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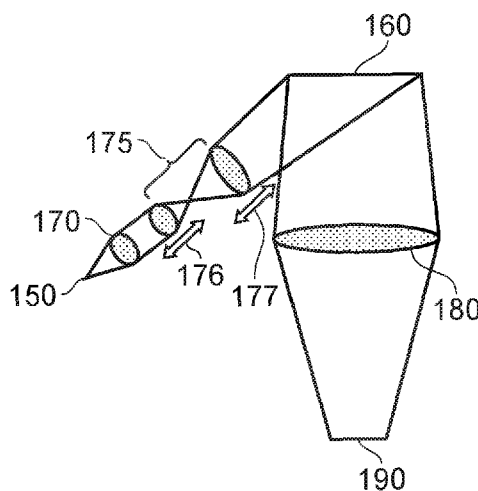


FIG. 5(a)

(57) Abstract: This invention concerns a spectroscopic apparatus comprising an optical input (150, 250), a dispersive device (160, 260) arranged to disperse light in a spectral direction across a detector (190, 290), an input lens (170, 172, 270) between the optical input (150, 250) and the dispersive device (160, 260) for collimating the light and a detector lens (180, 280) between the dispersive device (160, 260) and the detector (190, 290) for focusing the dispersed light onto the detector (190, 290). The apparatus may further comprise a positioner (165) for rotating the dispersive device (160) relative to the incoming optical axis to change the angle of incidence of the dispersive device (160) thereby adjusting the resulting spectral region dispersed across the detector (190), an input magnification adjuster (175) for adjusting the magnification of the light onto the dispersive device (160) and a controller arranged to adapt the input magnification adjuster (175) in response to the angle of incidence of the dispersive device. The apparatus may further comprise a beam splitter (300), between the optical input (270) and the dispersive device (260), the beam splitter (300) being arranged to split the light into a plurality of separate optical paths (320, 330) each path (320, 330) being directed to the dispersive device (260) to provide separate partial spectra across portions of the detector (290) and at least one magnification adjuster (275) in one of the plurality of separate optical paths (330) between the beam splitter (300) and the dispersive device (260) to optimise the beam diameter of the optical path (330) at the dispersive device (260).

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## SPECTROSCOPIC APPARATUS

### Field of Invention

The present invention relates to spectroscopy and more particularly to the control  
5 of resolution in a spectroscopic apparatus.

### Background

Spectroscopy is the study of the interaction of electromagnetic radiation, such as  
light, with matter. Light may interact with matter by reflection, transmission,  
10 absorption and scattering. One particular type of interaction is Raman scattering  
which occurs when light interacts with molecular vibrations. When a  
monochromatic light source, such as a laser, is used to illuminate a sample most of  
the resulting scattered light will be unchanged in energy (Raleigh Scattering); a very  
small proportion of the scattered light will be subject to Raman Scattering in which  
15 energy is either lost or gained during interaction with the molecules of the sample.  
The change in energy alters the frequency of the scattered light such that a spectrum  
may be detected (for example plotting the intensity of the scattered light for each  
energy/frequency). The spectra can be used to identify the material and properties  
of the material such as stresses, variations in crystallinity and amount of the  
20 material, which may for example be used to analyse the homogeneity of the  
material.

The present invention is specifically concerned with Raman Scattering and will be  
described herein in the context of Raman Spectroscopy. The skilled person will,  
25 however, appreciate that the invention may also have applications in other forms of  
Spectroscopy, particularly transmission or backscattered spectroscopy.

A typical commercially available Raman Spectrometer (for example of the type  
commercially available in the Applicants' "Renishaw inVia" range) is shown  
30 schematically in figure 1. The spectrometer 1 includes an entrance arrangement  
having an entrance slit 50 with an associated focus lens 52 for focusing the beam

onto the slit. Such an arrangement is generally disclosed, for example, in the applicants' earlier European Patent Application EP 0 543 578 and it will be appreciated that the slit confers one dimensional confocality to the scattered light. A known alternative arrangement to the slit may be an input of a fixed width, for example from the end of an optical fibre in a "fibre coupled spectrometer". The Spectrometer as shown in figure 1 comprises: at least one source 20 of monochromatic light, this is typically in the form of a single or multiple laser. An objective lens arrangement 30, which may be provided as part of an optical microscope, is provided for focusing light upon the sample 10 and for collecting the resultant scattered light from the sample. A filter 40 is provided for rejecting Raleigh scattered light. The filter 40 may also be a reflector for the incoming light. For example, the filter 40 may be a holographic Bragg diffraction filter. A dispersive device 60, such as a diffraction grating (or alternatively a prism), is provided for splitting the light into its constituent wavelengths/colours. A spectrometer input lens 70 (an "input lens") is provided to collimate the light from the entrance slit 50 (or optical fibre) collimating it onto the dispersive device 60. The output from the analyser 60, is focused by a spectrometer output lens 80 (a "detector lens") onto a detector 90 which is generally a CCD (and may be thermoelectrically cooled). A computer 95 is provided to collect, store and analyse the data recorded by the detector 90.

Whilst commercially available spectroscopic equipment is highly effective it is always desirable to provide improved resolution. Additionally, in some applications it is desirable to utilise fibre coupled equipment for providing the light source and the objective lens arrangement. When using a fibre coupled arrangement there may be less flexibility in controlling the input than when using an entrance slit. Accordingly, other means for optimising the apparatus may be desirable. Further, it is desirable to ensure that the resolution of a spectroscopic apparatus is optimised for a variety of grating centre wavelengths (which correspond to a variety of grating angles). Embodiments of the present invention may provide an improved spectroscopic apparatus which addresses one or more of these problems.

**Summary of Invention**

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Accordingly, in an aspect of the invention there is provided a spectroscopic apparatus comprising:

an optical input ;

10 a dispersive device arranged to disperse light in a spectral direction across a detector;

a positioner for rotating the dispersive device relative to the incoming optical axis to change the angle of incidence of the dispersive device thereby adjusting the resulting spectral region dispersed across the detector;

15 an input lens between the optical input and the dispersive device for collimating the light onto the dispersive device; and

a detector lens between the dispersive device and the detector for focusing the dispersed light onto the detector; wherein the apparatus further comprises:

an input magnification adjustor for adjusting the beam size of the light onto the dispersive device and

20 a controller arranged to adapt the input magnification adjuster in response to the angle of incidence of the dispersive device.

It will be appreciated that references herein to a “lens” or “optic” may refer to single lenses/optical elements or to groups of lenses/optical elements which are configured  
25 for a specific purpose. For example, in some embodiments of the invention the input lens and the anamorphic optic may be combined in a single optical element or optical group.

In some embodiments the magnification adjuster comprises a zoom lens (and may  
30 for example be a parfocal lens). Advantageously, a zoom lens allows for optimisation which is balanced across the Raman spectrum. The zoom lens may comprise at least two movable lens elements. For example, a first element may be moveable to adjust the magnification of the zoom lens and the second moveable

element may adjust the focus in response to the change in magnification. At least one drive may be provided for positioning the movable lens elements. When a single drive is utilised, a cam or other mechanical linkage may be provided to move multiple moveable elements relative to one another. In other embodiments each moveable element may be provided with a dedicated drive (which may for example provide a more adaptable configuration). The, or each, drive may for example be a servo motor.

As an alternative to adjusting the magnification by means of a variable lens such as a zoom lens, the magnification adjuster may comprise an optic substitution system. For example, the apparatus may comprise a plurality of lenses, each lens having a different focal length. A mechanism may be provided for exchanging the lenses into the optical path. It will be appreciated that such an optical substitution system may in some embodiments be configured to physically move optical components into and out of a fixed optical path. Alternatively, an optical substitution system may divert the optical path through different optical components in different configurations.

In some embodiments the magnification adjuster may be combined with the input lens. For example, an optical substitution system may exchange the input lens for a lens of different focal length. Alternatively, a fixed input lens may be provided, and the magnification adjuster may be a separate optical element or group.

The controller may be configured to use the magnification adjuster to maintain resolution across the spectral range. For example, the controller may be configured to store a series of magnification adjustor configurations for a corresponding series of dispersive device positions.

The magnification adjuster may be adapted to maximise the width of the dispersion device onto which incoming light is projected for each angle of incidence. The or each magnification adjustor configuration may be set to maximise the width of the

dispersive device utilised by the spectroscopic apparatus.

Additionally or alternatively, the magnification adjuster may be adapted to prevent overfilling of the dispersion device for each angle of incidence.

5

The magnification adjuster may adjust the magnification by changing the beam diameter. The adjuster may alter the beam diameter in a non-uniform manner. For example, the beam may be altered primarily in one axis. Thus, the magnification adjuster may be an anamorphic optic. An “anamorphic optic” as used herein may  
10 be understood to mean an optical element which primarily adjusts the magnification in one dimension (and may for example include an optic which only adjusts the magnification in one dimension or an optic which adjusts the magnification in one dimension by a greater amount than in the other dimension).

15 For example, the anamorphic optic may adjust the height of the light but not the width. The anamorphic optic may, thus be used to prevent overfilling of the dispersive device in one axis whilst not altering (or minimally altering) the magnification in the other axis. Thus, light loss can be avoided without adversely impacting resolution. The anamorphic optic may be a lens or a prism. For example,  
20 the anamorphic lens may for example comprise one or more cylindrical lenses. Alternatively, the anamorphic optic may comprise a prism or prism pair. If a single prism is used it may further influence the dispersion of the final spectrum.

In a further aspect of the invention, there is provided a spectroscopic apparatus  
25 comprising:

- an optical input;

- a dispersive device arranged to disperse light in a spectral direction across a detector;

- a beam splitter, between the optical input and the dispersive device, the  
30 beam splitter being arranged to split the light into a plurality of separate optical paths each path being directed to the dispersive device to provide separate partial

spectra across portions of the detector;

an input lens between the optical input and the beam splitter for collimating the light via the beam splitter to the dispersive device; and

a detector lens between the dispersive device and the detector for focusing  
5 the dispersed light onto the detector; wherein the apparatus further comprises:  
at least one magnification adjuster in one of the plurality of separate optical paths  
between the beam splitter and the dispersive device to optimise the beam diameter  
of the optical path.

The beam splitter may be a dichroic filter. The beam splitter may split the beam  
10 spectroscopically to maximise the amount of light in each partial spectra at the  
detector. Whilst the beam splitter may utilise the plurality of separate optical  
paths concurrently, it will also be appreciated that in some arrangements the  
“beam splitter” may alternatively act sequentially. For example, the beam splitter  
may comprise a moveable mirror for directing the light to a selected one of the  
15 plurality of separate optical paths.

The spectroscopic apparatus of an embodiment comprises a plurality of  
magnification adjusters each located in one of a plurality of separate optical paths.

20 As each optical path is arranged to have a different angle of incidence at the  
dispersive device, the scattered light in each path may not utilise the full width of  
the dispersive device. Accordingly, embodiments of the invention may utilise a  
magnification adjuster in at least one of a plurality of optical paths to optimise the  
width of the scattered light at the dispersive device for said optical path. The at  
25 least one magnification adjuster may balance the resolution across each partial  
spectra. In this context it may be understood that “balancing” may refer to ensuring  
that the resolution of each optical path, and therefore each partial spectra, is  
approximately equal. In some arrangements the balancing may be arranged to  
utilise the full available resolution of the spectroscopy apparatus in each optical  
30 path.

The at least one magnification adjuster balances the width of the associated optical path at the dispersion device. The, or each, magnification adjuster may for example be configured to ensure that its optical path utilises the full width of the dispersive device. Additionally or alternatively, the at least one magnification adjuster is adapted to prevent overfilling of the dispersion device by the associated optical path.

The dispersive device may be a diffractive device, for example a diffractive grating.

10 The optical input may comprise a coupling for receiving an optical fibre. Embodiments of the invention may be particularly useful for use in fibre optically coupled spectroscopic apparatus. In particular, in a fibre optically coupled spectroscopic apparatus there may be less direct control over the input since the input size and numerical aperture (which it may be appreciated defines the beam size for a given focal length) may be primarily defined by the fibre coupling rather than an adjustable entrance slit.

In use the optical input may receive scattered light from a sample illuminated with a source of monochromatic light. Accordingly the light may be scattered light. The scattered light may comprise Raman scattered light. The spectroscopic device may be a Raman spectroscopy device.

The detector may comprise a photo-detector, for example a two-dimensional photo detector. The detector may be a CCD, for example a two-dimensional CCD.

25

It is known to provide a spectroscopic apparatus in which the scattered light is passed through a beam splitter and directed to separate optical paths (sometimes referred to as “arms” of the spectroscopic apparatus). Such an arrangement is, for example, shown in the applicant’s earlier United States Patent US 5,638,173.

30

According to another aspect of the invention, there is provided a spectroscopic

apparatus comprising:

an optical input which, in use, receives scattered light from a sample illuminated with a source of monochromatic light;

5 a dispersive device arranged to disperse light in a spectral direction across a detector;

an input lens between the optical input and the dispersive device for collimating the scattered light onto the dispersive device; and

a detector lens between the dispersive device and the detector for focusing the dispersed light onto the detector;

10 wherein the apparatus further comprises an anamorphic optic for adjusting the magnification of the scattered light onto the dispersive device in a single dimension.

In arrangements having separate optical paths each optical path (or arm) may be directed to the dispersive device at a different angle of incidence. Thus, in some  
15 embodiments an anamorphic optic in accordance with an embodiment of the invention may be provided in one or more of the separate optical paths. Thus, a spectroscopic apparatus according to some embodiments of the invention may comprise: a beam splitter, between the optical input and the dispersive device, the beam splitter being arranged to split the scattered light into separate optical paths  
20 each path being directed to the dispersive device to provide separate partial spectra across portions of the detector. The anamorphic optic may be provided in at least one of said separate optical paths, between the beam splitter and the dispersive device, the anamorphic lens adjusting the beam dimensions in said optical path. In some embodiments each optical path may comprise an anamorphic optic. However,  
25 it may be appreciated that the angle of the optical path and the configuration of the apparatus may mean that at least one path does not require an anamorphic optic (for example, where a spectroscopic apparatus has  $n$  optical paths  $n-1$  optical paths may be provided with anamorphic optics to adjust the magnification in those paths).

30 Advantageously, the anamorphic optic may be arranged to allow variable adjustment of the magnification of the scattered light onto the dispersive device.

This variable adjustment may occur in situ within the spectroscopic apparatus. For example, embodiments of the invention may be configured to allow the magnification at the dispersive device to be varied without any adjustment of the overall configuration of the spectroscopic apparatus. This may be particularly  
5 useful in spectroscopic apparatus in which the angle of the dispersive device is adjusted to change the spectral area which is to be directed to the detector. Thus, in some embodiments a spectroscopic apparatus may comprise a positioner for setting the angle of incidence of the dispersive device relative to the input lens optical axis. The spectroscopic apparatus may further comprise a controller for  
10 adjusting the anamorphic lens in response to the angle of incidence.

Whilst the invention has been described above, it extends to any inventive combination of the features set out above or in the following description or drawings.

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### **Description of the Drawings**

Embodiments of the invention may be performed in various ways, and embodiments thereof will now be described by way of example only, reference being made to the accompanying drawings, in which:

20

**Figure 1** is a schematic representation of a known Raman Spectroscopy Apparatus;

**Figure 2** is a schematic representation of the optical path of a Raman Spectroscopy Apparatus in accordance with one embodiment of the invention;

25

**Figure 3** is a representation of scattered light at a diffraction grating;

**Figure 4** is a representation of scatter light at a diffraction grating illustrating the effect of anamorphic magnification in accordance with embodiments of the invention

30

**Figure 5** is a schematic representation of the optical path in a Raman Spectroscopy Apparatus in accordance with another embodiment of the invention; and

**Figure 6** is a schematic representation of the optical path in a beam splitting Raman Spectroscopy Apparatus in accordance with another embodiment of the invention.

5

### **Detail Description of Embodiments**

As discussed above, a typical prior art spectroscopic apparatus is shown in figure 1. Embodiments of the invention may use a generally similar overall configuration and, as such, corresponding components are indicated by reference numerals increased by 100. For the purpose of the following description the spectroscopic apparatus shall be considered from the optical input 50 only. It will be appreciated that the source 20 and objective arrangement 30, including the filter/reflector 40 may be of any conventional arrangement. For example, such components may be provided in the form of a microscope. Embodiments of the present invention are also particularly useful for use in fibre-coupled spectroscopic apparatus in which the objective may, for example, be part of a probe adapted for in-situ analysis of a sample.

The schematic of Figure 2 shows the optical path in a spectroscopic apparatus according to an embodiment. An optical input 150 which may be an entrance slit or an input from an optical fibre receives scattered light from a sample illuminated with a source of monochromatic light (generally a laser beam). The spectroscopic apparatus is generally a Raman Spectroscopic device and, as such, the light provided to the input 150 is generally pre-filtered to reject reflected and Raleigh scattered light and to transmit only Raman scattered light (in a relatively narrow wavelength band). The filtering may for example be carried out using a dichroic filter as is known in the art. The light from the optical input 150 is passed through an input lens 170 which focusses the Raman scattered light onto a dispersive device 160, which is generally a diffractive grating. The diffractive grating disperses the Raman scattered light in a spectral direction. The spectrum is then focused by a detector lens 180 onto a detector 190. The detector 190 is a digital image sensor,

typically a CCD, having a two-dimensional array of sensor elements.

The resolution of a spectroscopic apparatus is (in part) determined by the magnification of the optical input 150 at the detector 190. In an apparatus having an entrance slit as an optical input, the size of the input slit may be the primary means of controlling resolution; however, in a fibre coupled arrangement this may not be possible. It is advantageous to use a long focal length on the input lens 170 to minimise the magnification of the optical input. The focal length may, however, be limited as an increase in focal length increases the beam diameter at the diffraction grating 160. If the beam size exceeds the size of the grating 160 the resultant overfilling will cause light to be lost. As the spectral region of interest moves towards the red region the angle of the grating to the input light increases. Accordingly, the applicants have also identified that it is important to be aware that at an increased angle the size of the beam the grating can accept is reduced (as explained further below) whilst the dispersion is increased. It is also to be noted that in most Raman Spectroscopy the spectra of greatest interest is close to the laser line but the grating fill limitations result in spectroscopy apparatus typically producing high resolution at the “wrong” end of the range (i.e. the area which is least likely to contain useful spectral information).

The diffractive grating 160 may be provided with a positioner 165 to enable the angle of incidence of the grating 160 to be adjusted relative to the incoming scattered light. The positioner 165 could for example be a rotary drive such as a stepping motor. Figure 2(a) and 2(b) show examples of the grating 160 at two different angles of incidence. As will be appreciated by those skilled in the art, adjusting the angle of incidence between the grating 160 and the scattered light enables different parts of the spectrum to be directed to the CCD detector 190. An advantage of such arrangements is that the spectroscopic apparatus may provide relatively high spectral resolution and also enable the acquisition of data across a relatively wide spectrum.

When the angle of incidence is increased to a relatively high grating angle, as shown in Fig 2(b), the maximum beam width must be reduced to prevent overfilling the grating. As such, to maximise the resolution at both grating angles it is advantageous to have an input lens 170 of a first focal length for the low grating angle (figure 2(a)) and an input lens of a second, lower, focal length 172 for the high grating angle (figure 2(b)). This enables the fill of the grating 160 to be maintained at both grating angles. Accordingly, the resolution can be maintained as dispersion is changing. The lenses 170, 172 may be arranged to be substituted into and out of the optical path in any convenient manner. For example, the optical path could be diverted (for example by a reflector or prism) or a mechanism could be provided to physically swap the lenses in and out of the optical path. The computer 95 controlling the spectroscopic apparatus may be programmed to set the required optical arrangement for any given angle of the grating 160.

Grating fill will be further explained with reference to figures 3 and 4. Figures 3 and 4 exemplify the variation in grating fill with angle of incidence. Figure 3 exemplifies a low angle of incidence (it may be noted that the light is shown substantially perpendicular to the grating but this is merely for clarity purposes) figure 3(a) showing the relative angle between the light and the grating and figure 3(b) showing the fill of the light on the grating, in this case with a spot which substantially fills the grating. Figure 4(a) shows a relatively high angle of incidence between the grating and the incoming light. As shown in figure 4(b) the effective dimension (y in figure 4(b)) of the grating facing the incoming light is reduced in the direction perpendicular to the axis of rotation of the grating. As shown in figure 4(b) if the fill is maximised in the y direction the fill will not utilise the full width of the grating. As shown in figure 4(c) if the beam size is magnified to fill the width in the x direction (in other words the magnification is the same as in figure 3) there will be overfilling of the grating in the y direction resulting in loss of light.

Figure 4(d) illustrates the optimum situation, in accordance with embodiments, in which magnification is applied in an anamorphic manner to magnify the beam in

the x direction to fill the grating without a corresponding magnification in the y direction to cause overfilling. Thus, it will be appreciated that in embodiments of the invention at least one anamorphic optical component may be used when adjusting the magnification as shown in figure 2. Embodiments of the invention  
5 may provide anamorphic magnification by using cylindrical lenses. Alternatively or additionally, a prism or prism pair may be used.

In some embodiments, as shown in figure 5, may use an optical arrangement which enables the focal length of the incoming light to the grating 160 to be adjusted in  
10 situ. In the embodiment of figure 5, the apparatus includes a fixed input lens 170 and a zoom lens assembly 175 which allows a continuous variation of the magnification to be provided. The zoom lens typically comprises at least two lenses (or lens groups) which are moveable along the longitudinal direction of the optical path by positioners 176 and 177. The positioners 176, 177 may be servo motors to  
15 enable precise control of the position of each lens. As will be appreciated in the art, the adjustment of the two lenses of the zoom arrangement may comprise the movement of a first lens to adjust the magnification and movement of the second lens to maintain the focus of the light directed to the grating 160. The skilled person may note that the schematic representation of Figure 5 has a substantially collimated  
20 input from lens 170 to the zoom assembly, which is merely for simplicity. In practice, it will be appreciated (and well understood in the art of zoom lens design) that a two moving zoom lens system would require a non-collimated input from the lens 170 to achieve variable zoom.

25 Figure 5(a) shows the grating 160 at a relatively low angle of incidence and the zoom lens 175 in a corresponding position with a relatively large beam diameter (and a relatively high focal length). Figure 5(b) shows the grating 160 at a relatively high angle of incidence and the zoom lens 175 at a second, different, position providing a smaller beam diameter (and shorter focal length). It will be appreciated  
30 that a controller may be provided which uses the positioners 176, 177 to continuously alter the zoom lens setting as the grating 160 angle of incidence is

adjusted. In some cases, a series of predetermined stop positions may be set for the grating angle 160 along with corresponding zoom lens 175 configurations being stored by the control. For example, such stops could be set during configuration or calibration of the spectrographic apparatus.

5

As noted above, it is known to provide a spectroscopic apparatus in which the scattered light is passed through a beam splitter and directed to separate optical paths (sometimes refer to as “arms” of the spectroscopic apparatus). Such an arrangement is, for example shown in the Applicant’s earlier United States Patent  
10 US 5,638,173. Embodiments of the invention may also be utilised in such an arrangement to balance the grating fill on each optical path. Figure 6 shows an example of such an arrangement having two optical paths 320 and 330. The skilled person will, however, appreciate that the arrangement is equally applicable to arrangements having more optical paths.

15

The embodiment of figure 6 includes an optical input 250 and an input lens 270 which directs the scattered light towards the grating 260. A beam splitter 300 is provided between the input lens 270 and grating 260. The beam splitter may for example be a dichroic beam splitter which reflects a specified range of wavelengths  
20 and transmits a different specified range of wavelengths. The transmitted part of the spectrum passes through the beam splitter 300 along optical path 320 to the grating 260. The reflected part of the spectra is separated by the beam splitter 300 and passes via a mirror 310 into a second optical path 330 which is also directed to the grating 260 but with a resulting different angle of incidence to the first optical  
25 path 320. Thus, the spectroscopic apparatus according to the embodiment of figure 6 can be considered to have separate “arms” for different parts of the spectra. The resulting dispersed spectra from the grating are focused by detector lens 280 onto the CCD detector 290 as separate spectral stripes for each arm.

30 In accordance with embodiments of the invention, a beam expander 275 is provided on the optical path 330 to enable the fill of the beam at the grating 260 to be

maintained. Thus, the arrangement of figure 6 enables the resolution of both optical paths 320 and 330 to be optimised with the size of the image of the input for each arm being different. The beam expander 275 and input optic 270 can be selected to ensure that each arm of the spectroscopic apparatus is optimised to utilise the maximum width of the grating. The beam expanding arrangement on at least some of the arms may be anamorphic to prevent overfilling of the grating in one axis only. It may be appreciated that in a multi-arm system it may not be necessary to include a variable magnification control (such as a lens substitution or zoom system) since the grating angle may not require any variation in use (rather once set it is different for each arm). Accordingly, the magnification on each arm may require only an initial configuration/calibration. This may simplify control and remove the need for any moving parts within the optical path.

Although the invention has been described above with reference to preferred embodiments, it will be appreciated that various changes or modification may be made without departing from the scope of the invention as defined in the appended claims. For example, as will be appreciated by those skilled in the art, there are various methods in which the scanning of a sample and the acquisition of the resulting data by a CCD detector 190 may be performed and embodiments of the invention are not limited to any specific approach. For example, Raman spectroscopy may be carried out on a scanning basis to map an area of a sample. Further, it is known to illuminate a sample with a line focus rather than a point focus to allow acquisition of spectra from multiple points simultaneously. In such an arrangement the image of the line is arranged on the CCD detector 190 such that it extends orthogonally to the direction of the spectral dispersion. This enables efficient use of the two-dimensional nature of the CCD detector 190 to acquire multiple spectra simultaneously.

Further it is known, from the Applicant's International Patent Application No. WO 2008/090350 to use a continuous synchronised approach in which the CCD detector 190 is shifted from pixel to pixel at the same time as scanning the sample in the

longitudinal direction of the line focus. This approach enables a spectral map to be obtained without requiring a “step and stitch” process and helps avoid discontinuities.

- 5 The skilled person in the art may also appreciate that embodiments of the invention may be combined with other methods such as those from the Applicant’s earlier US Patent 8,305,571 B2 in which the charge from the CCD is passed to an output register and shifted along the register in a synchronous manner with the spectrum moving on the CCD. The effect of said method is to provide a wide spectrum to be
- 10 collected at a high resolution. The resolution may be further optimised in combination with embodiments of the invention further balancing resolution across the spectrum by varying the magnification with variations in the grating.

Claims

## 1. A spectroscopic apparatus comprising:

an optical input;

5 a dispersive device arranged to disperse light in a spectral direction across a detector;

a positioner for rotating the dispersive device relative to the incoming optical axis to change the angle of incidence of the dispersive device thereby adjusting the resulting spectral region dispersed across the detector;

10 an input lens between the optical input and the dispersive device for collimating the light

a detector lens between the dispersive device and the detector for focusing the dispersed light onto the detector; wherein the apparatus further comprises:

15 an input magnification adjuster for adjusting the magnification of the light onto the dispersive device and

a controller arranged to adapt the input magnification adjuster in response to the angle of incidence of the dispersive device.

20 2. The spectroscopic apparatus of claim 1, wherein the magnification adjuster comprises a zoom lens.

25 3. The spectroscopic apparatus of claim 2, wherein the zoom lens comprises at least two movable lens elements.

4. The spectroscopic apparatus of claim 3, wherein the apparatus further comprises at least one drive for positioning the movable lens elements.

5. The spectroscopic apparatus of claim 3, wherein the magnification adjuster comprises a plurality of lenses, each lens having a different focal length and a mechanism for exchanging the lenses into the optical path.
- 5      6. The spectroscopic apparatus of any preceding claim, wherein the controller uses the magnification adjuster to maintain resolution across the spectral range.
- 10      7. The spectroscopic apparatus of claim 6, wherein the magnification adjuster is adapted to maximise the width of the dispersion device onto which incoming light is projected for each angle of incidence.
- 15      8. The spectroscopic apparatus of claim 7, wherein the magnification adjuster is adapted to prevent overfilling of the dispersion device for each angle of incidence.
- 20      9. The spectroscopic apparatus of any of claim 8, wherein the magnification adjuster comprises an anamorphic lens.
- 25      10. A spectroscopic device as claimed in any preceding claim wherein the dispersive device is a diffractive grating.
- 30      11. A spectroscopic device as claimed in any preceding claim wherein the optical input comprises a coupling for receiving an optical fibre.
12. A spectroscopic device as claimed in any preceding claim, wherein the light comprises Raman scattered light and the spectroscopic device is a Raman spectroscopy device.
13. A spectroscopic device as claimed in any preceding claim wherein the detector comprises a two-dimensional CCD.

14. A spectroscopic apparatus comprising:

an optical input;

a dispersive device arranged to disperse light in a spectral direction across a detector;

5 a beam splitter, between the optical input and the dispersive device, the beam splitter being arranged to split the light into a plurality of separate optical paths each path being directed to the dispersive device to provide separate partial spectra across portions of the detector;

10 an input lens between the optical input and the beam splitter for collimating the light via the beam splitter to the dispersive device; and

a detector lens between the dispersive device and the detector for focusing the dispersed light onto the detector; wherein the apparatus further comprises:

15 at least one magnification adjuster in one of the plurality of separate optical paths between the beam splitter and the dispersive device to optimise the beam diameter of the optical path at the dispersive device.

20 15. The spectroscopic apparatus of claim 14, further comprising a plurality of magnification adjusters each located in one of a plurality of separate optical paths.

16. The spectroscopic apparatus of claim 14 or 15, wherein the at least one magnification adjuster balances the resolution across each partial spectra.

25 17. The spectroscopic apparatus of claim 16, wherein the at least one magnification adjuster balances the width of the associated optical path at the dispersion device.

18. The spectroscopic apparatus of claim 17, wherein the at least one magnification adjuster is adapted to prevent overfilling of the dispersion device by the associated optical path.
- 5 19. A spectroscopic device as claimed in any one of claims 14 to 18 wherein the dispersive device is a diffractive grating.
20. A spectroscopic device as claimed in any one of claims 14 to 19 wherein the optical input comprises a coupling for receiving an optical fibre.
- 10 21. A spectroscopic device as claimed in any one of claims 14 to 20, wherein the light comprises Raman scattered light and the spectroscopic device is a Raman spectroscopy device.
- 15 22. A spectroscopic device as claimed in any one of claims 14 to 21 wherein the detector comprises a two-dimensional CCD.
23. A spectroscopic device as claimed in any one of claims 14 to 22 wherein the beam splitter comprises a dichroic filter.
- 20

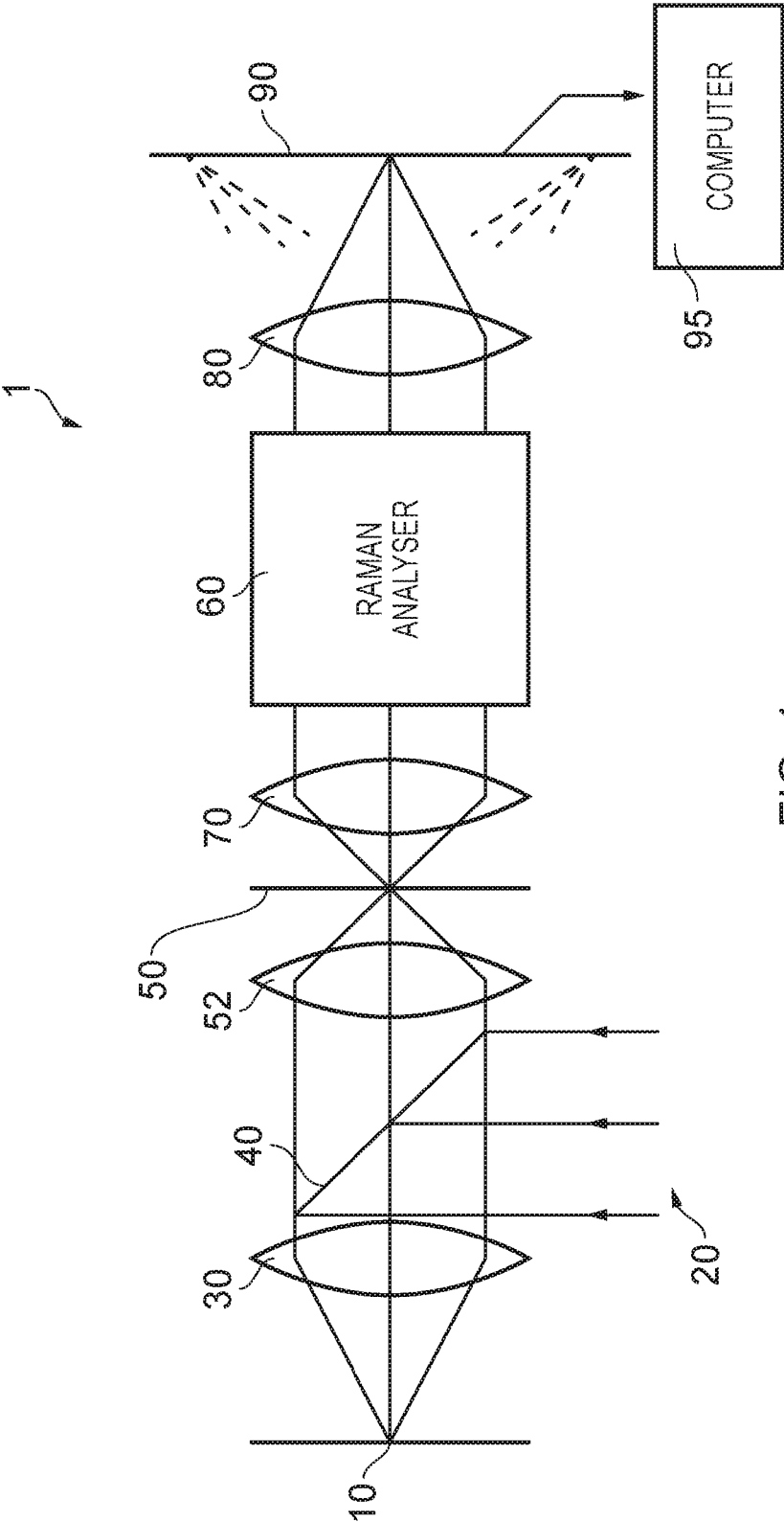


FIG. 1

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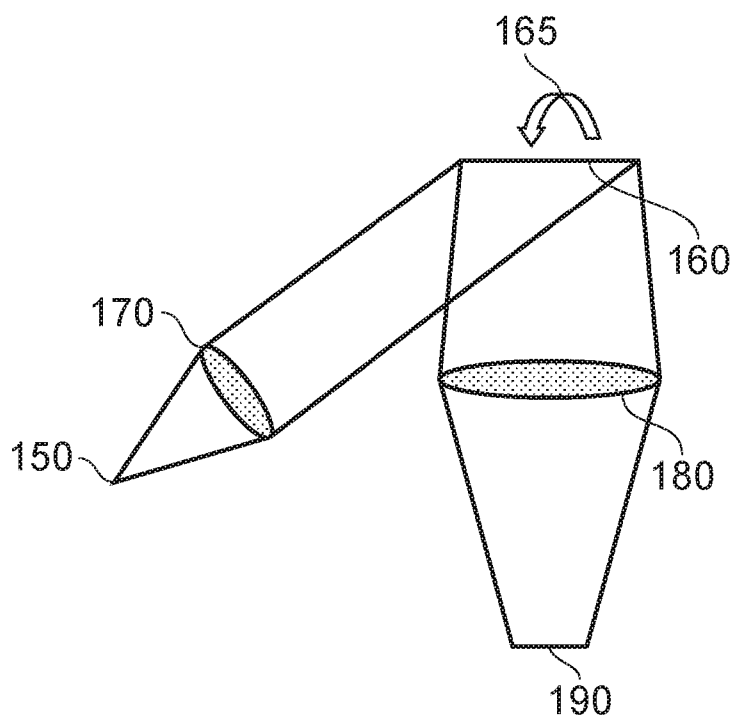


FIG. 2(a)

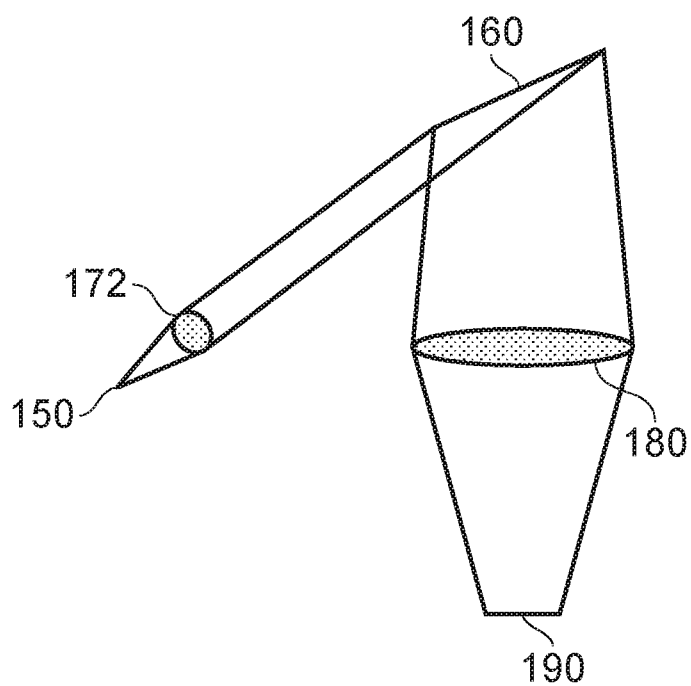


FIG. 2(b)

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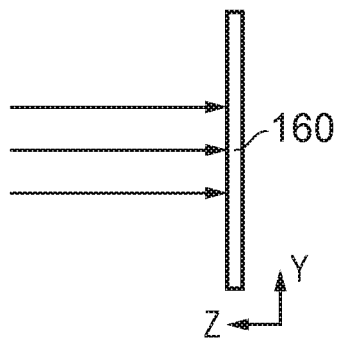


FIG. 3(a)

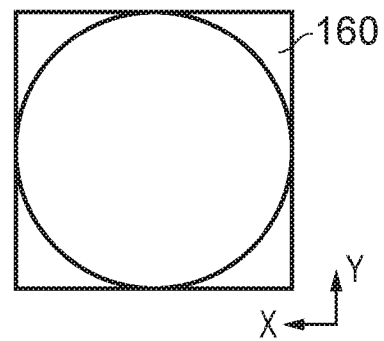


FIG. 3(b)

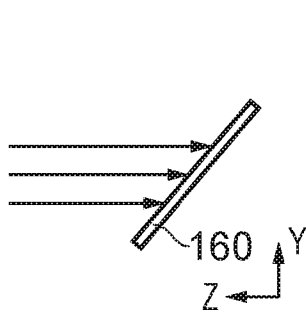


FIG. 4(a)

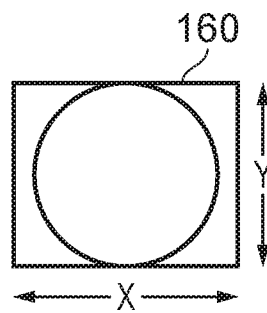


FIG. 4(b)

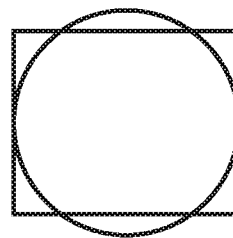


FIG. 4(c)

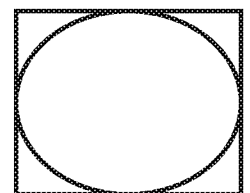


FIG. 4(d)

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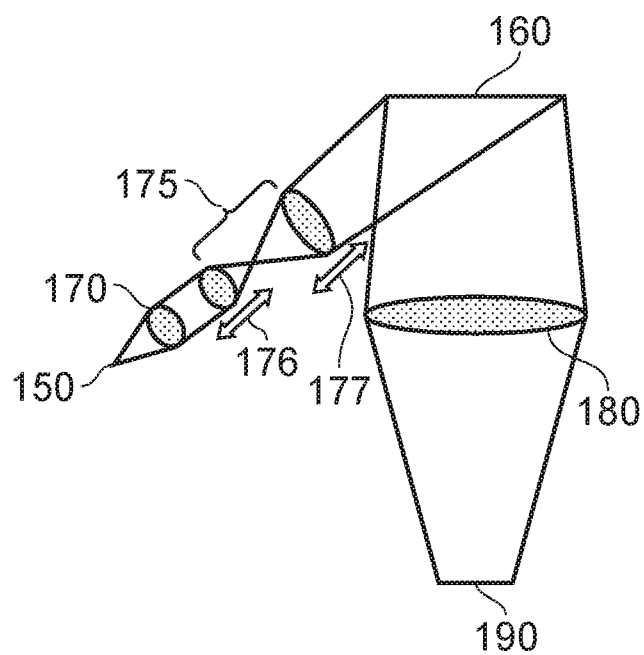


FIG. 5(a)

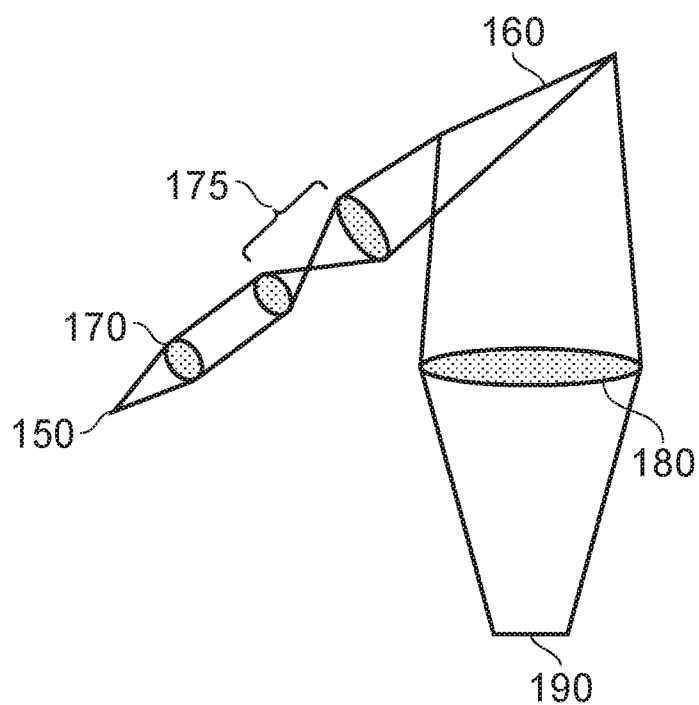


FIG. 5(b)

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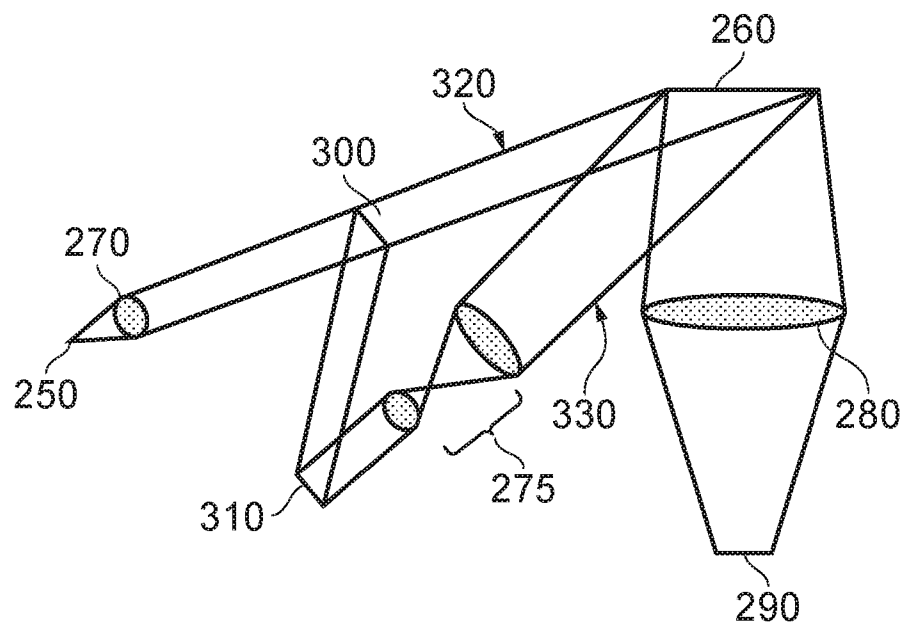


FIG. 6

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2020/050460

## A. CLASSIFICATION OF SUBJECT MATTER

INV. G01J3/02 G01J3/18 G01J3/28 G01J3/44  
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
G01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                     | Relevant to claim No. |
|-----------|------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 2002/044280 A1 (WEIGOLD ADAM MARK [AU] ET AL) 18 April 2002 (2002-04-18) paragraph [0036]; figure 1<br>-----        | 1-23                  |
| Y         | US 6 952 510 B1 (KARLSEN SCOTT R [US] ET AL) 4 October 2005 (2005-10-04) column 3, lines 18-49; figures 1,2,5<br>----- | 1-23                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

### \* Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search

27 May 2020

Date of mailing of the international search report

26/06/2020

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Authorized officer

Schmidt, Charlotte

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2020/050460

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date         |
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| -----                                     |                     |                            |                             |
| US 6952510                                | B1                  | 04-10-2005                 | NONE                        |
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