Micro Mirror Spectrometer

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1 Introduction

Infrared analysis is a well-established tool for measuring composition and purity of materials in industrial-, medical- and environmental applications. Traditional spectrometers , generally designed for laboratory use are too large and delicate or too costly for a lot of applications. In order to realize more compact and in particular cost-effective spectrometers MOEMS technology offers attractive possibilities. Therefore a micro mirror spectrometer has been developed. A scanning micro mirror is the essential element of this miniaturized basic monochromator set-up. Thereby polychromatic radiation is periodically dispersed into its spectral components and by an infrared detector. By means of rapid prototyping methods the micro mirror spectrometer is manufactured for the spectral range from 2 to 5 µm.

2 Functional Principle

The optical design of the spectrometer module is realized in a simple optical set-up according to a Littrow alignment. A scanning micro mechanical torsion mirror 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 large mirror surface together with a large tilt angle effects a high throughput and broad working range compared to other MEMS devices [1].

The functional principle is shown in Figure 1. After passing the sample transmitted light, generated by an infrared source, enters the spectrometer through a narrow entrance slit. A spherical mirror collimates the incident radiation towards the micro mechanical torsion mirror. There the radiation is reflected to a diffraction grating, which disperses the radiation into its spectral components and different orders of diffraction. According to the wavelength depended reflection angle the desired part of diffracted light reaches the exit slit via both micro mirror and collimator. Behind the exit slit a Mercury Cadmium Zinc Telluride (HgCdZnTe) detector and transimpedance amplifiers are arranged, which convert the monochromatic radiation acquired by the detector into electrical signals for processing.

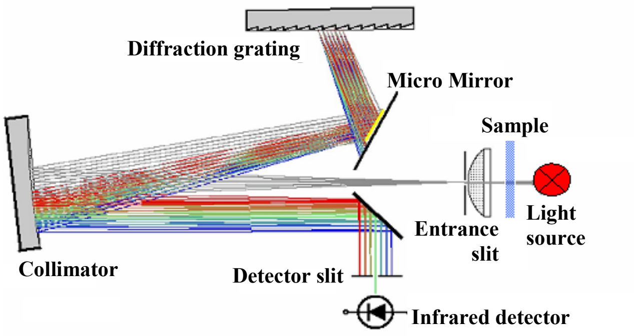

Fig. 1 : Optical diagram of the spectrometer

The wavelength selection depends on the tilt of the torsion mirror, which is driven by an alternating high voltage signal at its resonance frequency of about 270 Hz. During one half period of the mirror one complete spectrum is scanned – thus one basic measurement takes about 2 milliseconds. A position sensor observes the current mirror angle permanently. All preamplified signals from position and radiation sensors are sampled by analog to digital converters simultaneously. Subsequent digital signal processing ensures the elimination of MEMS tilt deviations. All data are preprocessed by embedded computing modules. These modules implement the control of the MEMS device, the analogue to digital conversion, the averaging of raw spectra and the data transfer to a personal computer, which calculates the transmission spectrum of the measured sample.

3. Packaging

The micro mirror spectrometer is manufactured by using rapid prototyping methods. Thereby the construction data are converted into volume data and transferred to a selective laser sintering machine, which builds up the prototype layer by layer from polyamide powder. No specific tools, moulds or any other mechanical processes are required. Post processing except thread cutting is unnecessary, too. This method allows a fast development and flexible design. Almost all electrical, optical and mechanical components can be integrated directly (Figure 2).

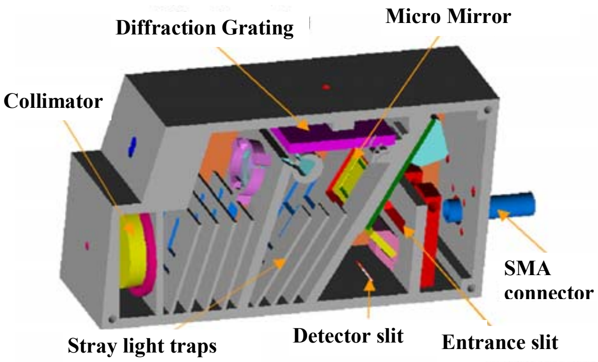

Fig. 2: Monolithic spectrometer set-up

4. Experimental Results

Beside spectral range and spectral resolution, important criteria for the selection of a spectral sensing device are the signal to noise ratio (SNR), signal stability, linearity and wavelength accuracy. The device has been evaluated with respect to these requirements. Both broadband and monochromatic radiation sources were used for characterization. Measurements were performed using conventional monochromators, interference filters and reference samples.

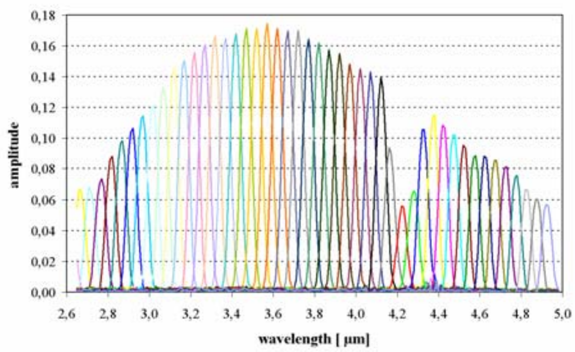

Fig. 3: Wavelength chart by measuring monochromatic light provided by a conventional monochromator

The spectrometer spectral range is determined by the diffraction grating properties as well as the maximum tilt angle of the micro mirror. Sensitivity within this range is determined by the spectral efficiencies of all components including radiation source and detectors. The spectral resolution was determined to be about 32 nm at full width at half maximum (FWHM) for slit widths of 230 µm. Figure 3 illustrates a wavelength chart obtained by measuring monochromatic light provided by a conventional monochromator at several wavelengths. The certain wavelength dependent shapes of peak amplitudes to be observed result from both monochromator output power and spectrometer efficiency. Furthermore it shows no wavelength deviation of the spectrometer signal from the monochromatic input. Basic measurements at spectral resolution of 40 nm yielded a SNR of approx. 35 to 1. It can be improved substantially by averaging to about the square root of the original values. Measuring the wavelength accuracy of a spectral line, a shift less than 1 nm per measurement time was recorded during 5 hours. Furthermore no significant amplitude deviations were obtained.

5. Summary

Micro mirror technology, developed, qualified and first deployed for the communication and laser technology, is also well suited for the realization of miniaturized and truly low priced spectrometers. The functional principle of such spectrometer modules was presented. Further versions of the system for different wavelength ranges, resolutions and instrument performances are in development.

Due to the flexible set-up and its cost-effective realization as well as the fast measuring time, the micro mirror spectrometer offers promising advantages compared to conventional spectrometers with respect to many more application possibilities. Small size and roughness of the device especially allow their application in harsh environments, for instance in process control [2].

6. References

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