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(54) An apparatus and method for analyzing a birefringent sample.

(57) The invention relates to an apparatus for analyzing birefringent samples. The apparatus having an illumination system comprising a first polarizer for providing an illumination beam with a first polarization direction to a sample and an analyzer provided with a second polarizer in front of an image sensor for analyzing light received from the sample. The polarization direction of the second polarizer is being crossed with respect to the first polarization direction. The analyzer comprises a spectrometric filter to analyze the polarization color of the fibers.

Dit octrooi is verleend ongeacht het bijgevoegde resultaat van het onderzoek naar de stand van de techniek en schriftelijke opinie. Het octrooischrift komt overeen met de oorspronkelijk ingediende stukken.

An apparatus and method for analyzing a birefringent sample

FIELD

The invention relates to the field of analyzing birefringent samples, and more specifically to an apparatus for analyzing a birefringent sample such as a fiber, the apparatus comprising:

a sample holder for holding the sample;

an illumination system comprising a first polarizer having a first polarization direction for providing a radiation beam with the first polarization direction to the sample; and,

an analyzer for analyzing radiation received from the sample, the analyzer comprising a second polarizer having a second polarization direction and an image sensor receiving radiation from the second polarizer.

BACKGROUND

Many textiles shed fibers. Only a mild contact with a shedding textile suffices to cause transfer of textile material to a receptor. If transferred material ('traces') can be attributed to a certain donor, it may establish a relation between a suspect and a crime scene, or between a suspect and a victim. The easy transfer of textile material thereby makes investigation of transferred fibers a powerful forensic tool.

Fiber traces present on a receptor can be collected using tapes. A main challenge in forensic fiber analyses is the sheer quantity of fibers that are present on such tapes in many cases. Tapes may contain hundreds or thousands of fibers, and scanning the tapes for relevant traces is often tiring and time-consuming.

Different automated microscopy systems, also called 'fiber finders', have been introduced to facilitate the process of fiber scanning. These systems are designed to scan a large surface and locate the relevant traces. Many forensic labs carried out tests to introduce the automated microscopy systems into their case work. However, it was generally found, that the automated microscopes did not discriminate fibers well enough and hence did not improve efficiency.

The poor discrimination achieved by the automated microscopy systems can be explained by their restricted optical capabilities. Most systems discriminate on a single parameter, namely fiber color as observed by a image sensor. Moreover, the magnification of these systems is low, and the illumination systems are limited to white light sources. The restrictions of the optical capabilities of these automated systems become apparent when they are compared to the full set of features available to microscopists and spectrometrists, which includes morphology, fluorescence, optical spectrometry, infrared spectrometry and polarization microscopy. The discrimination that can be reached by the combination of these sophisticated and powerful techniques exceeds the discrimination of current automated microscopy systems and explains the 'false positive' errors.

Optimisation of the optical capabilities of automated microscopes would improve automated microscopy systems. In addition, it would enable the objective discrimination of fibers and thereby facilitate a more scientific and numeric basis for forensic fiber investigation. An optical capability that has already been explored is spectrometric imaging of fiber color. Spectrometric detection was used on the Foster and Freeman FX5. The spectrometric resolution of this system is limited to seven wavelength regions. A newer approach to spectrometric detection is the use of a liquid crystal tunable filter (LCTF), as presented by Markstrom and Mabbott.

US6040905 discloses a fiber classing device with a light source directing light to a fiber sample. Light reflected by the sample is received by a photo sensitive detector. The photo sensitive detector may have a spectrometer.

EP 0 545 129 B1 discloses a method and apparatus to detect manmade fibers and/or defective fibers and/or other foreign materials in the processing of silk waste. A lap of silk fibers is illuminated by transparency with white light and is scanned by a first telecamera. The lap is further illuminated by transparency with polarized light and scanned by a second telecamera, or by the first telecamera. In a data processing system, the images taken by the telecamera(s) are processed and compared to determine the quantity, position, type and length of the faults and of the manmade fibers or foreign or defective fibers in the lap of silk fibres.

GB2461967 discloses an apparatus for the detection of foreign matter in or between fiber material. Fiber material may be illuminated with polarized light. A image sensor with a polarization filter may be used to analyze the fiber material.

A disadvantage of the method and apparatus of GB2461967 is a lack of accuracy in determining a color with the image sensor. Accordingly, fibers may not be classified with a high degree of accuracy.

SUMMARY

It would be desirable to provide an improved apparatus for analyzing fibers. It would also be desirable to provide an apparatus which may determine the color of a fiber with a heigh accuracy.

To better address one or more of these concerns, in a first aspect of the invention an apparatus for analyzing a birefringent sample is provided, the apparatus comprising:

a sample holder for holding the sample;

an illumination system comprising a first polarizer having a first polarization direction for providing a radiation beam with the first polarization direction to the sample; and,

an analyzer for analyzing radiation received from the sample, the analyzer comprising a second polarizer having a second polarization direction and an image sensor receiving radiation from the second polarizer, wherein the second polarization direction is crossed with respect to the first polarization direction and the apparatus comprises a wavelength tuner to analyze a polarization wavelength of the birefringent sample with the image sensor.

The apparatus for analyzing birefringent samples becomes more sensitive if the first and second polarizers are crossed such that no light is transmitted by the second polarizer if the polarization of the light is not changed by the birefringent sample. The background received by the image sensor will therefore appear as black in the image sensor image because no light will be transmitted from the background through the first and second polarizers. A fiber in the birefringent sample may alter the state of polarization of the light due to their birefringence, and will appear in the image with often a bright and beautiful color which is called the polarization color.

The polarization color or wavelength is useful for identification of the birefringent sample. With the wavelength tuner it becomes possible to determine the retardation that is caused for a particular wavelength by the birefringent sample and to identify the birefringent sample better. By using an image sensor a 2 dimensional image of the polarization color or wavelength can be obtained such that it becomes possible to distinguish between the polarization color or wavelength of the center of a birefringent sample and the edges of the birefringent sample. The polarization color at the edges of a fiber as a birefringent sample may be different than the polarization color at the center of the fiber.

In an embodiment, the first polarizer is a first beam splitter for splitting a beam into the radiation beam with the first polarization direction and a secondary beam. A beam splitter is a useful device for creating the radiation beam with the first polarization direction.

In an embodiment the illumination system comprises a second beam splitter for selectively recombining the beam with the first polarization direction and the secondary beam into a non-polarizing radiation beam. In this way we may alternately provide a radiation beam with a first polarization direction and a radiation beam without a predetermined polarization with the same illumination system. A shutter may therefore be provided in the secondary beam between the first and second beam splitter, the shutter selectively blocks the secondary beam to the second beam splitter to create a radiation beam with a first polarization direction or the shutter selectively opens to allow the secondary beam to pass to the second beam splitter to recombine with the beam with the first polarization direction to create a non-polarizing radiation beam. By using a shutter between the first and second beam splitter it becomes possible to rapidly switch between the radiation beam with a first polarization direction and the non-polarizing radiation beam. In this way it becomes possible to alternately measure the colors with crossed polarizers and with no polarization which is useful to measure a difference between the polarization color and the normal color.

In an embodiment the first and/or second polarizer is a rotatable polarizer to rotate the polarization direction of the first and or second polarizer. In this way it becomes possible to alternately measure the colors with crossed polarizers and with parallel polarizers which is useful to measure a difference between the two.

In an embodiment the illumination system comprises a broadband source and the wavelength tuner is a spectrometric filter positioned between the source and the image sensor to analyze a polarization wavelength of the sample with the analyzer. The spectrometric filter makes it possible to determine the polarization of a distinct wavelength.

In an embodiment the spectrometric filter is positioned between the sample and the image sensor. Alternatively, the spectrometric filter is positioned between the source and the sample.

According to an embodiment the spectrometric filter is an adjustable spectrometric filter which is adjustable to selectively allow a particular wavelength range to pass the filter while wavelengths outside the range are blocked.

According to an embodiment the spectrometric filter comprises a liquid crystal tunable filter functioning as the first or second polarizer and as the spectrometric filter. A liquid crystal tunable filter is already having polarizing properties which advantageously may be used in this application where a spectrometric filter is also necessary.

According to an embodiment the wavelength tuner comprises a radiation source with a tunable wavelength provided to the illumination system to analyze a polarization color of the fiber with the analyzer. The radiation source with a tunable wavelength may be a laser with an adjustable wavelength or a broadband source combine with a spectrometric filter.

According to an embodiment the apparatus comprises a controller connected to the wavelength tuner to adjust the wavelength over a long wavelength range and to store the image sensor images as a function of the wavelength in a memory of the controller.

In a further embodiment the illumination system comprises a lens to focus the radiation beam onto the sample. The lens may provide the radiation beam with the required intensity and form at the sample.

In a further embodiment the illumination system comprises a light source (e.g. a halogen lamp) for providing a white light radiation beam.

In a further embodiment the controller comprises a processor to divide the polarization color spectrum by a reference spectrum. The reference spectrum is the spectrum received if the fiber is illuminated with unpolarized white light. In this way one may correct for the sensitivity of the optical system for the apparatus and for the absorptive color of the fiber.

In an embodiment the illumination system, the sample holder and the analyzer are arranged such that the radiation beam is traversing from the illumination system through the sample to the analyzer. The fiber may be analyzed in transmission in this way.

In an embodiment the radiation beam comprises radiation from 400 to 720 nm. Hereby the fibers may be analyzed in the visible range of the wavelength spectrum.

In a further embodiment the invention relates to a method for analyzing a birefringent sample, the method comprising:

providing the sample in a sample holder;

illuminating the sample with a radiation beam with a first polarization direction;

allowing radiation received from the sample to traverse a second polarizer with a second polarization direction perpendicular to the first polarization direction to reach an image sensor;

taking images from the radiation from the fibers with the image sensor while selectively tuning a different wavelength to reach the image sensor.

According to a further embodiment the method comprises changing the first or second polarization direction. In this way images with crossed polarizer may be rapidly alternated with images with parallel polarization or no polarization.

These and other aspects of the invention will be more readily appreciated as the same becomes better understood by reference to the following detailed description and considered in connection with the accompanying drawings in which like reference symbols designate like parts.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

Figure 1 depicts an apparatus for analyzing a fiber in a sample according to the invention;

Figure 2 fibers imaged by a RGB camera in a microscope using a) unpolarized white light and b) crossed polarisation;

Figure 3a and 3b show the light transmission as a function of wavelength of the incoming light beam and the retardance;

Figure 4 depicts a spectrometric analysis of polarisation colours of samples with retardance of 500, 1000, and 1500 nm, which have a similar colour;

Figure 5 depicts a performance measurement of the polarisation optics;

Figure 6 depicts polarisation spectra of two test wave plates;

Figure 7 depicts a number of polarisation spectra from different positions along the width of a polyester fibre; and,

Figure 8 depicts a visual and polarisation spectra of polyester, acrylic, and nylon fibres in different colours.

DETAILED DESCRIPTION OF EMBODIMENTS

Figure 1 depicts an apparatus for analyzing a birefringent sample, such as a fiber according to the invention. The apparatus comprises: a sample holder 1 for holding the birefringent sample 3; and an illumination system comprising a first polarizer. The first polarizer is a first beam splitter 5 for splitting a primary beam 9 into a radiation beam 7 with a first polarization direction and a secondary beam 13. A second beam splitter 15 is used to selectively recombine the radiation beam 7 with the first polarization direction and the secondary beam 13 into a non-polarizing radiation beam.

The illumination system comprises a shutter 17 in the secondary beam 13 between the first and second beam splitter 5, 15, the shutter 17 selectively blocks the secondary beam 13 to the second beam splitter 15 to create a radiation beam with the first polarization direction or the shutter 17 selectively opens to allow the secondary beam 13 to pass to the second beam splitter 15 to recombine with the beam 7 with the first polarization direction to create a non-polarizing radiation beam. By using the shutter 17 between the first and second beam splitter 5, 15 it becomes possible to rapidly switch between a radiation beam with a first polarization direction and a non-polarizing radiation beam.

The illumination system is provided with first and second mirrors 19, 21 to redirect the radiation beam 7 with the first polarization direction and the secondary beam 13 respectively. The illumination system may include a first lens 23 and a second lens 25 to focus the radiation beam with the required intensity and form onto the sample 3. The first lens 23 may be an achromatic condenser lens (f=40mm), with a variable aperture (Edmund Optics).

The illumination system may have a light source 27 (e.g. a 100 W halogen lamp (Carl Zeiss B.V)) for providing a white light radiation beam with a wavelength of 400 to 740 nm.

The apparatus comprises an analyzer for analyzing radiation received from the sample 3 via an objective lens 33 (e.g. Mitutuyo 5x objective (Edmund Optics)). The analyzer comprises a liquid crystal tunable filter 31 (e.g. Varispec liquid crystal tunable filter (Cambridge Research Instruments)) functioning as the second polarizer and as the spectrometric filter (wavelength tuner) to transmit an adjustable and selectable wavelength of radiation to the image sensor e.g. camera 29. The camera 29 (e.g. Pike F100 B/W camera (Allied Vision Technologies)) may have a pixel size of 7.4 μm, which, combined with a 5x magnifying objective lens 33, leads to a theoretical spatial resolution of about 1.5 μm at the sample 3. The spectrometric filter is an adjustable spectrometric filter which is adjustable to selectively allow a particular wavelength range to pass the filter while wavelengths outside the range are blocked. In this way a very accurate analyses of the polarization color can be made.

The apparatus may have a controller 37 connected to the adjustable spectrometric filter 31 to adjust the wavelength of the filter over a long wavelength range and to store the camera 29 images as a function of the wavelength in a memory of the controller 37. The controller 37 may have a processor to divide the polarization color spectrum by a stored reference spectrum.

The only moving part needed in the optical set-up of the apparatus is the shutter 17. The two polarizing beam splitters 5,15 separate and recombine the illumination depending on the shutter 17. A polarized radiation beam is obtained by blocking the secondary beam using the shutter 17 and a non-polarizing radiation beam is obtained by opening the shutter 17.

Alternatively, the first and/or second polarizer is a rotatable polarizer to rotate the polarization direction of the first and or second polarizer.

A combination of two crossed polarizers, i.e. polarizers placed at right angles, do not transmit light. However, a change of the polarization state between the polarizers may lead to a partial or even full transmission by the second polarizer. This effect is illustrated in figure 2. Figure 2a shows the transmission image of three nylon fibers with different colors when they are illuminated by white light without any polarization (e.g. the shutter 17 is opened). The fibers have a thickness of about 22 µm. The background in this image is white as it transmits all incoming light.

Figure 2b shows the same fibers when placed between two crossed polarizers. The polarization color of the fibers is different from the 'normal' absorptive color of the sample, shown in figure 1a. The background appears black, as the light polarized by the first polarizer is not transmitted by the second polarizer. However, the fibers are visible in figure 1b, indicating that the fibers alter the polarization state of the incoming beam in such a way that part of the light is transmitted. Fibers alter the polarization state of light due to their birefringence, which means that the refractive index of a sample cannot be stated as a single value.

For most fibers, the refractive index experienced by light polarized parallel to the main axis of a fiber ($n_{\parallel}$) is different from the refractive index experienced by light polarized perpendicular to the main axis of a fiber ($n^{\perp}$), as shown in figure 1b.The refractive index of a material is proportional to the speed of light through that material. A polarized beam entering a birefringent sample placed at 45° with respect to the polarization of the incoming beam, will experience both refractive indices ($n_{\parallel}$ and $n^{\perp}$) and therefore 'split' into parts that travel at different speeds. During travel through the sample, a path difference, or 'retardance' between the split parts will develop and the interference between these parts alters the polarisation state of the light beam. The retardance R of a sample is related to the thickness of the sample d and it's birefringence Δn by:

$$R = d \cdot \Delta n$$

If the final retardance, i.e. the retardance after the light beam left the sample, equals the wavelength of the incoming beam (or a multiplex of this wavelength), the polarization is not effectively changed and the light will be blocked by the liquid crystal tunable filter 31 functioning as the second polarizer. In other cases however, the retardance alters the polarization state and light will be transmitted by the second polarizer. This principle is illustrated in figure 3, which is based on an illustration by Winchell.

The different plots in figure 3a show the light transmission as a function of wavelength of the incoming light beam (vertical axis) and the retardance Ret. (horizontal axis). The grey scale patterns in figure 3a shows the absorptions (black parts) and transmissions (white parts) and shows that the light transmission of the sample depends not only on the retardance, but also on the wavelength of the incoming beam. For example, a sample with a retardance of 1000 nm will induce full transmission of light received with a wavelength of 400 nm by the analyser and hence visibility in the resulting image. An incoming light beam with a wavelength of 500 nm will however not be changed effectively by the sample and thus the polarization will not be changed and it will not be visible in the resulting image.

Figure 3a shows the transmission patterns for a restricted number of wavelengths. It can however be inferred that patterns can be derived for all wavelengths in the same manner. A birefringent sample illuminated with white light will thus give rise to a complex set of light transmissions and blockages. This can be observed as polarisation colours as provided in a Michel-Lévy Chart which shows the visual color, such as the (simplified) chart shown in figure 3b.

Comparison of the polarisation colour of an unknown sample to the colours on a Michel-Lévy chart can reveal the retardance of the sample. Once the retardation and the thickness of a sample are determined, their product equals the sample birefringence and can be used for identification purposes. Tables for the identification of textile fibres based on their birefringence can be found in literature.

This procedure, used in many laboratories, includes a visual comparison of polarisation colours. This step is subjective and the colours that need to be discriminated may be very similar. For example, retardations of 500, 1000, and 1500 nm all may lead to a reddish colour. Moreover, polarisation colours become less and less distinct at higher retardations. It is for these reasons that observation of polarisation colours by a standard colour camera, as shown in figure 2b, is not considered promising.

Alternatively, retardance can be obtained using a device with a tunable, calibrated retardation, usually called a compensator. The compensator is placed in the light path to cancel ('compensate') the retardation of the sample. On full compensation, the sample will appear black in the microscopic image, and the retardation can be read from the compensator scale. The compensator yields rather accurate results, but has a limited range (often 4-6 'orders', which amounts to about 2000-3000nm). The retardance of many fibres, including most polyester fibres, can not be accurately analysed by a compensator due to the limited range.

It can be anticipated that spectrometric analysis may yield a more accurate description and discrimination of polarisation colours. Results of a few calculations are presented in figure 4. It is shown that samples with a retardance of 500, 1000, and 1500 nm, which have a similar colour (see figure 3b) may show markedly different polarisation spectra (black curves in figure 4). The aim of the current invention is to measure polarisation spectra (like the calculated spectra presented in figure 4) from real world samples with a high spatial resolution by tuning the wavelength (W) of the wavelength tuner e.g. liquid crystal tunable filter 31 (in figure 1) from 400nm to 720 nm while at the same time measuring the transmission (T) with the camera 29 of three samples with retardance of 500, 1000, and 1500 nm.

A second advantage of spectrometric analysis is the high accuracy with which samples with a slightly different retardance can be discriminated. To illustrate this advantage, every plot in figure 4 presents calculated polarisation spectra of samples that differ by only 20 nm. The plots show that the black curves (having retardances of 500, 1000, and 1500 nm) can clearly be distinguished from the grey curves (having retardances of 520 nm, 1020 nm, and 1520 nm) and the spectral resolution of even basic current spectrometers suffices to resolve these small changes. By contrast, it is hardly possible to reliably observe the colour differences caused by such small retardation differences by eye.

A third advantage of spectrometric observation is the high range of retardances that can be analysed. Using spectrometric observation Yang (H.H. Yang, M.P. Chouinard, and W.J. Lingg, Journal of Polymer Science: Polymer Physics Edition 20, 6, 981–987 (1982) determined the retardance of an aramide fibre to be 8529 nm. This retardance is far higher than the 2000-3000 nm that can be achieved with the use of a compensator.

Summarising, spectrometric analyses of polarisation colours (or polarisation spectra) allow the unambiguous and accurate determination of birefringence over a very high range.

Measurements

Procedures to drive the measurements were written in Matlab. In our procedure, the shutter time of the camera 29 (in Fig. 1) is optimised at every wavelength in such a way that the signal intensity of the reference spectra (see below) have an optimal intensity (set to approximately 50,000 counts for the used 16 bit camera 29). Variable shutter times have been implemented as the transmission of the liquid crystal tunable filter (LCTF) 31 spectrometer depends on the selected wavelength: transmission is relatively low for wavelengths near 400 nm. Analyses with a fixed shutter time therefore lead to high noise levels near 400 nm, or to saturation of the camera in higher wavelength ranges.

After the shutter times are optimised, three spectra are acquired:

- a reference spectrum, acquired with a depolarised excitation beam (no shutter in light path (see figure 1); No sample in light path;
- a VIS spectrum (or absorption spectrum), acquired with a depolarised excitation beam (no shutter in light path (see figure 1); Sample positioned in light path; and
- A polarisation spectrum, acquired with a polarised excitation beam (shutter in light path (see figure 1); Sample positioned in light path.

VIS spectra are divided by the reference spectrum to correct for the sensitivity of the optical system. Polarisation spectra are divided by VIS spectrum, to correct for both the sensitivity of the optical system and the absorptive colour of the sample.

A number of measurements in the current study do not require the spatial resolution supplied by the imaging system. In those cases, the acquired spectra were averaged before further processing.

Contrast ratios are calculated by dividing the reference spectra (unpolarised light) by the polarisation spectra, measured without a sample in the light path.

Samples

Fibre samples were obtained from Spinnerij Geldrop. The analysed fibres have a thickness of 18-25 mm. Samples were prepared in glass slides, using glycerine as the mounting medium.

Results and discussion

Contrast ratio

Initial tests showed transmission of light through crossed polarisers even without insertion of a sample. This is against expectations and indicates that the performance of the polarisation optics is not optimal. The performance of the polarisation optics was therefore evaluated by measuring the contrast ratio. The results, presented in figure 5, show that the contrast ratio (Con. R) is poor (<50) at wavelengths (W) below 450 nm. At higher wavelenghts, the contrast ratio is better. The low wavelength spectral region (<450) is excluded from further consideration because of the poor contrast.

Standard wave plates

The instrument was further tested using two standard first order wave plates provided with a Leica comparison microscope. These wave plates have a first order birefringence, i.e. 550 nm. However, the colour of the wave plates, when observed between crossed polarisers, is slightly different, and hence differences between the retardances of the wave plates are expected. Figure 6 shows the obtained polarisation spectra (e.g. the transmission of the wave plates as a function of the wavelength). Comparison of the experimental and theoretical spectra shows that the obtained value is close to the expected 550nm. The two wave plates, having a retardance differing by less than 10nm (e.g the difference between the black and the gray line) which can well be discriminated by the instrument.

Fibre analyses

In a next set of experiments, the birefringence of a fibres was studied. Textile fibres have a diameter of typically 10-20 µm and cover only a small part of the field of view of the microscope system. Individual fibres can however be analysed in the developed instrument, as the spatial resolution of our imaging system is around 1.5 µm. In fact, it is possible to derive information from different spots within a single fibre. This effect is shown in figure 7, where a number of polarisation spectra (transmission Tr. vs wavelength W) is provided. These spectra were obtained from different positions along the width of a polyester fibre, as illustrated by the drawn fibre in this figure. A detailed polarisation spectrum is obtained from the centre of the fibre. The retardance of the fibre is determined to be 3510 nm. This fibre has a thickness of 19 µm and the birefringence is calculated (see formula above) at 0.18, which is in agreement with literature values for polyester fibres.

Figure 7 shows that the polarisation signal from the centre of the fibre is clear, but that it's contrast decreases with increasing distance from the centre. The low contrast spectra do not show a decreasing retardance, as could be expected by the lower sample thickness. This effect is attributed to the differences in refractive indices of the fibre and that of the surrounding fluid (glycerine). Due to these differences, the fibre acts as a cylinder lens, and the path length of light through the fibre is not defined accurately. In this case, optimal information is obtained from the centre region of the fibre, while the contrast in adjacent regions is less clear. The high spatial resolution of the system enables selection of the optimal polarisation spectra to calculate the retardance.

Preliminary identification

In a next experiment, a set containing different types of fibres was analysed. The set contained polyester, acrylic, and nylon fibres in different colours, namely white (i.e. colourless), red, green and blue. The visual (VIS, figure 8a, 8c, 8e, and 8g) and polarisation (Pol) spectra (figure 8b, 8d, 8f and 8h) of these fibres are provided. Figure 8a and b show data obtained from white (colourless) fibres. As expected, the VIS spectra of these fibre show high transmission values. The polarisation spectra are however widely different for the different materials.

- The transmission observed in the polarisation spectrum of the acrylic fibre (black solid curve, fibre diameter 23 µm) is very low, which indicates a low birefringence.
- The polyester fibre yields a far more detailed spectrum (grey solid curve), containing different bands. The corresponding retardance was determined to be around 3554 nm. The diameter of this fibre is around 19 µm, and the calculated birefringence is thus around 0,19.

- The retardance of the polyamide spectrum (black dotted curve) is determined to be around 1044 nm. The diameter of this fibre is around 22 µm, and the calculated birefringence is thus around 0,047.

These values are in good agreement with values determined by other techniques7, and indicate that polarisation spectra can be used for a preliminary identification of fibres.

The fibres shown in figure 2b indicate that the colour of different nylon fibres can be discriminated. These colour differences can be explained by random changes between the birefringence of the displayed fibres, by convolution of the absorptive colour with the polarisation colour, or by a combination of these factors. The data processing procedure proposed in the current study implies division of acquired polarisation spectra by the VIS spectrum of the same fibre. The polarisation spectra are thus corrected for the absorptive colour and should solely carry the information about the birefringence of the analysed sample.

To test the data processing procedure, a number of coloured fibres (red;8c, green;8e, blue;8g) have been analysed. The acquired data is presented in figure 8c-h. The colour of the various spectra is represented by the VIS spectra on the left. The colour information is not observed in the polarisation spectra presented on the right. Instead, the similarity of polarisation spectra of white fibres of equal identity (see figure 8b) is directly clear. Small differences are observed, especially for the blue polyester and nylon fibre. These changes are explained by a higher retardance of the involved fibres. The variation of values for the retardances of fibres of the same type are indicated in figure 8. The differences between observed retardances indicate that the calculated retardances cannot only be used for a preliminary identification, but also to discriminate fibres of the same type.

As required, detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary of the invention, which can be embodied in various forms. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention in virtually any appropriately detailed structure. Further, the terms and phrases used herein are not intended to be limiting, but rather, to provide an understandable description of the invention.

The terms "a"/"an", as used herein, are defined as one or more than one. The term plurality, as used herein, is defined as two or more than two. The term another, as used herein, is defined as at least a second or more. The terms including and/or having, as used herein, are defined as comprising (i.e., open language, not excluding other elements or steps). Any reference signs in the claims should not be construed as limiting the scope of the claims or the invention.

The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

CONCLUSIES

1. Inrichting voor het analyseren van een dubbelbrekend monster, welke inrichting omvat:

een monsterhouder voor het vasthouden van het monster;

een belichtingsstelsel omvattende een eerste polarisator met een eerste polarisatierichting voor het verschaffen van een stralingsbundel met de eerste polarisatierichting aan het monster; en,

een analysator voor het analyseren van ontvangen straling van het monster, de analysator omvattende een tweede polarisator met een tweede polarisatierichting en een beeldsensor voor het ontvangen van straling van de tweede polarisator, waarbij de tweede polarisatierichting wordt gekruist ten opzichte van de eerste polarisatierichting en de inrichting omvat een golflengte tuner voor het analyseren van een polarisatiekleur van het dubbelbrekende monster met de beeldsensor.

2. Inrichting volgens conclusie 1, waarbij de eerste polarisator is een eerste bundelsplitser voor het splitsen van een primaire bundel in de stralingsbundel met de eerste polarisatierichting en een secundaire bundel.

3. Inrichting volgens conclusie 2, waarbij het belichtingsstelsel een tweede bundelsplitser omvat voor het selectief combineren van de stralingsbundel met de eerste polarisatierichting en de secundaire bundel in een niet-polariserende stralingsbundel en het belichtingsstelsel omvat een sluiter in de secundaire bundel tussen de eerste en tweede bundelsplitser, de sluiter blokkeert selectief de secundaire bundel naar de tweede bundelsplitser om de stralingsbundel te maken met de eerste polarisatierichting of de sluiter selectief opent zodat de secundaire bundel passeert naar de tweede bundelsplitser om te recombineren met de stralingsbundel met een eerste polarisatierichting om een niet-polariserende stralingsbundel te maken.

4. Inrichting volgens een der voorgaande conclusies, waarbij de eerste en / of tweede polarisator is een roteerbare polarisator om de polarisatierichting van de eerste en of tweede polarisator te roteren.

5. Inrichting volgens een der voorgaande conclusies, waarbij het belichtingsstelsel omvat een breedband bron en de golflengte tuner is een spectrometrische filter geplaatst tussen de bron en de beeldsensor om een polarisatie kleur van het monster met de analysator te analyseren.

6. Inrichting volgens conclusie 5, waarbij het spectrometrische filter is gepositioneerd tussen het monster en de beeldsensor.

7. Inrichting volgens conclusie 5, waarbij het spectrometrische filter is geplaatst tussen de bron en het monster.

8. Inrichting volgens een der conclusies 5 tot 7, waarbij het spectrometrische filter is een instelbaar spectrometrisch filter die instelbaar selectief toestaat dat een bepaald golflengtebereik het filter passeert terwijl golflengten buiten het bereik worden geblokkeerd.

9. Inrichting volgens een der conclusies 5 tot 8, waarbij het spectrometrische filter omvat een vloeibaar kristal instelbaar filter die functioneert als de eerste of tweede polarisator en het spectrometrische filter.

10. Inrichting volgens een der conclusies 1 tot 4, waarbij de golflengte tuner omvat een stralingsbron met een instelbare golflengte voorzien aan het belichtingsstelsel om een polarisatie kleur van de vezel met de analysator te analyseren.

11. Inrichting volgens een der voorgaande conclusies, waarbij de inrichting omvat een controller verbonden met de golflengte tuner om de golflengte in te stellen over een lang golflengte bereik en de beeldsensor beelden op te slaan als functie van de golflengte in een geheugen van de controller.

12. Inrichting volgens conclusie 11, waarbij de controller omvat een processor om de polarisatie kleur voor de kleur absorptie van het monster te corrigeren.

13. Inrichting volgens een der voorgaande conclusies, waarbij het belichtingsstelsel, de monsterhouder en de analysator zodanig zijn aangebracht dat de stralingsbundel loopt van het belichtingsstelsel door het monster naar de analysator.

14. Inrichting volgens een der voorgaande conclusies, waarbij het monster een dubbelbrekende vezel omvat.

15. Werkwijze voor het analyseren van een dubbelbrekend monster, welke werkwijze omvat:

het verschaffen van het monster in een monsterhouder;

het verlichten van het monster met een stralingsbundel met een eerste polarisatierichting;

het toestaan van straling ontvangen van het monster om een tweede polarisator met een tweede polarisatierichting loodrecht op de eerste polarisatierichting te doorkruisen om een beeldsensor te bereiken;

het nemen van beelden van de straling van de vezels met de beeldsensor terwijl selectief af te stemmen op een andere golflengte om de beeldsensor te bereiken.

16. Werkwijze volgens conclusie 15, waarbij de werkwijze omvat het veranderen van de eerste of tweede polarisatierichting.

Fig. 1

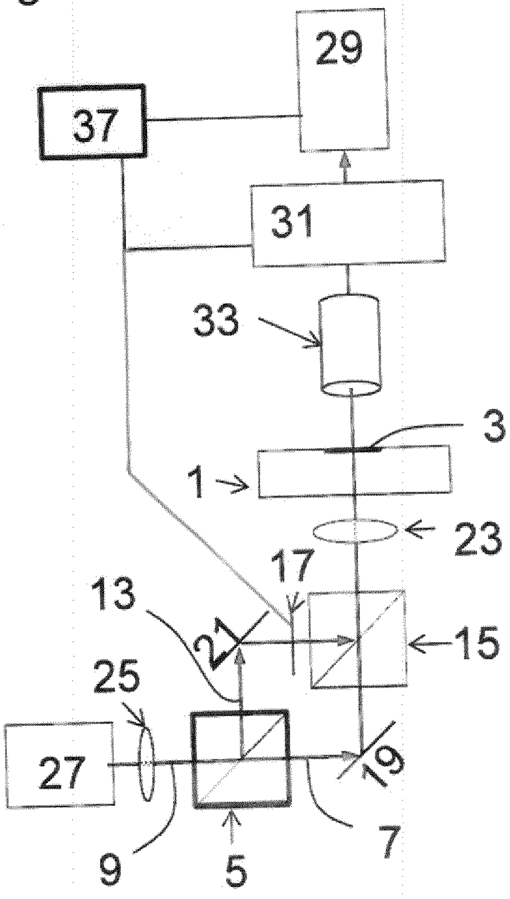


Fig. 2

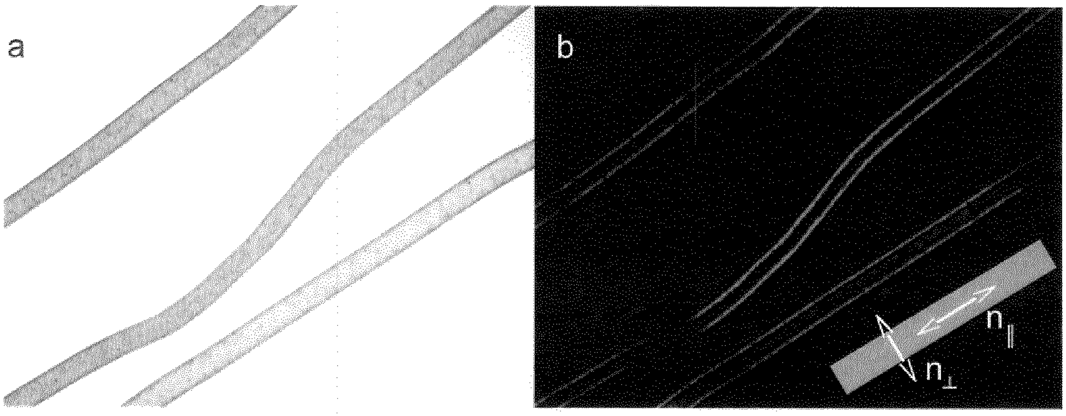


Fig. 3

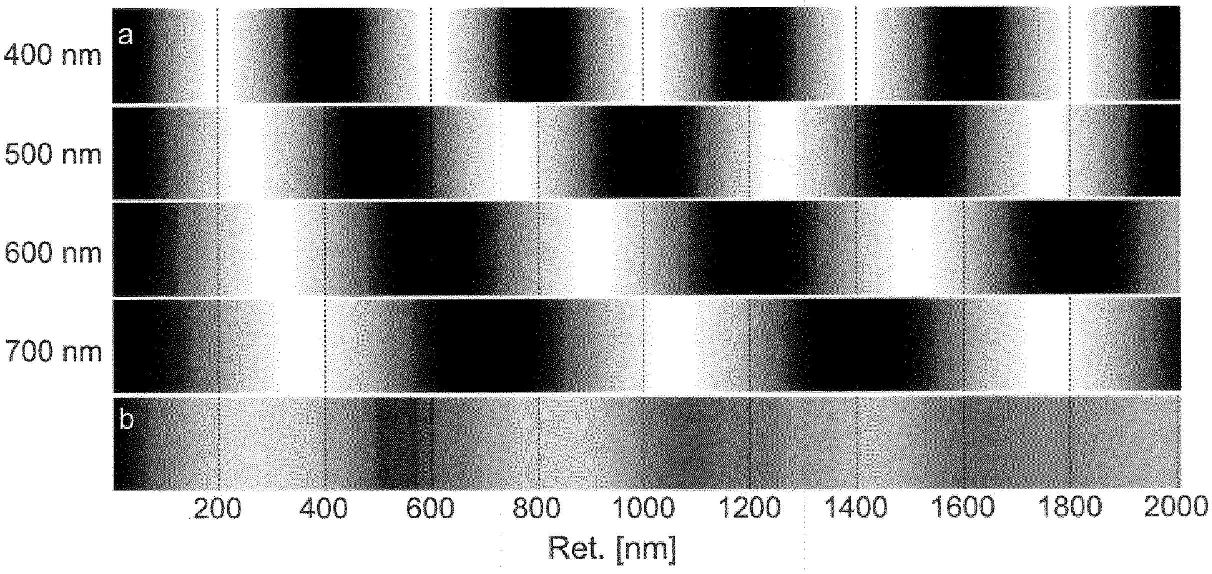
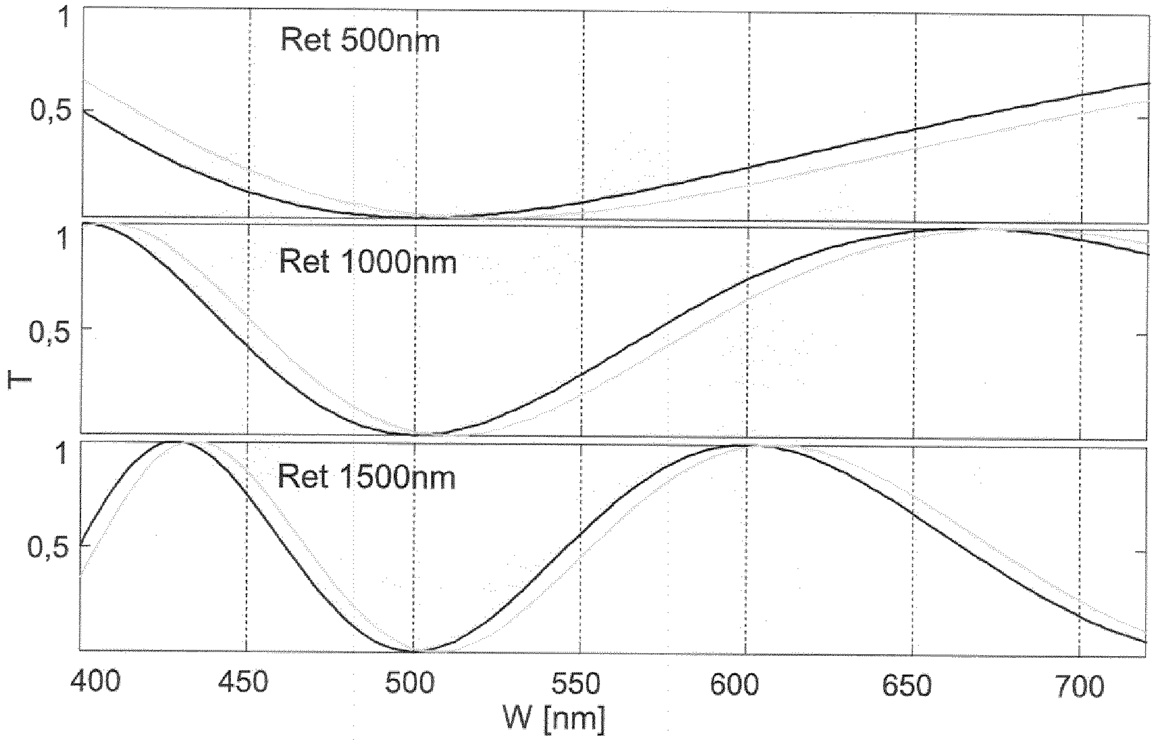
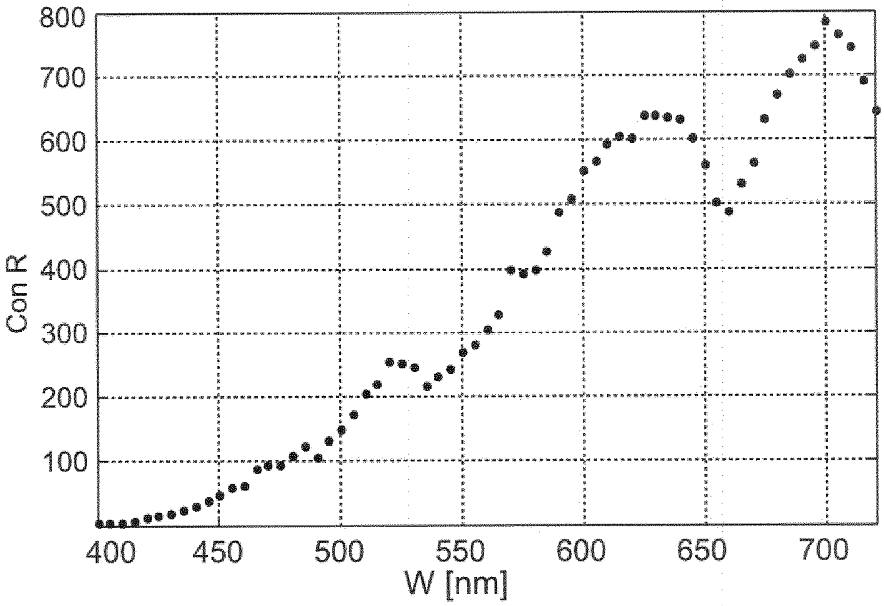

400 nm
500 nm
600 nm
700 nm
a
b
200
400
600
800
1000
1200
1400
1600
1800
2000
Ret. [nm]

Fig. 4



Ret 500nm
Ret 1000nm
Ret 1500nm
1
0,5
1
0,5
1
0,5
T
400
450
500
550
600
650
700
W [nm]

Fig. 5



800
700
600
500
400
300
200
100
Con R
400
450
500
550
600
650
700
W [nm]

Fig. 6

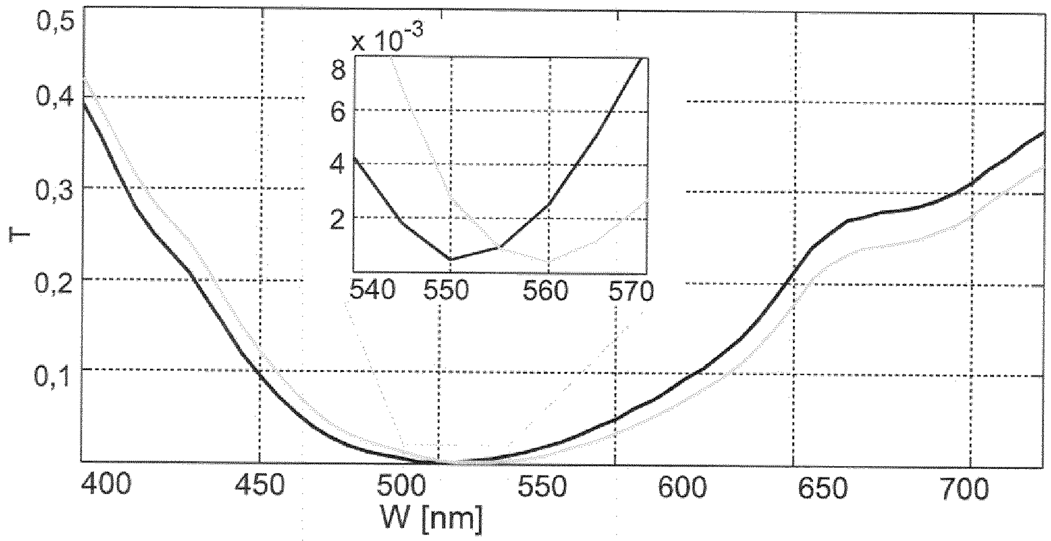

0,5
0,4
0,3
0,2
0,1
T
400
450
500
550
600
650
700
W [nm]
x 10^-3
8
6
4
2
540
550
560
570

Fig. 7

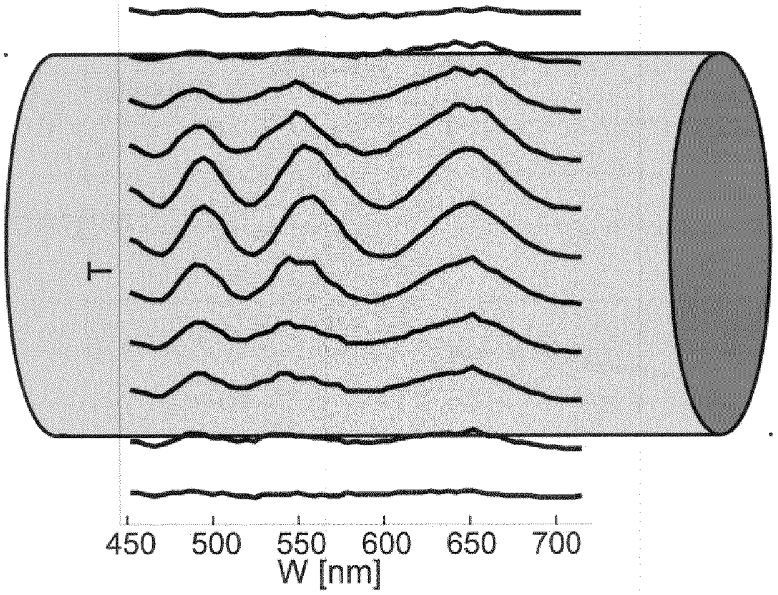
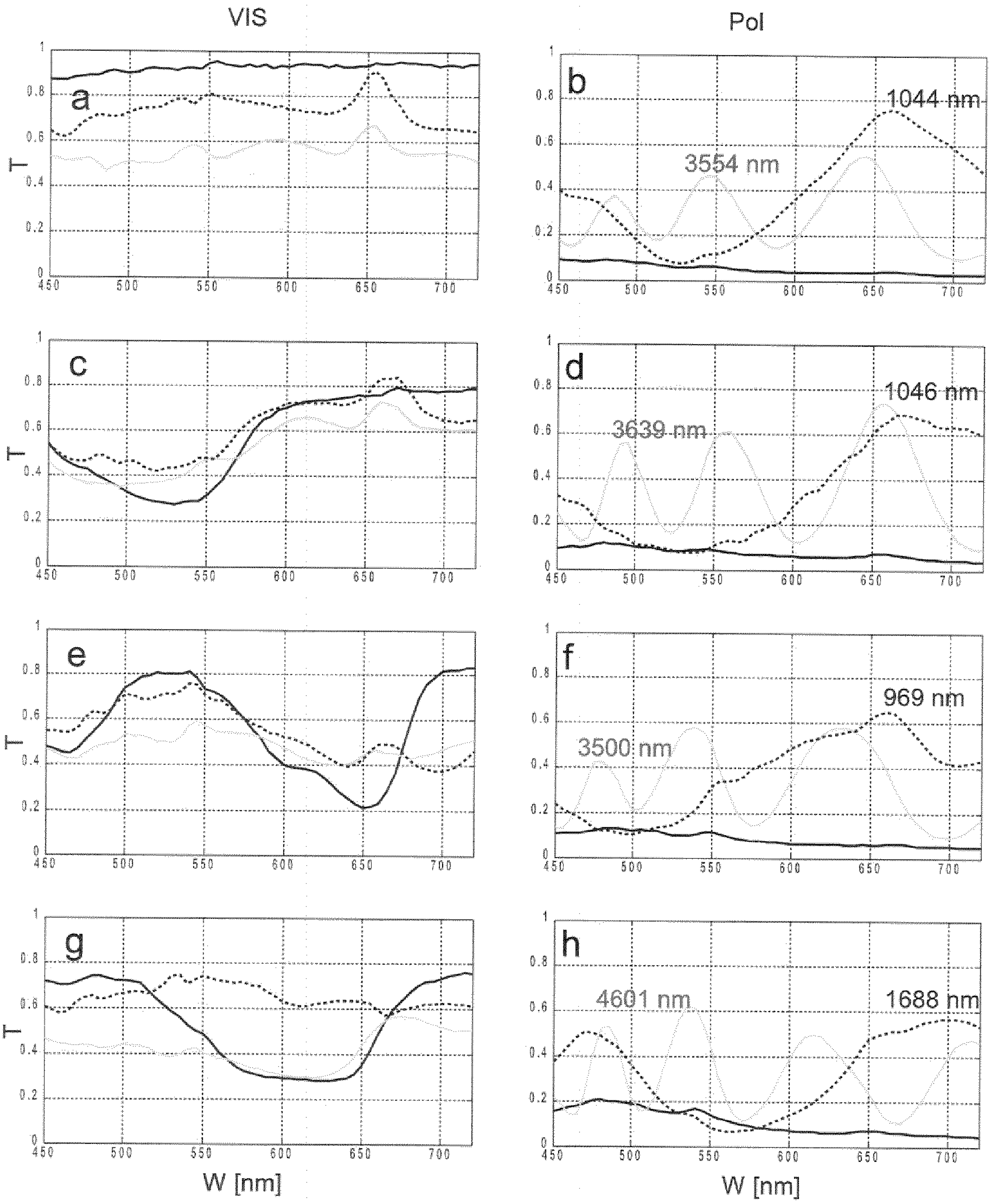


Fig 8


VIS
Pol
a
b
c
d
e
f
g
h
T
W [nm]
1044 nm
3554 nm
1046 nm
3639 nm
969 nm
3500 nm
4601 nm
1688 nm
0
0.2
0.4
0.6
0.8
1
450
500
550
600
650
700

ABSTRACT

The invention relates to an apparatus for analyzing birefringent samples. The apparatus having an illumination system comprising a first polarizer for providing an illumination beam with a first polarization direction to a sample and an analyzer provided with a second polarizer in front of an image sensor for analyzing light received from the sample. The polarization direction of the second polarizer is being crossed with respect to the first polarization direction. The analyzer comprises a spectrometric filter to analyze the polarization color of the fibers.

SAMENWERKINGSVERDRAG (PCT)

RAPPORT BETREFFENDE NIEUWHEIDSONDERZOEK VAN INTERNATIONAAL TYPE

IDENTIFICATIE VAN DE NATIONALE AANVRAGE	KENMERK VAN DE AANVRAGER OF VAN DE GEMACHTIGDE **P31740NL00/JFL**
Nederlands aanvraag nr. **2013443**	Indieningsdatum **09-09-2014**
	Ingeroepen voorrangsdatum
Aanvrager (Naam) **Nederlands Forensisch Instituut**	
Datum van het verzoek voor een onderzoek van internationaal type **29-11-2014**	Door de Instantie voor Internationaal Onderzoek aan het verzoek voor een onderzoek van internationaal type toegekend nr. **SN63104**

I. CLASSIFICATIE VAN HET ONDERWERP (bij toepassing van verschillende classificaties, alle classificatiesymbolen opgeven)

Volgens de internationale classificatie (IPC)

G01N21/23;G01J4/00;G01N33/36

II. ONDERZOCHTE GEBIEDEN VAN DE TECHNIEK

Onderzochte minimumdocumentatie

Classificatiesysteem	Classificatiesymbolen
IPC	**G01N;G01J**

Onderzochte andere documentatie dan de minimum documentatie, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

III.	☐	**GEEN ONDERZOEK MOGELIJK VOOR BEPAALDE CONCLUSIES**	(opmerkingen op aanvullingsblad)
IV.	☐	**GEBREK AAN EENHEID VAN UITVINDING**	(opmerkingen op aanvullingsblad)

Form PCT/ISA 201 A (11/2000)

ONDERZOEKSRAPPORT BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

Nummer van het verzoek om een onderzoek naar de stand van de techniek
NL 2013443

A. CLASSIFICATIE VAN HET ONDERWERP
INV. G01N21/23 G01J4/00 G01N33/36
ADD.

Volgens de Internationale Classificatie van octrooien (IPC) of zowel volgens de nationale classificatie als volgens de IPC.

B. ONDERZOCHTE GEBIEDEN VAN DE TECHNIEK

Onderzochte miminum documentatie (classificatie gevolgd door classificatiesymbolen)
G01N G01J

Onderzochte andere documentatie dan de mimimum documentatie, voor dergelijke documenten, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

Tijdens het onderzoek geraadpleegde elektronische gegevensbestanden (naam van de gegevensbestanden en, waar uitvoerbaar, gebruikte trefwoorden)

EPO-Internal, WPI Data, INSPEC

C. VAN BELANG GEACHTE DOCUMENTEN

Categorie °	Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages	Van belang voor conclusie nr.
X	US 2006/170907 A1 (TUSCHEL DAVID [US]) 3 augustus 2006 (2006-08-03) * alineas [0002], [0005], [0014] - [0024], [0038]; figuur 1 * -----	1-16
A	US 7 952 711 B1 (CHEN XIAOJUN [US] ET AL) 31 mei 2011 (2011-05-31) * kolom 7, regels 25-27; figuur 1 * -----	4,10,16
A	US 2012/176617 A1 (JACKSON ANDREW ROBERT WILLIAM [GB] ET AL) 12 juli 2012 (2012-07-12) * alineas [0001], [0002] * -----	10,14,15
A	US 5 828 500 A (KIDA ATSUSHI [JP] ET AL) 27 oktober 1998 (1998-10-27) * kolom 3, regel 52 - kolom 5, regel 11; figuur 1 * ----- -/--	4,16

☒ Verdere documenten worden vermeld in het vervolg van vak C.

☒ Leden van dezelfde octrooifamilie zijn vermeld in een bijlage

° Speciale categorieën van aangehaalde documenten

"A" niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft

"D" in de octrooiaanvrage vermeld

"E" eerdere octrooi(aanvrage), gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven

"L" om andere redenen vermelde literatuur

"O" niet-schriftelijke stand van de techniek

"P" tussen de voorrangsdatum en de indieningsdatum gepubliceerde literatuur

"T" na de indieningsdatum of de voorrangsdatum gepubliceerde literatuur die niet bezwarend is voor de octrooiaanvrage, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding

"X" de conclusie wordt als niet nieuw of niet inventief beschouwd ten opzichte van deze literatuur

"Y" de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geciteerde literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht

"&" lid van dezelfde octrooifamilie of overeenkomstige octrooipublicatie

Datum waarop het onderzoek naar de stand van de techniek van internationaal type werd voltooid 20 april 2015	Verzenddatum van het rapport van het onderzoek naar de stand van de techniek van internationaal type
Naam en adres van de instantie European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	De bevoegde ambtenaar Duijs, Eric

1

ONDERZOEKSRAPPORT BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

Nummer van het verzoek om een onderzoek naar de stand van de techniek
NL 2013443

C.(Vervolg). VAN BELANG GEACHTE DOCUMENTEN

Categorie °	Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages	Van belang voor conclusie nr.
A	US 2013/070331 A1 (DEWA PAUL G [US] ET AL) 21 maart 2013 (2013-03-21) * alineas [0002], [0007] - [0011] * -----	2,3,16

1

Formulier PCT/ISA/201 (vervolg tweede blad) (Januari 2004)

ONDERZOEKSRAPPORT BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

Informatie over leden van dezelfde octrooifamilie

Nummer van het verzoek om een onderzoek naar de stand van de techniek
NL 2013443

In het rapport genoemd octrooigeschrift	Datum van publicatie	Overeenkomend(e) geschrift(en)	Datum van publicatie
US 2006170907 A1	03-08-2006	GEEN	
US 7952711 B1	31-05-2011	GEEN	
US 2012176617 A1	12-07-2012	EP 2452179 A2	16-05-2012
		GB 2467810 A	18-08-2010
		US 2012176617 A1	12-07-2012
		WO 2011004139 A2	13-01-2011
US 5828500 A	27-10-1998	GEEN	
US 2013070331 A1	21-03-2013	EP 2758827 A1	30-07-2014
		US 2013070331 A1	21-03-2013
		WO 2013043386 A1	28-03-2013

WRITTEN OPINION

File No. SN63104	Filing date *(day/month/year)* 09.09.2014	Priority date *(day/month/year)*	Application No. NL2013443

International Patent Classification (IPC)
INV. G01N21/23 G01J4/00 G01N33/36

Applicant
Nederlands Forensisch Instituut

This opinion contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☒ Box No. VII Certain defects in the application
- ☒ Box No. VIII Certain observations on the application

Examiner
Duijs, Eric

Application number
NL2013443

WRITTEN OPINION

Box No. I Basis of this opinion

1. This opinion has been established on the basis of the latest set of claims filed before the start of the search.
2. With regard to any **nucleotide and/or amino acid sequence** disclosed in the application and necessary to the claimed invention, this opinion has been established on the basis of:

   a. type of material:

   ☐ a sequence listing

   ☐ table(s) related to the sequence listing

   b. format of material:

   ☐ on paper

   ☐ in electronic form

   c. time of filing/furnishing:

   ☐ contained in the application as filed.

   ☐ filed together with the application in electronic form.

   ☐ furnished subsequently for the purposes of search.

3. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.
4. Additional comments:

Box No. V Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty	Yes:	Claims	2-4, 7, 10, 14, 16
	No:	Claims	1, 5, 6, 8, 9, 11-13, 15
Inventive step	Yes:	Claims	
	No:	Claims	1-16
Industrial applicability	Yes:	Claims	1-16
	No:	Claims	

2. Citations and explanations

see separate sheet

WRITTEN OPINION

Box No. VII Certain defects in the application

see separate sheet

Box No. VIII Certain observations on the application

see separate sheet

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1 Reference is made to the following documents:

D1	US 2006/170907 A1 (TUSCHEL DAVID [US])
D2	US 7 952 711 B1 (CHEN XIAOJUN [US] ET AL)
D3	US 2012/176617 A1 (JACKSON ANDREW ROBERT WILLIAM [GB] ET AL)
D4	US 5 828 500 A (KIDA ATSUSHI [JP] ET AL)
D5	US 2013/070331 A1 (DEWA PAUL G [US] ET AL)

2 **Lack of novelty and lack of inventive step**

The present application does not meet the criteria of patentability, because the subject-matter of **claims 1, 5, 6, 8, 9, 11-13 and 15** is not new, and because the subject-matter of **claims 1-16** does not involve an inventive step:

2.1 **Independent APPARATUS claim 1**:

2.1.1 **D1** discloses an:

Inrichting (FIG. 1; par. 2, 5, 14, 15) *voor het analyseren van een dubbelbrekend monster* 100, *welke inrichting omvat:*
-- *een monsterhouder* 105 (par. 15) *voor het vasthouden van het monster* 100*;*

-- *een belichtingsstelsel omvattende een eerste polarisator* 102 (par. 20) *met een eerste polarisatierichting voor het verschaffen van een stralingsbundel met de eerste polarisatierichting aan het monster* 100*; en,*
-- *een analysator voor het analyseren van ontvangen straling* 118 (par. 19) *van het monster* 100, *de analysator omvattende een tweede polarisator* 103 (par. 20) *met een tweede polarisatierichting en*

-- *een beeldsensor* 145 (par. 24) *voor het ontvangen van straling* 118 *van de tweede polarisator* 103,

-- *waarbij de tweede polarisatierichting wordt gekruist ten opzichte van de eerste polarisatierichting* (par. 20: "The second polarizing filter 103 is oriented 90° with respect to the first polarizing filter 102") *en*

-- *de inrichting omvat een golflengte tuner* 140 (par. 23) *voor het analyseren van een polarisatiekleur van het dubbelbrekende monster* 100 *met de beeldsensor* 145.

Hence the subject-matter of **claim 1** is not new.

2.2 **Independent METHOD claim 15**:

D1 discloses a:

Werkwijze voor het analyseren van een dubbelbrekend monster 100 (par. 1, 5, 15), *welke werkwijze omvat:*
-- *het verschaffen van het monster* 100 *in een monsterhouder* 105 (par. 15);

-- *het verlichten van het monster* 100 *met een stralingsbundel met een eerste polarisatierichting* (par. 20: polarizing filter 102);
-- *het toestaan van straling* 118 (par. 19) *ontvangen van het monster* 100 *om een tweede polarisator* 103 (par. 20) *met een tweede polarisatierichting loodrecht op de eerste polarisatierichting te doorkruisen om een beeldsensor* 145 (par. 24) *te bereiken;*
-- *het nemen van beelden van de straling van de vezels [het monster* 100*] met de beeldsensor* 145 *terwijl selectief af te stemmen op een andere golflengte om de beeldsensor* 145 *te bereiken* (par. 23, 24).

Hence the subject-matter of **claim 15** is not new.

2.3 **Dependent claims 2-14 and 16** do not contain any features which, in combination with the features of any claim to which they refer, meet the requirements of novelty and/or inventive step:

-- **Claims 2, 3, 16**: it would be obvious for the skilled person of **D1**, to allow measurement with non-polarized light, differently polarized light, or parallel polarizers, to use a polarization switching apparatus as disclosed in **D5** (par. 7-11);

-- **Claims 4, 16**: it would be obvious for the skilled person of **D1**, to allow measurement with non-polarized light, differently polarized light, or parallel polarizers, by rotating the polarizer 102 and/or 103, as is generally known in the art of polarization spectroscopy (e.g. see **D2**, FIG. 1 or **D4**, FIG. 1, col. 5, l. 1-6);

-- **Claim 5**: see **D1** (FIG 1; par. 18: "white light source 101"; par. 23: "tunable filter 140 ... LCTF");

-- **Claim 6**: see **D1** (FIG 1; par. 15: "sampe 100"; par. 18: "white light source 101"; par. 23: "tunable filter 140 ... LCTF");

-- **Claim 7**: obvious alternative position of the LCTF in view of **D1** (FIG 1; par. 15: "sampe 100"; par. 18: "white light source 101"; par. 23: "tunable filter 140 ... LCTF");

-- **Claims 8, 9**: see **D1** (par. 23: "tunable filter 140 ... LCTF");

-- **Claim 10**: obvious alternative means to provide polychromatic light in view of **D1** (FIG 1; par. 18: "white light source 101"; par. 23: "tunable filter 140 ... LCTF") and e.g. see **D2** (col. 7, l. 25-27);

-- **Claims 11, 12**: see **D1** (par. 23: "The tunable filter 140 is responsive to second control signals, generated by the processor 150, wherein the second control signals establish the predetermined wavelength bands"; par. 24: "The first detector 145 is responsive to third control signals generated by the processor 150.... In one embodiment, the two-dimensional array of detection elements 145 produces digital images of the entire view of the sample as processed by tunable filter 140"; par. 38);

-- **Claim 13**: see **D1** (FIG 1: polarizing filter 102 --> sample 100 --> polarizing filter 103);

-- **Claim 14**: obvious selection of a sample in view of **D1** (par. 15: "sample 100") and **D3** (par. 1, 2: "forensic analysis of fibres found at crime scenes", "fibres (e.g. as used in fabrics) are also birefringent").

Re Item VII

Certain defects in the application

3 The relevant background art disclosed in **D1** is not mentioned in the description, nor is this document identified therein.

4 The features of the claims are not provided with **reference signs** placed in parentheses.

5 Names, trademarks or trade names, such as "**Matlab**", used in the description on p. 10, l. 23, should be identified as such by providing them with the symbol ® or ™.

Re Item VIII

Certain observations on the application

6 The reference to "*de vezel*" in **claim 10** is unclear. It appears that **claim 10** should have been made dependent on **claim 14**.

7 The reference to "*de vezels*" in the last two lines of **claim 15** is unclear. It appears that "*de vezels*" should have replaced with "*de monsters*".

8 The subject-matter of **claim 4** is unclear, since **claim 1** stipulates that a crossed polarisation arrangement is used in the present invention, whereas according to **claim 4** the polarization directions may be changed such that there is no crossed polarisation arrangement.