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MOCVD Grown AlAs/GaAs Bragg Reflectors for Photodetector Application

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Optical filters of the form $(AlAs/GaAs)^n$ were fabricated on GaAs p-n junction photodiodes and their optical characteristics were investigated. 100 % reflectivity was obtained at some specific wavelength which was accurately determined by the thicknesses of the layers. Selective suppression of spectral photoresponse of the diodes corresponding to the reflection spectra was obtained. AlGaAs p-n junction photodiode was grown on the above photodiode to fabricate the wavelength dividing photodiode. Improvement in dividing characteristics was obtained by the effects of the filter. The usefulness of (AlAs/GaAs) filters for GaAs photodiode is shown in this paper.

§1. Introduction

The easiness to grow multi-layers and excellent controllability of MOCVD (Metal Organic CVD) method are very suitable to fabricate the devices including multi-thin layers such as super lattices and Bragg reflectors(BR). BR is different from super lattice in the sense that BR makes use of the difference in refractive indices of the two materials. The combination of two materials with different refractive indices has interesting application of optical filters.

This paper describes the fabrication of optical filters composed of AlAs and GaAs by MOCVD method and their application to optical detectors. By forming the optical filter on the p-n junction photodetectors, the spectral response can be controlled. Some photodiodes with optical filter are fabricated. As this filter has crystallinity, another optical or electrical devices can be fabricated on this optical filters. The wavelength dividing photodiode with optical filter which is first proposed in our previous paper[1] is demonstrated as an example of this kind of application.

§2. MOCVD Growth of AlAs and GaAs

Vertical square type reactor was used to grow thin multi-layers of AlAs and GaAs. Thin (0.1 mm) carbon substrate holder was heated by infrared lamp. To avoid the exposure of substrate holder to the air, the substrate was loaded on the holder in H_2 gas ambient. Special attentions were paid to the tubing to obtain rapid transition between AlAs and GaAs[2].

Trimethylgallium, trimethylaluminium and 100 % AsH_3 were used as source gases. Substrates were (100) oriented n-type (n=2E18 cm^{-3}) GaAs. Total H_2 gas flow rate was 3 l/min, and the growth temperature was 600 °C. All growth were performed at atmospheric pressure. Group III mole fraction (III/H_2) for the growth of thin layers was fixed at 7.1E-5, and the mole ratio of group V to III was 50. The growth was interrupted for 10 sec before the subsequent layers to ensure the abrupt interfaces.

It is well known that the growth rate in MOCVD method is proportional to the group III atom mloe fraction[3]. But, during these experiments, it is found that the growth rate depends on the growth time when the growth time is shorter than 2 min., as shown in Fig.1 where the averaged grown layer thickness of AlAs and GaAs is plotted against the growth time. The broken line shows the constant growth rate of 46.5 nm/min which is determined by III/H_2. The proportionality of the growth rate to III/H_2 is only valid for the thick layer growth.

The interface abruptness was checked by Auger in-depth profiling to be below 5 nm.

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§3. Photodiodes with Optical Filters

The most simple type of filter composed with AlAs and GaAs is of the form air/(HL)^n/GaAs, where H and L mean GaAs and AlAs layers with the thickness equal to the quarter wavelength, respectively, and n is the layer number of the filter. When the Bragg condition is satisfied in the layers, the incident light is perfectly reflected and no light can transmit these layers at specific light wavelength λ_0 which is determined by the layer thicknesses in the filter[1].

Alternative AlAs/GaAs were grown after growing non-doped n-GaAs (n=1E16 cm^{-3}, 2 μm), Zn-doped p-GaAs (p=5E18 cm^{-3}, 1 μm) p-n junction photodiode layers on n-GaAs substrate. The SEM crosssection of this type of photodiode is shown in Fig.2. The reflectivity spectra of these wafers are shown in Fig.3 for three samples with the same GaAs layer thickness and different AlAs layer thickness. When the optical thicknesses of the two layers coincide (# 161), the reflectivity reaches 100 %, the spectral half width becomes narrower and the small higher order peaks appear.

The reflectivity spectra for several samples with different layer thickness are shown in Fig.4. The peak wavelength λ_0 can be chosen by the layer thicknesses. λ_0 is shown as a function of the growth time for one period of AlAs and GaAs in Fig.5. λ_0 almost linearly increases with increasing the growth time at a rate 3.43 nm/sec.

Figure 6 shows λ_0 as a function of the layer thickness of one period, d_1+d_2. The solid line is the calculated value using the following approximate expression of refractive index N of $Al_xGa_{1-x}As$[4]

$$N=0.48E_p+2.5-0.63x.$$

where E_p is the photon energy in eV. There is a very good agreement between measured and calculated values. The departure from the calculated line indicates the difference in the optical thicknesses of AlAs and GaAs. One example of such departure is plotted in Fig.6 by a triangle (Δ) for a sample #160 shown in Fig.3.

The photodiodes shown schematically in Fig.7 are fabricated from the grown wafers. A-B etchant and H_2O_2+NH_3 at pH=8.5 are used to selectively remove AlAs and GaAs, respectively. H_2SO_4+H_2O_2+H_2O is used to etch the GaAs p-n junction mesas.

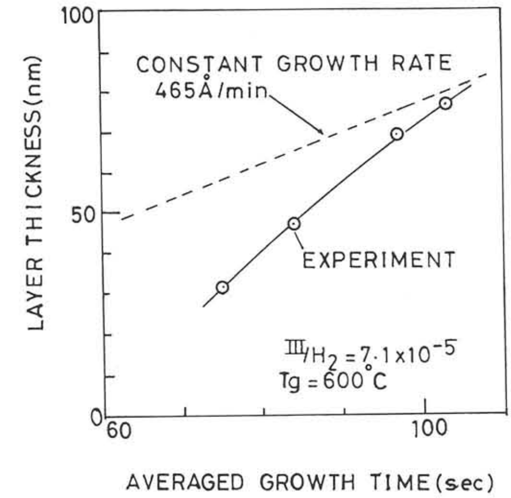

Fig.1 Grown layer thickness vs. growth time.

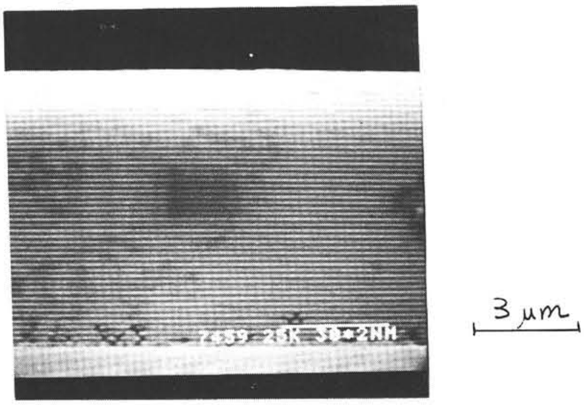

Fig.2 SEM photograph of (AlAs/GaAs)^n type filter.

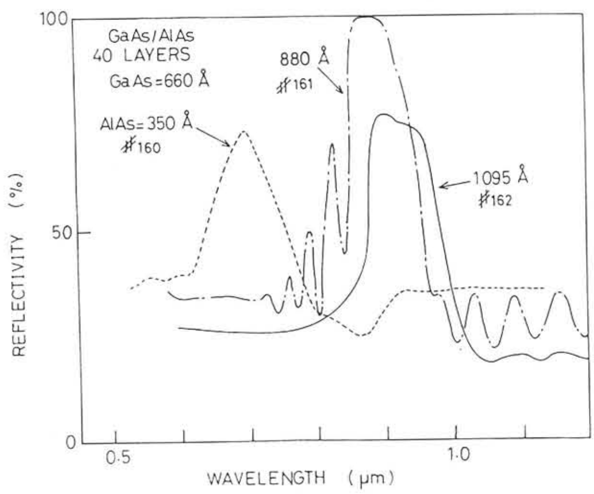

Fig.3 Reflectivity spectra of the filters.

The SEM photograph of the completed device is shown in Fig.8.

The example of the spectral response of the photodiode is shown in Fig.9 together with the reflectivity. The maxima (minima) in reflectivity correspond to minima (maxima) in the response. Thus, the response is selectively suppressed at specific wavelength. By combining several this type of filters with different λ_0, the photodiode sensitive in narrow spectral region can be fabricated.

§4 Wavelength Dividing Photodiode

The another interesting application of the filter described above is the wavelength dividing photodiode shown in Fig.10[1]. This device is designed to divide the incident light wavelength by making use of the band gap difference of GaAs and $Al_{.1}Ga_{.9}As$[5]. But, as the incident photon energy comes near to the band gap energy of AlGaAs, the wavelength division becomes insufficient. By inserting $(HL)^n$ type filter between AlGaAs and GaAs photodiodes as shown in Fig.10, the shorter wavelength light that should be absorbed in AlGaAs but is not absorbed is selectively reflected back to AlGaAs, thus, preventing the imperfect wavelength dividing.

$Al_{.1}Ga_{.9}As$ p-n junction was formed on the photodiode with filter described in previous section. λ_0 of the filter is selected to be 750 nm. The spectral response of the diode is shown in Fig.11. Sensitivities of GaAs and AlGaAs diodes at 750 nm are suppressed and enhanced, respectively by the effect of the filter sandwitched in the two photodiodes. The sensitivity of AlGaAs diode is lower than that of GaAs. Reason is as follows. The growth is once stopped after growing GaAs p-n junction and $(AlAs/GaAs)^n$ to check the reflectivity, then AlGaAs diode is fabricated. The surface might be somewhat deteriorated during the reflectivity measurement. The characteristics of AlGaAs diode will be much improved by the proper growth.

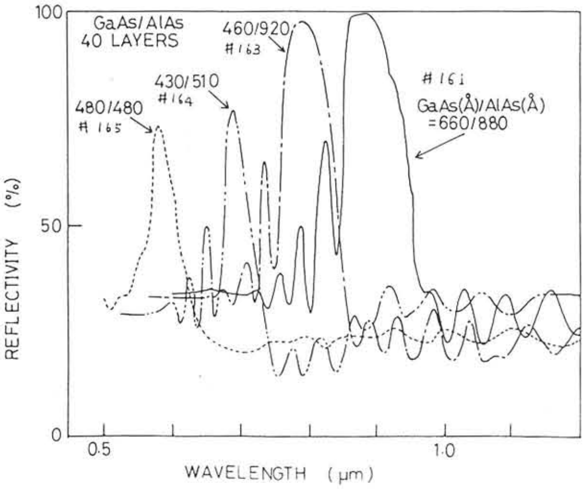

Fig.4 Reflectivity spectra for various samples with different layer thicknesses.

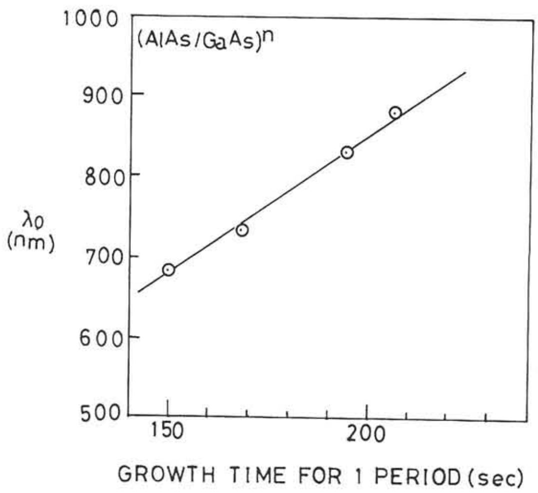

Fig.5 λ_0 as a function of the growth time.

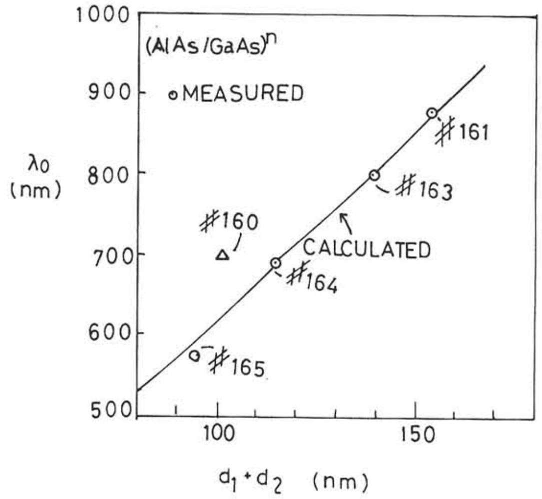

Fig.6 λ_0 as a function of thickness of one period of AlAs and GaAs.

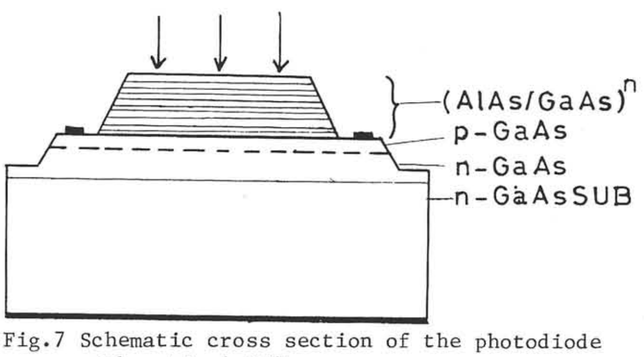

Fig.7 Schematic cross section of the photodiode with optical filter.

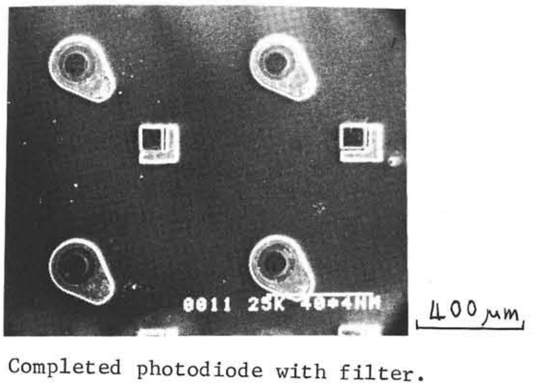

Fig.8 Completed photodiode with filter.

§5 Conclusion

Optical filters of the form $(AlAs/GaAs)^n$ were fabricated on GaAs p-n junction photodiodes by MO-CVD, and were investigated in detail. It was found that the growth rate depended on the growth time when the growth time was shorter than 2 min. The 100 % reflectivity was obtained at a specific wavelength which was accurately determined by the layer thickness in the filter. Wavelength dividing photodiode including this type of optical filter was fabricated, and the improvement in wavelength division was obtained.

Other type of filter characteristics can be obtained by the proper designing of the thin film filters[6]. Some of these are now under fabrication.

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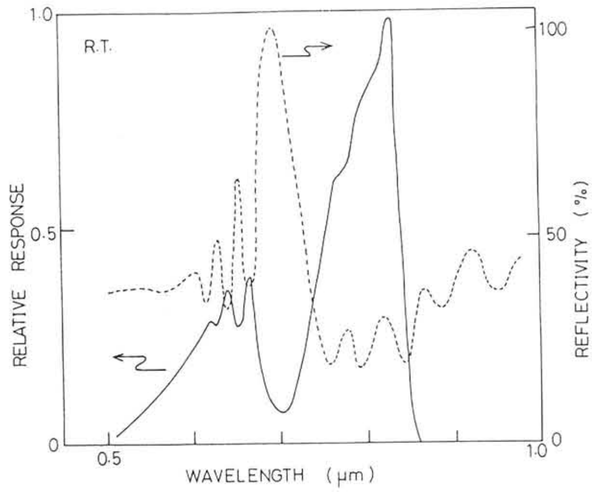

Fig.9 Spectral response and reflectivity of the photodiode.

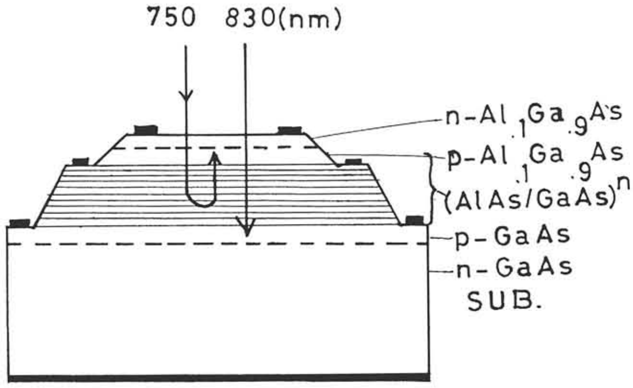

Fig.10 Schematic cross section of wavelength dividing photodiode.

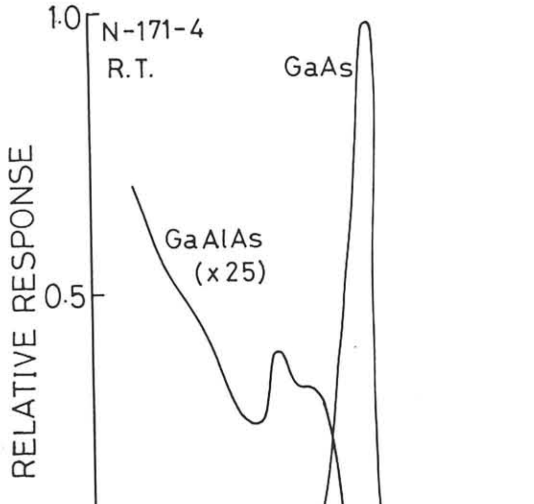

Fig.11 Spectral response of the wavelength dividing photodiode.