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# Size Effect Modulation Light Sources
## — Analysis and Preliminary Experiments —

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The static characteristics of a new field effect semiconductor light source are analysed, in which the photon emission rate is modulated by the gate voltage mainly through changes in spatial distributions of the carriers. Photoluminescence measurements on a GaAlAs single quantum well structure subject to an electric field at 80 K were performed for testing the proposed idea. The photoluminescence intensity at a fixed wavelength was quenched by about 25 % with an applied average field of $\sim 1 \times 10^{5}$ V/cm.

## § 1. Introduction

Much efforts have been concentrated into works on quantum well (QW) optical devices, producing some new device concepts as well as interesting physical phenomena.1)-2) As one of the physical phenomena, Mendez and his coworkers,3) recently, have reported the field induced quenching of the photoluminescence (PL) from GaAlAs QWs at cryogenic temperature, suggesting the general (not specific) application of the PL quencinhg to a variety of optoelectronics. We have proposed a high speed field effect laser or light emitting device, independent of their work, showing a possibilty of the sucessful operation of the proposed device with a specific structure.4) In the proposed device, the photon emission rate is controlled by the gate voltage mainly through changes in spatial distributions of the carriers in the QW active layer while carrier concentrations are kept almost constant. From the above-mentioned mechanism, one can expect a very high speed operation of the devices, not limited by recombination life time of the injected carriers.

In this paper, we shall show the theoretical results on the changes in the electron- and hole-wave functions in the active layers, gain spectra for gate field, perpendicular to the QW active layers, in the proposed device as well as the preliminary experimental results on the influence of the electric field for the emission from GaAs QWs at 80 K.

## § 2. Analysis

Shown in Fig.1 is the proposed device structure where electrons and holes are injected into a very thin active region from n- and p-type cladding $Ga_{1-x}Al_xAs$ regions, respectively, and electric fields perpendicular to the injection current flows are applied through insulating $Ga_{1-y}Al_yAs$ (y> x) layers. When a sufficient

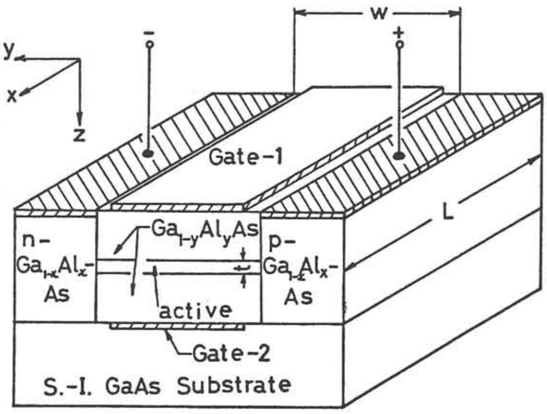


Figure 1

positive voltage is applied to the upper gate electrode (Gate-1) and a negative voltage with a similar magnitude is applied to the lower gate electrode (Gate-2), the injected electrons and holes are accumulated at the upper and lower sides, respectively, in the active region. The spatial separation of the carriers may bring about a reduction in momentum matrix elements related to electron-hole recombination, i.e., a reduction in photon emission rates.

Wave functions associated with electrons and holes in the QW have been estimated by solving self-consistently Schrödinger's and Poisson's equations, predicting the

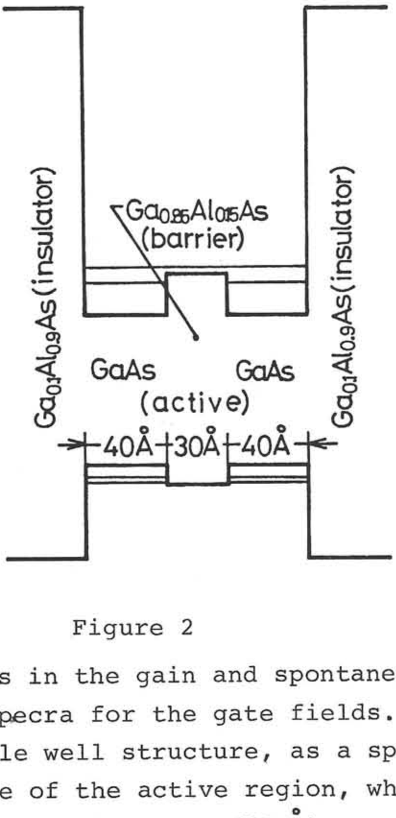
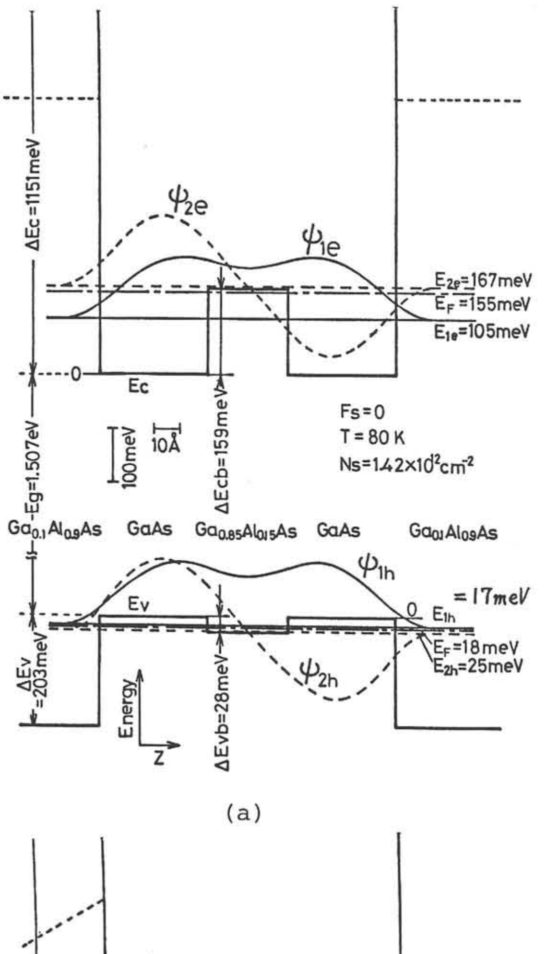


Figure 2

changes in the gain and spontaneous emission specra for the gate fields. Consider a double well structure, as a specific example of the active region, which consists of active GaAs (40 Å), coupling barrier $Ga_{0.85}Al_{0.15}As$ (30 Å) and confining $Ga_{0.1}Al_{0.9}As$ layers, as shown in Fig.2. On the analysis, it has been assumed that the p-n junction consisting of p-$Ga_{1-x}Al_xAs$, the active region and n-type $Ga_{1-x}Al_xAs$ is connected to a constant voltage source to inject carriers into the active region.

Figure 3(a) and (b) show the estimated wave functions for zero gate field and an applied field $F_s$ of $3x10^5$ V/cm, respectively, at 80 K under applied junction voltage of 1.68 volt which gives a surface carrier density of $1.42x10^{12}$ $cm^{-2}$ for zero



(a)

(b)

Figure 3

gate field. The gain spectra in the device at 80 K are shown in Fig.4. A significant reduction in the peak gains due to the lowest state transitions (1e-1h) can be expected with the increasing field up to $3.5\times10^5$ V/cm while an increase in the peak gains due to the transitions including higher states (1e-2h, 2e-1h) appear over the field. The latter fact is brought about by a nonsymmetry of the potential, i.e., a break of the selection rule induced by the applied field. The peak gain together with the total spontaneous emission rate are quenched significantly by the applied field while the carrier density are kept almost constant for a field less than $2\times10^5$ V/cm as shown in Fig.5.

The switching characteristics expected from the results in Fig.5 are drawn schematically in Fig.6. The relatively slow changes in the spontaneous emission and gain coefficient associated with the slight changes in the carrier densites of which speed is determined by recombination life time $\tau$ after the very fast switching associated with the transversal redistribution of the carriers ( 10 psec) may be seen.

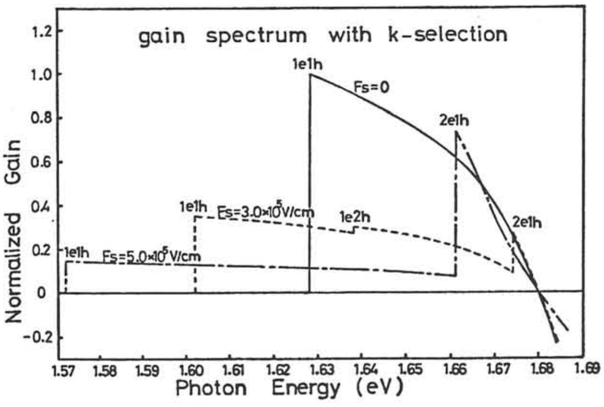


Figure 4

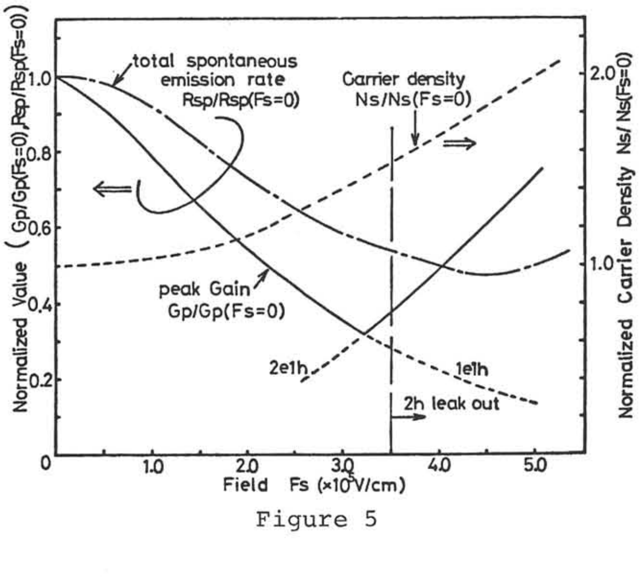


Figure 5

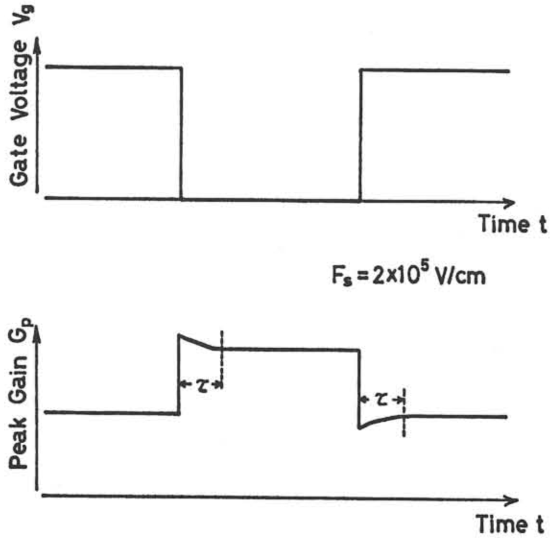


Figure 6

§3. Preliminary Experiments

PL measurements on GaAlAs multi-QW structures subject to an electric field were reported by Mendez et al.[3] The experiments have been performed under a low excitation at a low temperature. They observed a drastic reduction of PL intensities due to exciton and electron-to-impurity recombination with increasing field. Their results seem to support apparently the above-mentioned basic idea. But, as a general tendency, the PL intensity may become less sensitive to the field as temperature and excitation level increase. Then, we have measured spontaneous emission from a GaAlAs QW active layer at 80 K pumped by a pulsed dye laser (λ~6300 Å, 5 nsec) to test the idea under a more practical situation. The samples were grown by MBE on semi-insulating GaAs substrates and consists of 1 $\mu$m $Ga_{0.4}Al_{0.6}As$, 100 Å GaAs and 1 $\mu$m $Ga_{0.4}Al_{0.6}As$ layers, as shown in Fig.7, which were undoped. The maximum

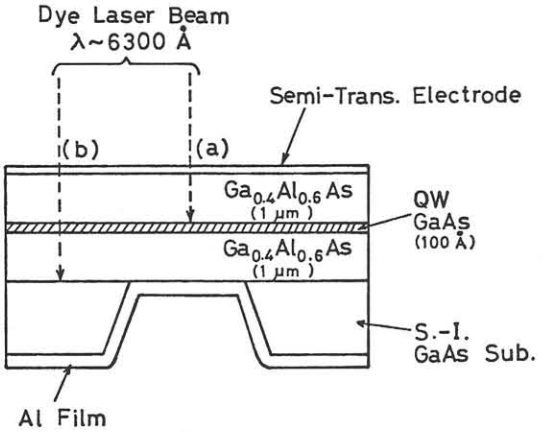


Figure 7

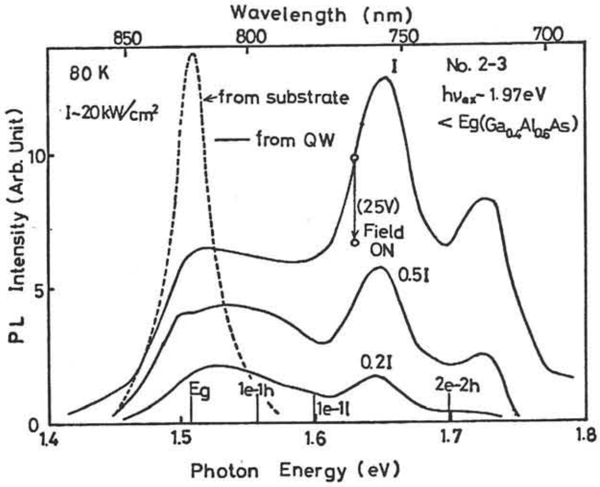


Figure 8

excitation power density was around 20 KW /cm$^2$, sufficient to realize population inversion in the active layer. The photon energy of the exciting light $h\nu_{ex} \sim 1.97$ eV is smaller than the band gap energy in the $Ga_{0.4}Al_{0.6}AS$ layers at 80 K so that the GaAs QW may be excited selectively.

Figure 8 shows the observed emission spectra for various pumping levels. When the central part ((a) in the figure) was excited, PL spectra (solid lines in the figure) with peaks at photon energies over the band gap energy $E_g$ in GaAs were observed, showing a clear band filling with the increasing excitation level. These spectra are due to electron-hole recombination in the GaAs QW. On the other hand, when the outer part (b) appart from the part (a), only the PL from the GaAs substrate was observed.

We found a reduction in the emission intensity at a fixed wavelength of 7600 Å by an applied pulse voltage of 25 V between the semitransparent (Pd or ZnO film) and bottom Al electrodes, as shown in Fig.8 although no reliable data on the emission spectra under an applied voltage has been obtained because of an instability which may be due to photo-capacitance effect in the $Ga_{0.4}Al_{0.6}As$ confining layers.

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