Torsion angle measurement for a silicon based non-silicon optical micro-mirror

Luo Yuan, Zhang Yi, Xu Xiaodong
Chongqing University of Posts & Telecommunications, Chongqing, CHINA, 400065
E-mail: melouyuan@263.net

Abstract. A micro-mirror is the key structure of a MEMS optical switch or variable optical attenuator. The torsion angle is an essential parameter of micro-mirror. In this paper, the torsion angle of a silicon based non-silicon optical micro-mirror is measured by using hybrid optical and digital image processing technology. The result shows that the measurement scheme works well and the micro-mirror will rotate more than 15 degrees while the driving voltage is 15V.

1. Introduction
Optical switches are becoming a core technology for AON (All-Optical Network) and MEMS optical switches are at the competitive edge because of their compactness, high integration level, and their cheapness can be manufactured in large scale [1][2]. Micro-mirrors are the key structure for most MEMS optical switches or variable optical attenuators. In order to have a switch or attenuation function, a micro-mirror should be moved or rotated by the driving of actuators. So the torsion angle of the micro-mirror is an essential parameter of the micro-mirror because it determines the characteristics of the device. After designing and fabricating a set of silicon based non-silicon torsion micro-mirrors, the torsion angle is measured by using hybrid optical and digital image processing technology. After data processing, the result shows that the measurement scheme works well and the micro-mirror will rotate 15 degrees while the driven voltage is 15V.

2. Structure of a silicon based non-silicon optical torsion micro-mirror
Fig.1 shows the structure of a micromirror for a 2D optical switch.

Figure 1. Schematic of a micromirror for an optical switch
The rotation of the micro-mirror is actuated by an electrostatic force. The relation between the size of the mirror and the voltage can be analyzed by solving the moment equation. The analysis shows that the thickness of the torsion beam plays an essential role in the driving voltage of the micro-mirror [3].

3. Measurement of torsion angle for silicon-based non-silicon micro-mirror optical switch

A silicon based NiCrAu micro-mirror for an optical switch has been designed and fabricated successfully. The released micro-mirror is shown as Fig.2.

![Figure 2. A released NiCrAu micro-mirror](image)

Torsion is the working mode of this kind of micro-mirror. The relation between the torsion angle and the driving voltage must be measured. Schiltges and other researchers have developed an experimental system for torsion measurement as Fig.2 shows. The torsion angle can be tested by the optical system using a He-Ne laser and a photoelectric diode. But the test is difficult and the result is perfect [4].

Because the size of micro-mirror is very small (300nm×200nm), it is very difficult to build an optical coupling measurement system. So, digital image processing is used to assist the test of torsion angle.

3.1. Testing principle of torsion angle by digital image process

The testing principle for torsion angle by using digital image processing is shown as Fig.3.

![Figure 3. Test principle of torsion angle by digital image process](image)

When the mirror-mirror is being driven by electrostatic voltage and rotates a small angle, the length of the micro-mirror will change. By testing the length difference \( \delta \) before and after torsion and using formula 1, the torsion angle can be calculated conveniently.

\[
\theta = \arccos \left( \frac{L - \delta}{L} \right) = \arccos \left( 1 - \frac{\delta}{L} \right)
\]  

(1)

From formula 1, we also know that the accurate value of \( \delta \) and \( L \) is not needed for the test. We can just calculate the torsion angle by knowing the ratio of \( \delta \) and \( L \) that is \( \frac{\delta}{L} \).
3.2. Measurement system and its development
The testing theory looks very simple but we found it is not very easy to have an accurate measurement result because of the blur produced by being out of focus. When the micro-mirror is driven electrostatically, the edge of micro-mirror will move and the image of the edge will become more and more blurred as figure 4 shows. So, digital image processing should be used to eliminate the effect of moving out of focus.

![Figure 4. Blur caused by moving out of focus](image)

In order to eliminate the error caused by blur, a digital image processing program should be used to deal with the images. A digital image processing program based on Matlab is built to collect the images and pick up the edge of the micro-mirror. After that, it can fulfill the pixel count and give the final result of torsion angle. The block diagram of the testing system with both the digital image processing system and the optical system can be shown as figure 5.

![Figure 5. Reading microscope with image collection system of micromirror](image)

![Figure 6. Flow diagram of digital image processing](image)

By using digital image processing, the images have been edge enhanced and it is easy for the computer to find the edge of the mirror and calculate the length change after the mirror rotates. The main arithmetic of the program is a self-adapting smoothing and high-pass filter. And according to the
image of micro-mirror, the micro-mirror image is first rotated and makes the edge of mirror-mirror horizontal or vertical. So the directional filter arithmetic operators such as prewitt or sobel can be used successfully. After that, a threshold will be selected by analyzing the histogram and the image change to a black-white image. By counting the pixel number before and after the rotation three times in a different place for each image, a final result will be gained by averaging. A total process flow diagram is shown as figure 6.

3.3. Result
The test date of torsion experiment is shown as table 1.

| Times | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|-------|----|----|----|----|----|----|----|----|
| Pixel account before rotation | 366 | 366 | 357 | 363 | 363 | 357 | 366 | 360 |
| Pixel account after rotation | 348 | 351 | 342 | 345 | 348 | 342 | 345 | 348 |
| Torsion angle $\theta_i$ | 18.04 | 16.46 | 16.66 | 18.11 | 16.52 | 16.66 | 18.04 | 16.59 |

Data processing

$$\bar{\theta} = \frac{\sum \theta_i}{n} = 17.13^o, \quad \sigma = \sqrt{\frac{\sum \theta_i^2}{n-1} - \left(\frac{\sum \theta_i}{n}\right)^2} = 0.772$$

By using an image processing program, it is clear that the edge of the micro-mirror is easier to find than the initial image. And from table 1, a conclusion can be drawn that the micro-mirror will rotate more than 15 degrees when the driving voltage is 15V. But the coherence is not very good. Also a very important thing must be considered that the characteristics of microcopy and CCD such as magnification, resolving power and aberration will influence the test accuracy. More work should be done to make the test system more effective.

4. Conclusion
After fabricating a silicon-based non-silicon micro-mirror for an optical switch, a testing system has been built. The torsion angle of the micro-mirror has been measured by using hybrid optical and digital image processing system. The result shows that the micro-mirror can rotate more than 15 degrees when the driving voltage is 15V.

Acknowledgement
This research work is supported by item of Chongqing University of Posts & Telecommunications, No.2005-50

References
[1] Ford, Vladimir, Aksyuk, Bishop, Walker, Wavelength Add-Drop Switching Using Tilting Micromirrors, IEEE J. Lightwave Tech. 1999, 17(3), 904~905
[2] S.-S. Lee, L.-S. Huang, C.-J. Kim, and M.C. Wu, Free-space fiber optic switches based on MEMS vertical torsion mirror, Journal of Lightwave Technology, 1999, 17, 7~13
[3] Luo Yuan, Fu Hongqiao, Huang Shanglian, Study on a MEMS silicon-based non-silicon mirror for an optical switch, Chinese Optics Letters, 2003,1(10), 616~618
[4] http://www.springerlink.com/index/7Y166UX7GH4230LN.pdf