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Fabrication of a vertical reflow microlens with silylation technology

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Abstract

The fabrication of a vertical reflow microlens (VRM) has been demonstrated by the thermal reflow method and succeeding silylative treatment on the lens surface, which can provide an appropriate stability and control of the lens curvature, and therefore can be applied to the micro optical/optoelectronic bench. By virtue of the strong adhesive force and cohesion, the VRM is formed by hanging the photoresist on a standing wall and then reflowing the photoresist. In order to enhance the thermal stability and reliability, the reflowed VRM is exposed to a silylative reagent (hexamethyl cyclotrisilazane, HMCTS) to form a hard shell.

To characterize the VRM, we use a 1.31-μm-wavelength optical beam emerging from a single-mode fiber as light source and utilize the beam scanner, BeamScope P5, to observe the far-field angle. A simulation model based on the wave optics is constructed to compare with the measurement results. According to the comparison, the modeling result agrees well with the measured data and proves the effectiveness of the VRM in beam focusing.

Keywords: Vertical microlens; Microlens; Polymer; Reflow; Silylation

1. Introduction

In the optoelectronic systems, especially the integrated micro-systems, there are always the coupling issues concerning optical injection and extraction efficiencies. In the two-dimensional integrated micro-optics, such as FSMOB (Free-Space Micro Optical Bench) [1] or 2DIO (Two-Dimensional Integrated Optics) [2], in which lightwave traverses in the direction parallel to the substrate, beam convergence or collimation is achieved by vertical-type microlens, such as Fresnel microlens based on micro-hinge technology [3], the waveguide microlens using the graded-index dielectric deposition [4], or the out of plane refractive microlens based on direct lithography [5].

In the recent years, the polymer has been widely used in the process by reflow method [6], which can form a high-quality refractive microlens. The polymer reflow process, however, mostly is used for the formation of planar-type microlens nowadays, which has its optical axis perpendicular to the lens substrate. Therefore, it cannot be integrated directly into the in-plane micro optical/optoelectronic systems.

We have already reported on a polymeric vertical micolens using dip method [7]. In this article, we shall demonstrate a novel vertical reflow microlens (VRM) fabrication that can provide the control of radius of curvature. In addition, by using the thermal reflow and silylation process, the VRM has a smooth profile and provides appropriate thermal stability for an optoelectronic system.

2. Experimental

Due to the consideration of being integrated with the edge-emitting laser, which exhibits erect elliptic far-field pattern, this novel VRM is first demonstrated on the InP wafer and one of the fabricated biconvex VRMs is shown in Fig. 1.

Fig. 2 illustrates the flow chart of VRM fabrication process. The VRM process starts with depositing a 2000 Å SiN_x film and then patterning 30-μm-width strips etching mask. A standing wall on the InP wafer surface is formed through a deep 4

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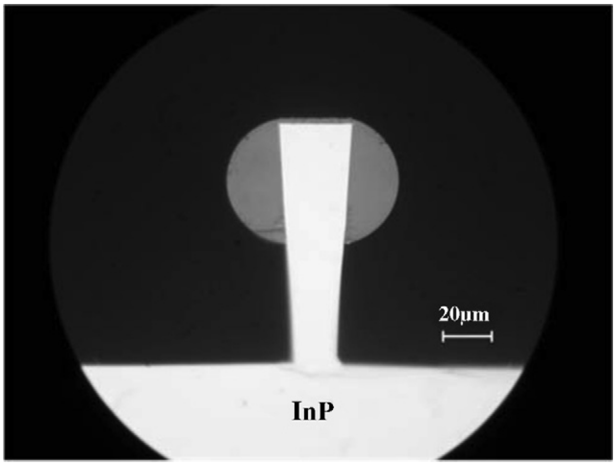

Fig. 1. Cross-section of a symmetric biconvex VRM fabricated by reflow method and silylation technology.

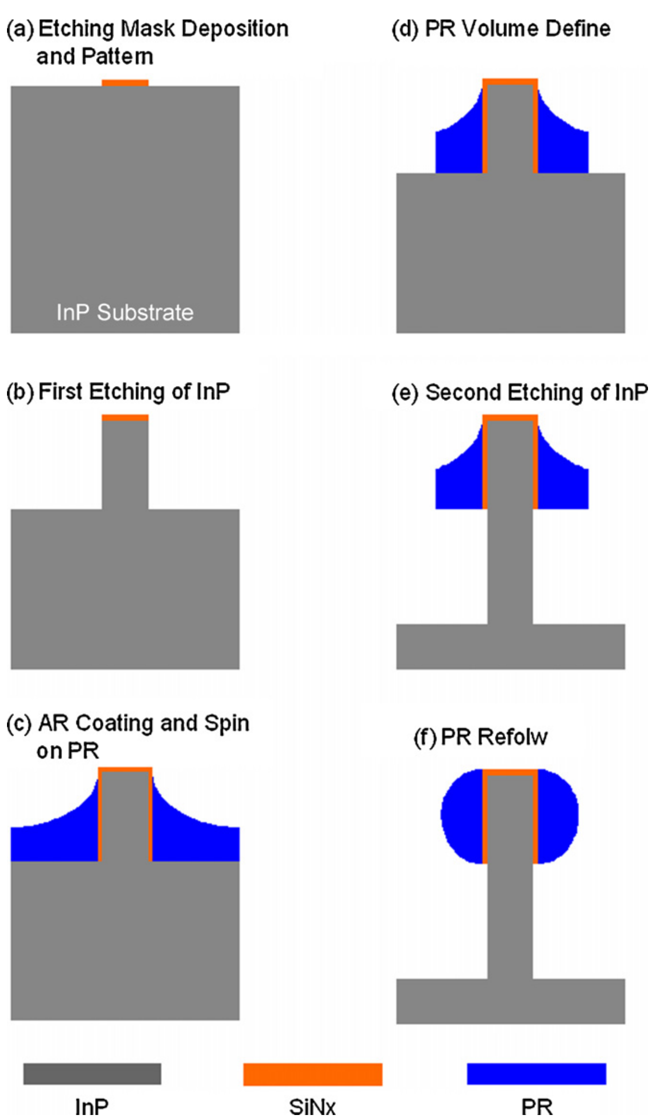

Fig. 2. Flow chart of VRM fabrication process.

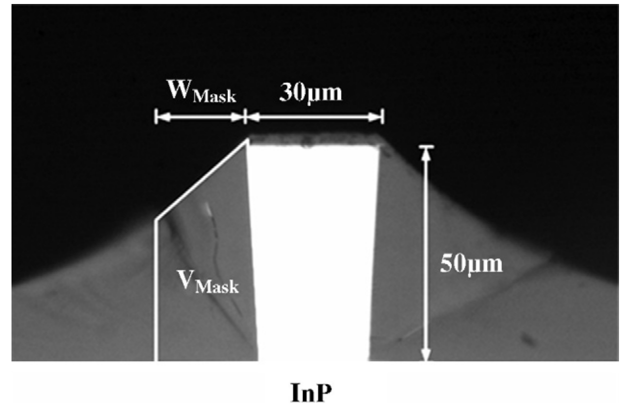

Fig. 3. Cross-section of the coverage profile after spinning and baking the photoresist.

wet-etch process using the 1HCl: $3H_3PO_4$ etching solution with an etching rate of 1 μm/min. The wall height after etching is 50 μm. To reduce the reflection loss, both sides of the semiconductor wall are deposited with a 1800 Å SiN_x film as the anti-reflective coating layer. The photoresist ma-P 1240 is then spun onto the substrate and, after baking at 150 °C for 30 min on hotplate, the resist exhibits a coverage profile illustrated in Fig. 3. To define the resist volume (V_{mask}), which determines lens curvature and thickness, we mask the useful region of a width W_{mask}, make exposure, and dissolve unwanted photoresist in the developer.

To detach the photoresist left on the substrate from the bottom InP surface, the substrate is again immersed in the 1HCl:$3H_3PO_4$ etching solution for about 50 min, which does not affect the standing wall of InP obtained from the first etch due to the protection of AR coating and photoresist. The InP etching proceeds not only downwardly, but also laterally, and undercuts the photoresist, as illustrated in the left of Fig. 4. Hanging the photoresist on the wall without touching the ground or falling off before thermal reflow is the key step to successfully form the VRM. Besides, the total InP etching should be deep enough to

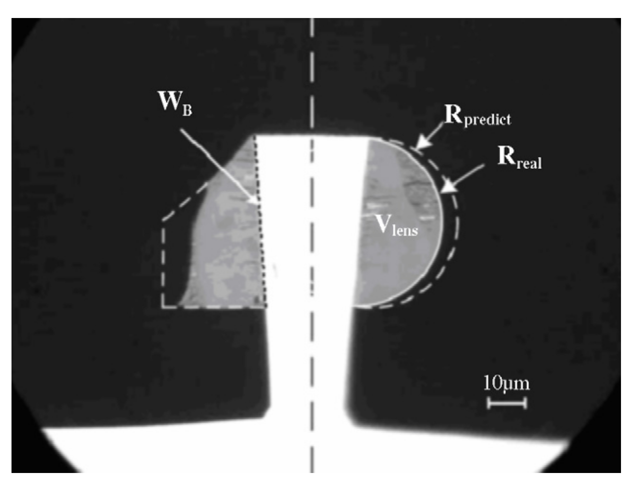

Fig. 4. The profiles of the photoresist before (left) and after (right) thermal reflow process.