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Design and experiment of spectrometer based on scanning micro-grating integrating with angle sensor ☆

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HIGHLIGHTS

- A compact, low cost, high speed, non-destructive testing NIR spectrometer is developed.
- Finished many difficult experiments and design a good test environment for MOEMS grating test.
- The results are excellent for the spectrometer based on MOEMS grating device development.
- Designed spectrometer shows advantage and feasibility for miniature spectrometer based on MOEMS device.

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ABSTRACT

A compact, low cost, high speed, non-destructive testing NIR (near infrared) spectrometer optical system based on MOEMS grating device is developed. The MOEMS grating works as the prismatic element and wavelength scanning element in our optical system. The MOEMS grating enables the design of compact grating spectrometers capable of acquiring full spectra using a single detector element. This MOEMS grating is driven by electromagnetic force and integrated with angle sensor which used to monitored deflection angle while the grating working. Comparing with the traditional spectral system, there is a new structure with a single detector and worked at high frequency. With the characteristics of MOEMS grating, the structure of the spectrometer system is proposed. After calculating the parameters of the optical path, ZEMAX optical software is used to simulate the system. According the ZEMAX output file of the 3D model, the prototype is designed by SolidWorks rapidly, fabricated. Designed for a wavelength range between 800 nm and 1500 nm, the spectrometer optical system features a spectral resolution of 16 nm with the volume of 97 mm × 81.7 mm × 81 mm. For the purpose of reduce modulated effect of sinusoidal rotation, spectral intensity of the different wavelength should be compensated by software method in the further. The system satisfies the demand of NIR micro-spectrometer with a single detector.

1. Introductions

Infrared analysis is a powerful tool for measuring purity of materials and composition in solid state, liquid state and gaseity applications [1–3]. However, most conventional near-IR spectrometers are comparatively large, unmovable and expensive and used in the lab only. On account of the advantages of non-destroy testing, fast and convenient, it widely applies in many domains, such as optics examination, biochemistry analysis, industry automatic detection, and astronomy research. In order to realize more compact and in particular cost-effective spectrometers MOEMS technology offers attractive possibilities [4,5].

Presently, the Germany Fraunhofer institute has developed a micro-mirror spectrometer and a micro-electro-mechanical scanning grating spectrometer, they used separate phase sensor to monitor the maximum deflection angle [6,7]. America Polychromix Company pushed out a programmable DTS spectrometer. In general, MOEMS has significant value on science and practical application. However, most of the MOEMS spectrometer does not used the integrated angle sensor to monitor the deflection angle. So, the energy consuming and size of system are enlarged. Therefore, based on fundamental structure of grating spectrometer, a NIR spectrometer with the core component of MOEMS grating is proposed.

In our design, we used the MOEMS grating that integrated with angle sensor for this system, and it can reduce the some necessary parameter (such as the size, cost and energy consuming) and improve the performance of the spectrometer. Furthermore, the angle sensor is not only used to the monitor the grating deflection angle continuously but also used to reconstruct the spectrum and closed

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loop control the deflection status of the grating. Additionally, optical part of this system is designed by ZEMAX and the mechanical part of the system designed by SolidWorks, respectively. It should be noted that we used the model export (ZEMAX) for mechanical part design (SolidWorks), and it improve our working efficiency remarkably.

2. Design of the NIR spectrometer

The NIR spectrometer mainly consists with source, sample accessory, dispersed system and detection system and signal process system. This paper focuses on the design and fabrication of dispersed system. According to the demands of the spectrometer, the optical resolution and the pixel resolution can be calculated by the formulation bellow.

Optical resolution $\delta\lambda$ [8]:

$$\delta\lambda = \frac{a_1 d}{m f_1} \cdot \cos i \cdot \cos\sigma \quad (1)$$

where a_1 is width of the slit, m is spectral order, f_1 is focal length of collimating lens, d is grating constant, i is angle of incidence of grating, σ is diffraction angle of grating.

Pixel resolution $\delta\lambda'$:

$$\delta\lambda' = \frac{dp\cos\varphi}{m f_2} \cdot \cos\sigma \quad (2)$$

where p is center distance of the pixel, f_2 is focal length of imaging lens.

As the result of the calculation, both parameters of the structure and the lens are shown in Tables 1 and 2.

3. Simulation of the NIR spectrometer

The based principle of this optical design is Littrow dispersive structure. Light generated by an infrared source, enters the spectrometer through a narrow entrance slit. A spherical mirror collimates the incident radiation towards the MOEMS grating. For avoiding the monochromatic radiation power too weak and large energy consume, the focus of collimating mirror is 50 mm. There the radiation is reflected to a diffraction grating, which disperses the radiation into its spectral components and different orders of diffraction. The desired part of diffracted light reaches the exit slit via both mirror and collimator, and corresponding to a special deflection angle of the grating surface. Behind the exit slit an Indium Gallium Arsenide (InGaAs) photodiode detector fixed, which convert the monochromatic radiation into electrical signals for processing. A negative-feedback transimpedance configuration circuit is used for amplifying small current signals and converting that to a voltage, while the op-amp maintains the detector near zero-volt bias for lowest noise. After data processing, the spectrum can be measured.

In this design, an electromagnetic force drive scanning micromechanical torsion grating optimized for that application is the central component. The mechanical properties of this micro-component strongly influence the device performance parameters like resolution and accuracy. The electromagnetic drive grating surface together with a large tilt angle affects a high throughput and broad working range compared to other MOEMS devices. The optical structure is shown in Fig. 1(a). We designed this system by ZEMAX and set the wavelength of monochromatic radiation and angle of MOEMS grating as multi-configuration. The wavelength range of this design is 800–1500 nm, the resolution is 10 nm; the grating constant is 250 line/mm; the focus of collimator is 50 mm; the width of input slit is 260 μm. As Fig. 1(b) shows, the output of monochromatic radiation changed simultaneously while angle of MOEMS grating changed.

4. Spectrometer set-up and test

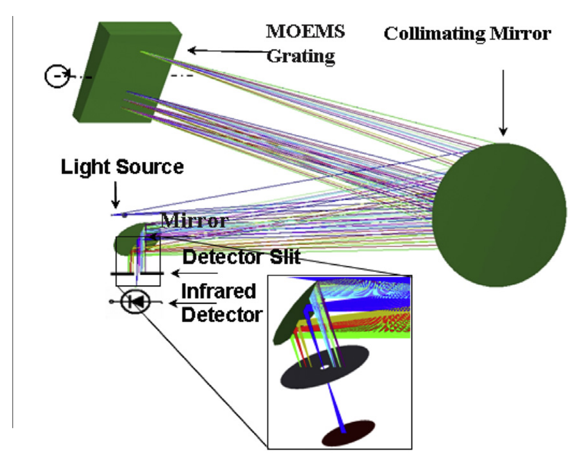
This MOEMS grating spectrometer is manufactured by MOEMS fabrication process and traditional mechanical methods. As Fig. 2 (a) shows, the micro-grating is fabricated by MOEMS fabrication process and packaged by PCB and plastic case. This micro-grating is fabricated by n-(100) type silicon, driven by electromagnetic force. There is an electromagnetic angle sensor integrated with this micro-grating which can be used to detect the deflection angle and

Table 1
Parameter of the structure.

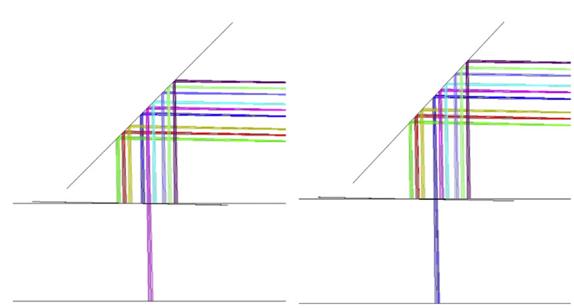
Parameter	Value
Object distance (mm)	50
Operating wavelength (nm)	800–1500
NA	0.1
The type of detector	InGaAs
Input slit (μm)	260
Image distance (mm)	50
Designed wavelength (nm)	1500
The photosensitive area diameter of detector (mm)	1
Grating (lines/mm)	250

Table 2
Parameters of the optical surface.

Surface type	Radius (mm)	Glass
Collimating reflection mirror	50	Bk7 with Al plating
MOEMS grating	Infinity	Silicon/Al



(a) optical structure



(b) wavelength scanning

Fig. 1. 3D layout of the simulation.