

Dispersive compact Fourier transform spectrometer for the visible.

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ABSTRACT

A dispersive compact Fourier transform spectrometer is realized which operates in the visible wavelength range. No moving parts, no imaging system and compactness are the characteristics of this spectrometer. It is based on a novel beam splitter design, which reduces the influence of the size of the light source and therefore the spatial coherence requirements. The effect of dispersion due to an asymmetric configuration is described. A mathematical correction to get rid of eventual mirror distortion is reported. Finally, some considerations on noise and a method to reduce its influence are presented. A resolution of 3nm was measured at 633nm.

INTRODUCTION

Fourier transform (FT) spectrometers compared to grating spectrometers provide the advantage, that the accessible wavelength range is not limited by higher diffraction orders [1]. Commonly used FT-IR spectrometers with moving parts require a high mechanical precision and provide medium to high resolution, especially in the NIR and IR wavelength range. In this work, we investigate the potential and limitations of miniature FT spectrometers without moving parts for the visible wavelength range for applications requiring moderate resolution (10nm) but a good stray light suppression (better than 20dB, corresponding to less than 1%).

EXPERIMENTAL SET-UP AND DISPERSION

The Fourier transform spectrometer under investigation is a spatially modulated Michelson interferometer as shown in Fig. 1(a).

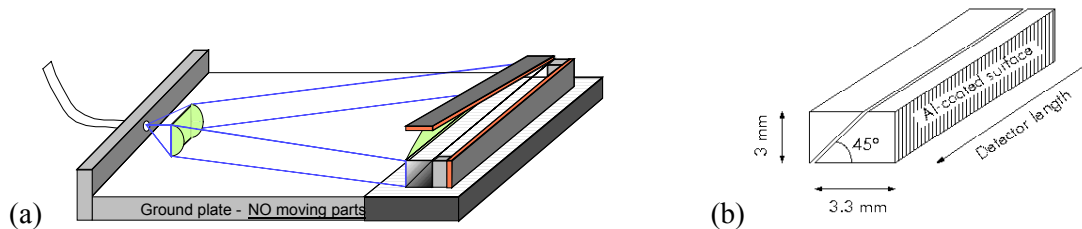


Fig. 1: (a) Drawing of the assembly of the pieces (cylindrical lens, collimating lens, oblong beam splitter and tilt mirror); (b) drawing of the non-conventional beam splitter geometry.

Due to the tilt of the mirror in one branch of the interferometer, the optical path difference varies linearly with the lateral position. Thus an interference is created which is recorded with a 1024 pixel photodiode array. In order to keep the set-up compact, no lens is used to image the mirror plane onto the detector array. A non-conventional configuration of the beam splitting permits to shorten the distance between the mirrors and the detector. Consequently it is possible to use a high numerical aperture non-achromatic collimating lens, as well as a large source size. Combined with the use of a cylindrical lens, we obtain a relatively high throughput spectrometer without deteriorating the visibility of the interferogram. The beam splitter is of elongated construction [Fig. 1(b)] and has a face coated with aluminum, which is used as a reflector. Such a design leads to a simplified assembly of the interferometer since one mirror only has to be adjusted. In addition, due to the light travelling through BK7 (0.3mm) in one branch and through air in the other one, we get a strong dispersion effect.

EXPERIMENTAL RESULTS

In spatially modulated FTS, the resolution is strongly limited by the moderate amount of total sampling points, which corresponds to the number of pixel of the detector array. This fact does not permit to reach a large maximum optical path difference L , which is the only parameter that gives the resolution of a FTS:

$$\delta\sigma = \frac{1}{L} \quad (1)$$

where $\delta\sigma$ is the resolution in wavenumber. Our spectrometer has a resolution which is better than 10nm in the visible and the near infrared wavelength range (350nm - 1000nm). This resolution is reasonable for applications like color measurements.

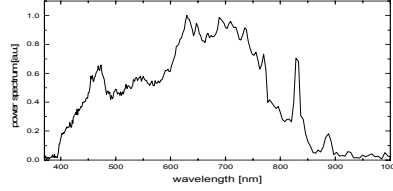


Fig. 2: Measurement of a high-pressure Xenon lamp.

The stray light suppression ability is a critical issue for miniature spectrometers, as well as grating spectrometers. It can be either measured by observing a narrow spectral line (laser) or by measuring the extinction spectrum of a blue-blocking filter. We have measured the extinction of a HeNe line and of a long pass filter GG495. Both measurements show that the stray light suppression is better than 20dB (1%). Contrary to grating spectrometers the amount of stray light is not reduced when the spectral bandwidth of the incoupled light is reduced. This indicates that the origin of stray light is not physical but primarily introduced by the Fourier transform of imperfections caused by dust or impurities on the optical components. Filtering can reduce the influence of these noisy contributions and thus enhance the stray light suppression. We have applied two different way of processing the interferogram. We have measured the inhomogeneities of the white light illumination without interference and taken them into account. The modulations of the inhomogeneities around the mean value of this white light measurement without interference (normalized to 1) allows us to create a proportionality vector which is then multiplied by the recorded interferogram. The second option is an apodization procedure with several types of suitable functions like a triangular function, Happ-Genzel or Blackman-Harris filters [2]. Unfortunately this well-known processing in FTS cannot be applied to a non-symmetric interferogram [Fig. 3(a)] since the center of the interference is not defined. In fact the dispersion effect creates a phase delay for each wavelength contribution; the path difference zero is different for each wavelength. In order to apply apodization, an additional symmetrization step is therefore necessary. We have calculated the phase delay $\Delta\varphi(\lambda)$ generated by 0.3mm of BK7:

$$\Delta\varphi(\lambda) = \frac{2\pi}{\lambda} 2d[n(\lambda) - n_{600nm}] \quad (2)$$

where d is the thickness of BK7 (0.3mm), $n(\lambda)$ is the index of refraction of BK7 in function of the wavelength λ and n_{600nm} is the index corresponding to 600nm that we take as a reference. Then we add it to the perfect phase in the Fourier calculation to obtain the power spectrum $B(\sigma)$ in function of the wavenumber σ ($\sigma=1/\lambda$):

$$B_{\sigma} = \int_{\delta} I_R(\delta) e^{-i2\pi(\sigma\delta + \Delta\varphi)} \quad (3)$$

where δ are the path differences between each neighboring pixel. Figure 3 shows a non-symmetric interferogram before and after the phase correction.

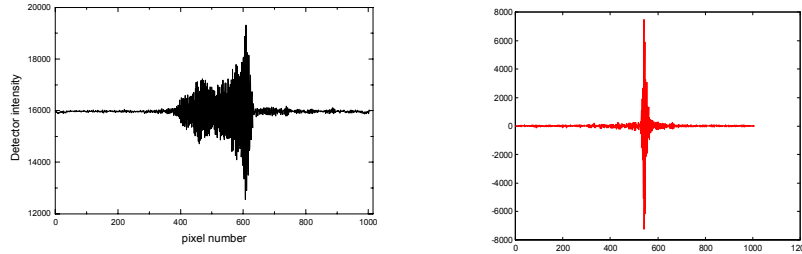


Fig. 3: (a) Non symmetric interferogram converted into a symmetric interferogram (b).

In addition to that, dispersion can be used as a benefit factor for resolution enhancement [3]. This effect will be studied further on.

DISTORTION OF THE TILT MIRROR

The unique assembly step of the spectrometer is the gluing of the tilt mirror. Due to the very compact dimensions of the mirror (1.5mm x 5mm x 38mm), it happens that during curing of the glue the mirror bends. We have measured a deformation of 1 or 2 microns which is large enough to create an important discrepancy in the power spectrum (Fig. 4). To get rid of this distortion we have measured the interference of a HeNe line and then determined the distance difference Δd from the linear shape at each point of the bent mirror. The phase deviance $\Delta\varphi$ is:

$$\Delta\varphi(\lambda) = \frac{2\pi}{\lambda} 2\Delta d \quad (4)$$

where Δd is the path difference coming from the distortion. This phase delay is to be introduced in the Fourier calculation in order to correct the spectrum (see Eq. 3).

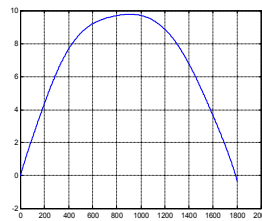


Fig. 4: Measured phase deviance along the tilt mirror (plotted in radians).

CONCLUSION

In this paper we have presented a dispersive spatially modulated FTS based on a Michelson interferometer. A non-standard beam splitting configuration leads to compactness and reduced demands concerning spatial coherence which, combined with a cylindrical lens, enhances the throughput. Measurements have shown that this type of spectrometer is well suited for applications in the visible wavelength range, which do not require a high resolution but need a good stray light suppression. Two methods to reduce the influence of light inhomogeneities are presented. Finally we have suggested a way to correct an eventual distortion of the tilt mirror. Measurements with a photodiode array of 1024 pixel have shown a resolution of 3nm at 633nm and a stray light suppression of 20dB with a GG495 filter.

REFERENCES

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