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Metalorganic VPE growth of GaInP and related semiconductors for mobile communication device application

Takashi Udagawa[†]
Showa Denko Central Research Laboratory (Chichibu) 1505 Shimokagemori, Chichibu, Saitama, Japan 369-1871
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Abstract Metal-organic VPE (MOVPE) epitaxial growth procedure and related device fabrication technique are reported for GaInP-based epitaxial materials and devices. For GaInP/GaInAs two-dimensional electron-gas field-effect transistor (TEGFET), a promising epitaxial stacking structure resulting in enhanced electron mobility is given. In conjunction with this, a new device fabrication technique to improve luminous intensity of GaInP-based LED is also shown.

Key words MOVPE, TEGFET, LED, GaInP, AlGaInP, GaInAs, Mobility, Luminous intensity

1. Introduction

Recent development in the mobile communication equipment requires MOVPE-grown GaInP-based epitaxial materials for microwave low-noise two-dimensional electron gas (TEG) field effect transistor (FET), hetero bipolar transistor (HBT), high-brightness light emitting diode (LED) etc..

In general, GaInP-based TEGFET employs GaInP epitaxial layer as a spacer for GaInAs channel layer. Since poor transconductance (gm) results in degraded noise-figure (NF) for the low-noise TEGFET, it is therefore important to improve the mobility of the TEG accumulated at the GaInP spacer/GaInAs channel hetero-interface.

In conjunction with demand of high-performance of GaInP electronic devices, improvement of luminous intensity is vitally required to visible GaInP-based LED, such as AlGaInP double-hetero (DH) structure yellowish-green LED, for high-bright display.

In this report, MOVPE growth technique to improve the electron mobility of the GaInP-based pseudomorphic heterojunction TEGFET structure using compositionally graded $Ga_YIn_{1-Y}P$ epitaxial layer as a spacer is shown. Additionally, new fabrication technique to increase the luminous intensity of AlGaInP DH LED is also presented.

2. Experimental

2.1. Stacking structure for GaInP/GaInAs pseudomorphic TEGFET [1, 2]

An epitaxial structure for the TEGFET comprised from LEC-grown semi-insulating GaAs substrate ($\rho > 10^7\ \Omega \cdot cm$)/5-periods $Al_{0.30}Ga_{0.70}As$-GaAs ($p < 10^{14}\ cm^{-3}$) super lattice buffer layer/un-doped n-$Ga_{1-x}In_xAs$ channel layer/undoped n-$Ga_YIn_{1-Y}P$ spacer layer/n-$Ga_{0.49}In_{0.51}P$ electron-supply layer/Si-doped GaAs cap layer ($n > 2 \times 10^{18}\ cm^{-3}$) was grown by TMG/TMI/$PH_3$/$AsH_3$/$H_2$ low-pressure MOCVD system (AIX-2400G III, AIXTRON AG., Germany) at about 640°C under the pressure of about 10^4 Pa. Indium composition (= X) of 12 nm-thick $Ga_{1-x}In_xAs$ channel layer was set to 0.20. Carrier concentration of the $Ga_{0.51}In_{0.49}P$ electron-supply layer was adjusted around $2 \times 10^{18}\ cm^{-3}$ by controlling the doping amount of Si_2H_6. In the TEGFET structure, the $Ga_YIn_{1-Y}P$ layer which had graded composition of Ga(= Y) decreased linearly from 0.70 at the interface to 0.51 was utilized as the spacer. The graded composition was given by alternating linearly the TMG/TMI flow ratio. The thickness of the spacer layer was set to 7 nm.

2.2. Stacking structure for AlGaInP DH yellowish-green LED

An epitaxial wafer was grown on p-GaAs substrate by TMG/TMI/PH_3/H_2 low-pressure MOCVD system at 730°C. The epitaxial wafer involved Zn-doped GaAs

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[†]Corresponding author
Tel: 81-494-23-6117
Fax: 81-494-25-0830
E-mail: Takasi_Udagawa@sdk.co.jp

buffer layer, Zn-doped $Al_{0.40}Ga_{0.60}As/Al_{0.90}Ga_{0.10}As$ DBR layer, Zn-doped $A_{0.70}Ga_{0.30})_{0.50}In_{0.50}$ lower clad layer, undoped-$(Al_{0.14}Ga_{0.86})_{0.50}In_{0.50}P$ active layer, and Se-doped $(Al_{0.70}Ga_{0.30})_{0.50}In_{0.50}P$ upper clad layer as reported previously [3].

3. Results and Discussion

3.1. Enhancement of TEG mobility in the GaInP/GaInAs TEGFET

To improve the compositional abruptness at the hetero-interface to the $Ga_{0.80}In_{0.20}As$ channel layer, the graded $Ga_YIn_{1-Y}P$ spacer was initiated to grow by flowing PH_3 few seconds later from the arsenic source (AsH_3) for the growth of $Ga_{0.80}In_{0.20}As$ channel was interrupted. A quantum Hall-effect measurement was done to recognize the existence of two-dimensional electron gas at 4.2 K under magnetic field strength up to 8 Tesla (T). Figure 1 shows magnetic field strength dependence of Hall resistance representing periodical plateaus labeled i = 6, 8, 10, and 12 in Hall resistance (kΩ). Because of the equivalent value of arithmetical product of the labeled plateau number and Hall resistance, i.e., ~25.8 kΩ, the existence of two-dimensional electron-gas was actually revealed. Comparison on the Hall mobility and sheet carrier concentration (n_s) measured by van der Pauw method was also made be- tween the TEGFET structure equipped with the $Ga_{0.51}In_{0.49}P$ spacer of the constant Ga composition (= 0.51). Table 1 summarizes the electric properties of the TEGFET structure. Contrary to the maximum room-temperature mobility (μ_{RT}) about 5,700 $cm^2/V \cdot s$ at n_s of 1.4×10^{12} cm^{-2} for $Ga_{0.80}In_{0.20}As/Ga_{0.51}In_{0.49}P$ unequipped with the graded compositional spacer, the graded $Ga_YIn_{1-Y}P$ ($Y = 0.70 \rightarrow 0.51$) gave μ_{RT} of 6,300 $cm^2/V \cdot s$ at $n_s = 1.4\times10^{12}$ cm^{-2} about 25 % larger to that of the non-graded compositional $Ga_{0.51}In_{0.49}P$ spacer system. Obtainable mobility reaches up to about 200,000 $cm^2/V \cdot s$ at 1.6 K. The high mobility is considered to result from the enlargement of conduction-band off-set by increasing the Ga composition at the graded $Ga_YIn_{1-Y}P$ spacer/$Ga_{0.80}In_{0.20}As$ channel heterojunction interface.

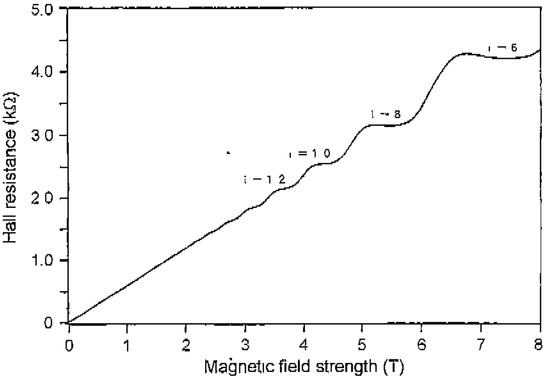

Fig. 1. Magnetic field strength (T) dependence of Hall resistance (kΩ) for GaInP/GaInAs TEGFET structure equipped with graded GaInP spacer.

3.2. Fabrication of high luminous intensity AlGaInP DH LED

Utilizing the epitaxial structure mentioned above, yellowish-green AlGaInP DH LED was fabricated. On the surface of the upper clad layer mentioned above, twelve AuGe/Au dispersed ohmic electrodes were placed with a centered circular pad electrode with diameter of 110 μm as shown in the Fig. 2. Especially to diffuse operation current widely and homogeneously to emission area, eight dispersed electrodes were placed on the circumference of radius of about 90 μm. The other four electrodes at the corners on the upper clad surface were designed to disperse on the circumference of the radius of about 110 μm on the basis of computer calculation of recombination efficiency [3]. The surface of the upper clad layer equipped with the dispersed ohmic electrodes was covered with transpar-

Table 1
Hall mobility (μ) and sheet carrier concentration (n_s) of GaInP/GaInAs TEGFET structure with conventional and graded spacer [1]

Spacer	Conventional spacer		Graded spacer	
Temperature	μ ($cm^2/V \cdot s$)	n_s ($\times10^{12}$ cm^{-2})	μ ($cm^2/V \cdot s$)	n_s ($\times10^{12}$ cm^{-2})
300 K	5,600	1.4	6,300	1.4
77 K	25,000	1.4	32,000	1.4
1.6 K	67,000	1.5	200,000	1.5

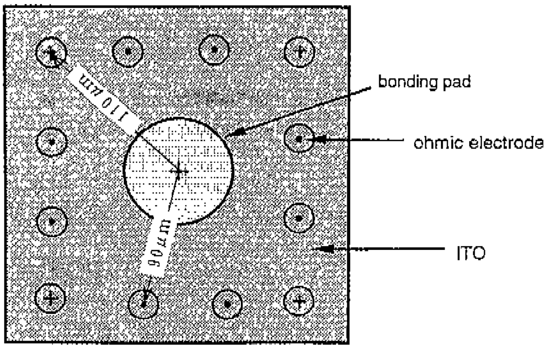

Fig. 2. Disperse configuration manner of ohmic electrodes for AlGaInP DH yellowish-green LED.

nt current spreading layer comprised from 550 nm-thick indium-tin-oxide (ITO) with resistivity of about $5\times10^{-5}\,\Omega\cdot$cm. On the central region of the ITO current spreading layer, circular Au pad electrode with 110 μm in diameter was formed. A rectangular LED with 260 μm×260 μm in chip size was then fabricated [3].

3.3. Optical performance of the AlGaInP DH LED with dispersed ohmic electrodes

To ascertain homogeneity of emission intensity form the emission area, emission intensity distribution of the AlGaInP yellowish-green LED was investigated by tracing near-field emission pattern. In the near-field pattern, a region with the same color indicates that the same intensity emission results in form the region. Figure 3 shows the intensity distribution of the AlGaInP LED at the forward current (= If) of 3 mA. The homogeneous color-distribution in the near-field pattern demonstrates that the disperse configuration manner of ohmic electrodes makes it possible to emit yellowish-green light with homogeneous intensity from the whole of the exposed emission area. This confirms that disperse configuration of ohmic electrodes is an effective way to spread the operation current to whole of the emission area. By the disperse configuration of ohmic-electrodes, homogeneous intensity emission was obtained even at a low forward injection current (If) even 2~3 mA as shown in the Fig. 3. The AlGaInP LED with the dispersed ohmic electrodes gave out-put power of 0.15 mW (@ If = 20 mA) for yellowish-green light with emission wavelength (= λ) of 570 nm. Forward voltage (Vf) at If of 20 mA was 2.1 V~2.3 V. In conjunction with the high transparency of the ITO window layer over 90 % for yellowish-green band, the brightness of the yellowish-green LED with λ of 574 nm reached to 35 mcd which is twice times larger than that of conventional GaP yellowish-green LED. The improvement of luminous intensity by the dispersed electrode configuration was also recognized for yellow-, orange-, and red-band AlGaInP DH LEDs.

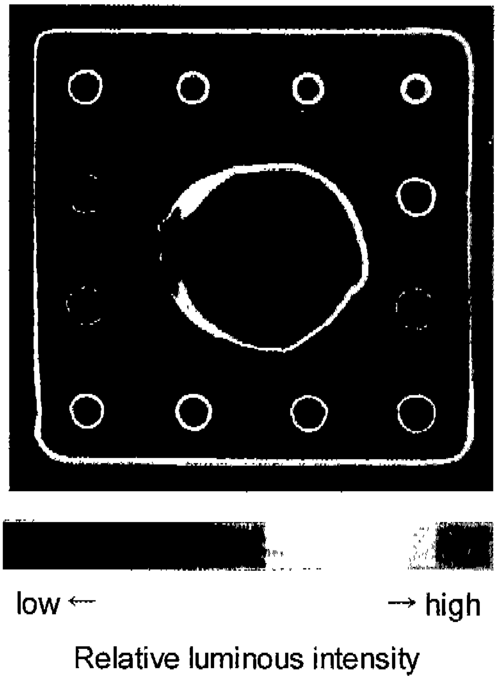

Fig. 3. Near field emission pattern of yellowish-green AlGaInP LED with dispersed ohmic electrode configuration at If = 3 mG.

4. Conclusion

In summary, the spacer layer which consist of compositionally graded Ga$_Y$In$_{1-Y}$P is effective to obtain high mobility TEG in the pseudomorphic GaInP/GaInAs hetero-junction FET structure. Concerning to the fabrication technique for AlGaInP LED, the dispersed configuration technique of ohmic electrodes is one of promising way to spread widely the injection current to emission area, and thus to obtain high-brightness AlGaInP LED.

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