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Diffusion Characteristics of Zn in n-GaAlAs(Si) during LPE

Kim Kwang Hwi, Han Ju Myong

Abstract We have studied the diffusion characteristics of Zn into GaAlAs(Si) layer during LPE to produce the structures of GaAlAs IREDs based on self-diffused p-n junction.

As the results of the experiment, the diffusion depth increases exponentially till about 10μm with increasing Zn content, but it saturates beyond that. And the diffusion depth increases when the mol fraction x of p-$Ga_{1-x}Al_xAs$ contained Zn is higher.

Key words LPE(liquid phase epitaxy), GaAs, Zn diffusion

Introduction

The great leader Comrade **Kim Il Sung** said as follows.

"Long-term research should be conducted with a view to opening up new scientific fields and introducing the latest developments in science and technology widely in the national economy." ("**KIM IL SUNG** WORKS" Vol. 35 P. 313)

The Zn diffusion in GaAs and GaAlAs is an important process forming p-n junctions in DH laser diodes, optical ICs and solar cells [1, 2]. The conventional Zn doping methods contain closed tube methods keeping chips and Zn source in an evacuated ampoule in a constant temperature, opened tube one and Zn ion implantation methods.

Recently several methods were proposed, where Zn is diffused into GaAlAs and GaAs using a limited space in LPE boat with opened tube [2, 3]. But with the Zn diffusion using LPE boat, it is difficult to yield the high doping level of about $10^{19}cm^{-3}$ and it has some disadvantages like low process representation due to the Zn loss during thermal treatment.

In this paper we have considered the diffusion characteristics of Zn into GaAlAs(Si) layer during LPE to produce the structures of GaAlAs IREDs based on self-diffused p-n junction.

1. Change of p-n Junction Depth Depending on the Content of Zn

In common Zn diffusion [1, 5] experiments reported previously, they used vapor Zn sources in sealed ampoule or considered the diffusion depth keeping the GaAs solution included Zn contacted to be diffused chips in a constant temperature. But in the LPE process to achieve the structure of GaAlAs IREDs based on self-diffused p-n junction, a $n-Ga_{1-x_2}Al_{x_2}As(Si)$ solid solution is contacted with a $p-Ga_{1-x_2}Al_{x_2}As(Zn)$ and Zn in the grown p-type layer diffuses into n-type layer during the epitaxial growth of $p-Ga_{1-x_2}Al_{x_2}As(Zn)$. So it is complicated to interpret it. Thus in this paper we have avoided the theoretical analysis and considered the relation between the Zn content in

p-GaAlAs(Zn) and the junction depth only experimentally.

The temperature was decreased from 870℃ to 630℃ for 240 minutes with a cooling rate of 1.0℃/min. Namely the cooling rate and the duration were kept constant and the relation between the junction depth x_j and the mass of Zn m_{Zn} was studied (Fig. 1).

As seen in Fig. 1, the junction depth increases rapidly with increasing of Zn content and at certain amount of m_{Zn} it trends to be saturated. The saturated junction depth is about 10μm. This is completely different with the other common diffusion methods. Usually at the vapor or solution diffusion, the junction depth with X_{Zn} is known as follows.

$$x_j = \text{const}[X_{Zn}]^{m/4}\sqrt{t}\,(m \approx 2 \sim 2.7)$$

where X_{Zn} is the concentration of Zn in the solution. In our experiment, however, in the range of low amount of Zn the junction depth increases almost exponentially and is saturated since about 10 μm.

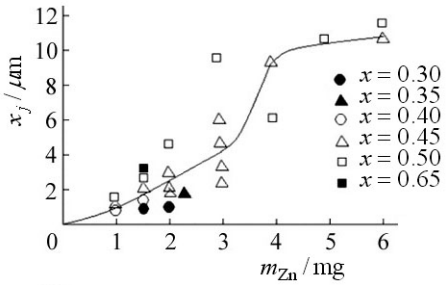

Fig. 1. The change of the junction depth versus m_{Zn}

This can be explained as follows. The Si dopant has a concentration gradient along the growth direction during the first growth of n-$Ga_{1-x1}Al_{x1}As$ layer and the donor concentration of Si decreases rapidly near the inversion temperature (Fig. 2). It shows that from about 10μm near the junction the donor concentration decreases exponentially and it is relatively uniform before. In our production process for the devices, the growth solution of p-type is brought to be contacted with the substrate just before the inversion of conduction type occurs in n layer. At that time Zn diffusing into 1st layer increases the junction depth with the amount of Zn in the range of low concentration of donor, rapidly. In the range of high concentration of Si donor, however, though the amount of Zn is increased, the junction depth trend to increase no longer, because Zn might have to compensate the high concentration of Si. In short, the reason for the considerable difference between our experimental results and the others is just that there is a gradient of the donor concentration in n-type layer.

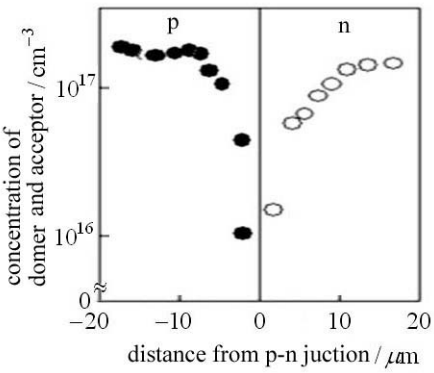

Fig. 2. Donor concentration near the inversion temperature

2. The Influence of the Composition x_2 for p-$Ga_{1-x2}Al_{x2}As$(Zn) on the Zn Diffusion

In our experiment the diffusion depth of Zn is depend on not only Zn content but also the composition of the growth solution for p-type layer.

The measured curves for junction depth versus the composition x_2 at m_{Zn}=1.5 and 2.0mg are shown in Fig. 3.

As seen in the Fig. 3, the junction depth increases almost linearly with the composition x_2 of p-type layer. The reason might be interpreted as follows.

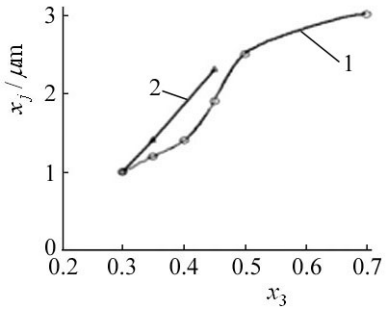

Fig. 3. Change of the junction depth versus the composition of p-layer
1, 2: in case m_{Zn} = 1.5, 2.0mg

In a liquid phase isotherm in Ga-rich GaAlAs saturated solution the concentration of As decreases with increasing of Al concentration[3]. As a results, the concentration of Ga vacancy in the n-type grown layer decreases, too. The concentration of Ga vacancy in $Ga_{1-x}Al_xAs$ ternary system is lower than that in GaAs binary one and the higher the composition x is, the lower the concentration of Ga vacancy is.

Because the band gap of $Ga_{1-x}Al_xAs$ ternary system is wider and the melting point is also higher than GaAs(the melting point of AlAs is 1 600℃, while that of GaAs 1 238℃). And the greater the composition x is, the higher melting point is, so the binding power of Ga atoms (binding energy) is also greater. If the binding power is greater, it is more difficult to make the Ga vacancies. So as decreasing the concentration of the Ga vacancies, Zn atoms diffuse by the way of rapid permeation rather than slow substitution. This means that the Al content in p-layer plays a role of a catalyst in this diffusion process. Therefore it can be said that the needed junction depth can be adjusted by not only Zn content but also the composition of the p-layer.

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