Ruthenium-doped semi-insulating InP buried InGaAlAs/InAlAs MQWs modulators

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Ruthenium (Ru) doped InP buried electro-absorption optical modulators are demonstrated for the first time. Ru-doped InP burying semi-insulating layers were grown by conventional MOVPE growth. Layers with high resistivities of 10^8~10^9 Ωcm were obtained easily and reproducibly. The capacitance of the modulator was reduced because the inter-diffusion between transition metal and zinc decreased, significantly.

The semi-insulating buried structure has been extensively investigated for the optical devices based on InP.[1] However, inter-diffusion between semi-insulating dopant iron (Fe) and p-type dopant zinc (Zn) occurs and the p-type region expands into the Fe-doped semi-insulating InP region. As a result, the capacitance and the leakage current of optical devices increases.

Doping InP with ruthenium (Ru) in order to obtain semi-insulating InP was recently reported. Ru does not suffer from inter-diffuse with Zn and it has a very low diffusion coefficient in InP.[2] And 1.48um pumping laser diodes with Ru-doped InP semi-insulating layers have been demonstrated.[3] On the other hand, leak tight semi-insulating layer is also very important for reverse-bias devices such as optical modulators. In this paper, we demonstrate electro-absorption modulators buried with a Ru-doped InP semi-insulating layer.

Growths of InGaAlAs/InAlAs MQWs were performed in a conventional low pressure MOVPE apparatus with a vertical reactor and a leak-tight system. The growth conditions for the MQWs layers for the modulator are described previously.[4] The mesa structure to be buried was defined by reactive ion etching and wet chemical etching. The Ru-doped InP semi-insulating layers were grown in the same apparatus. TMI, phosphine and bis(η^5 –2,4-dimethilpentadienyle) ruthenium(II)[2] were used as precursors. Only hydrogen gas was used as a carrier. No decomposition of the Ru precursor was observed over a period of six months of growth, though such decomposition was reported by Dadger et al.[2] High resisitivity layers of 10^8~10^9 Ωcm were easily obtained with the structures of n/Ru:InP/n and p/Ru:InP:p.

A schematic diagram of a typical electro-absorption modulator is shown in Fig.1. In order to examine the differences, in burying materials, three types of burying layers were grown: a polyamide layer, an Fe-doped InP semi-insulating layer, and a Ru doped InP semi-insulating layer. The MQWs wafers to be examined were high-mesa types for polyamide-buried structure, because the influence on the inter-diffusion of Zn was remarkable.

Figures 2(a), (b) and (c) show the photocurrent spectra of these modulators with applied voltage as a parameter. The incident light polarizations of were TM mode. Clear exciton absorptions are observed in the spectra from the polyamide buried modulator. However, clear exciton responses are not observed in the spectra form the Fe-doped InP buried modulator. On the other hand, in the Ru-doped InP buried modulator, the electro-absorption effect is similar to that for the polyamide buried modulator. Remarkable exciton absorptions are observed and, moreover, that exciton absorptions shift largely.

The capacitances of these modulators at zero bias are 5, 10 and 6pF for polyamide, Fe-doped InP, and Ru-doped InP, respectively. When the modulator was buried with Fe-doped InP, Zn from the p-type layer inter-diffused into the Fe-doped semi-insulator region. As a result, capacitance became larger. On the other hand, when the modulator was buried with Ru-doped InP, the inter-diffusion was small, and the capacitance reduced by half that for Fe-doped InP. This value is as same as that of the polyamide buried modulator.

Figure 3 shows the relationship between applied voltage and transmission power intensity for TM and TE modes. The incident light wavelength was 1.55 um. The transmitted optical losses were 6.6 and 7.3 dB for TM and TE modes, respectively, and polarization dependent loss (PDL) was within 1dB. We have also been able to reduced the insertion loss by using a semi-insulating InP burying layers, which is made possible due to the quasi-spherical field pattern of the guided mode that is obtained by reducing the vertical and transverse optical confinement.

In summary, we grew a Ru-doped semi-insulating InP layer by conventional MOVPE, and used this Ru-doped layer for burying electro absorption modulators. Ru-doped semi-insulating layers have less inter-diffusion with Zn than an Fe-doped layer, and are also very suitable for reverse bias optical devices.