SCANNED PHOTOLUMINESCENCE OF GaAlAs/GaAs/GaAlAs DOUBLE HETEROSTRUCTURES CORRECTED ON THE REFLECTANCE MAP.

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The photoluminescence mapping of the heterostructures consisting of transparent upper Ga0.4Al0.6As layer under the active GaAs layer were investigated. The correction on the reflectance coefficient is proposed to exclude the influence of the upper layer thickness non-uniformity on the photoluminescence map. The dependence of photoluminescence spectrum on the upper layer thickness is considered.

INTRODUCTION

Photoluminescence mapping is a valuable technique for epitaxial process characterization. The important properties of growing A3B5 epitaxial layers are quality (i.e. defect density), alloy composition, doping level and the spatial uniformity of all of them above. The integral photoluminescence and spectral photoluminescence parameters (peak wavelength $\lambda_{\text{max}}$, $\lambda_{\text{a}}$, $\lambda_{\text{c}}$, $\delta\lambda=\lambda_{\text{a}}-\lambda_{\text{c}}$) maps are widely used for these properties characterization (Ref.(1)). The continuing tightening of tolerances demanded by increasing device sophistication have generated a need for improvement of the photoluminescence methods. For example the doping level variation in the case of Ga0.4 Al0.6As / GaAs / Ga0.4 Al0.6As heterostructures used for photocathodes (Ref.(3)) should not exceed 10%. To reveal the doping level non-uniformity of the order of 10% the error of $\lambda_{\text{a}}$ ($\lambda_{\text{a}}$, $\lambda_{\text{c}}$) must be at least less then 1 nm. The spatial uniformity of the photoluminescence in GaAs layer of the photocathodes must be better than 10%. However direct estimation of the integral photoluminescence and $\lambda_{\text{max}}$, $\lambda_{\text{a}}$, $\lambda_{\text{c}}$ uniformity can give additional error compared with these values and confusing results if the transparent upper layer covers the active layer emitting photoluminescence. This paper represents the correction approach to overcome this drawback of photoluminescence method.

EXPERIMENTAL

The used apparatus is designed for integral and spectral parameters of the photoluminescence and reflectance coefficient mapping. The wafer is translated under HeNe or LED ($\lambda=0.67 \mu\text{m}$) lasers. The probe size is typically 50 $\mu\text{m}$. The emitted or reflected light is detected using Si photodiode and amplifier. For the spectral photoluminescence parameters mapping the emitted light is spectrally analyzed using a fast-scanning grating monochromator. The wafer is simultaneously rotated and translated, such that the laser spot describes a spiral path on it. Typical wafer maps in integral photoluminescence or reflectance data acquisition mode, which are acquired in approximately 3 min, consist of data points every 125$\mu\text{m}$ on 50mm diameter wafer (approximately 160000 points). The spectral ($\lambda_{\text{max}}$, $\lambda_{\text{a}}$, $\lambda_{\text{c}}$) maps with the same data
density can be obtained in 30 min. This data density is necessary to clearly distinguish particulates, crystallographic defects and cleaning stains. The investigated structure for photocathode was grown by MOCVD on 2 inch diameter GaAs substrate. This structure consist of a nominally 1.8 μm thick p-type (Na=5 \times 10^{18} \text{cm}^{-3}) layer of Ga_{0.4}Al_{0.6}As grown on 2.5 μm thick p-type (Na=8 \times 10^{18} \text{cm}^{-3}) GaAs on 1.8 μm thick p-type (Na=5 \times 10^{18} \text{cm}^{-3}) of Ga_{0.4}Al_{0.6}As on GaAs semiinsulator substrate. The reflectance coefficient and photoluminescence maps of this structure are compared in figure 1 (a,b).

![Image of reflectance coefficient and integral PL intensity](image)

Fig1. The maps of the reflectance coefficient (a) and the integral PL intensity (b) of Ga_{0.4}Al_{0.6}As/GaAs/ Ga_{0.4}Al_{0.6}As double heterostructure.

**DISCUSSION**

The scanning reflectance map of this structure (fig. 1a) consists of the light and dark fringes typical for the reflectance map in Ref.(2) where each fringe is a contour of equal thickness of upper layer. The thickness variation between fringes is given by excitation light wavelength $\lambda_m$ divided by two times the index of refraction in upper layer Ga_{0.4}Al_{0.6}As and equals 100nm. The photoluminescence map (fig1b) of this structure reveals practically the same fringe pictures (fig.1a, 1b). Taking into account that photoluminance emerges from the GaAs layer, this effect may be due to the spatial modulation of the incident light intensity transmitted through the upper layer of GaAl_{0.6}As_{0.4} or relaxation of photoluminescence intensity emerging from layer of GaAs and getting out through upper layer. The incident light intensity modulation due to upper layer thickness $t$ variation was calculated using (Ref.(10) the transmittance $T$ as function of $t$

$$T = \frac{r_1^2 + r_2^2 - r_1^2 \cdot r_2^2 - 1}{1 + r_1^2 \cdot r_2^2 + 2 \cdot r_1 \cdot r_2 \cdot \cos \varphi}$$

**[1]**
where

\[
\begin{align*}
  r_1 &= \frac{1 - n_1}{1 + n_1} \\
  r_2 &= \frac{1 - n_1}{1 + n_1} \\
  \varphi &= \frac{4 \pi \cdot n_1 \cdot t}{\lambda_{in}}
\end{align*}
\]

\(n_1, n_2\) are the refractive indexes in \(\text{Ga}_{0.4} \text{Al}_{0.6}\text{As}\) and \(\text{GaAs}\) layers at the incident light wavelength \(\lambda_{in}\). According to calculations \(T(t, \lambda_{in})\), the photoluminescence intensity variation can achieve 12%. For evaluation of the detected photoluminescence flux getting out through upper layer it was taken into account the geometrical configuration of the pick up objective lens. The photoluminescence flux at wavelength \(\lambda\) collected by objective lens can be obtained by integration over output angels

\[
I(\lambda, t) = 2\pi \int \frac{\varpsi^2}{\varpsi_1^2 + r_1^2 + r_1^2 \cdot r_2^2 - 1} \sin(\varpsi) \cdot I_0(\lambda) d\varpsi
\]

where

\[
\theta = \frac{4 \cdot \pi \cdot n_1 \cdot t \cdot \cos(\alpha)}{\lambda}, \quad \alpha = \sin^{-1} \left[ \frac{n_1 \sin(\varpsi)}{n_1} \right],
\]

\[
\alpha_{1,2} = \sin^{-1} \left[ \frac{\sin(\beta_{1,2})}{n_1} \right], \quad \varpsi_{1,2} = \sin^{-1} \left[ \frac{n_1 \cdot \sin(\alpha_{1,2})}{n_2} \right]
\]

\(I_0(\lambda)\) is photoluminescence intensity per steradian emerging from active \(\text{GaAs}\) layer; \(\beta_1, \beta_2\) are the minimum and maximum angles at which objective lens collects the light. Integration of \(I(\lambda, t)\) over the photoluminescence spectrum gives detected photoluminescence \(I_1(t)\) variations due to the thickness \(t\) non-uniformity's less than 3%. These calculations explain the photoluminescence and reflectance maps similarity and the magnitude of the fringe modulation. Moreover using photoluminescence, reflectance maps and appropriate procedure one can exclude the upper layer influence to get real picture of photoluminescence distribution over the whole wafer. For this purpose the photoluminescence value in each point of the map should be divided on \(T-1-R\), where \(R\) is the measured reflectance coefficient in this point. Using this recalculation we have got corrected photoluminescence map free from the fringes picture typical for interference effects (fig.2). The nonuniformity of the corrected PL map is mainly due to the properties of the \(\text{GaAs}\) layer and its boundaries. The influence of the upper layer on the luminescence spectrum from the active \(\text{GaAs}\) layer has been analyzed. For this purpose the typical photoluminescence spectrum \(I_0(\lambda)\) was recalculated into \(I(\lambda)\) using expression (2). The resulting spectrums of this recalculation for \(t=1950\text{nm}\) and \(t=2050\text{nm}\) are represented in fig.3. It is shown that the shape of the spectrum is disturbed and the spectrum shift is the function of the upper layer thickness. The value of the \(\lambda_{max}\) shift is 4.1nm. Mapping of the photoluminescence peak wavelength demonstrates variation of \(\lambda_{max}\) close to this value.
Fig. 2 The map of the integral PL intensity of Ga$_{0.4}$Al$_{0.6}$As/GaAs/ Ga$_{0.4}$Al$_{0.6}$As double heterostructures corrected on the reflectance coefficient.

Fig. 3 The photoluminescence spectrums of Ga$_{0.4}$Al$_{0.6}$As /GaAs/ Ga$_{0.4}$Al$_{0.6}$As double heterostructures calculated for the thickness of upper layer t=2050nm (curve1) and 1990nm (2).

CONCLUSION

It is shown that the photoluminescence distribution over the wafer can be strongly influenced by upper transparent layer under active layer. To exclude this influence the photoluminescence magnitude should be normalized on measured transparency T=1-R of upper layer at the wavelength of incident light. It was demonstrated that the dependence of the peak wavelength and $\lambda_-$, $\lambda_+$, $\delta\lambda$ on upper layer thickness must be taken into account.

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REFERENCES

Journals

Books