

Experimental study of Fourier transform spectrometer based on MEMS micro-mirror

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We propose a new Fourier transform spectrometer based on programmable microelectromechanical systems (MEMS) micro-mirror and an improved Michelson interferometer. The principle of the spectrometer is theoretically analyzed. A signal acquisition unit and an experimental set-up are designed. The spectrum of the polychromatic light source is obtained at a slantwise reflector angle of 0.238° . The spectrum is analyzed by this system within the near infrared. The experimental results show that the spectral accuracy is less than 3 nm, and the signal-to-noise ratio (SNR) is 18 dB. The spectral resolution is less than 16 nm.

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Fourier transform spectrometers are widely applied for trace substance detection in infrared, especially in the mid-infrared range, because of its salient advantages, such as high signal-to-noise ratio (SNR), large luminous flux, wide spectral range, and high resolving capability^[1–6]. In the past years, a variety of miniaturized Fourier transform spectrometers have been presented by various groups^[2,3,7–13]. However, most of these spectrometers are expensive and difficult to produce in real-world applications. To achieve portability, low cost, and fast detection of specific hazardous substances with strong absorption in mid-infrared range, we introduce a miniaturized and inexpensive Fourier transform spectrometer, which has the same measurement range, but inferior resolution compared with the conventional Fourier transform spectrometer.

New miniature Fourier transform spectrometer based on microelectromechanical systems (MEMS) micro-mirror is presented (Fig. 1). A programmable MEMS micro-mirror and an improved Michelson interferometer are used in the system to replace the moving mirror system of the traditional Fourier transform spectrometer. Compared with the traditional Fourier transform spectrometer, this Fourier transform spectrometer is small and shock resistant.

The incident light is collimated onto the improved Michelson interferometer. The beam splitter (BS) sends half of the light to the flat reflector arm and the other half to the slantwise reflector arm. Interference occurs when the reflected lights recombine at the BS. The interference light then passes through the sample and carries the sample information. The programmable MEMS micro-mirror sequentially reflects the interference light with different optical path differences (OPDs) to the single point detector. The programmable MEMS micro-mirror is a kind of optomechanics element. The optical part is composed of aluminized micro-mirrors, which are suitable optical mirrors. The micro-mirror is set on a yoke, and the yoke is linked to a strut by a hinge. Every micro-mirror is driven by the electrostatic force between the micro-mirror and address electrodes. The micro-mirrors are controlled

by the digital driving circuit and independently rotated by $\pm 12^\circ$ from the unpowered position^[6].

During operation, every column of the programmable MEMS micro-mirror sequentially reflects the interference light to the convergence lens. The single point detector sequentially transforms the interference light into electric signals for processing. During the signal processing, the electric signal that corresponds to the interference light is processed by inverse Fourier transform. The spectrum is then obtained.

The optical path at the dip reflector margin (DM) point of the slantwise reflector is equal to the optic path of the flat reflector, as shown in Fig. 1. The inclination angle of the slantwise reflector is θ , which is correlated with spectral resolution and error margin^[3,14]. The DM point of the slantwise reflector corresponds to the rightmost column of the MEMS micro-mirrors. Thus, the OPD between the light reflected by the first column and that by the n th column is shown as

$$x = 2n\tau \tan \theta, \quad (1)$$

where x is the OPD, n is the serial number of columns, and τ is the column width of the micro-mirror. In this

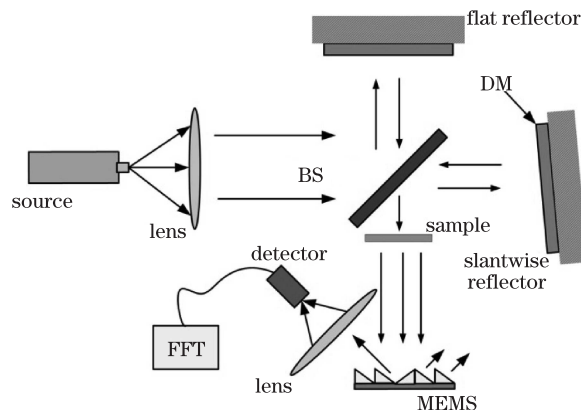


Fig. 1. Block diagram of the spectrometer.

letter, I_0 is the light intensity of the collimated light that

enters into the interferometer. Furthermore, $B_0(\nu) = I_0(\nu) \times H_0(\nu)$, where $H_0(\nu)$ is the error coefficient of the system. The interference light intensity of a column is expressed as

$$I(n) = \int_{v_1}^{v_2} \frac{1}{2m} B_0(\nu) [1 + \cos(4\pi\nu n\tau \tan \theta)] d\nu, \quad (2)$$

where m is the total number of columns of the MEMS micro-mirror, and ν is the wave number. Based on the principle of the Fourier transform spectrometer, the constant part of Eq. (2) is omitted^[2-5]. In this system, the interference light intensity signal is discrete because of switch selection role of the MEMS micro-mirror. Therefore, the spectrum can be calculated by inverse cosine Fourier transform.

$$B_\nu = \sum_0^m I(x_n) \cos(4\pi\nu n\tau \tan \theta), \quad (3)$$

where B_ν is the spectrum intensity with wave number ν . The spectrogram of the whole light bands can be obtained by calculating the spectrum intensity individually.

An experimental system is then established based on the theoretical analysis (Fig. 2). One face of the cube BS is silver coated to form the flat reflector. The optical reflector is mounted on the adjacent arm of the Michelson interferometer set-up at an inclination angle to form the slantwise reflector. No moving element is present, so the Michelson interferometer is compact and shock resistant. Given that the MEMS micro-mirror turns with a space angle, we design a fixed installation to hold the driving circuit board of the MEMS micro-mirror and ensure that the output beam of the interferometer is accurately reflected to the convergence lens by the MEMS micro-mirror. The tested interference pattern is shown in Fig. 3. The spectrum

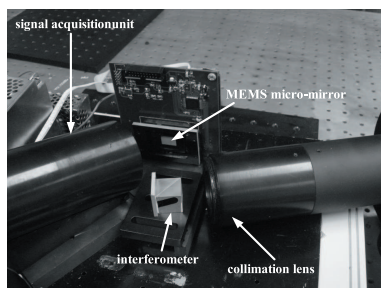


Fig. 2. Experimental system setup.

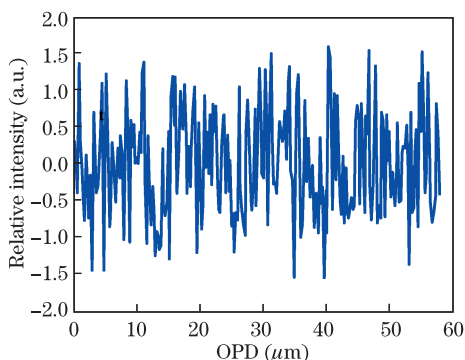


Fig. 3. Interference pattern.

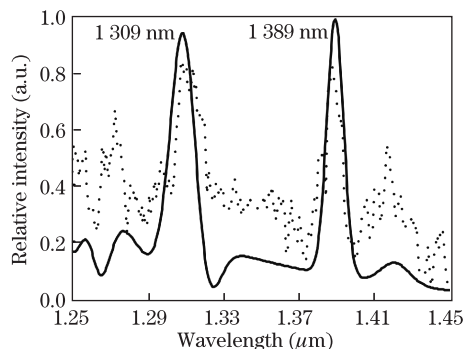


Fig. 4. Spectrum measured by our system.

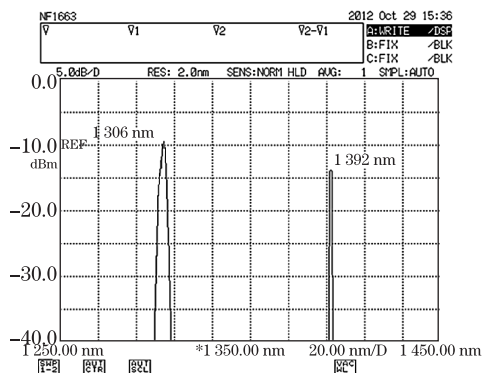


Fig. 5. Spectrum measured by AQ6317B.

of the source measured by our system is shown in Fig. 4. The standard spectrum of the experimental light source is shown in Fig. 5.

The standard spectrum is measured using Ando AQ6317B, which is a high-performance spectrometer with measuring range from 600 to 1750 nm. The inclination angle of the slantwise reflector is 0.238° . The interference data is saved, and the spectrum is obtained using Eq. (3), which is indicated by the broken line in Fig. 4. The emendatory spectrogram shown as the continuous line in Fig. 4 is obtained by calculating the interpolation and fitting. Based on the emendatory spectrogram, the spectral accuracy is less than 3 nm. Based on the spectral line of 1392 nm, the half-bandwidth spectrum resolution is less than 16 nm. The experiment results show that the SNR is 18 dB.

In conclusion, the experimental results demonstrate the feasibility of our system. The practical working spectral range of the system should be changed to mid-infrared region (from 4000 to 1330 cm^{-1}) to detect the functional group of organic matter, such as methane and octane. The spectral range and resolution of the current setup are 21997 and 85.9 cm^{-1} , respectively. We can increase the inclination of the slantwise reflector to enhance the measured spectrum resolution. When the inclination of the slantwise reflector is increased to 1° , the resolution is 20 cm^{-1} and the measurement spectral range decreases to 5235 cm^{-1} , which covers the whole mid-infrared region. Thus, the system can be used for measurements in mid-infrared region. Furthermore, this system has low cost and provides fast detection of most organic matters. This spectrometer is stable and inexpensive compared with the traditional Fourier transform spectrometer because of the absence of movable components.

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