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Fabrication and Characterization of Sub-100 μm Diameter Gallium Phosphide Solid Immersion Lens Arrays

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Fabrication and testing of a sub-100 μm gallium phosphide solid immersion lens is described with suitable sphericity (<160 nm deviation) to a marginal ray angle of 42° for NA up to 2.2 inside the material.
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KEYWORDS: solid immersion lens, lithography, gallium phosphide, phase-shifting interferometry

1. Introduction

As the data storage industry searches for methods to increase data density, systems that employ solid immersion lens (SIL) technology are under serious investigation.[1,2] The SIL increases data density by reducing spot size $s = \lambda/(n \sin\theta)$, where λ is the wavelength in air, n is the SIL's refractive index and θ is the marginal ray angle inside the SIL. In the case of common glass SILs, the maximum index of refraction is limited to around $n = 2.0$. Alternative materials, like gallium phosphide (GaP) and zinc sulphide (ZnS), are attractive due to their high indices of refraction, but they are difficult to fabricate. For example, there have been several examples of using GaP to create micro lenses,[3,4] but none that reach the mechanical aspect ratio needed for a hemispherical SIL. This paper examines a new manufacturing process and the associated testing technology that is used to fabricate inexpensive arrays of hemispherical micro-SILs. The approximately 60 μm diameter SILs are made from GaP, which has a large refractive index ($n = 3.3$) in the visible. The hemispherical micro-SILs obtain a maximum surface departure of 160 nm over a marginal ray angle of $\theta = 42°$. The resulting micro-SILs exhibit $\mathrm{NA} = n \sin\theta = 2.2$. The fabrication technique can also be applied to other materials, like ZnS, that are more transmissive at $\lambda = 405$ nm.

2. Fabrication

The hemispherical GaP microlens fabrication is carried out in the clean room manufacturing facility at MEMS Optical in Huntsville, AL. The effort comprises two principal steps: (1) photolithographic patterning to create an etch mask; and (2) transferring the photoresist pattern into the GaP wafer by plasma etching. After two iterations of the process, good quality hemispheres were achieved.

The technique used for the first iteration consists of patterning a positive photoresist etch mask in the form of hemispheres using a traditional reflow process, with the base diameter of the lens being constrained by a structure etched into the wafer surface. The lithography process yields nearly spherical shapes for the photoresist etch mask. However, the etching process into GaP results in conically shaped lenses, as shown in Fig. 1. The conical shape is the result of GaP selectivity, where selectivity is defined as the ratio of substrate material etching rate to photoresist pattern etching rate. The photoresist hemispheres require a selectivity of less than 1 : 1 in order to correctly transfer the photoresist pattern into the GaP. The etch processing is performed in a modern inductively coupled plasma (ICP) etcher using a combination of halogen gases and other non-reactive gases. In this situation, GaP etches approximately three times more rapidly (selectivity in the range of 2.5 : 1 to 3.5 : 1) than the photoresist etch mask.

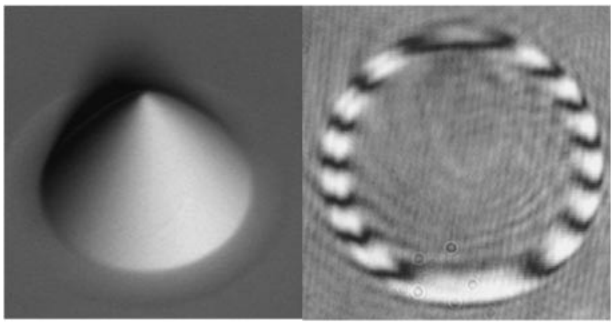

Fig. 1. (a) SEM photograph of initial batch of GaP SILs (b) fringe pattern from initial GaP SIL batch.

In the second iteration, a new etching process was developed to produce more hemispherical lens shapes in GaP. The new etch process uses aspheric photoresist mask patterns with greater diameter and sag-height aspect ratios than for the reflow hemispherical photoresist pattern. The aspheric shapes are produced with gray-scale lithography. These aspheric patterns are chosen so that the lens profiles being processed could be measured with the existing metrology tools at MEMS Optical. Parameters measured include lens radius of curvature and surface quality. The masks are optimized to capitalize on the 3 : 1 selectivity range, where the best quality etching is obtained with GaP. An additional modification in the etching process is to reduce the plasma loading, which is the percentage of wafer exposed to the plasma during etching, by approximately 50%. (For the first iteration that produced conical lenses, the wafer loading is 100% at the end of the etch process.) For better shape control and better uniformity, the initial loading starts around 30% exposed area and finishes at 50%. The revised layout approach results in lenses at the bottom of holes, as depicted in the scanning electron microscope image

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