MOCVD Work for SEED Devices

O'Dae Kwon
Department of Electronics and Electrical Engineering
POSTECH(Pohang University of Science & Technology)
Pohang 790-784, KOREA

Optical modulators and switches such as the self electro-optic effect device (SEED), which are based upon the quantum confined Stark effect(QCSE) from p - i [GaAs/AlGaAs multiple quantum well(MQW)] - n structures, have been extensively studied for phtonic switching applications.[1] Recently, InGaAs/GaAs MQW structures also have been investigated with an intention of operating at $1.064\mu m$, the wavelenghth where a diode pumped Nd:YAG laser can serve as a handy and powerful optical source.[2] On the other hand, shallow quantum(SQW) structures turned out to generate strong low-field electroabsorption. In this review, I will consider the metalorganic chemical vapor deposition(MOCVD) technique,[3] employed in our laboratory for growing the GaAs/AlGaAs SQWs as well as the InGaAs/GaAs SQWs, together with the device performances of both the GaAs and InGaAs SEEDs.

For the GaAs SEED quantum well structure to be successful, it is critical to obtain the lowest possible value of background carrier concentration in the AlGaAs quantum barriers to obtain the best field uniformity through the absorption region. We have been able to control the background carrier concentration at a level as low as $\sim 6 \times 10^{14} cm^{-3}$ by using the growth temperature-controlled compensation of residual acceptors and donors. According to the previous efforts to obtain high purity AlGaAs layers by the MOCVD technique using the methyl precursors, the acceptor impurity in AlGaAs is intrinsic to the decomposition process of trimethyl aluminum and is known to be carbon. There are however also some donor impurities such as silicon. Therefore a low background carrier concentration can be realized, when both the acceptorlike carbon and donorlike silicon compensate each other. Figure 1 illustrates the temperature dependence of the net carrier concentration which governs the electrical properties of material, for the intentionally undoped $Al_xGa_{1-x}As$ layer grown by low pressure MOCVD, where x=0.04 for 4% SQW structures. The net carrier concentration shows a decrease with increasing growth temperature up to 735°C, and a further temperature increase alters the type of

AlGaAs layer. The symmetric SEED of the p-i[4% SQW]-n grown with the compensation method exhibited the device's contrast ratios as high as 2.9:1 with 50 pairs of 100Å-GaAs/100Å-AlGaAs quantum wells.

Next we describe recent work indicating that one can utilize the InGaAs/GaAs SQW system, which adds low field and high power capabilities to the merits of high power source and substrate transparency, yet without relying upon the sophisticated techniques such as strained-compensated structure and patterned substrate.[4] Such an InGaAs/GaAs SQW system will be particulary useful in a flip-chip integration of the phtonic IC to electronic silicon ICs in the future.

The fabrication of the $In_xGa_{1-x}As/GaAs$ SEED diode(Fig. 3) is based upon MOVPE-grown SQW structure with $x < 0.05$. The MOVPE growing conditions are similar to the case reported before [3] in general except that the present growing temperature was maintained at 670°C, downtuned for the InGaAs layer growth, and that as another precursor for the In element, ethyl-dimethyl-indium was added to the previous source-gas system. After the mesa etching and metalization, the diode's substrate was thinned to about $250\mu m$ and glued to a glass slide with a usual optical epoxy. The observed breakdown voltage was about 40 V and the diode's leakage current was only 65 pA at -20 V bias, or 3.6 nA/cm^2 leakage current density for the present diode size of $1.65 \times 10^{-2} cm^2$. The background carrier concentration of the intrinsic active layer is estimated to be around $5 \times 10^{14}/cm^3$ from the C-V mesurements. We feel that electrical properties measured as above also confirms the active region being free of any misfit dislocations.

The operating wavelength is around 900 nm, also suitable for the diode-pumped Cr:LiSrAlF6 laser, which is tunable from 760 nm to larger than 1,000 nm, as one potential power source. Furthermore, for a strained system like the InGaAs/GaAs MQW, the epoxy is usually limited to a critical thickness to keep the grown psudomorphic film free of any misfit dislocation. Recent studies of the strained system, however, suggest a sharp increase of the critical dimension as the strained system becomes shallow. Perhaps by the same reason, our strained system of the InGaAs/GaAs shallow quantum well turned out to form an active region clean and thick(over $2\mu m$) enough to exhibit room-temperature exciton peaks as sharp as the unstrained GaAs/AlGaAs shallow system. Figs. 2a,b show such photocurrent spectra of a pin diode with 50 pairs of 100Å-InGaAs/100Å-GaAs SQWs (x=0.04) with various bias voltages, compared with the case of GaAs/AlGaAs SQW system. The average contrast ratio of the InGaAs SEED diode was 2.1:1 at the exciton peak though, a bit lower than the GaAs SEED. Undoubtedly, we can expect still more improved performance here once this new SQW structure is optimized after more detailed work of obtaining maximun performance as hinted in the excellent photocurrent spectra.

Recent developments on the practical SEED applications such as the photonic switching or the 'Smart Pixel' work at AT&T Bell Labs., however, point to wafer-scale and large scale integration. It is rather stringent industrial requirement toward high yield, high throughput, high performance and low cost. The wafer diameter also keeps growing to 2, 3, and 4 inches accordingly. For the wafer-scale uniform performance requirement, we have made reflectivity measurements over the whole surface of a 2"-diam. epi-wafer. Some exemplary data are given in Fig. 4 from quadrant(four-corner) reflection measurements, which shows ever-changing signatures of Fabry-Perot peaks.[5]

When the SEED structure contains the matching AlGaAs/AlAs reflector stack and is treated with a proper AR-coating, one would observe a uniform reflection plateau throughout the SEED wafer, only modified with the corresponding excitonic absorption peak such as Fig. 5. Successful MOCVD growths should be able to reproduce reliable wafers, say within 2% uniformity. For this purpose, we are now investigating the details of reflector stack formation in particular because of the sensitive behavior of reflection centers. Preliminary results look rather promising in the context that we have a better control of growing rates and that we can predict the degree of asymmetry in the reflection plateau and correlate it with MOCVD growth parameters.[6]

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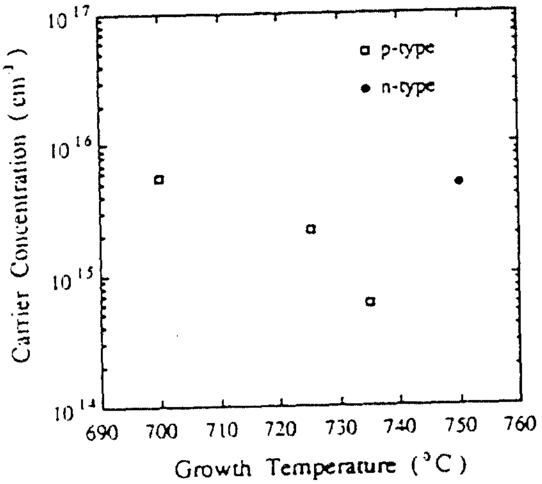
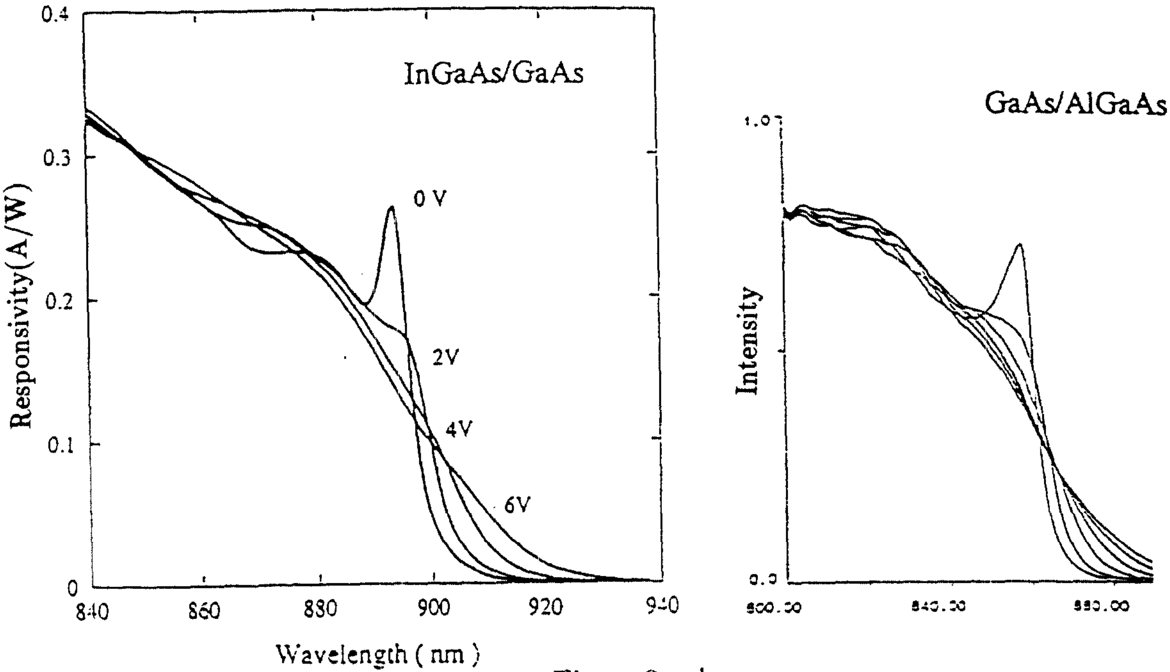
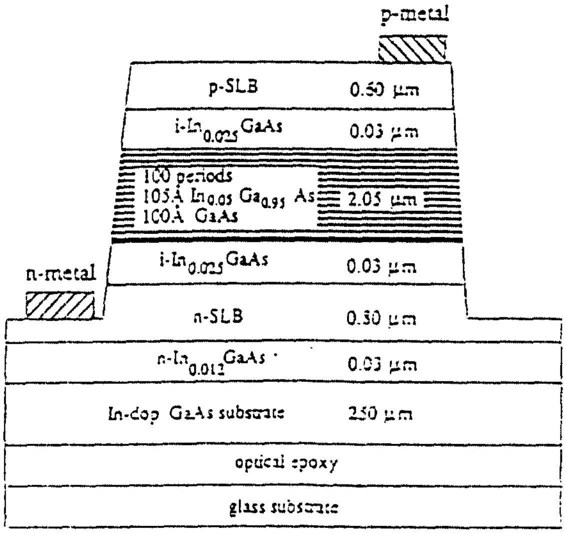
Fig. 1





Figs. 2 a,b

Fig. 3



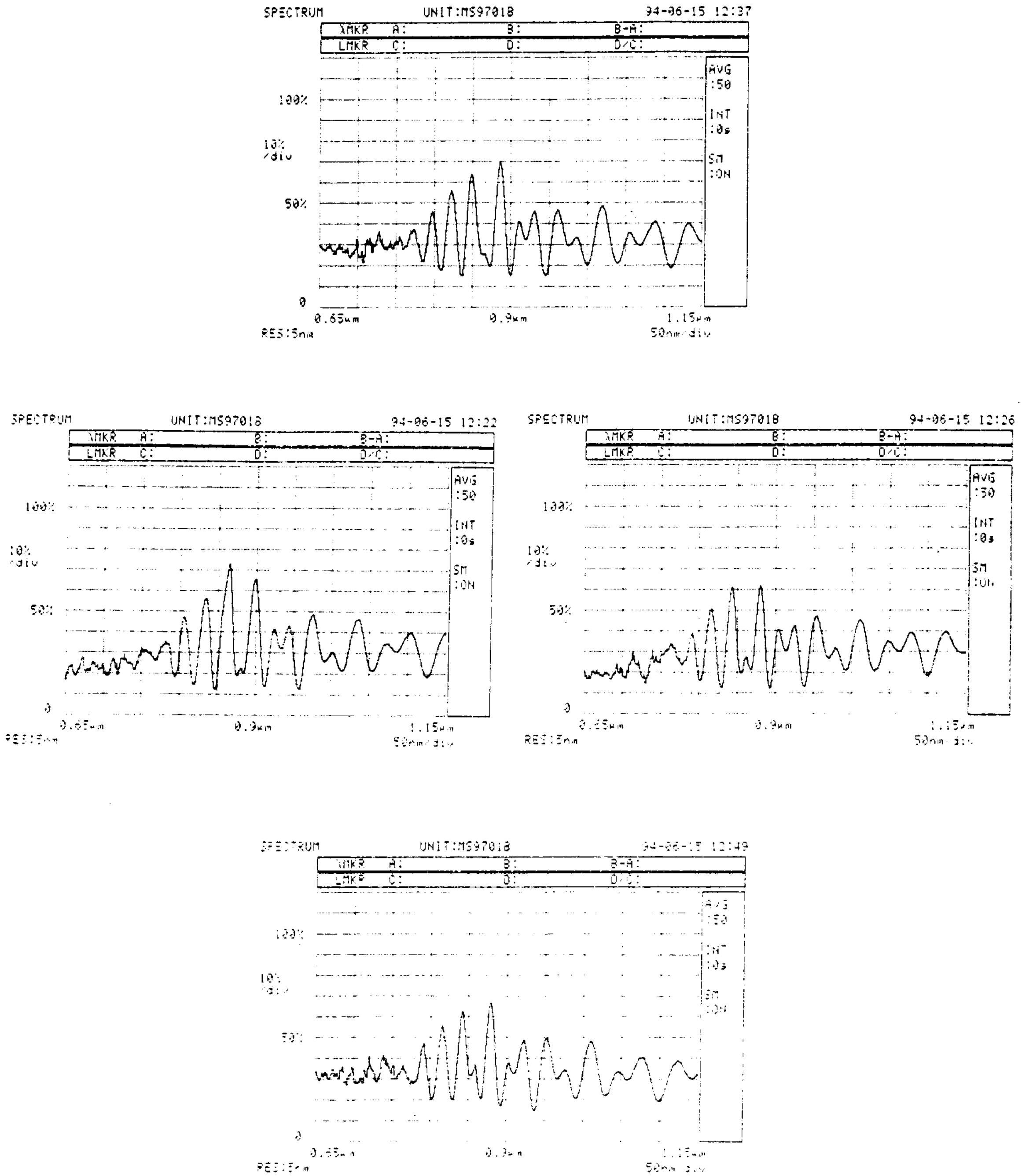

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Fig. 4

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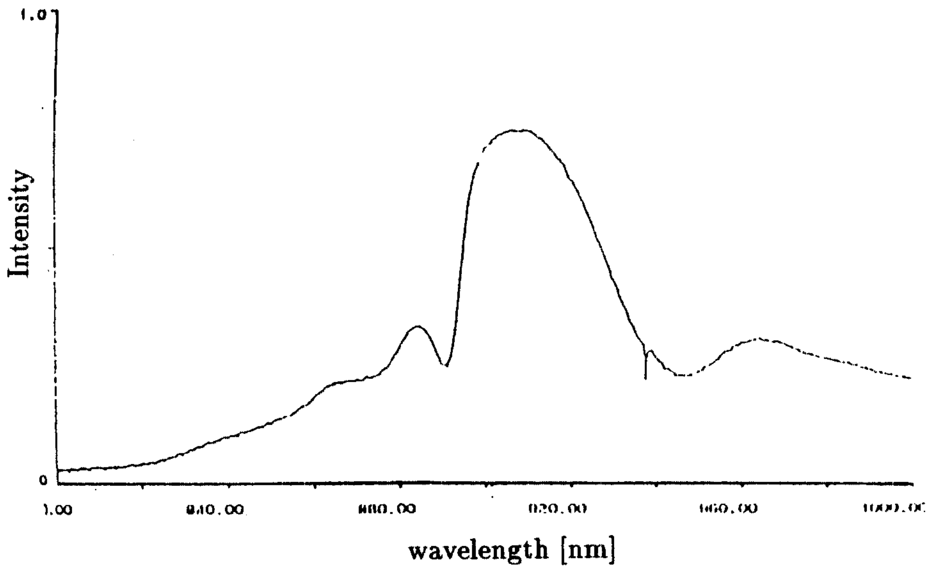

Fig. 5