# Micro actuated grating for multi-beam optical pickups


Chi-Hung Lee[a], Yi Chiu[b], Han-Ping D. Shieh[c]
[a] Department of Photonics & Institute of Electro-optical Engineering,
[b] Department of Electrical and Control Engineering,
[c] Department of Photonics & Display Institute,
National Chiao Tung University, Hsin-Chu 300, Taiwan, R. O. C.



## ABSTRACT

A stress-induced curved \micro actuator with a grating attached at the end is demonstrated for recordable optical storage applications. The actuator and the grating were fabricated using a two-layer poly-silicon and one-layer silicon nitride micro-machining process. Three diffracted beams with equal intensity from the grating were generated when a voltage is applied to the actuator to switch its position. The single-beam and multi-beam configurations can be used for writing and reading data in the disc, respectively.



**Keywords:** binary grating, actuator, micro-machining, optical pickup


## 1. INTRODUCTION

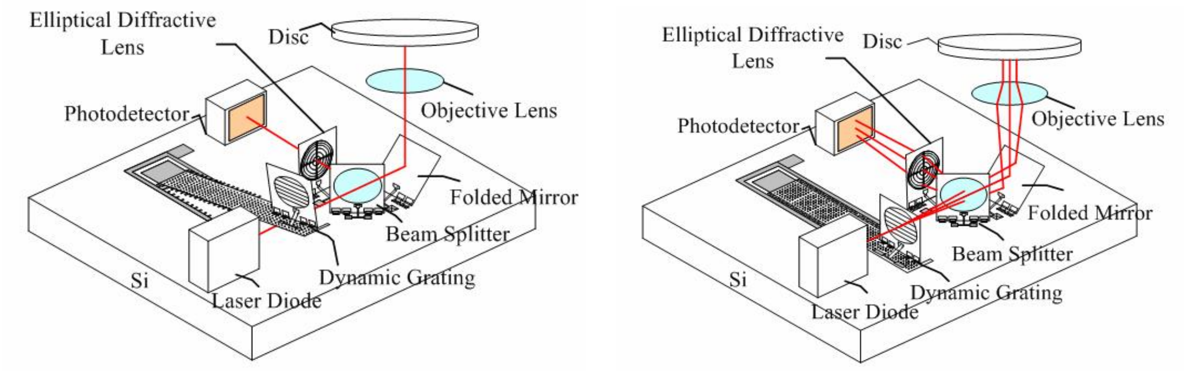
Increasing the data rate in optical storage systems has attracted much research effort, particularly for high definition TV recording which requires a data-transfer rate of more than 100 Mbps. In conventional CD and DVD drives, an optical pickup (OPU) with a single laser beam is used for sequential data retrieving. The data rate is proportional to the rotation speed of the spindle motor. However, the maximum rotation speed is limited by the dynamic characteristics of the objective lens actuator. Using multiple beams in parallel is a straightforward solution to increase the data rate. Several methods have been demonstrated to achieve simultaneous reading of multiple tracks, such as generating multiple beams by using a diffractive optical element [1-2], using a diode laser array[3], or a combination of laser diodes and a beam combiner[4]. Alon et al. proposed a pickup using the diffractive optical element method [1]. A grating was used to split an illumination beam into multiple beams to read several tracks of the optical storage medium. The reading beams can be generated uniformly by a grating; however, they are not suitable for multi-beam recording due to insufficient power in each beam. To overcome the limitation, Shih proposed an optical pickup employing a liquid crystal grating to switch alternatively between single-beam recording and multi-beam reading [5]. The liquid crystal grating, however, is of large size and high cost.

In this paper, we present a micro-silicon-based free-space switchable grating to switch between single-beam recording and multi-beam reading. The switchable grating is composed of a binary phase micro-grating and a bimorph actuator. Low stress silicon nitride is used as the optical material of the binary phase grating for its high transparency in the visible spectrum rang and the superior chemical and mechanical properties. The switching function is achieved using an electrostatic driven stress-induced curved polysilicon.

## 2. DEVICE DESIGN

The free-space integrated micro-optical pickup is based on the surface micromachining technology. As shown in Fig. 1, optical components, including an elliptical diffractive lens, a folded mirror, a polarization beam splitter and a switchable grating, are monolithically integrated on a silicon substrate. The vertical binary phase grating is fabricated on a stress-induced actuator and can be raised above the path of the incident beam for data recording (Fig. 1(a)) and lowered to create multiple beams for data retrieving under variable electro-static force. (Fig. 1(b)).


Optical Data Storage 2007, edited by Bernard Bell, Takeshi Shimano
Proc. of SPIE Vol. 6620, 66200I, (2007) · 0277-786X/07/$18 · doi: 10.1117/12.738632




(a) Single-beam state (b) Multi-beam state

Fig. 1. Schematic of the micro-optical pickup with a switchable grating:(a) single-beam recording and (b) multi-beam reading.

### 2.1 Binary phase micro-grating

A three-beam system is used to demonstrate the proposed pickup. To read data on the disc, three beams with equal intensities in the 0th and the ±1st orders are generated by a grating. The diffraction angle is determined by the optical system layout such as the working distance, the thickness of the cover layer of the disc, and the spacing between the 0th and the ±1st order beams on the disc, as shown in Fig. 2.

To determine the diffraction angle of the first-order beams, we assumed 40-μm spacing between focused spots on the disc. Because the spot spacing is larger than the track pitch, the array of spot would be positioned at an angle from radial direction in practical applications. The micro-pickup is designed to read a DVD-like disc, which has a 100-μm thick cover layer with refractive index of 1.6. If the working distance between the objective lens and the cover layer is 460 μm, under the thin lens approximation for the objective lens, the diffraction angle, $\theta$, is about 4.35°. For a transmissive grating with $\theta$=4.35°, m=1 and $\lambda$=632.8 nm, the period $\Lambda$ is about 8.35 μm, derived from the equation $\Lambda\times\sin\theta=m\times\lambda$. $\Lambda$=8 μm was selected in the design. To reduce the process complexity, a grating with rectangular shape was designed using the commercial software G-Solver.

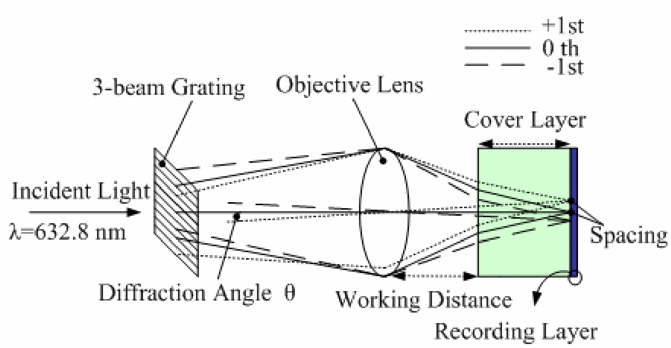



Fig. 2. Optical path of the three beams for reading.

The energy in the diffracted beams $I_0$ and $I_1$of the grating can be determined by the period Λ, the line-width w and the depth of the grating D as follows [6];

$$I_O = [(2f-1)\sin\phi^2 + \cos^2\phi \tag{1}$$

$$I_1 = [2(\frac{\sin m\pi f}{m\pi})\sin\phi]^2$$

where m=1 is the diffracted order and f=w/Λ is the ratio of the line-width to the grating period, and phas shift ψ is related to the depth of the grating D and the refractive index *n* of the grating material by the formula

$$\frac{D(n-1)}{\lambda} = \frac{\phi}{180} \tag{2}$$

where n=2.102+0.008i is the index of refraction of low-stress silicon nitride, the grating material, at λ=632.8 nm.

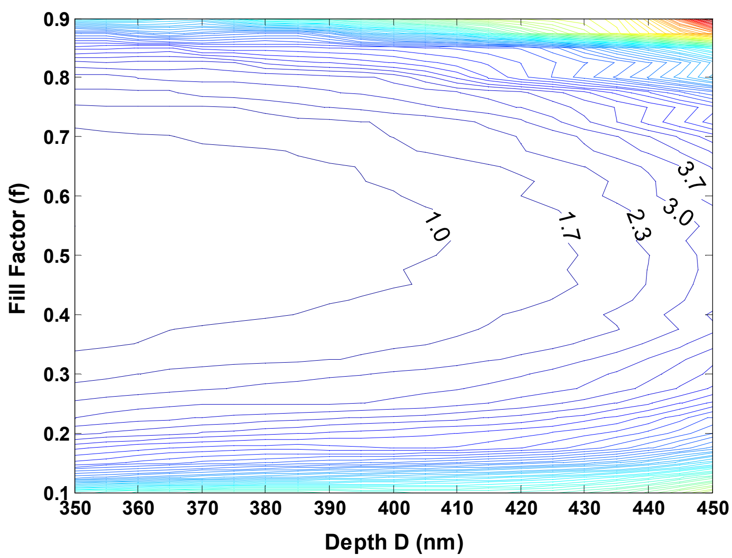



Fig. 3. Diffraction ratio ($I_0/I_{\pm1}$) contours.

The contour plot of the diffraction ratio $I_0/I_{\pm1}$ is shown in Fig. 3 as a function of the fill factor f and the grating depth D. As can be seen, a diffraction ratio $I_0/I_{\pm1}$ of about 1 can be obtained provided that f=0.5 and D=404nm.

**2.2 Bimorph actuator for the switcable grating**

To switch between the state of single beam and the state of multiple beams, the actuation distance in the free end of the bimorph actuator needs to be larger than the illumination range of the incident beam on the optical axis. In a standard electrostatic parallel-plate actuator, actuation distance is determined by the balance between the electrostatic force and the mechanical restoring force. For a linear restoring force, the controllable actuation distance is only one third of the gap between two parallel electrodes [7]. To overcome the limited actuation distance, Rosa *et al*. proposed an external electrode bi-morph actuator to operate over the entire range of motion by preventing electrostatic pull-in instability [8].

However, the fringe effect between the moving and the fixed external electrodes is relatively insufficient to obtain enough actuating force.Accordingly, the bimorph actuator used in this paper is based on the design demonstrated by Chiou et al. [9], which used comb-shape external electrodes and post heat treatment to achieve higher actuation distance under lower voltages.

As illustrated in Fig. 4, the proposed switchable grating consists of a $2000 \times 260$ μm$^2$ bimorph beam anchored to a bonding pad and a binary phase grating attached to the other end using microhinges and microspring latches. Movable comb fingers are connected to the bimorph beams on both sides; fixed comb fingers are connected to the nitride isolation layer on the surface. The engaged length of the comb finger is 180 μm. A Cr-Au stress layer is deposited on the polysilicon layer to curve up the bimorph beam after releasing because the Cr-Au is under tensile residual stress while the polysilicon is under compressive residual stress. To actuate the switch, a voltage is applied between the fixed and movable fingers. The fringing electrostatic field can then pull the curled bimorph beam down toward the substrate.

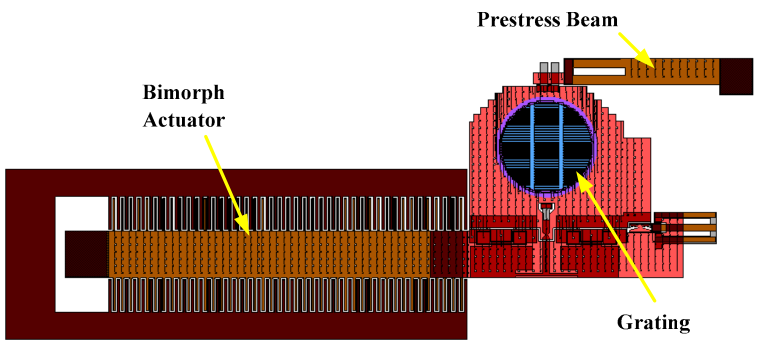



Fig. 4. Layout of the proposed switchable grating mounted at the end of a bimorph actuator. The pre-stress beam is used to assist lifting the released grating during the assembly.

## 3. DEVICE FABRICATION

To fabricate the device, an isolation layer of 0.6 μm thick silicon nitride (SiN) was first deposited. After growing a 2-μm-thick sacrificial silicon dioxide ($SiO_2$), 0.7-μm-deep dimples and 2-μm-deep anchors were then patterned in the sacrificial layer shown in Fig. 5(a). The first structural poly-Si and optical layer $SiN_x$ were then deposited and patterned to form a frame shown in Fig. 5(b). The thickness of $SiN_x$ layers would be further reduced to the target value at the HF releasing step. After growing a 2-μm-thick $SiO_2$ and patterning anchors, the second structural poly-Si layer was deposited and patterned to implement the micro-spring latches and the first layer of cantilever beam. The wafer was annealed for two hours at 1050℃ in nitrogen to reduce the residual film stress. A 140-nm-thick Cr film and a 0.5-μm -thick Au film were deposited on the cantilever to induce the internal stresses shown in Fig. 5(c). Upon releasing in hydrofluoric (HF) vapor at 40 $^{o}$C, the cantilever beam curved upward to lift the micrograting off the substrate. A micro-probe was then used to assemble the micrograting to vertical position.

The SEM micrograph of the switchable grating with a central aperture of 500 μm in diameter is shown in Fig. 6(a). Using the same process, the switchable grating was integrated with other components to form the micro optical pickup shown in Fig. 6(b).

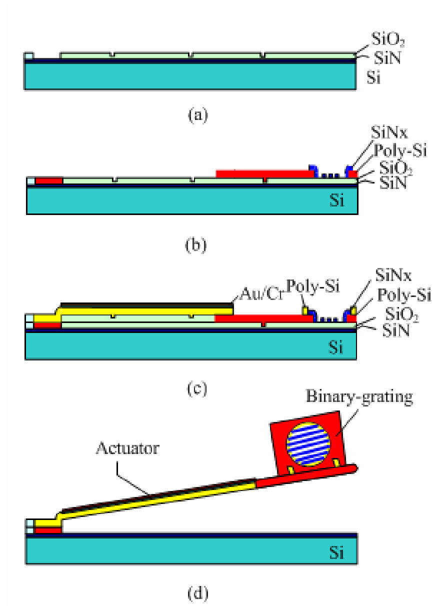
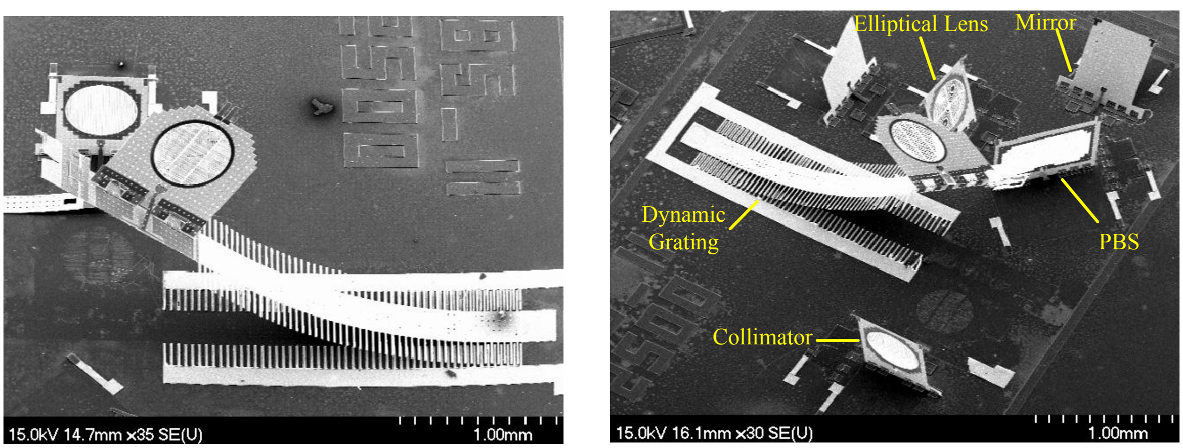



Fig. 5. Process flow for the dynamic grating. (a) The first dimple-etch and anchor-etch after the first silicon dioxide deposition. (b)Low stress silicon nitride patterning after the first poly-silicon deposition and patterning. (c) The Cr/Au films and the second poly-silicon deposition and patterning after the second silicon dioxide deposition and the second anchor-etch. (d) Releasing and assembly.




(a) (b)

Fig. 6. SEM of a (a) dynamic grating and (b) micro optical elements in a optical pickup.

## 4. EXPERIMENTAL RESULTS AND DISCUSSIONS

The static characteristics of the bimorph actuator with a grating were obtained by applying a dc bias driving voltage at the fixed comb fingers. The measured lift height of the free end versus the applied dc bias driving voltage is shown in Fig. 7. Between 24 volts and 64 volts, a steep gradient is observed for the electrostatic force from the comb fingers overwhelming the restoring force of the stress-induced curved beam. After 64 volts, the gradient reduces for most movable comb fingers contacting the substrate.

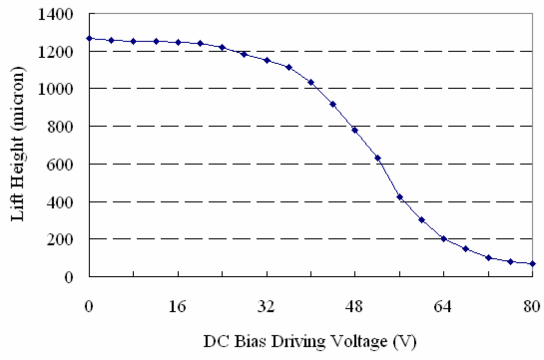
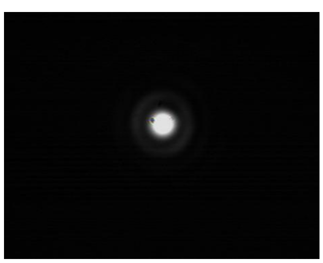



Fig. 7. Static lift heights of the free end versus dc bias driving voltages.

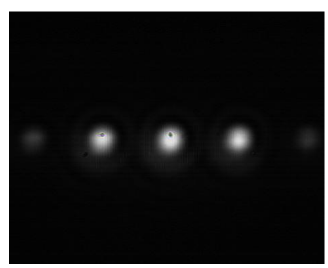
To measure the optical performance of the micro devices, a He-Ne laser at λ=632.8nm was used as the light source. To block the noise from outside of the optical pattern area, an aperture of a diameter 350 μm was used to yield the incident beam size, which is smaller than the grating area of a diameter 500μm. The beam alignment tolerance is 75μm in the measurement. A polarizer was adjusted to obtain the required polarization states. The optical patterns were measured by a CCD camera positioned at 10 mm from the switchable grating.

As shown in Fig. 8 (a), no voltage was applied, so that the incident beam propagated directly for recording use. As shown in Fig. 8(b), an external voltage of 80 volts was applied to have the incident beam pass through the binary phase grating for reading use. For the micro-grating, the measured Gaussian beam widths of the -1st, 0th, and +1st order beams were 271 μm, 293 μm, and 278 μm, respectively, which means the diffraction intensity distribution is symmetric. The measured diffraction angle at far field was 4.51°, which agrees well with the theoretical value of 4.53°. The normalized measured diffraction intensities of the -1st order beam, 0th order beam and the +1st order beam are 0.93,1 and 0.91, respectively. There was 57.1% of the incident power distributed among the three useful orders whereas the calculated efficiency was 67.6%. The deviation from the target value of 1 for each beam was mainly due to the thickness variation, index variation, dimples, the roughness of the sidewall and the surface of the grating. The mean roughness was 5.3 nm in average, which introduced phase variation and affected the energy distribution of the diffracted beams.

The thickness variation and roughness of the silicon nitride film as influenced by film growth and HF releasing can cause phase differences and scattering of the light at the interface. Besides, the thermal stress between the silicon nitride film and the poly-silicon plate distorted the intensity profile of the main beam.



(a)



(b)

Fig. 8. Diffraction patterns (a) before and (b) after applying voltage to the actuator.

## 5. CONCLUSION

Using a two-layer poly-silicon and one-layer low stress silicon nitride surface micromachining process, a dynamic micro-grating composed of a binary phase grating and a bimorph actuator was demonstrated. The optical pattern area of the grating is 500 μm in diameter. The voltage required to switch the grating is 80 volts. The measured diffraction angle is 4.51°. The normalized measured diffraction intensities of the -1st order beam, 0th order beam and the +1st order beam are 0.93,1 and 0.91. The optical performance of the dynamic grating shows its potential for integration with other micro-optical elements for multibeam optical pickups application.


## ACKNOWLEDGEMENTS

This work is supported by the Ministry of Economic Affairs under grant number 95-EC-17-A-07-S1-011.


## REFERENCES


1. A. Alon and J. Finkelstein: World Patent WO 98/37554 (1998)
2. A. Alon and T. Kosoburd, ''Multi-beam optical pickup,'' U.S. Patent. No. 6,411,573 (2002)
3. R. Katayama, K. Yoshihara, Y. Yamanaka, M. Tsunekane, K. Kayanuma, T. Iwanaga, O. Okada, and Y. Ono, ''Multi-beam optical disk drive for high data transfer rate systems,'' Jpn. J. Appl. Phys., Part **1** **31**~2B, 630-634 (1992)
4. H. Okumura, K. Arai, N. Kawamura, H. Tokumaru, and H. Okuda, ''Multi-beam light source using optical waveguide for optical recording,''Proc. SPIE **4090**, 329–334 (2000)
5. Hsi-Fu Shih, "Multiple-beam liquid crystal grating for the recordable optical pickup head," Jpn. J. Appl. Phys., Vol. **44**, No. 4A, 1815–1817 (2005)
6. W.-H. Lee, "High effieicency multiple gratings," Appl. Opt. **18,** (13), 2152-2158 (1979)
7. Chan E K and Dutton R W, "Effects of capacitors, resistors and residual charge on the static and dynamic performance of electrostatically-actuated devices," Proc. SPIE Symposium on the Design and Test of MEMS/MOEMS Devices (Paris) **3680,** 120–130 (1999)
8. Rosa M A, Bruyker D D, Volkel A R, Peeters E and Dunec J, "A novel external electrode configuration for the electrostatic actuation of MEMS based devices," J. Micromech. Microeng. **14,** 446–451(2004)
9. J C Chiou and Y J Lin, "A novel large displacement electrostatic actuator: pre-stress comb-drive actuator," J. Micromech. Microeng. **15**, 1641–1648 (2005)
10. F. P. Beer and E. R. Johnston, *Mechanics of Materials*. 2nd Ed., (McGraw-Hill, NY, 1992)