Design and Fabrication of a Small-Form-Factor Optical Pickup Head

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This paper presents the design and fabrication of a small-form-factor optical pickup head (OPH) for both red and blue wavelength. A holographic optical element (HOE) is used for beam splitting, aberration correction, and servo-signal generation to reduce the number of components and simplify the assembly procedure. In addition to demonstrating this OPH by using existing discrete components, several key components and processes are developed to use micro-electro-mechanical system (MEMS) technology to facilitate batch fabrication and wafer level assembly of the micro OPU.

***Index Terms*—Assembly, batch fabrication, MEMS, optical pickup head, small form factor.**

I. Introduction

THE demand of mobility and portability of multimedia data prompts the development of small data storage devices such as small-form-factor (SFF) optical drives, micro hard disk drives, and flash memory sticks. Several efforts had been made to develop such SFF optical drives for either red or blue wavelength [1]–[9]. In order to compete with other technologies, the miniaturization, fabrication, and assembly of the SFF optical drives must be addressed from the perspective of mass production. Optical pickup heads (OPH) are the most important modules in optical drives. Traditionally they are made of discrete passive and active components which are assembled with stringent demand of precision. As the size is reduced for SFF drives, the assembly of micro optical components becomes more difficult, costly, and time consuming. To alleviate this problem, the optical system can be simplified by using multi-functional holographic optical elements (HOE) to reduce the number of components [4]. Micro-electro-mechanical system (MEMS) technology can also be used to fabricate precisely defined and aligned micro parts in batch processes to reduce the assembly cost [8], [9].

In this paper, we extend the prior efforts further to investigate and demonstrate the feasibility of using MEMS technology to facilitate wafer-level assembly and packaging of SFF OPH. A SFF OPU was designed for both red and blue wavelength. An HOE was used for beam splitting, aberration correction, and servo-signal generation. The optical design was first demonstrated by using discrete components only. Two methods of fabricating micro prisms in pairs at the wafer level are proposed in this paper. Wafer level assembly of the pickup heads by using these micro prisms is demonstrated.

II. Optical Design

In [4], a finite-conjugate SFF OPH was developed, as shown in Fig. 1. Two micro prisms MP1 and MP2 with parallel 45° surfaces were used to fold the optical path to fit into the compact space. For the incident light onto the disk, the zeroth order diffracted beam of the HOE was used to read the disk. However, on the returning path, the first order beam was used in order to separate reflected light from the source light in the optical path. The same optical configuration was used to design for the 405 nm wavelength in [10]. The dimension of prisms was common in both systems. However, the aspherical objective lens with 0.65 NA and a corresponding HOE at the blue wavelength were re-designed so that the correct astigmatic focusing error signal (FES) could be generated on the detector, as shown in Fig. 2. The linear range of the FES is about 4 μm. The total size of the OPU is 6.5 mm (L) $\times$ 3.0 mm (W) $\times$ 3.3 mm (H). The optical specifications of the two systems are summarized in Table I.

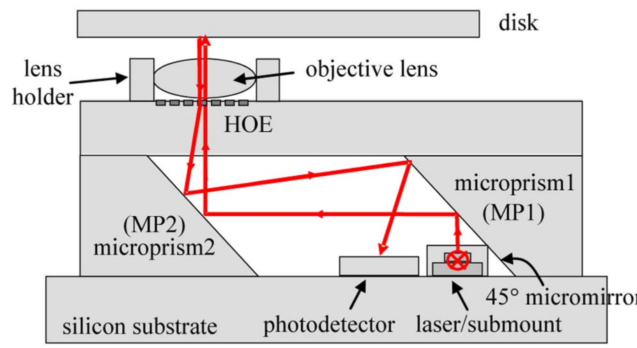

Fig. 1. Optical system of SFF OPH.

The optical design was first verified by using discrete prisms, objective lenses, laser diodes (LD), and photo diodes (PD) at the red wavelength. The HOE was etched in the SiO_2 film deposited on a piece of BK7 glass. A flip chip bonder with 1 μm positioning accuracy was used to pick and place the LD and PD on a silicon platform. Alignment marks and aluminum wire traces for signal routing were patterned on the platform in advanced. The assembled OPH is shown in Fig. 3. The full width at half maximum of the focused spot was measured to be 0.487 μm and 0.478 μm in the radial and tangential directions, respectively. They are smaller than the spot size of about 0.52 μm in traditional DVD systems. Therefore, the design concept and the

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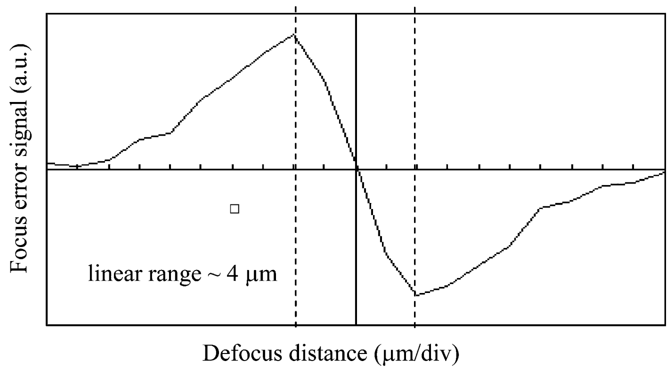

Fig. 2. Simulated S-curve of the focusing error signal (FES).

TABLE I
OPTICAL SYSTEM SPECIFICATIONS

Wavelength	654 nm	405 nm
image-object relation	finite-conjugate	finite-conjugate
disc cover layer	0 mm (surface recording)	0 mm (surface recording)
object NA (laser side)	0.1	0.1
image NA (disk side)	0.65	0.65
focal length	0.525 mm	0.670 mm
clear aperture diameter	1.0 mm	1.1 mm

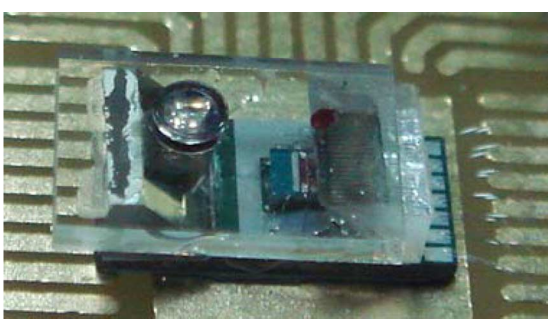

Fig. 3. Assembled OPH by using discrete components.

assembly accuracy are both verified. The dynamic measurement of the S curve and the RF signals are currently under way.

III. BATCH ASSSEMBLY PROCESS

MEMS technology has been applied to fabricate micro components and modules in wafers. However, handling and packaging of these micro parts becomes a major challenge since they are small, fragile and susceptible to contamination after release. Wafer level assembly is an effective way to reduce the risk and cost of packaging by handling the fabricated devices at the wafer level as much as possible. In SFF OPH and other micro optical systems, components such as laser diodes can not be fabricated in silicon wafers. Nevertheless, silicon can still be used to fabricate micro opto-mechanical parts such as reflective mirrors, alignment patterns, and common platform carriers on which all other components reside. The advantage of micro fabrication is that the fabricated components are aligned automatically to each other by the photolithography process. Therefore the misalignment introduced in the traditional assembly process can be greatly reduced. In the following, two approaches are proposed to fabricate the two parallel micro prisms MP1 and MP2. A wafer level batch assembly process of the SFF OPH is also developed and demonstrated.

A. Silicon Parallel Prisms

The (111) Si surfaces have long been used to fabricate slant reflective surfaces by anisotropic wet chemical etching. In this paper, a silicon wafer with two parallel wet-etched surfaces is used to replace the two micro prisms in Fig. 1. A wafer level assembly process is also developed so that the LD and PD are sealed in a closed chamber before the wafer is diced into individual OPH. Fig. 4 shows the fabrication and assembly processes. In Fig. 4(a), LPCVD insulation nitride layer and aluminum electrical routing are prepared on the Si platform wafer. Meanwhile, a 1.4-mm-thick 9.7° off-cut mirror wafer is also deposited with LPCVD nitride and etching windows are patterned on both sides. The thickness of the mirror wafer is determined from the prism height in Fig. 1. In Fig. 4(b), LD and PD chips are placed and bonded to the platform wafer by using a flip chip bonder. The mirror wafer is wet etched to form the parallel mirrors. The surface roughness is smaller than 10 nm within a 100 μm × 100 μm area. Finally, a cover glass wafer, the mirror wafer, and the platform wafer are bonded and then diced, as shown in Fig. 4(c). The electrical components and their bonding wires are sealed by the wafer stack in chambers. Thus, the dicing process will not damage or contaminate the components and the mirrors inside the chambers. The dicing of the wafer into individual OPH is composed of two steps: the first cut is a partial cut and the second cut is a through-wafer cut to separate the OPH modules and uncover the contact pads on the platform substrate. The finished OPH unit is indicated by the dashed line in Fig. 4(c). The HOE can be etched on the cover glass wafer. As a result, all components except for the LD, PD and objective lens are fabricated and assembled in wafers in this process. In consideration of possible fabrication and assembly tolerance, another approach is to fabricate the HOE in a different glass so that it can be used to adjust the optical path to compensate for the above errors when it is bonded to the cover glass, as shown in Fig. 4(c). In this case, the total thickness of the HOE glass and the cover glass is equal to the original thickness as shown in Fig. 1. Fig. 5 demonstrates the fabricated wafers and diced OPH without the HOE glass. A 2 × 2 array of OPH modules was used to demonstrate the proposed wafer level assembly process, as shown in Fig. 5(b). The diced OPH in Fig. 5(c) was mounted on a print circuit board for electrical testing, as shown in Fig. 5(d). An objective lens was mounted on the cover glass to collimate the laser beam.

B. SU-8 Parallel Prisms

In addition to the silicon process, SU-8 photoresist was also used to fabricate the parallel prisms. Compared to silicon, SU-8 offers more design flexibility since the geometry of the fabricated polymer structures is not limited by the crystalline planes as in silicon.

The two parallel prisms were fabricated in SU-8 by using an inclined photolithography process [11], as detailed in Fig. 6. First a 1.4-mm-thick SU-8 layer is spin coated on the substrate.

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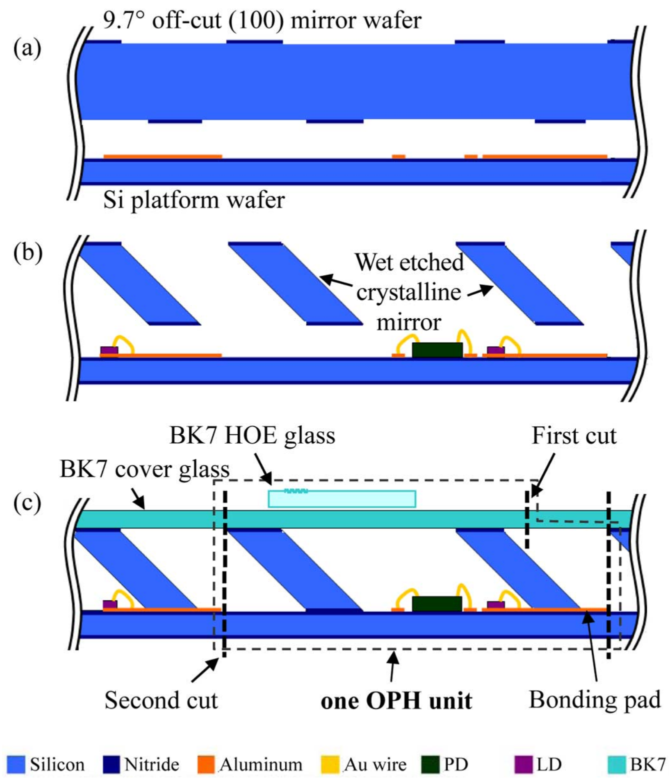

Fig. 4. Batch fabrication processes for the SFF OPH.

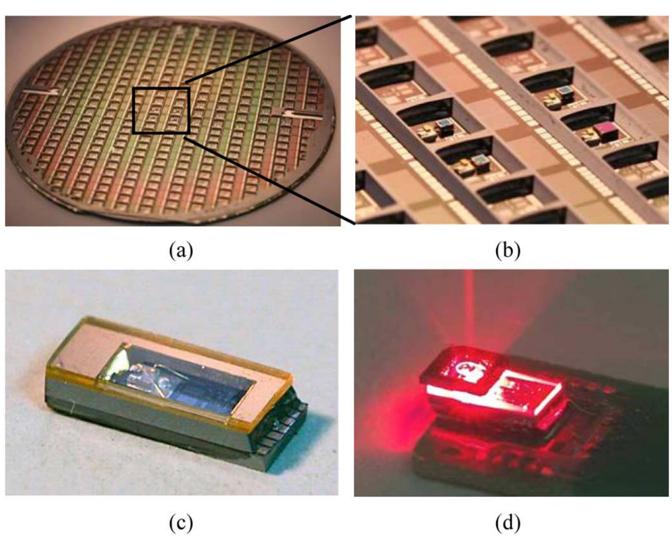

Fig. 5. (a) Wet etched mirror wafer bonded to the platform wafer, (b) four of the modules have PD/LD bonded and wired, (c) diced OPH module with cover glass, (d) electrical test of the OPH in (c).

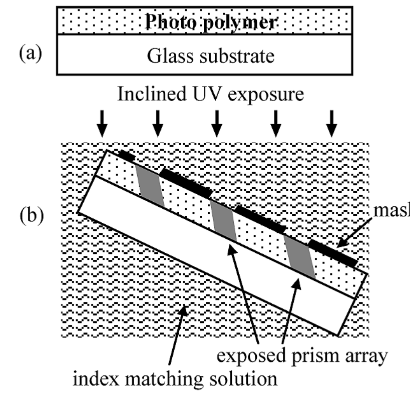

Fig. 6. Process flow of micro prism array fabrication.

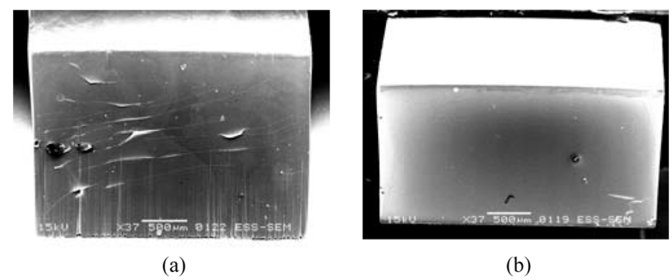

Fig. 7. SEM images of the SU8 prism: (a) exposed with ordinary-resolution laser glass mask and no UV filter, (b) exposed with high-resolution e-beam quartz mask and UV filter.

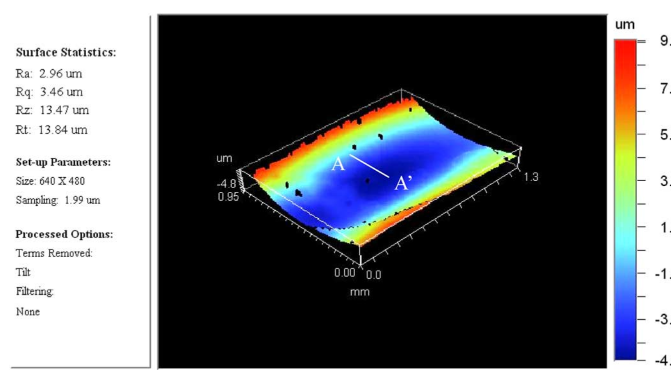

Fig. 8. Interferometeric measurement of the surface profile of the prism fabricated with a filter and a high-resolution e-beam quartz mask.

After a soft bake at 95°C for 8 h, the wafer is brought into contact with the photo mask. The two are held together by a specially design holder and exposed to the UV light at the desired angle, as shown in Fig. 6(b). To reduce reflection of the UV light from the substrate during exposure, the sample is immersed in a glycerol solution which has a matching refractive index to the substrate. The angle of the incident UV light must also be adjusted to account for the refraction at the air/glycerol interface. Post exposure bake is performed at 95°C for 60 min after the exposure and the wafer is cooled down to room temperature. After development, the prism arrays are completed as shown in Fig. 6(b).

The exposure setup and conditions have great effects on the surface quality of developed prisms. Fig. 7 shows the comparison of micro prisms fabricated with two different conditions. In Fig. 7(a), an ordinary laser glass mask was used. The rugged edges of the mask caused the stripes on the developed surfaces in the vertical exposure direction. In Fig. 7(b), an e-beam mask with higher resolution and less edge ruggedness was used. Since the high absorption of SU-8 in short wavelength can cause a tapered geometry of the exposed prism, a UV filter was also used in the aligner to cut the short wavelength UV (365 nm) to have better control of the exposed and developed edges and overall geometry. It can be clearly seen that the prism surface

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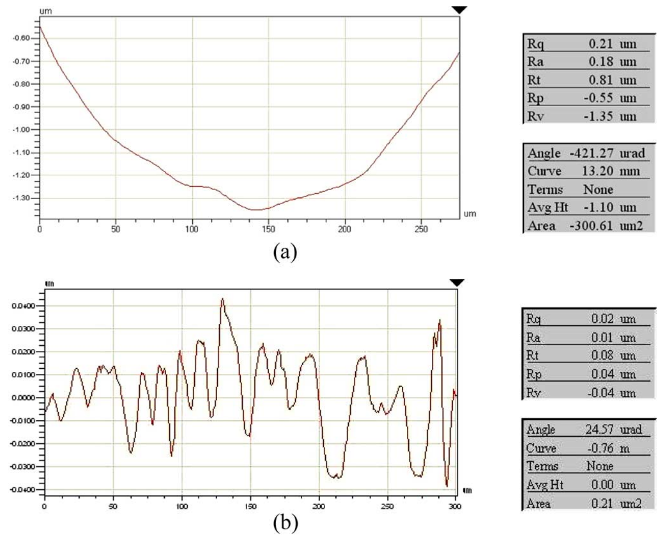

Fig. 9. WYKO interferometric profile measurement: (a) before hard bake, $R_t = 0.81$ μm, (b) after hard bake, $R_t = 0.08$ μm (measurement length: 270 μm).

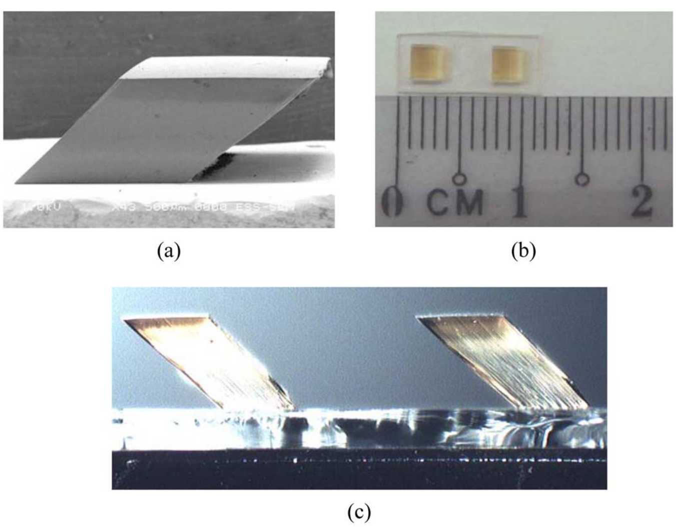

Fig. 10. Fabricated SU8 micro prism: (a) SEM of a single prism, (b) top view of a pair of prisms, (c) side view of a pair of prisms.

has been improved significantly compared to Fig. 7(a). The surface profile was found by interferometric WYKO measurements to have a large curvature, as shown in Fig. 8. In such a large measured area (1.3×0.95 mm^2), the maximum peak-to-valley profile height R_t is about 13.84 μm, which is not acceptable for optical applications if the entire prism surface will be used. In order to reduce the surface curvature and improve the flatness, a hard bake at 200°C for 80 min was employed to reflow and flatten the polymer material. For a more quantitative assessment of the surface quality, Fig. 9(a) shows the AA' profile before the hard bake. The peak-to-valley value is 0.81 μm. Fig. 9(b) shows the profile after the hard bake where the peak-to-valley value is reduced to 0.08 μm. Therefore, thermal treatment can indeed improve the flatness of the fabricated prism surfaces. Even though the measurement range in Fig. 9 is less than 300 μm in length, the optimal exposure and bake parameters are currently being investigated for an optical-quality surface with a dimension up to the mm range. Fig. 10 shows the micro prisms fabricated using the process in Fig. 6. Fig. 10(a) is the SEM of a single prism. Fig. 10(b) and (c) are two prisms diced in pair from the substrate, which can be used to replace the two micro prisms MP1 and MP2 in Fig. 1. A similar batch assembly process of the OPH similar to that described in the last section can also be developed.

IV. Conclusion

MEMS technology was developed for batch fabrication and wafer level assembly of small-form-factor optical pickup head. Laser diodes, photo diodes, and objective lenses are assembled by pick-and-place or flip-chip processes. Prisms and silicon platforms are fabricated and assembled at wafer level. When the assembled wafer stacks are diced, the electronics are sealed protected inside a chamber. Therefore, the cost can be reduced and yield and reliability the micro fabricated OPH can be enhanced.

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