

Description

Title

Fourier-Transform Spectrometer and Method of Operating a Fourier-Transform Spectrometer

State of the art

The invention relates to a device or a method according to the preamble of the independent claims.

Currently, research is being done on the possibility of producing a miniaturized spectrometer, which depending on the application, can record spectrums in the visible range, in the near-infrared range or in the mid-infrared range. Such a spectrometer would be of interest particularly for installation in handheld devices such as smartphones for chemical analysis. The documents WO 2011093794 A1, WO 2015015493 A2 and EP 1882917 B1 describe examples of such spectrometers. An early, non-miniature form of a static Fourier-Transform Spectrometer is proposed by Zhang (Zhang et al., "A static polarization imaging spectrometer based on a Savart polariscope", Optics Communications 203, 2002) in a form of an imaging Savart polariscope, termed as Polarization Imaging Spectrometer (Polarization Imaging Spectrometer, PIS) referred to and improved in subsequent publications on the maximum acceptance angle.

The document US 7719677 B2 describes a Fourier-Transform Spectrometer, which includes a Sagnac interferometer. After passing through the Sagnac interferometer, the light passes through a lens system comprising a converging lens and a cylindrical lens, and subsequently reaches a 2D-sensor array.

Disclosure of the invention

Against this background information, with the approach presented here, a Fourier-Transform Spectrometer, a Method for Operating a Fourier-Transform Spectrometer, furthermore a device, which uses this method, and finally a corresponding computer program according to the main claims are presented. Through the measures stated in the dependent claims, advantageous refinements and improvements of the independent claim device are possible.

A Fourier-Transform Spectrometer with one polariscope unit with at least two birefringent crystals is presented, the Fourier-Transform Spectrometer having the following features:

- a detector unit for detecting light rays; and
- a lens unit arranged between the polariscope unit and the detector unit, comprising at least of one lens element for directing the light rays onto the detector unit; wherein the lens unit has a focal length changeable by means of the lens element to switch the Fourier-Transform Spectrometer between different operation modes.

The terms 'Fourier-Transform Spectrometer', 'Fourier-Transform-Infrared Spectrometer', 'Fourier-Transformation-Infrared Spectrometer' or short 'FTIR Spectrometer' may refer to a miniature spectrometer for infrared spectroscopy. In this case, a spectrum is not determined by direct measurement of the wavelength-dependent radiation intensity, but calculated by a Fourier Transformation of a measured interferogram. A polariscope unit can be understood as a Savart polariscope, also called a Savart element'. For example, the interferogram may be measured by the detector unit. A lens unit may be understood as a lens system comprising one or more lens elements. A lens element, can be understood, for example, as a converging or diverging lens. The lens element may be displaceable within the Fourier-Transform Spectrometer. Depending on the embodiment, the lens element may be a variable focal length lens, such as a liquid crystal lens, a liquid lens or a polymer lens. Alternatively, the lens element may have a fixed focal length. For example, the lens unit may have a focal length changeable by the lens element between at least a first focal length value and a second focal length value in order to switch the Fourier-Transform Spectrometer between at least a first operating mode associated with the first focal length value and a second operating mode associated with the second focal length value.

The approach presented herein is based on the findings that a miniaturized Fourier-Transform Spectrometer can be created using a movable lens system, which can be switched between several operating modes.

5 For example, the static Fourier-Transform Spectrometer may be configured such that an achievable resolution for long wavelengths and a lowest measurable wave length (sampling-theorem) are determined for given components and geometries. On the other hand, the approach presented herein provides a much more flexible spectrometer by using modified image geometry. For example, this can be operated in a first mode, 10 so that it can still measure even with very short wavelengths but has a reduced resolution at long wavelengths. For example, in a second mode, the spectrometer may be operated such that a minimum measurable wavelength is longer than in the first mode but better resolution is achieved in the range of long wavelengths. For example, in a third mode, the spectrometer may additionally be operated to optimize the signal- 15 to-noise ratio.

According to an embodiment, a distance between the detector unit and the lens element may be changeable. This can ensure that the detector unit is always in the focal plane when the focal length of the lens element changes. 20

According to a further embodiment, the lens element may have a changeable focal length. This embodiment enables a simple and precise change in the focal length of the lens unit.

In this case, the lens element may be configured as liquid crystal lens, liquid lens or polymer lens or as a combination of at least two of said lenses. Thereby, the focal length of the lens unit can be changed by using only one lens element.

5 It is also an advantage if the lens element is made of at least two lens parts displaceable relative to each other and each having a polynomial surface, also known as Alvarez or Lohmann lens. Also, with this embodiment, a precise adjustment of the focal length of the lens unit can be ensured at relatively low cost.

10 According to a further embodiment, the lens unit may comprise at least one further lens element for directing the light rays onto the detector unit. The lens element can be arranged between the further lens element and the detector unit. For example, the lens element and the further lens element can be arranged one after another in a common beam path to the detector unit. For example, the further lens element can be a movable
15 lens, as in the case of the lens element, or additionally or alternatively, a variable focal length lens. A multiple deflection or bundling of the light rays can be achieved with this embodiment.

It is advantageous if a distance between the lens element and the further lens element
20 or, additionally or alternatively, a distance between the detector unit and the further lens element is changeable. As a result, the lens unit can be configured, for example, as parfocal or varifocal object lens.

According to another embodiment, the lens element and the further lens element may
25 have different focal lengths from one another. Hence, the focal length can be changed between two fixed values with little effort.

The approach presented herein also provides a Method of Operating a Fourier-Transform Spectrometer according to any one of the preceding embodiments, the method comprising the steps of:

- 5 Changing the focal length of the lens unit by means of the lens element to switch the Fourier-Transform Spectrometer between different operation modes.

According to one embodiment, the method comprises a step of the method of the lens unit and/or the detector unit so that the detector unit is in a focal plane of the lens unit.

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For example, this method may be implemented in software or hardware or in combination of software and hardware, for example, in a control unit.

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The approach presented herein provides also a device, which is configured to implement, to control or to implement the steps of a variant of a method presented herein in corresponding devices. Also, with this embodiment of the invention in the form of a device, the object underlying the invention can be solved quickly and efficiently.

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In this case, the device may have at least one computing unit for processing signals or data, at least one storage unit for storing signals or data, at least one interface to a sensor or an actuator for the reading sensor signals from the sensor or for sending data or control signals to the sensor or actuator and/or at least one communication interface for reading or sending data embedded in a communication protocol. For example, the computing unit may be a signal processor, a microcontroller or the like, wherein the storage unit may be a flash memory, an EPROM or a magnetic storage unit. The communication interface may be configured to read or to send data wirelessly and/or by wire, wherein a communication interface that is able to read or send data by wire, for example, electrically or optically read this data from a corresponding data transmission line or send in a corresponding data transmission line.

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In the present case, a device can be understood as an electrical device, which processes sensor signals and sends control and/or data signals, depending on their type. The device may have an interface, which may be formed in hardware and/or software. In the case of a hardware-based embodiment, the interfaces can be part of a so-called ASIC system, for example, which contains a wide variety of functions of the device. However, it is also possible that the interfaces are separate, integrated circuits

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or at least partially consist of discrete components. In the case of software design, the interfaces may be software modules, which are, for example, present on a microcontroller in addition to other software modules.

5 Embodiments of the invention are illustrated in the drawings and explained in more detail in the following description. Shown are:

Fig. 1 a schematic drawing of a static imaging Savart polariscope according to Zhang;

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Fig. 2 a schematic drawing of a Fourier-Transform Spectrometer according to one embodiment;

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Fig. 3 a schematic drawing of a first operating mode of a Fourier-Transform Spectrometer according to one embodiment;

Fig. 4 a schematic drawing of a second operating mode of a Fourier-Transform Spectrometer according to one embodiment;

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Fig. 5 a schematic drawing of a third operating mode of a Fourier-Transform Spectrometer according to one embodiment;

Fig. 6 a schematic drawing of different positions of lens elements of a lens unit according to one embodiment;

Fig. 7 a schematic drawing of different positions of lens parts of a lens element according to one embodiment;

Fig. 8 a flow chart of a method according to one embodiment; and

Fig. 9 a schematic diagram of a device according to one embodiment.

In the following description of favourable embodiments of the present invention, the same or similar reference numerals are used for the elements of similar meaning and depicted in the various Figures, wherein a repeated description of these elements is omitted.

Fig. 1 shows a schematic drawing of a static, imaging Savart polariscope 100 according Zhang. In this case, a path difference between two rays is generated by means of birefringence. There are no moving elements required to generate the path difference. The light passing through the Savart polariscope is subsequently imaged by a lens 102 onto a detector 104. The image on the detector 104 then shows the object to be imaged including an intensity variation due to the interference. In operation, the polariscope is controlled to move at a known speed over an object to be measured. In the process, an image is continuously taken, from which an associated interferogram can be calculated for each point of the object and subsequently fourier-transformed.

Fig. 2 shows a schematic drawing of a Fourier-Transform Spectrometer 200 according to one exemplary embodiment, hereinafter called spectrometer 200 in short. The spectrometer 200 includes one detector unit 202 for the detection of light rays. One lens unit 204 is arranged opposite of detector unit 202. According to this embodiment, the lens unit 204 is configured as a lens system comprising of a lens element 206 and further lens element 208 arranged between the lens element 206 and the detector unit 202 for directing the light rays towards the detector unit 202. For example, both lens elements 206, 208 have different focal lengths, whereby the further lens element 208 is arranged in a way that can be shifted in relation to the detector unit 202. Hence, by shifting the further lens element 208, the focal length of lens unit 204 can be varied, enabling switching of the spectrometer 200 in different operation modes. In doing this, the position of the detector unit 202 should be adjusted into the new focal plane.

Alternatively, the lens unit 204 has for example only the lens element 206. In this case, the lens element 206 can be configured as a lens with changeable focal length, e.g. as liquid crystal lens, liquid lens or polymer lens. Additionally, the lens element 206 may be arranged to be moveable relative to the detector unit 202. Also in this way, a flexible and precise adjustment of the focal length of the lens unit 204 can be ensured.

By way of example, the spectrometer 200 in Fig. 2 is realised as a micro-spectrometer based on a Savart polariscope with moveable lens system. In this case, a corresponding Savart element 210, also called 'polariscope unit', is connected upstream of the lens unit 204. Between the Savart element 210 and the lens unit 204, an analyser 212 is arranged. A diffuser 214 is connected upstream of the Savart element 210. Between the diffuser 214 and the Savart element 210, a pre-filter 216 and a polariser 218 are arranged, wherein the polariser 218 is arranged between the pre-filter 216 and the Savart element 210. The pre-filter 216, particularly a long-pass-filter, may be placed in any position before the detector unit 202.

Depending on the exemplary embodiment, the Savart element 210 is configured, for example, as follows:

- two birefringent crystals of the same material, the first crystal and the second crystal each having an optical axis of 45 degree to the surface, the major plane of the second crystal being rotated 90 degrees relative to the first crystal;
- two birefringent crystals as above, wherein in the second crystal the optical axis is oriented at a different angle to the surface, but the major plane is still rotated 90 degree to the first crystal;

- two identical birefringent crystals with an achromatic half-wave plate arranged between the crystals, the optical axis being at an angle of 45 degree to the surface and the major planes of the two crystals are parallel to each other;

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- four birefringent crystals, wherein the first two crystals are negatively birefringent and the second two crystals are positively birefringent and apart from that, the crystals are arranged like in the first case.

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Fig. 3 shows a schematic drawing of a first operating mode of a Fourier-Transform Spectrometer 200 according to one exemplary embodiment, for example, a spectrometer as described above in Fig. 2. Shown is an operating mode of the spectrometer 200, wherein the lens element 206 has a short focal length. The detector unit 202 is arranged in a focal plane of the lens element 206. On the right of the detector unit 202, a first interferogram 300 assigned to the first operating mode and recorded by means of the detector unit 202 is shown schematically. According to this embodiment, the lens element 206 is a lens with variable position and focal length. A horizontal distance between the lens element 206 and the detector unit 202 is marked by a double arrow.

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Fig. 4 shows a schematic drawing of a second operating mode of a Fourier-Transform Spectrometer 200 according to one exemplary embodiment. In this case, the lens element 206 has a longer focal length than in Fig. 3. Accordingly, the lens element 206 has a longer horizontal distance from the detector unit 202 than in Fig. 3. On the right next to the detector unit 202, analogous to Fig 3, a second interferogram 400 assigned to the second operating mode and recorded by the detector unit 102 is shown schematically, which represents a magnification of the first interferogram.

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Fig. 5 shows a schematic drawing of a third operating mode of a Fourier-Transform Spectrometer 200 according to one exemplary embodiment. In contrast to both Figures 3 and 4, the lens element 206 has here a focal length lying between the focal lengths of the first and second operating modes. To the right of the detector unit 202, a third interferogram 500 is shown. Shown is the application of the average focal length in a spectrum in which the spectral intensity distribution varies only slowly over the wave lengths, i.e. where no sharp absorption dips or other sharp spectral characteristics are present. At the same time, an edge region of the third interferogram 500 in which the

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interferogram has noises around a constant intensity, does not bring any new information, but only degrades the signal-to-noise ratio of the spectrum obtained by Fourier transformation.

Fig. 6 shows a schematic drawing of different positions of the lens elements 206, 208 of a lens unit 204 according to one exemplary embodiment, for example, a lens unit as described above with reference to Figures 2 to 5. Shown is a schematic of a parfocal lens, in which two lenses in the form of the two lens elements 206, 208 are moved to vary the focal length and at the same time to keep an image on the detector unit 202 in the focus.

Shown are a first position 600, a second position 602 and a third position 604 of the lens unit 204. According to this embodiment, the lens unit 204 includes, in addition to the two lens elements 206, 208, a first auxiliary lens element 606 and a second auxiliary lens element 608, wherein the two lens elements 606, 608 are arranged between the further lens element 208 and the detector unit 202 and the further lens element 208 is arranged between the lens element 206 and the first auxiliary lens element 606. By way of example, the lens element 206 and the two additional sensor elements 606, 608 are formed as bi-convex converging lenses, while the further lens element 208 is formed as bi-concave diverging lens.

In the first position 600, the further lens element 208 is located, for example, centrally between the lens element 206 and the first auxiliary lens element 606. In the second position 602, the further lens element 208 is closer to the lens element 206, so that a distance between the two lens elements 206, 208 is shorter than a distance between the other lens element 208 and the first auxiliary lens element 606. In addition, a distance between the lens element 206 and the detector unit 202 has been slightly increased by shifting the lens element 206 towards the detector unit 202 compared to the first position 600. In the third position 604, the further lens element 208 is closer to the first auxiliary lens element 606, so that now the distance between the two lens elements 206, 208 is longer than the distance between the further lens element 208 and the first additional lens element 606. In addition, the distance between the lens element 206 and the detector unit 202 is slightly reduced by shifting the lens element 206 towards of the detector unit 202 compared to the first position 600.

Fig. 7 shows a schematic drawing of different positions of lens parts 700, 702 of a lens element 206 according to one exemplary embodiment, for example, a lens element 206,

as described above with reference to Figures 2 to 6. According to this embodiment, the lens element 206 is configured as a so-called Alvarez lens that is as a lens comprising of a first lens part 700 and a second lens part 702, wherein the two lens parts 700, 702 each has a polynomial surface. The polynomial surfaces of both lens parts 700, 702 are arranged opposite to each other and, depending on the embodiment, adjacent to each other or spaced from each other. In addition, the two lens parts 700, 702 are laterally displaceable relative to one another. The two lens parts 700, 702 are each shown in a neutral position 704, a position 706 with negative total refractive power or a position 708 with positive refractive power.

In a first configuration 710, light rays pass from left to right within a focal plane. A second configuration 702 represents an internal cubic surface configuration of the lens element 206 [source: Sergio Barbero, "The Alvarez and Lohmann refractive lenses revisited", Opt. Express 17, 9376-9390 (2009)].

Fig. 8 shows a flow chart of a method 800 according to one exemplary embodiment. The method 800 for operating a Fourier-Transform Spectrometer, such as a spectrometer previously described with reference to Figures 2 to 7, includes a step 810, in which the focal length of the lens unit is changed by means of the lens element to switch the Fourier-Transform Spectrometer between the different operation modes. According to one exemplary embodiment, a method of the lens unit and/or of the detector unit takes place in a further step, so that the detector unit is in a focal plane of the lens unit.

Fig. 9 shows a schematic drawing of a device 900 according to one exemplary embodiment. For example, the device 900 may be used to carry out a method as described above with reference to Fig. 8. The device 900 has a modification unit 910, which is designed to change the focal length of the lens unit by controlling the lens element. For this purpose, the modification unit 910 sends a corresponding control signal 912 to the lens element or an actuator coupled to the lens element.

In the following, various exemplary embodiments of the approach presented herein are described again by other words.

Primarily, the approach presented herein uses the fact, that by means of a movable lens system in form of the lens unit 204, a magnification of an interferogram can be variably set to the detector unit 202, for example, a detector (array) of a Savart polariscope. As the dimensions of the detector unit 202 and the size or spacing of the pixels are fixed, a sampling frequency of the interferogram, a maximum imageable phase difference and a portion of the detector unit 202, on which the part of the interferogram is imaged, whose oscillations are still distinguishable from the detector noise, are directly determined by the magnification of the interferogram. As a result, a minimum measurable wave length without aliasing problems (in combination with an optical long-pass pre-filter), an achievable resolution and an achievable signal-to-noise ratio can be determined in the same order.

Therefore, the advantage of the approach presented herein lies in the fact that, depending on the desired measurement scenario, one of the above-mentioned variables can be optimised or a trade-off matched with the measuring situation can be set.

In particular, if the size of the detector is a limiting criterion due to its price, it is advantageous if a broad functionality regarding resolution and smallest measurable wavelength can be realised with a small detector.

5 As shown in Fig. 2, the ray path of the spectrometer 200 may be optionally supplemented by a pre-filter 216, which may be in principle arranged at another position, but before the detector unit 202. The focusing optics is configured by a lens system, comprising of at least two movable lenses in form of the lens element 206, 208.

10 The movable lens system comprising of at least two lenses with fixed focal length can also be considered as an effective movable lens with variable focal length. As shown in Figures 3 and 4, a magnification or elongation or a reduction or compression of the interferogram can be achieved on the detector unit 202.

15 The Savart polariscope assigns each angle of incidence to a certain phase difference between the two split rays. The two collimated ray bundles shown in Figures 3 and 4 (in this case, a ray represents the sum of rays split by the polariscope) thus lead to the same intensity spot on the detector unit 202 due to lens imaging. As the impact point on the detector unit 202 is further outside in case of long focal lengths, an elongation of the interferogram is achieved when using the longer focal length.

20 The interferogram is a continuous function of the angle of incidence, which is scanned by the detector unit 202 at discrete points, i.e. for discrete phase differences. The local sampling frequency is determined by the size or the mutual spacing of the pixels of the detector unit 202. Thus, the sampling frequency of the interferogram is determined by
25 the size of the pixels and the magnification of the interferogram on the detector unit 202. The larger the magnification i.e. the longer the focal length, the closer are the sampling points in the interferogram i.e. the longer is the sampling frequency.

The sampling theorem states that the sampling frequency should be at least as twice as high as the largest frequency component occurring in the signal to be sampled. If this is not the case, so-called aliasing effects are the result, which distort the signal, comparable with the wheel rims of a moving car in a film, which seem to turn backwards. If there are frequency components in the signal to be sampled, which would violate the sampling theorem, they should be filtered out before the sampling.

As short high frequency wavelengths in the interference pattern lead to high frequency oscillations in the case of a Fourier-Transform Spectrometer, light with too short waves should therefore be filtered out by means of a long-pass filter in order to be able to scan the associated interferogram fast enough.

The resolution of a Fourier-Transform Spectrometer at a given wave length λ_0 is approximately $FWHM \approx \frac{\lambda_0^2}{\Delta_{\max}}$, where $\Delta_{\max}$ is the maximum optical path difference recorded in the interferogram. The resolution will worsen for long wavelengths. This is because the resolution is constant only in wave numbers or frequencies, but not in wavelengths. In the Fourier-Transform Spectrometer, apart from the thickness of the birefringent crystal and the refractive index contrast in the birefringent crystal between ordinary and extraordinary rays, the maximum optical path difference is determined by the size of the detector unit 202 in relation to the lens image and the maximum usable angle of incidence. Hence, Figures 3 and 4 show how the choice of focal length affects the shortest scannable wavelength and the resolution.

Thus, a large optical path difference can be imaged on the detector unit 202 for a short focal length, so that a high resolution can be achieved. However, due to the fixed pixel size, the interferogram can be scanned only at a low rate, thereby increasing the shortest scannable wave length. If shorter wavelength components are present in the spectrum to be measured, they should be filtered out by means of an optical pre-filter, since otherwise they can disturb the evaluation massively.

For a large focal length, only a short optical path length difference is imaged on the detector unit 202, so that the resolution is reduced. However, this area of the interferogram can be sampled finer, so that even shorter wavelengths can be

evaluated. Depending on the spectrum to be measured, a long-pass filter with shorter path wavelength may be required for this mode but this can be omitted in cases where no corresponding wavelength components are present in the light to be measured.

5 Of course, there are also useful image modes or focal lengths between these two extremes. For a spectrum to be measured with broader features that is for a spectrum that spans over a wide range of wavelengths, the interferogram outside of the central region drops rapidly to zero. The detected signal strength can then no longer be distinguished from the noise of the detector pixels. A recording or evaluation of the
10 interferogram in a larger range than the nominally non-zero signal then no longer leads to an improvement of the signal, since the signal-to-noise ratio decreases. Hence, a recording as shown in Fig. 5 can be unfavourable. Instead, the interferogram with a slightly longer focal length should be magnified on the detector unit 202 so that the range of resolvable oscillations covers just the entire detector surface. As a result, the
15 maximum signal-to-noise ratio is finely scanned.

The advantages of these different modes may be used variably in a Fourier-Transform Spectrometer if the focal length of the lens can be varied while ensuring that the detector unit 202 is in the focal plane of the lens unit 204. This can be achieved by
20 means of a movable lens system. Such zoom lenses exist in different embodiments, the basic principle of which is that two lenses with the focal lengths f_1 and f_2 and a mutual distance d have a common focal length f according to the equation $1/f = 1/f_1 + 1/f_2 - d/(f_1 \cdot f_2)$ or expressed by the refractive power $\Phi = 1/f$: $\Phi = \Phi_1 + \Phi_2 - d \cdot \Phi_1 \cdot \Phi_2$. The principle of such lens zoom is shown in Fig. 6. The first three lenses 206, 208, 606
25 form a so-called afocal zoom system ('afocal', because a collimated ray in turn leaves the system as a collimated ray). If the central lens 208 is moved, the magnification of the afocal zoom changes. The focal length, called 'effective focal length' in a lens system, changes. The effective focal length is the distance between a focal plane and an intersection of an imaginary elongated edge ray entering from the left side with a
30 corresponding ray focused on the focal plane (both rays are represented by a dotted black line). In addition to the central lens 208 of the zoom system, the first lens 206 is also slightly moved to compensate for the otherwise occurring shift of the focal plane, which can also be referred to as a parfocal lens. This is done either by two separate
35 motors or by a single motor that linearly moves the central lens 208, and a mechanical connection to a corresponding, in general non-linear translation for repositioning the first lens 206. For example, based on the described principle, there are lenses used in

filming, where zooming is required to keep the image sharp. For example, if the preservation of the image sharpness is not critical, only the central lens 208 is shifted. Thereafter, the entire lens system should be adjusted to refocus, which can also be referred to as varifocal lens. For example, with smartphones, such lenses can be moved using oscillation coils. In addition, the movement of the lenses may be realised, for example, by using shape memory alloys, piezomotors or piezo MEMS or MEMS actuators.

As an alternative to a displaceable lens system, single variable focal length lenses may also be used, such as liquid crystal lenses, LCoS-lenses which achieve phase retardation by the birefringent nature of liquid crystals, liquid lens with a liquid membrane whose shape is shaped by an applied voltage and whose surface tension can be changed, or polymer lenses whose form can be changed by an external electrical voltage, such as polymer volume or as membranes. Furthermore, varifocal lenses based on the so-called Alvarez principle, also called Alvarez or Lohmann lenses, can be used, as shown in Fig. 7. Such lens includes two elements 700, 702 with cubic phase retardation, which change their focal length when transversely displaced. In this case, the respective surface of the element is in the form of a third-degree polynomial.

Additionally, an associated long-pass filter may be used for each lens focal length adjustment to ensure that the sampling theorem will not be violated. In a simple embodiment with only two lens settings, this is done for example by means of manually sliding a filter cap in front of a Savart element. For multiple lens settings, the filter can also be realised as filter wheel. Alternatively, a tunable long-pass filter can be used.

According to a further embodiment, the lens system is not tunable, but has two or more separate lenses with different focal lengths, which map to two or more different detectors at different distances. In this case, a corresponding pre-filter should be used for each imaging path.

If an exemplary embodiment includes a "and/or" conjunction between a first feature and a second feature, it should be read that the embodiment according to one embodiment has the first feature as well as the second feature and according to another embodiment either only the first feature or only the second feature.

Claims

- 5
1. Fourier-Transform Spectrometer (200) with a polariscope unit (210),
comprising at least two birefringent crystals, wherein the Fourier-Transform
Spectrometer (200) having the following features:

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 - a detector unit (202) for detecting light rays; and
 - a lens unit (204), arranged between the polariscope unit (210) and the
detector unit (202), comprising at least one lens element (206) for directing
the light rays onto the detector unit (202), wherein the lens unit (204) has a
15 focal length changeable by means of the lens element (206) to switch the
Fourier-Transform Spectrometer (200) between different operation modes.
 2. Fourier-Transform Spectrometer (200) according to claim 1, where the
distance between the detector unit (202) and the lens element (206) is
20 changeable.
 3. Fourier-Transform Spectrometer (200) according to one of the preceding
claims, where the lens element (206) has a changeable focal length.
 - 25 4. Fourier-Transform Spectrometer (200) according to one of the preceding
claims, where the lens element (206) comprises liquid crystal lens and/or liquid
lens and/or polymer lens.
 - 30 5. Fourier-Transform Spectrometer (200) according to one of the preceding
claims, where the lens element (206) comprises at least two lens parts
displaceable relative to each other and each having a polynomial surface (700,
702).
 - 35 6. Fourier-Transform Spectrometer (200) according to one of the preceding
claims, where the lens unit (204) consists at least one further lens element

(208) for directing the light rays onto the detector unit (202), wherein the lens element (206) is arranged between the further lens element (208) and the detector unit (202).

- 5 7. Fourier-Transform Spectrometer (200) according to claim 6, where a distance between the lens element (206) and the further lens element (208) and/or between the detector unit (202) and the further lens element (208) is changeable.
- 10 8. Fourier-Transform Spectrometer (200) according to claim 6 or 7, where the lens element (206) and the further lens element (208) have focal lengths different from each other.
- 15 9. Method (800) for operation of a Fourier-Transform Spectrometer (200) according to one of the claims 1 to 8, wherein the method (800) comprises the following step:
- 20 changing (810) the focal length of the lens unit (204) by means of the lens element (206) to switch the Fourier-Transform Spectrometer (200) between different operation modes.
- 25 10. Method (800) according to claim 9, with a step of the method of the lens unit (204) and/or the detector unit (202), so that the detector unit (202) is placed in a focal plane of the lens unit (204).
11. Device (900) with a unit (910), being configured to execute and/or control the method (800) according to claim 9 or 10.