Development of a New 9.5mm Height Ultra Slim Super Multi Drive Incorporating a Grayscale Diffractive Optic

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1. Introduction

A new 9.5mm height DVD/CD ultra slim super multi drive was developed to compete in the market. We developed a grayscale technology to fabricate a grayscale diffractive optic used in the new drive for focusing with the astigmatic method. The new grayscale diffractive optic brought technical improvement compared to conventional binary optics and realized a cost competitive drive. Technologies used in this new optical drive are reported.

2. The new Ultra Slim Super Multi Drive

A new 9.5mm height DVD/CD Ultra Slim Super Multi Drive was developed with a new technology. The new drive consists of DVD and CD optical system sharing all the optics, three beam gratings, integrated prism, collimator, and objective lens. Fig.1 shows a perspective view of the drive.

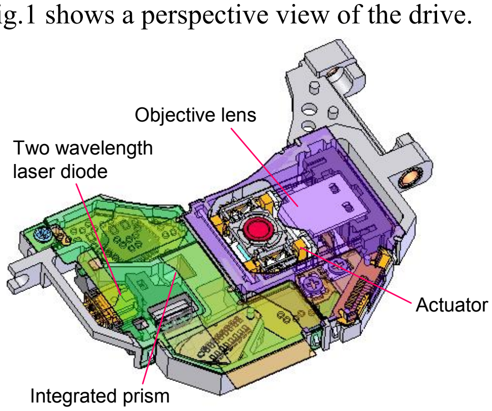

Fig. 1: The new Ultra Slim Super Multi Drive.

The two wavelength laser diode emits a single-mode laser beam at a wavelength of 665nm for DVD or 785nm for CD. The laser beam passes through wavelength selective three beam gratings, integrated prism, collimator and objective lens. The returning beam from the disc comes back to the integrated prism and is reflected by a polarization beam splitter inside the prism. The beam is directed to a grayscale diffractive optic, which is an astigmatic mirror and generates astigmatic aberration. Two sets of quad-detector arrays generate electrical signals to compute the focus error signal and the push-pull signals as it receives the astigmatic beam from the grayscale optic. The differential push pull method and the in-line differential push pull method are used for DVD and CD tracking, respectively. Fig. 2 shows the detail of the integrated prism. Fig. 3 depicts the beam paths around the prism.

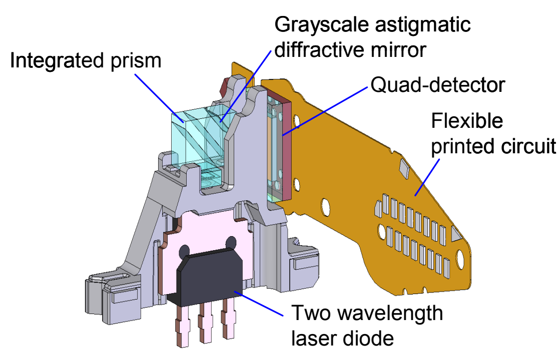

Fig. 2: Integrated prism with grayscale diffractive astigmatic mirror.

The grayscale diffractive optic is fabricated on a wafer using grayscale photolithography and is covered with reflective coating. The wafer is glued with other wafers with polarization beam splitter over-coated and diced to form the integrated prism, which is a distinct and proprietary element of the Panasonic super slim drives. Grayscale optics drastically improve the diffraction efficiency compared to binary optics. The diffractive astigmatic mirror could have been made with a Fresnel zone plate by binary lithography but the diffraction efficiency is so low that undesired diffraction gives rise to a drive quality problem. The combination of the integrated prism and the embedded grayscale diffractive astigmatic mirror significantly reduces cost compared to optical drives of semi-discrete type in which a separate astigmatic lens and a lens holder are necessary.

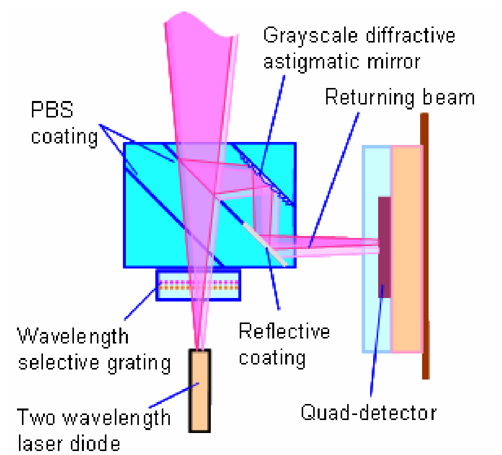

Fig. 3: Beam paths around the integrated prism.

3. The grayscale technology

We were the first in successfully developing a grayscale photolithography using Laser Direct Write (LDW) grayscale mask with mass-production level in quality, namely the yield of production, which mainly depends on the shape error and surface quality, is such that the factory accepts. The LDW grayscale mask is a commercial product of Canyon Materials Inc. [1], CA, USA. The transmittance of LDW masks changes proportionally to the applied heat[2].

A focused laser beam can write precise grayscale pattern on LDW mask. Once a grayscale mask is prepared, regular photolithography process follows, i.e., exposure by a stepper, bake, development, and plasma etching are carried out to manufacture the final optic. Fig. 4 shows a microscope picture of an actual grayscale mask pattern of the grayscale diffractive astigmatic mirror, cross sectional profile of the white light interferometer measurement data along the mirror center (dotted line) of the final element, and the shape error from the design. There are some spurious measurement errors at each break point of the mirror due to the discontinuity, which are not counted in the shape error. The RMS shape error being less than 10nm excluding the measurement errors, the agreement of the design and measurement is good enough for mass-production.

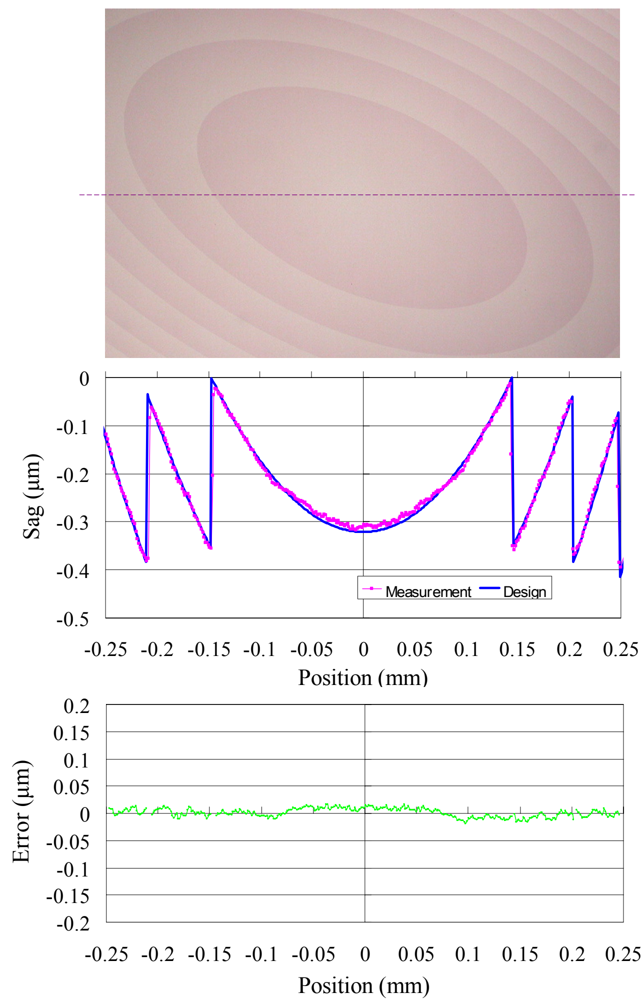

Fig. 4: Grayscale mask (top), design and actual interferometer measurement (middle), shape error (bottom) for the grayscale astigmatic mirror.

The greatest technical improvement in using grayscale optics is its high diffraction efficiency compared to binary optics. We could achieve about 85% diffraction efficiency while conventional binary hologram, which used to be employed in older version of our drives, had only about 32% in diffraction efficiency. This difference made significant increase in signal to noise ratio of the signal processing for focusing and tracking.

Furthermore, one of the advantages of using the LDW mask over other grayscale masks such as HEBS (High Energy Beam Sensitive) mask[1)], which is the complementary mask of LDW, and half-tone grayscale mask[3)] is that the blurring at the break point of the phase jump in a diffractive optical pattern on LDW mask is much less, which is of significant importance for the diffraction efficiency of the final optic. The blurring at the break point on the final optic in case of LDW mask is no more than 1µm in combination with the use of a 5X image reduction stepper. Although this blurring creates about 15% diffraction loss, the associated stray light forms relatively uniform background light as is known[4)] and it does not give significant negative effect on the signal processing. The HEBS mask and the half-tone grayscale mask can not achieve this accuracy. It is well known in the scope of scalar diffraction theory that the diffraction efficiency rapidly drops as the blurring increases[5)]. We can not expect 85% diffraction efficiency with blurring that is beyond 1µm.

Another key technology is an in-house grayscale laser writer system with excellent stability and repeatability. A diode pumped solid state green laser is used for mask writing with about 0.8 ~ 2µm spot size depending on the objective lens. The laser beam is modulated by an Acousto-Optic Modulator (AOM) through a 16-bit D/A converter. Linear air bearing stages are used to translate in 2 axes the LDW mask and are synchronized with the laser trigger signal based on the pattern data. A real time auto-focusing system captures the surface of the mask so that it keeps focusing over large area. Fig. 5 depicts a schematic of the grayscale laser writer. The graylevel being given in up to 65535, the laser writer can write extremely smooth profile of an optic pattern all over the pattern area with *real* grayscale tone whereas lower graylevel, e.g., 256 levels, often suffers step like profile.

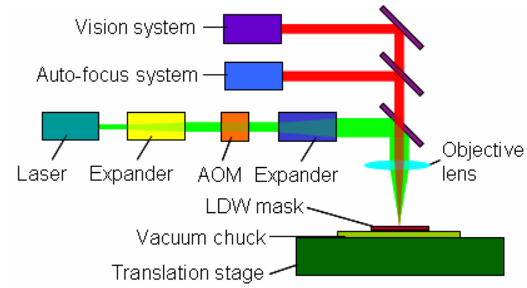

Fig. 5: Schematic of in-house laser writer.

The main features of the system are the following.

1. Stability of laser power : < 1% PV
2. Repeatability of focusing : < ±0.5µm PV
3. Repeatability of stage : < 0.5µm PV

To the best of our knowledge, these specs are not achieved for commercially available laser writers.

4. Conclusion

We have developed a grayscale technology and were the first in successfully mass-producing a 9.5mm height Ultra Slim Super Multi Drive incorporating a grayscale diffractive optic. The technology improved the signal quality by increasing the diffraction efficiency of the diffractive optic and brought significant reduction of cost per drive as a result. Consequently the technology made our optical drives very competitive in terms of technology and cost.

5. References

1) http://www.canyonmaterials.com
2) V. P. Korolkov et al., Application of grays-scale LDW-glass masks for fabrication of high-efficiency DOEs, *Proceedings of the SPIE – The International Society for Optical Engineering*, Vol. 3633, p.129-138 (1999).
3) G. Gal, Method for fabricating microlenses, United States Patent, 5310623.
4) D.A. Buralli and G. M. Morris, Effects of diffraction efficiency on the modulation transfer function of diffractive lenses, *Appl. Opt*. Vol. 31, p.4389 (1992).
5) T. Fujita, H. Nishihara, J. Koyama, Blazed gratings and Fresnel lenses fabricated by electron-beam lithography, *Optics Letters*, Vol. **7**, No. 12, p. 578 (1982).