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Resolution improvement and general study in moving-optical-wedge Fourier transform spectrometer

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ABSTRACT

We propose two modifications to the ordinary moving-optical-wedge interferometer as it works as Fourier transform spectrometer. First we propose new direction of motion of the wedge and the second is of structure of that moving wedge by attaching a mirror to it. We increase the maximum OPD by maximizing the displacement. On the other side we obtain factor (OPD/Displacement) less than two for immunity against motion error fluctuations. Upon using both of the two modifications at the same time we get very high resolution. Typically obtained values are fractions in (1/cm). Actually, we increase the maximum optical path difference to improve resolution. Further, we present a general study of the interferometer regarding: reflection, transmission, and phase difference in the interferometer. We discuss how these parameters affect performance of the system. These parameters degrade the interferometer performance.

1. Introduction

Infrared spectroscopy has a wide range of applications in various fields like chemistry, pharmaceuticals, and biomedicine. Fourier transform spectrometers have the throughput and multiplex advantages when compared to ordinary dispersive type. In this work we are interested in using a wedge based interferometer as a Fourier transform spectrometer (FTS). Actually wedges or prisms are widely used for controlling optical paths in interferometers such as Fabry–Perot Interferometer (FPI) and Michelson Interferometer (MI) e.g. the construction of FPI with prism reflector and prism systems for synchronous control of optical path and spectral selection in its smooth-tunable single-mode (longitudinal mode) generation [1–3]. In [4] a modified MI is proposed which has two identical refractive hexagonal prisms. This configuration enabled the maintenance of very high throughput efficiency. An integrated prism scanning interferometer whose optical paths are stabilized by corner cube is proposed in [5].

In ordinary FTS a Michelson interferometer is used in which a mirror is moved longitudinally to achieve optical path difference (OPD). This motion is susceptible to velocity variations and mechanical disturbances which introduces errors to the computed spectrum. These errors are analyzed in [6–10]. To minimize the effect of these motion errors the moving mirror is replaced by a moving wedge [11–13]. In this configuration the optical path difference is obtained by moving a wedge (right angled prism) of a dielectric material instead of a mirror. This type can be considered as a refractively scanned interferometer. In this configuration the wedge displacement is multiplied by factor of less than two to obtain the OPD. This should be a compared to a factor of two for the moving mirror configuration. Thus for the same motion error in the mirror and the wedge it will be multiplied by two in MI and by a factor less than two in the wedge case, so we get motion error reduction proportional to the optical to mechanical scan ratio which is two for MI and less than two for a wedge scanning interferometer.

Actually such moving-optical-wedge interferometer was previously proposed in [14]. This is a special case of a refractively scanned interferometer where the scan direction of the wedge has the property of maintaining a stationary geometric aperture stop image while changing the optical path difference and thereby maintains a large Haidinger fringe and hence field widening. This interferometer is compensated by virtue of having identical prisms in both arms placed at the same angle to the beam. The aim of such an interferometer was to only widen the field-of-view and getting better throughput. Actually, a beam of light will diverge less if it travels more in a dielectric instead of air. The main difference between the configurations in [11–13] and in [14] is that the latter used only one wedge in the moving arm of the interferometer and the former used two wedges in the moving arm, one of them is fixed and the other is moving. In the reference arm, [14] used a single wedge and in [11–13] used a parallel plate to compensate for dispersion at zero optical path difference (ZPD).

Due to the importance of such a moving-optical-wedge interferometer in [11–13] we previously studied it from different prospects. First in [15] we showed that it is less susceptible to diffraction effects. We

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used a Gaussian beam model to study such an effect. Actually again the divergence of a Gaussian beam will be less as it propagates in the dielectric material of the wedge. The interferometer designs presented in [11–13] will have less divergence in the double wedge material by virtue of refraction, but will not maintain a stationary geometric aperture stop image while changing the optical path difference as a result the Haidinger fringes are not fixed large and hence will show negligible field widening. Second in [16] we analyzed the advantage of suppression of the effects of motion errors mentioned in [11]. We showed that the effects of linear translational vibration will be suppressed and showed the high sensitivity of the wedge interferometer to rotational vibration. Moreover errors due to temperature fluctuations in the wedge material are considered in [16]. Third in [17] we studied refractive index dispersion in the wedge material. We proposed a numerical technique to compensate for such dispersion. Then in [18] we added modifications to the configuration [11]. It should be stressed again that in [11–13] they proposed a moving-optical-wedge interferometers that were comprised of two wedges in one arm (moving arm) and a compensating plate in the other arm (reference arm) and to compensate for dispersion effects at ZPD. In [18] we replaced such a compensating plate in the reference arm by a couple of wedges identical to that in the other arm. In [18] it is shown that such a configuration has advantages of symmetry in visibility pattern, symmetry in interferogram and more throughput.

A major problem in configurations in [11–13] is that the displacement of the moving wedge is multiplied by a factor less than two to obtain OPD. This should be compared to ordinary MI where the displacement of the mirror is multiplied by a factor of two to obtain the OPD. Thus the maximum attainable OPD in the wedge is less than that obtained in the case of moving mirror if we have the same maximum displacement. Thus the attainable resolution by wedge interferometer is poorer than that of moving mirror configuration. This makes a severe problem for the case of design by micro-electro-mechanical systems MEMS technology where we have a limited wedge displacement. To overcome this problem in [18] we proposed moving two wedges separately one in each arm instead of moving only one wedge. The two wedges move consecutively synchronous so one is used for positive OPD and the other for negative OPD. Moreover, our major concerns in this work is how to increase the maximum attainable OPD in such a moving-optical-interferometer and still retaining the same value of the factor relating displacement and OPD which was the major advantage of such an interferometer. So, we try to have reduced the OPD/displacement factor to get motion error suppression and still have longer maximum attainable displacement to increase the max OPD and thus improve resolution.

In this work we propose two modifications to the moving-optical-wedge interferometers presented in [11–13,19]. This paper is organized as follows. Section 2 presents the theoretical analysis of previous and our proposed wedge configurations. Section 3 presents numerical results of analyzing such configurations. Section 4 presents the discussion and Section 5 presents the conclusion.

2. Theoretical analysis

The light intensity measured by a detector after neglecting the DC terms in ordinary MI for different mirror positions is given by

$$I(x) = \int_0^\infty S(\sigma)\cos(2\pi\sigma x)d\sigma \tag{1}$$

where, x is the optical path difference between the two arms of the interferometer that comes from a translating mirror or wedge. Further, S is the spectral density of the light source and σ is the wavenumber i.e. reciprocal of wavelength. $I(x)$ is called the interferogram. Upon applying the Fourier transform to the interferogram we obtain the spectrum as

$$S(\sigma) = FT[I(x)] = \int_{-\infty}^\infty I(x)\exp(-2\pi j\sigma x)dx. \tag{2}$$

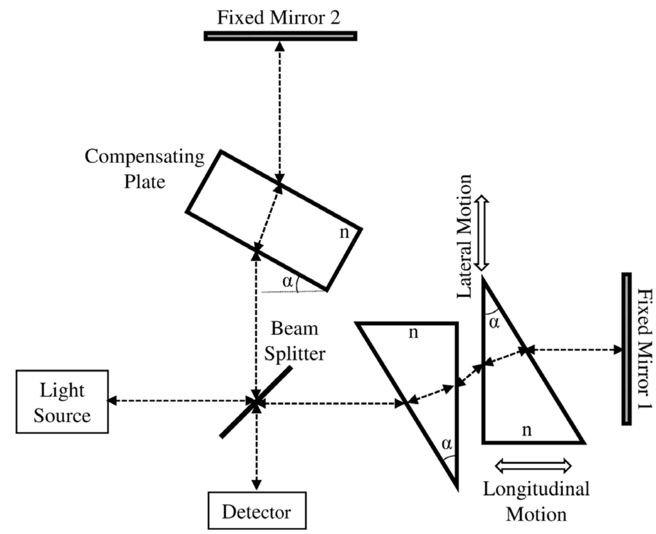

Fig. 1. Ordinary moving-optical-wedge interferometer.

Actually given the finite length of the interferograms, resolution in the spectral wavenumber domain, $\Delta\sigma$ is limited by the maximum OPD as

$$\Delta\sigma = \frac{1}{Max.OPD}. \tag{3}$$

In ordinary mirror based MI OPD, x, is given by

$$OPD = x = F_0 L \tag{4}$$

where $F_0 = 2$. In the following subsections to obtain OPD we will consider moving a dielectric wedge (prism) instead of a mirror and this is what we call the moving-optical-wedge interferometer. Further, we discuss the principles of such interferometers for configurations previously published by others along with our novel modifications to them.

2.1. Previous configurations and first modification

From [14] we present a sketch of the configuration of the moving-optical-wedge interferometer proposed by Bouchareine and Connes. It consists of a beam splitter and two dielectric wedges (right angled prisms). Each wedge is in a separate arm of the interferometer. The back side of each wedge is silvered i.e. coated with a highly reflective coating so this side works as a mirror. One of the wedges is stationary and fixed and the other is moving. The aim of proposing this configuration is getting a wide field-of-view. Further, the motion of the wedge results in the optical path difference OPD. In [14] they proposed motion of wedge in direction normal to the light ray in the wedge so we call it lateral motion. So, as a new modification of this configuration, we propose motion a long the other side of the right angle and call it longitudinal motion. Actually, an extra modification can be considered by moving the wedge along its hypotenuse. This modification although was not considered by authors in [14] it is not new since similar motion is introduced by others as we will see next.

In Fig. 1 we present another configuration proposed in [11].

The interferometer consists of a beam splitter and two fixed mirrors. In one arm there are two wedges one is fixed and the other is moving whose motion results in OPD. The right angle side in both of the wedges is parallel to each other. Since the right angle sides of the wedges meet we call it Back-to-Back (BB) configuration. Finally, in the second arm there exists a tilted parallel plate which compensates for dispersion only at ZPD. The double-arrowed thick lines which surround the moving wedge indicate direction of motion. In [11] they proposed the motion of the wedge along its right angle side i.e. vertical motion. Moreover,