN/GaN/Al_2O_3 heterostructures. Yellow PL was measured in heterostructures grown on these substrates. We will further monitor correlation between the intensity and uniformity of yellow PL, heterostructure growth technology and parameters of microwave transistors made from the heterostructures on different substrates.

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