Meltback Micro-lens Array for New Optical Devices

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Abstract

The mechanisms of the meltback etching and regrowth processes are studied experimentally. The depth and time of the meltback is poltted with the experimental data and fitted with some functions. The method to reduce the anisotropy and elliminate the gallium is lands are also developed. It is possible to fabricate the AlGaAs micro-lens array by the use of the process and apply it to a new optical devices.

I. Introduction

Micro-lenses have become important in the development of laser-beam application systems such as optical communication systems coupling the laser light into an optical fiber or external cavity and optical signal processing systems. Micro-lens arrays can also improve the poor fill factors of the semiconductor laser arrays. Array of micro-lens can be used in optical instruments including line scanners, copying machines and CCD image sensors. The micro-lens arrays may also be used as an interface in future optical computer systems. Lenses fabricated in semiconductors are particularly attractive because of their large refractive indices and the potential for monolithic integration with a variety of optoelectronic devices. Refractive micro-lenses have recently been fabricated in glass by diffusion [1] and in InP by ion beam etching. [2, 3]

As optoelectronic devices are widely used, the fabrication technology of small optical components on one chip becomes important. The micro-lenses or other optical devices have been fabricated separately and needed to be bonded for integration with other optical devices.

In this work, it is adopted the meltback as a method to fabricate the micro-lens or other devices integrated with it. It is a characteristic phenomena occurred in LPE only. There is no meltback etch in MOCVD or MBE. It has been known as an unpredictable and un controllable process compared to the general wet or dry etch. So there were not consideration to apply it as a fabrication process except to clean the substrate before epitaxy or reduce the thermal damage in the care of InP system. [4]

Exceptionally in the fabrication process of AlGaAs/GaAs laser diode, inner stripe formation is done by the difference of etch rate between GaAs and AlGaAs. [5] In optical device care, the circular shape of the crystal structure is needed to obtain the lens and other devices integrated with it. [6] In this experimental work, the isotropic etching of GaAs and regrowth are investigated. And the mechanism in them are studied. Finally it is applied to the process of surface emitting optical devices.

II. Meltback Etching Mechanism

It is defined as meltback etch that crystal substrate is damaged or etched by the under saturated melt in LPE. If the gallium melt of undersaturation is wetted on the crystalline GaAs substrate, it will be melted back untill equilibrium or saturation state in LPE. For the isotropic property of meltback etch, circular or lens shape of the crystal can be obtained.

K. Pak and his coworkers have investigated with experiment and analyzed with numerical work the crossection of the meltback curvature in InP system. As their observation, the crossectional flatness is increased with the time evolution of the etch for the higher density of the solutes. [7]

One another group has studied some benefit of aluminium addition to the melt. When changing the hydrodynamic properties of the melt, e.g. by adding aluminium, the melted back crater bottom is smother. Convection is depressed.[8]

The arsenic concentration in the gallium melt are behaved as

C_{As}=2352.8exp(12404/Teq) ---------------- (1)

ΔT=T-Teq --------------------- (2)

The ΔT is known as the degree of under-saturation. When ΔT is larger than zero then the melted back else crystal grown in LPE. The control parameters in melt back etch shape are such as meltback time (to determine the etched depth), mask-opening width (to control the lens curvature) and the degree of under saturation for the gallium melt (ΔT), to decide the etching speed and the surface flatness). It is obtained the circular lens-like shape by the regrowth to fill the meltback well. First it is formed the (50 -200 mm)m SiO_2 mask by the photolithography. After the substrate metal cleaning and D.I. rinsing, it is laded with the gallium of undersaturation on the graphite boat. It is melted back and regrown after the 120min homogenization with hydrogen ambient LPE furnace. n the experiment, the weight ratio of Al/Ga is 1.4wg/g in the melt of 780°C, which is the liguidus composition of an $Al_{0.5}Ga_{0.5}As$ if as is saturated into this Ga-Al melt.

Typical process parameters are such as the meltback time of 2~30sec, regrowth cooling rate of 0.2°C/min and regrowth time of 30-100min.

We make observation to the surface and the crossectional view of of the regrown region thru the optical microscope (x400 maximum) and SEM. Especially the interface of the crossection of the edge is stained with the solution of $HF:H_2O_2: H_2O$ = 1:1:10. After etching out the GaAs back substrate selectively with NH_4OH system, the regrown circular region should be remained..

In the fig.1 the plots are the depth of meltback etch with respect to the meltback time (sec) . The one with gentle slope is the case of the aluminum addition to the gallium melt (Al/Ga=1.4*mg/g*). And the other is the case without aluminum. With respect to the linear fit, the former follows with

$d = 2.8t + 3.38$ ---------------- *(1)*

and the latter follows with

$d = 16.5t - 58.7$ --------------- *(2)*

where *t m* is the meltback time and *d* is the depth of the meltback etch.

In the comparison, it is easier for the case of aluminum addition to control the depth of meltback etch than without aluminum. It also reduces the undersaturation degree of the gallium melt. So it will remove or reduce the gallium arrested regions in the regrowth process. The same or similar effects are expected in the case of poly-crytalline GaAs addition .

The depth is linearly proportional to the time at initial contacts (untill 20 seconds). And it is changed to be proportional to the square root of time after then as shown in fig.2. It is thought that the initial t^1 - dependence is determined by the kinetics limited process at the interface between the GaAs crystal and Ga melt. And $t^{0.5}$ -dependence results from the decrease in the etching speed due to the local lowering of ΔT around the etched interface because the etched As is incorporated locally in to the Ga melt. The etching profile and $t^{0.5}$ dependence are very similar to the case of the impurity diffusion into the semiconductor materials [4] . For the optical devices with lensed or circular surface, we should do meltback etch with the time less than 20 seconds. So it is accepted the linear dependence between the meltback depth and time.

III. Non-ideal Hemispherical Surface Anisotropy in Meltback Process

For the meltback etch is considered as isotropic but there is also an anisotropy in the process in LPE. It is not ideal for the lens shape to obtain. The anisotropic plane is parallel to the [100] [110] direction groups of GaAs substrate independent with the wiping off direction. Fig.3 shows the three different etch and regrowth shape with SEM photolithograph. The anisotropic side is observed in the figure. It goes to non-ideal lens shape with the time evolution. It is also thought that the etching process goes from the surface kinetics limited process to the diffusion limited process.

Arrested Gallium Island in the Regrowth

Fig.4 is the surface and crossectional photo-micrographs with some process condition of meltback etch and regrowth. In the figures there are gallium island in the center and edges of the regrowth. It is caused by the carryover of still-undersaturated gallium melt to the next well to be grown. It hinder the regrowth of the next well untill the gallium melt be homogenized to saturation. In the experiment, it is used the two phase cooling method that the arsenic solute is abundant. There are two kinds of gallium island described above. One in the center is confined by the growth speed difference between the side of the opening window and bottom, of the melted back. The other in the edges on which the (010) and (001) directions are met are confined because the [100] crystal oriented growth rate is high. As mentioned above section, it can be reduced by addition of aluminum.

IV. Micro-lens Array

By the use of the meltback and regrowth , new fabrication method is developed. It is easy to control the lens parameters such as the numerical aperture, the focal length and the lens size compared to the methods described above. Fig.5 shows an array of micro-lens fabricated by the method. The fabrication condition are tm=8 sec., tg= 40 min.. For the conditions, no gallium carry-over is shown on the wafer. It is simple in the process and well compatible in the integration with other optical devices. It can be a good candidate for the surface emitting diodes to lengthen their vertical cavity. And above the other properties, it is very compatible with the well developed LPE technology.

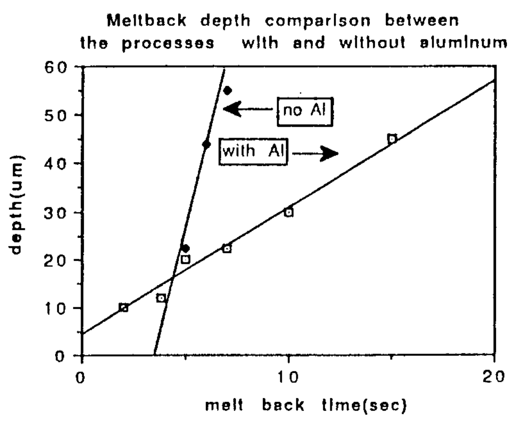

Fig.1 Meltback depth versus time relations with and without aluminum (Al/Ga=1.4mg/g, weight ratio)

V. Conclusion

By the relation between the depth and time of the meltback, it is easier for the case of aluminum addition to control the depth of meltback etch than without aluminium. It also reduces the undersaturation of the gallium melt and remove or reduce the gallium arrested regions in the regrowth. The meltback etch depth curve is linear dependence to the time at initial contact and is changed to square-root dependence. By the observation of regrown region with optical and scanning electron microscope, there are anisotropies in [110] or [110] direction.It is useful to the optical device fabrication such as micro-lenses and surface emitting diodes. For them, the more improvement will be done in the process control.

References

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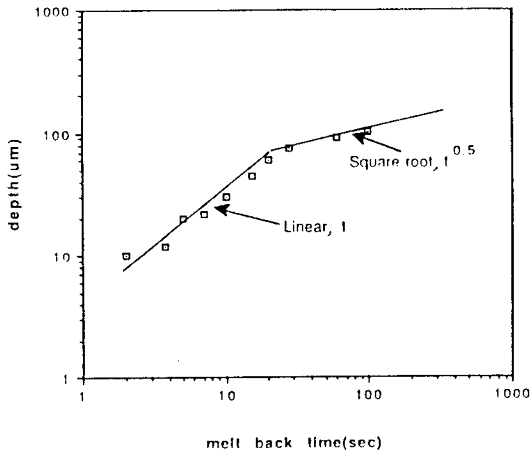


Fig.2 Meltback depth versus time relations with logarithm (with Al)

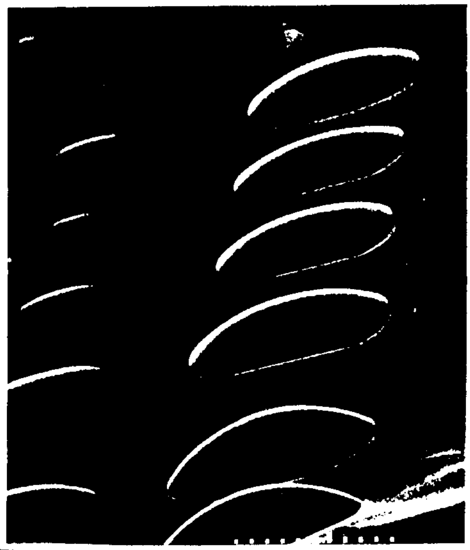


Fig.5 One example of the micro-lens array (lenses with different mask openings)

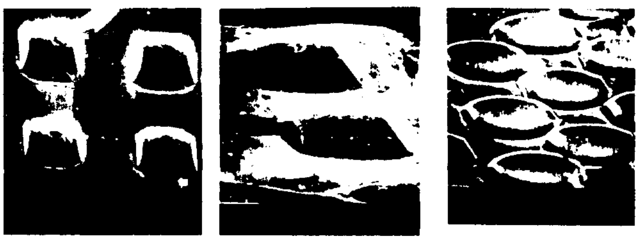
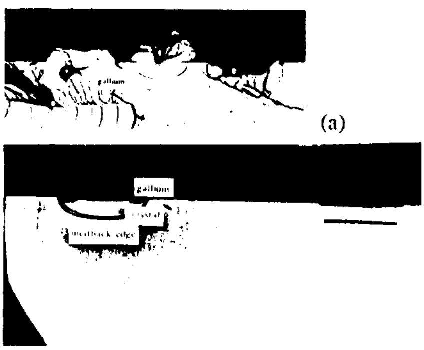


Fig.3 The meltback and regrowth shape formed by the different conditions (a) (b) (c)



(a)

(b)

Fig.4 Crossectional photomicrograph of the regrown layer (a)gallium island in the center (b)gallium island at the edges