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Optik 121 (2010) 843–846

Optik Optics
www.elsevier.de/ijleo

Two-dimensional optical micro-scanner on silicon technology

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Received 17 June 2008; accepted 30 September 2008

Abstract

A two-dimensional optical micro-scanner, which main components are two mobile flat and a concave micro-mirrors, is designed such that, all optical components can be fabricated on the same substratum. The optical parameters, which physical dimensions are between 50 and 500 μm, are obtained within the geometrical optics. The optical performance is evaluated by means of the MTF and Rayleigh resolution criteria, given 80% of modulation for a frequency of 8 cycles/mm with a Gaussian source, the resolution limit is 30 μm.

Keywords: Optical design; Micro-mirrors; Micro-optical systems; Integrated optics; Oslo

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1. Introduction

The optical scanner systems can be found in scientific and industrial applications, such as bar-code reading systems, optical data storage, printers, laser surgery, and displays. Most of these optical scanner systems are composed of mirrors to bend the light, and lenses or curved mirrors for the focusing [1–4].

The MEMS (Micro-Electro-Mechanical-Systems) technology (systems miniaturization) has been involved in other applications, besides the production of integrated electronic and mechanical systems; one of these applications is the design and fabrication of micro-optical systems classified as MOEMS (Micro-Opto-Electro-Mechanical-Systems) [5,6].

We successfully have produced spherical micro-depressions on crystalline silicon through photolithography and humid etching techniques [7,8]. Furthermore, we have designed and simulated electrostatic flat micro-mirrors, to be also fabricated by means of photolithography and superficial micro-machined [9].

Taking as base the disciplines previously mentioned (optical scanner systems and MOEMS), the two-dimensional optical micro-scanner design, which is composed of two mobile flat and a concave conical micro-mirrors, is proposed. Geometrical optics, particularly the optical path way [1–4]; and the simulation optical program OSLO, are used to obtain the optical parameters, and the lateral amplification, Modulation Transfer Function and Rayleigh's resolution criteria of the two dimensional optical micro-scanner system [1,4,10].

The goal is design an optical system that, during the fabrication process, can get all the optical components on the same substratum to avoid misalignment.

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doi:10.1016/j.ijleo.2008.09.048

2. Two-dimensional optical micro-scanner

2.1. General description

A sketch of two-dimensional optical micro-scanner is shown in Fig. 1: The beam light enters through window V_1 at an angle β, and the mirrors E_1, E_2, E_3, and E_4 reflect it up to the window V_2. E_1 and E_3 are mobile flat mirrors [9] of the same dimension with orthogonal rotation axes, which means that the mirrors can be tilted, E_3 on Z axis and E_1 on X axis, respectively.

Mirror E_3 is tilted anticlockwise in such a way that the beam light goes to the far edge of mirror E_4. Thus, $\theta_{\max}$ represents the maximum angle, at which the beam light reaches the concave mirror E_4. Such that, the mirror E_3 scans in the Z direction, while E_1 scans in the X direction.

The total scan angle depends on the following design characteristics (see Fig. 1):

(a) The size of mirror E_4 [7,8].
(b) The separation distance between ground and the mirror E_2, H.
(c) The separation distance between mirrors E_3 and E_4, d.
(d) The mechanical–electrostatic characteristics of the mobile flat mirrors [9].

2.2. Design of the two-dimensional optical micro-scanner

In order to estimate the optical parameters (size of mirrors, separations between surfaces, etc.), a Gaussian beam light of 50 μm, simulated through two astigmatic lenses in OSLO premium edition 6.2 [10,11], is consider to compute the optical characteristics of the two-dimensional optical micro-scanner.

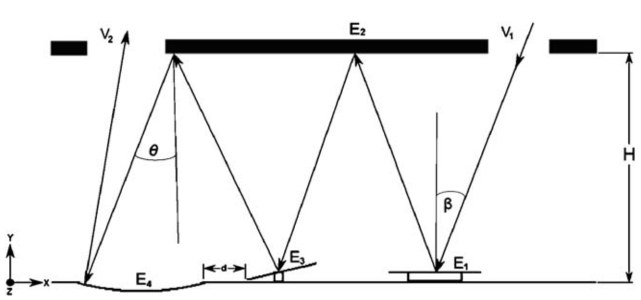

Fig. 1. Sketch of the 2-D micro-scanner's optical system. β entrance angle of light beam, $\theta_{\max}$ maximum angle at which beam light can reach the edge of mirror E_4, E_1 and E_3 mobile flat mirrors, E_2 and E_4, static flat and conical mirrors, respectively; V_1 and V_2 entrance and scan windows, respectively; h separation distance between ground and the mirror E_2; d is the distance between mirrors E_4 and E_3.

The separation distance, H, between the ground and mirror E_2, the movement of micro-mirrors (mechanical–electrostatic characteristics [9]) E_1 and E_3, and size of mirror E_4 are responsible for the scan area and the resolution. Of course, the resolution depends also on the shape of mirror E_4, thus $\theta_{\max}$ was used to compute H.

Fig. 2 shows some of the physical dimensions applied to start the optical design: The larger micro-depression, obtained in our facilities [7,8], was used as the diameter of mirror E_4 that is 500 μm. The separation distance between the static conic mirror E_4 and the mobile flat mirror E_3, d, is 50 μm, which is enough to protect the mirror E_4 during the fabrication process of micro-mirrors [9] E_3 and E_1.

The dimensions of the mobile flat micro-mirrors, E_1 and E_3, are 50 μm large × 40 μm width. The mirrors have a movement of 2.1° and its flatness is enough to bend the light in the visible range [9].

We have found, by using geometrical optics, by means the OSLO$^{\mathrm{TM}}$ Premium Edition program, an acceptable $\theta_{\max}$ of 8.33° (with an angle of entrance beam light $\beta = 7°$), for the conical mirror [7,8], which parameters are given in Table 1. Then the length obtained for H is 1,445 μm. It can be computed the optical pathway through the two-dimensional optical micro-scanner, which is 7225 μm since V_1–V_2, and leads to the lateral magnification of 0.18.

2.3. Optical performance of the two-dimensional micro-scanner optical system

Fig. 3 shows a ray tracing scheme obtained in OSLO, a simulation where a point source is used to illuminate a pair of astigmatic lenses and a collimating lens is placed to obtain a beam [11] of 50 μm, and we apply Gaussian ray tracing to simulate a source with perfect Gaussian mode [10,11]. This source illuminates the two-dimensional micro-scanner optical system with an angle $\beta = 7°$.

The maximum exploration angle, $\theta_{\max}$, is reached when E_1 is static and E_3 has its maximum displacement in the Z axis [9], 2.1°.

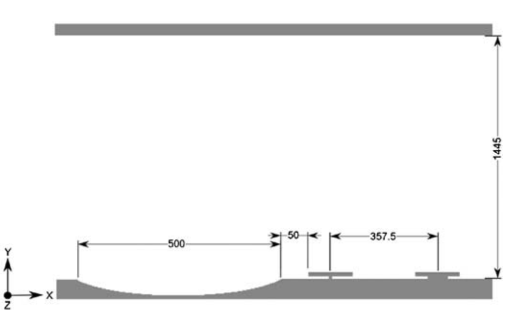

Fig. 2. Physical dimensions of two-dimensional optical micro-scanner, given in microns.

Table 1. Parameters of the mirror E_4: diameter and focal length produced on crystalline silicon, for 10 µm etching technology.

Diameter (µm)	Radii of curvature (µm)	Focal length (µm)	Conic constant
500	2890	1445	−6.5

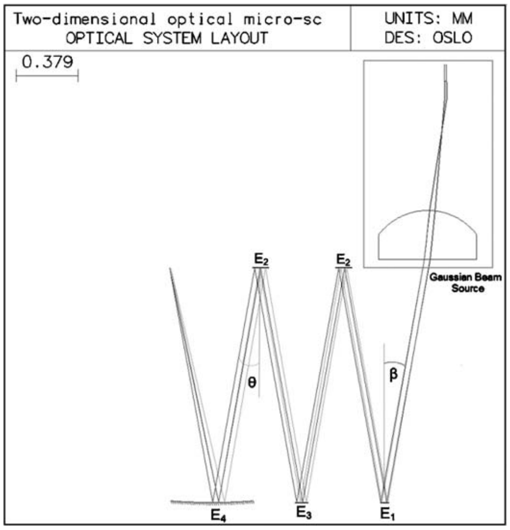

Fig. 3. Scheme obtained by OSLO for the two-dimensional micro-scanner optical system illuminated by a Gaussian beam source.

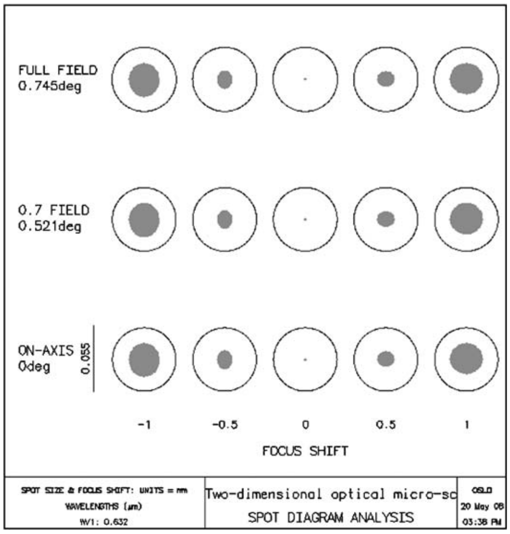

Fig. 4. Spot diagram of two-dimensional micro-scanner optical system when is reached the maximum exploration angle, θ_{max}.

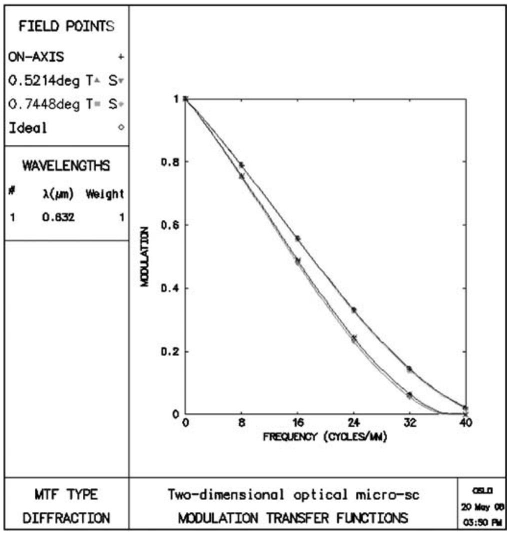

Fig. 5. Pot of the MTF type diffraction generated by OSLO.

Fig. 4 shows a spot diagram generated by OSLO for the two-dimensional micro-scanner optical system. Since it can be observed that the spots are within the Airy disk. The image size is approximately of 7.9 µm.

Fig. 5 shows a plot of the MTF versus frequency, which can be observed that the cutoff frequency, when the MTF is zero [1,4], is 43 cycles/mm. Thus the frequency of resolution limit is approximately [1,4] of 35 cycles/mm. And the image size resolution limit is calculated through the Rayleigh's resolution criteria [1,4]:

$$Z = \frac{0.61\lambda}{NA} \tag{1}$$

For $\lambda = 632\,\text{nm} \Rightarrow Z \approx 30\,\mu\text{m}$.

3. Conclusions

We have showed, using geometrical optics and the OSLO simulation optical software, that a two-dimensional optical micro-scanner can be designed to be fabricated on silicon technology, under the MOEMS concept for the visible spectrum. Taking the characteristics of micro-depressions [7,8] and mobile flat micro-mirrors [9] designed in previous works, the global design proposed includes the fabrication of all its optical components (mirrors) on the same substratum, suppressing misalignment and chromatic aberration.

Based on the applied analysis to the micro-scanner optical system, we find that, although it is an optical system limited by diffraction, it conserves a good resolution in agreement with the MTF curve and the Rayleigh's resolution criteria.

Acknowledgments

This work was partially supported by CONACyT Py. 59890. Gabriela Molar-Velázquez thank to CONACyT for the scholarship #128954. The authors want to thank to Gabriel Sagarzazu for his ideas to the design concept for this two-dimensional micro-scanner optical system, as well to the Dr. Perla C. García F. for her support and professional advice.

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