[0005] Dry eye analysis can be considered as cornea and ambient tissue physical property changes. Corneal dystrophies, aging and diseases, however, can complicate dry eye analysis as the physical property changes due to disease or aging may relate to the cornea as well as the ambient tissues' components' (e.g., hydration, collagen and keratocytes) changes or corneal component non-uniformity changes.

[0006] Conventional methods and systems for monitoring chemical components changes in cornea as well as ambient tissues still focus on monitoring the surface of cornea as well as ambient tissues. However, to fully characterize a subject's dry eye mechanism, it is crucial and significant that the overall eye evaluation necessarily include corneal as well as ambient tissue layer thickness changes and chemical components changes resolved into individual layers.

[0007] Thus, what is needed are systems and methods for dry eye analysis which evaluates corneal and ambient tissue layer thickness changes and chemical components changes within individual layers of a subject's eye with enhanced sensitivity and selectivity. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

SUMMARY

[0008] According to at least one embodiment of the present invention, a dry eye analysis system using terahertz (THz) radiation is provided. The system includes a terahertz radiation measuring system, a smart box interface, and a signal processing unit. The terahertz radiation measuring system includes a terahertz radiation generator configured to project a THz wave onto a surface of an eye, a stage configured to focus the THz wave to the surface of the eye or a layer below the surface of the eye, and a terahertz radiation detector

configured to detect a reflected THz wave. The terahertz radiation generator includes an optical delay line configured to provide a sampling rate of the THz wave of at least 150Hz. The reflected wave is a reflection of the projected THz wave reflected from the surface of the eye or a layer below the surface of the eye as a result of projecting the THZ wave onto the surface of the eye. The smart box interface is between the THz wave and the eye. The smart box interface includes a smart box having a low refractive index material and/or a hydration absorption material for enhancement of sensitivity or selectivity of analysis of properties of the one or more layers of the eye. The signal processing unit includes a computing device. The signal processing unit is configured to communicate with the terahertz radiation detector to analyse the properties of one or more layers of the eye in response to the THz wave reflected from the surface of the eye or a layer below the surface of the eye. The properties of the one or more layers of the eye include a thickness of the eye's cornea and ambient tissues and an amount of a plurality of chemical components in the one or more layers of the eye. The signal processing unit is further configured to extract the analyzed properties of the one or more layers of the eye.

[0009] According to another embodiment of the present invention, a dry eye analysis method using THz radiation is provided. The method includes projecting a THz wave onto a surface of an eye such that a sampling rate of the THz wave is at least 150Hz; focusing the THz wave to the surface of the eye or a layer below the surface of the eye; and detecting a reflected wave being a reflection of the projected THz wave reflected from the surface of the eye or a layer below the surface of the eye as a result of projecting the THz wave onto the surface of the eye. The method further includes determining properties of one or more layers of the eye in response to the THz wave reflected from the surface of the eye or a layer below the surface of the eye, the properties of the one or more layers of the eye including a thickness of the eye's cornea and ambient tissues and an amount of a plurality of chemical components in the one or more layers of the eye, and extracting the properties of the one or

more layers of the eye. Projecting the THz wave onto the surface of the eye includes disposing a smart box interface between the THz wave and the eye. The smart box interface includes a smart box having a low refractive index material and/or a hydration absorption material for enhancement of sensitivity or selectivity of analysis of the properties of the one or more layers of the eye.

[0010] According to a further embodiment of the present invention, a computer readable medium comprising instructions which, when executed by a system, make the system perform the dry eye analysis method using THz radiation as described is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views and which together with the detailed description below are incorporated in and form part of the specification, serve to illustrate various embodiments and to explain various principles and advantages in accordance with a present embodiment.

[0012] FIG. 1 depicts an illustration of a terahertz radiation measuring system in accordance with present embodiments.

[0013] FIG. 2 depicts a flowchart of a method for dry eye analysis in accordance with the present embodiments using the terahertz radiation measuring system of FIG. 1.

[0014] FIG. 3 depicts an illustration of a system for dry eye analysis in accordance with the present embodiments using the terahertz radiation measuring system of FIG. 1.

[0015] FIG. 4 depicts a planar cross-sectional view of a smart box interface for use with the system of FIG. 3 to enhance sensitivity and/or selectivity of dry eye analysis of an eye in accordance with the present embodiments.

[0016] FIG. 5 depicts a graph of terahertz radiation signals of hydroxide bonds and free liquid water at different concentrations as measured by the system of FIG. 3 in accordance with the present embodiments.

CLAIMS

1. A dry eye analysis system using terahertz (THz) radiation, the system comprising:

a terahertz radiation measuring system comprising:

a terahertz radiation generator configured to project a THz wave onto a surface of an eye, the terahertz radiation generator comprising an optical delay line configured to provide a sampling rate of the THz wave of at least 150Hz;

a stage configured to focus the THz wave to the surface of the eye or a layer below the surface of the eye; and

a terahertz radiation detector configured to detect a reflected THz wave, said reflected THz wave being a reflection of the projected THz wave reflected from the surface of the eye or a layer below the surface of the eye as a result of projecting the THZ wave onto the surface of the eye;

a smart box interface between the THz wave and the eye, the smart box interface comprising a smart box comprising a low refractive index material and/or a hydration absorption material for enhancement of sensitivity or selectivity of analysis of properties of the one or more layers of the eye; and

a signal processing unit comprising a computing device, the signal processing unit configured to communicate with the terahertz radiation detector to analyze the properties of one or more layers of the eye in response to the THz wave reflected from the surface of the eye or a layer below the surface of the eye, the properties of the one or more layers of the eye comprising a thickness of the eye's cornea and ambient tissues and an amount of a plurality of chemical components in the one or more layers of the

eye, wherein the signal processing unit is further configured to extract the analyzed properties of the one or more layers of the eye.

2. The system in accordance with Claim 1, wherein the chemical components of the eye's layers comprise a chemical component selected from collagen, hydration and keratocytes.

3. The system in accordance with Claim 1, wherein the computing device is configured to calculate a relative corneal composition of the chemical components in the eye's cornea.

4. The system in accordance with Claim 1, wherein the computing device is configured to determine an absolute corneal composition of the chemical components at positions of different cornea layer interfaces using a predefined calibration method, and wherein the different cornea layer interfaces comprise an interface between the eye's cornea and a layer selected from an epithelium layer, a stromal layer, and an endothelium layer.

5. The system in accordance with Claim 4, wherein the computing device is configured to calculate a point value that is an absolute corneal hydration for at least one local region of the eye's cornea.

6. The system in accordance with Claim 1, wherein the computing device is configured to calculate an overall average of one or both of the thickness or the chemical components of the eye's cornea in response to the THz wave reflected from

the surface of the eye or a layer below the surface of the eye using a predetermined model.

7. The system in accordance with any of the preceding claims, wherein the terahertz radiation measuring system further comprises an illumination optical system coupled to the terahertz radiation generator to provide oblique-angle terahertz radiation illumination of the surface of the eye and coupled to the terahertz radiation detector to provide the reflected wave thereto.

8. The system in accordance with Claim 7, wherein the illumination optical system comprises two off-axis parabolic (OAP) mirrors,

wherein a first mirror of the two OAP mirrors is arranged in an optical path of the terahertz radiation generator and is configured to receive the THz wave emitted from the terahertz radiation generator and reflect at least a portion of the THz wave to project the at least a portion of the THz wave onto the surface of the eye, and

wherein a second mirror of the two OAP mirrors is arranged in a symmetrical position to the first mirror with respect to the eye and is configured to receive at least a portion of the THz wave reflected from the eye.

9. The system in accordance with any of the preceding claims, wherein the terahertz radiation detector is configured to detect the reflected wave within a frequency band of 0.1 THz to 10 THz.

10. The system in accordance with any of the preceding claims, wherein the terahertz radiation generator further comprises:

a femtosecond laser configured to generate the THz wave; and

a terahertz radiation signal emitter configured to emit the THz wave onto the surface of the eye.

11. A dry eye analysis method using terahertz (THz) radiation, the method comprising the steps of:

projecting a THz wave onto a surface of an eye such that a sampling rate of the THz wave is at least 150Hz;

focusing the THz wave to the surface of the eye or a layer below the surface of the eye;

detecting a reflected THz wave being a reflection of the projected THz wave reflected from the surface of the eye or a layer below the surface of the eye as a result of projecting the THz wave onto the surface of the eye; and

determining properties of one or more layers of the eye in response to the THz wave reflected from the surface of the eye or a layer below the surface of the eye, the properties of the one or more layers of the eye comprising a thickness of the eye's cornea and ambient tissues and an amount of a plurality of chemical components in the one or more layers of the eye; and

extracting the properties of the one or more layers of the eye;

wherein projecting the THz wave onto the surface of the eye comprises disposing a smart box interface between the THz wave and the eye, the smart box interface comprising a smart box comprising a low refractive index material and/or a hydration absorption material for enhancement of sensitivity or selectivity of analysis of the properties of the one or more layers of the eye.

12. The method in accordance with Claim 11, wherein the chemical components of the eye's layers comprise a chemical component selected from collagen, hydration and keratocytes.

13. The method in accordance with Claim 11, wherein the step of determining the properties of the one or more layers of the eye comprises calculating a relative corneal composition of the chemical components in the eye's cornea.

14. The method in accordance with Claim 11, wherein the step of determining the properties of the one or more layers of the eye comprises determining an absolute corneal composition of the chemical components at positions of different cornea layer interfaces using a predefined calibration method, wherein the different cornea layer interfaces comprise an interface between the eye's cornea and a layer selected from an epithelium layer, a stromal layer, and an endothelium layer.

15. The method in accordance with Claim 14, wherein determining the absolute corneal composition of the chemical components comprises calculating a point value that is an absolute corneal hydration for at least one local region of the eye's cornea.

16. The method in accordance with Claim 14, wherein determining the absolute corneal composition of the chemical components comprises calculating an overall average of one or both of the thickness or the chemical components of the eye's cornea in response to the THz wave reflected from the surface of the eye or a layer below the surface of the eye using a predetermined model.

17. A computer readable medium comprising instructions which, when executed by a system, make the system perform the dry eye analysis method using terahertz (THz) radiation according to any one of Claims 11 to 16.