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Three Terminal Light Emitting Device with Functions of Current Injection and of Field Control

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We have proposed a field effect light emitting devices[1)] with capability of a fast emission switching free from life time limitation. As a result of the systematic photoluminescence (PL) measurements from QW structures, we have confirmed the several field effects on light emission from QW and demonstrated the completely life time free switching of the PL intensity by pulsed electric fields[2)-4)]. From the practical view points of device application, the field control of light emission must be realized with the device capable of current injection.

Here, we report the first demonstration of light emission control by use of field effects under the practical current injection situation. Prior to description of the experimental results, we explain the concept of the field control of light emission in our proposed device with the following simple rate equation,

$$\partial N / \partial t = G - N / \tau_r - N / \tau_{nr}$$

where G is the carrier injection rate, N is the electron (or hole) density in the well, τ_r and τ_{nr} is the radiative and nonradiative recombination life time, respectively. As is evident from the equation, the switching speed of the usual light emitting diode modulated by injection current is essentially limited by τ_r. However, the proposed device makes use of the field-induced change in τ_r to modulate the emission rate N/τ_r, instead of the change in N, so that switching speed of the device can be free from the life time limitation[4)]. Also, the field-induced light intensity modulation under the condition of a completely constant carrier density was realized by combining the field-induced increase in τ_r with shortening in τ_{nr} due to carrier escaping from QW to barrier[4)]. The modulation scheme caused by field-induced change in radiative life time without any changes in carrier density is the essence of the original proposal on field controlled light emitting device[1)].

To realize the above mentioned operation with the practical device, we adopt a possible device structure[5)] as shown in Fig.1. In this structure, carriers are injected from the emitter into base region, and the field applied to the QW in the base region can be controlled by changing the base-collector bias voltage (V_{bc}). The injected carriers from the emitter should not fully sweep out from the base to the collector region, and some of them should be always trapped in the base region. The light intensity modulation in the proposed device does not rely on the change in carrier density, but make use of the fast switching of the radiative recombination rate in QW structure caused by the field effect, in marked contrast to the previously reported laser transistor[6)]

Figure 2 shows the schematic structure of the device used in the experiments. Each GaAs and AlGaAs layer was sequentially grown by molecular beam epitaxy. The wafers were fabricated into mesa structure using a selective etching to be able to contact to emitter and base region. The emitter was biased positively with respect to the base at ground potential to inject holes into QW, while the V_{bc} was changed to control the electric field applied to the QW.

Figure 3 shows the emission spectra at room temperature for various V_{bc}. At V_{bc}=0, the built-in field of collector-base p-i-n junction is applied to the QW structure and the field would be zero at V_{bc} of +3.0V by cancelling the built-in potential. As the V_{bc} is decreasing, the emission intensity was quenched and its peak energy was significantly shifted to the lower energy side. The energy shift values of the emission peak almost agree with the theoretical values of the field-induced changes in transition energy. This means that the electric field is sufficiently applied to the QW structure and can be controlled by V_{bc} in the device.

Figure 4(a) shows one of the transient response of emission intensity for pulsed V_{bc} at 100K. When the emitter current of 2mA was injected, the collector current did not flow by decreasing the V_{bc} down to 2V (see Fig.4(b)). This means that the injected carriers are effectively trapped in the base region due to high base-collector hetero potential. The light intensity decreased and increased at the time of the field switching from lower to higher and vice versa, respectively. The following recovery and decay of the light intensity, which appear after the field-induced switching, may be caused by the change in carrier density in the QW after the field-induced sudden change in the recombination life time. We checked with the similar way to the previous PL works[2)3)] that the obtained data were not affected by the electromagnetic couplings and that the emission induced by the carrier injection from the collector side at lower field condition did not exist. The measured transient response data are consistent with our former work by use of PL technique.[2)-4)]

In Summary, we have demonstrated the field control of light emission with the device which has functions of current injection and of field control, for the first time.

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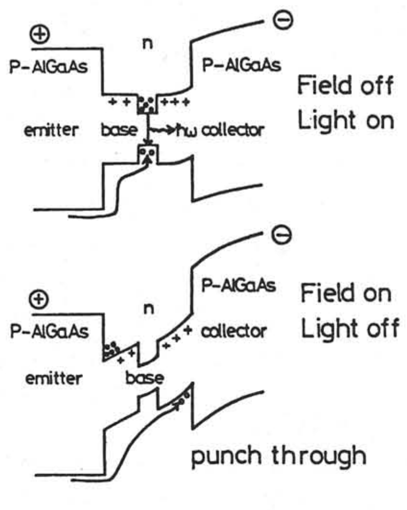

Fig.1 Energy band diagrams of the proposed light emitter.

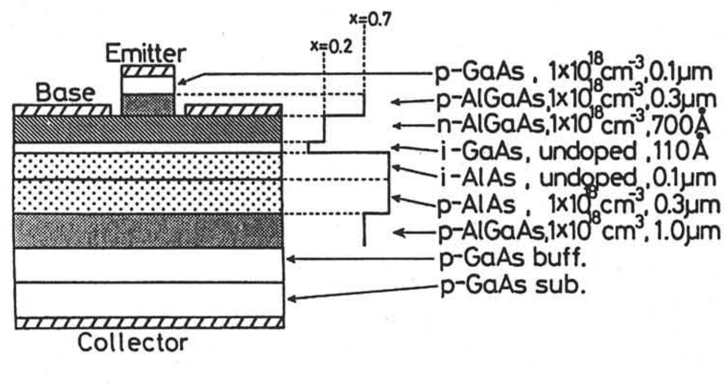

Fig.2 Schematic cross-sectional view of the device used in the experiments.

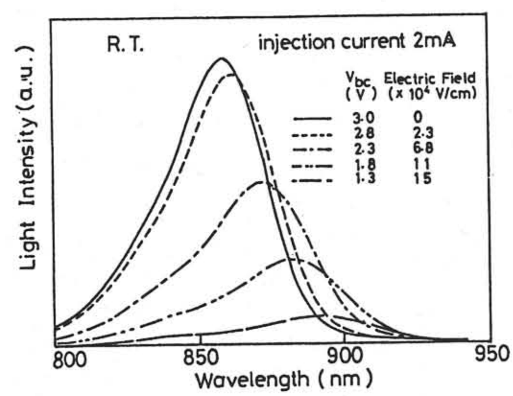

Fig.3 Emission spectra for various base-collector voltages at room temperature.

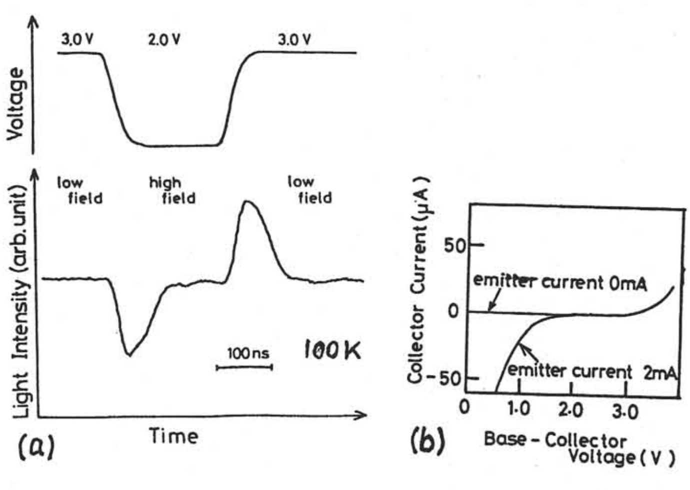

Fig.4 (a)Transient response of the emission intensity for a pulsed base-collector voltage (upper trace) at 100K. The resolution is 10nsec. (b)The collector current vs. base-collector voltage characteristics.