

A NON-DESTRUCTIVE SYSTEM AND METHOD FOR DETERMINING THE QUALITY OF CHINESE HERB USING TERAHERTZ TIME-DOMAIN SPECTROSCOPY

FIELD OF THE INVENTION

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The present invention relates to a system and method for non-destructively determining the quality of Chinese herb. More particularly, the present invention relates to a system and method for non-destructively determining the quality of Chinese herb housed in packaging, using terahertz time-domain spectroscopy.

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BACKGROUND

Chinese herb has been used as herbal remedy in eastern Asia for at least 2000 years due to its therapeutic effects, which are attributable to anticancer, antidiabetic, antistress, antioxidant, and immunomodulatory activities. It was revealed that the pharmacological effects of Chinese herb vary according to its cultivation age and the parts used. Compared to young plants, aged Chinese herb plants exert stronger pharmaceutical value. Quality assessments of Chinese herb are important since its content of bioactive compounds varies with the cultivation age. Authentication of Chinese herb has been mainly performed by assessing, morphological characteristics, smell, or taste. Conventionally, the age of Chinese herb is determined depending mainly on morphological properties.

For example, traces left on the head and rhizome of Chinese herb roots, the development of rootlets, and overall shapes of roots are analysed by naked eyes. Alternatively, annual rings are visualized with dye to determine the age of Chinese herb. Recently, near infrared spectroscopy and chromatography-mass spectroscopy has been introduced to determine the age of Chinese herb roots, but it is difficult to apply in practice because such method is destructive, it requires sample preparation and takes a long period of time.

Optical techniques can probe the individual atomic bonds within a molecule. Oscillations of these atomic bonds generate discrete vibrational modes which characterize the material; traditionally mid-infrared Fourier transform or Raman spectroscopic techniques have been used. However, it should be noted that Raman spectroscopy can create an additional serious problem in that the laser excitation can induce a phase change, or initiate photochemical reactions, in samples being interrogated, and fluorescence from

the sample may swamp any Raman signal. More recently, there has been an increased use of NIR spectroscopy; this presents problems in that the spectra obtained will consist of many combinations and overtone bands of the fundamental vibrations observed in the mid-infrared, making analysis difficult.

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Traditionally, quality control in pharmaceutical and food companies has been carried out after manufacturing by means of subsequent laboratory analysis. To improve consumer safety, several monitoring plans and protocols have been established by the European Commission on the basis of existing legislation. However, regulation systems are costly and entire batches need to be discarded when quality specifications are not fulfilled.

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Therefore, the need of analytical technologies that can be implemented throughout the whole manufacturing process encouraged the introduction of spectroscopic techniques such as far- and near-infrared (FIR, NIR) spectroscopy, Raman spectroscopy or nuclear magnetic resonance (N1VIR) in pharmaceutical companies, as well as microbiological, immunological and chromatographic methods in the medical and nutritional sector. Such techniques partially solved the problem, but still suffer from being too time-consuming, as the samples usually require pre-treatment before measurements and analysis could take place. Such techniques are also destructive and invasive, as either the analysed products require specific preparation or the same analysing technique is susceptible of affecting the chemical properties of the substances.

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Withal, the search for novel real-time, non-destructive, non-invasive detection devices stimulated further research in terahertz (THz) technologies, there is few information available on the nature of the THz spectra in many compounds. THz radiation is electromagnetic radiation lying between the microwave and the infrared ranges of the spectrum (usually 0.1-10 THz). Although this frequency band is present in our everyday life, it has remained unexplored until recently due to the lack of efficient and compact THz sources and detectors. The absence of suitable technology for this part of the spectrum led to the designation of the "THz gap". This technological gap has been narrowed down in the last decades due to major advances in both optical and microwave technologies.

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The THz range has gained its reputation due to the innumerable physical processes undergone by matter at these frequencies. A multitude of organic compounds and simple molecules do exhibit vibrational and rotational transitions, causing phonon resonance in crystalline structures and bond vibrations in general solids and liquids.

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It is therefore desirable to provide a system and method for non-destructively determining the quality of Chinese herb that seeks to address at least one of the problems described hereinabove, or at least to provide an alternative.

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SUMMARY OF INVENTION

In accordance with a first aspect of this invention, a system for non-destructively determining the quality of a Chinese herb housed in packaging is provided. The system
10 comprises a femtosecond laser source for generating terahertz pulses; a transmitter coupled to the femtosecond laser source for emitting terahertz radiation in response to the terahertz pulses; an optical system configured to illuminate terahertz radiation from the transmitter onto at least one surface of the Chinese herb housed in packaging and to receive the terahertz radiation reflected by or transmitted through the Chinese herb
15 housed in packaging to provide a return beam of terahertz radiation, and wherein the optical system further comprises a digital optical phase conjugation system configured to defocus the terahertz radiation to at least one sub-interface of the Chinese herb housed in packaging; a detector configured to detect and receive the return beam of terahertz radiation and generate an electrical signal in response to the return beam of terahertz
20 radiation; a signal processing system coupled to the detector, the signal processing system configured to process the generated signal into spectral data for determining the quality of the Chinese herb housed in packaging by comparing and matching the collected spectral data to a predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

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In one embodiment, the signal processing system comprises an algorithm for correlating the quality of the Chinese herb housed in packaging with respect to the predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

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In one embodiment, the optical system further comprises a first lens and a second lens arranged spaced apart along the optical path, wherein the first lens is configured to illuminate terahertz radiation from the transmitter onto the Chinese herb housed in packaging and the second lens is configured to receive the terahertz radiation reflected
35 by or transmitted through the Chinese herb housed in packaging to provide the return beam of terahertz signal.

In one embodiment, the optical system further comprises a first pair of off-axis parabolic mirrors coupled to the transmitter to focus the terahertz radiation onto the Chinese herb housed in packaging; and a second pair of off-axis parabolic mirrors coupled to the detector to pick up the terahertz radiation reflected from the Chinese herb housed in
5 packaging.

In one embodiment, the digital optical phase conjugation system is configured to defocus the terahertz radiation to at least one sub-interface of the Chinese herb housed in packaging to do a THz-time domain system sampling to obtain information about the
10 Chinese herb.

In accordance with a second aspect of this invention, a method of non-destructively determining the quality of a Chinese herb housed in packaging using terahertz time-domain spectroscopy is provided. The method comprises illuminating terahertz radiation
15 onto the Chinese herb housed in packaging; measuring a terahertz signal reflected from at least one surface of the packaging of the Chinese herb to obtain a first reading; shifting a focal point of the terahertz radiation onto a Chinese herb/packaging interface of the Chinese herb housed in packaging; measuring a terahertz signal reflected from the Chinese herb /packaging interface to obtain a second reading; defocusing the terahertz
20 radiation into the Chinese herb housed in packaging and measuring a terahertz signal reflected from the Chinese herb to obtain a third reading; carrying out Fast Fourier transform of the first, the second and the third readings and auto-correct the data using time domain delay to obtain a set of spectral data; calculating an absorption spectra based on the first, the second and the third readings; and determining the quality of the
25 Chinese herb housed in packaging by comparing and matching the collected set of spectral data and/or the absorption spectra to a predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

In one embodiment, the step of determining the quality of the Chinese herb housed in packaging includes determining at least one of the properties selected from the group consisting of type, purity, authenticity and composition of the Chinese herb housed in packaging by comparing and matching the collected set of spectral data to the predetermined database consisting of terahertz reflectance spectra information of
30 different types of Chinese herbs with different profiles.

In other embodiment, the step of determining the quality of the Chinese herb housed in packaging includes determining at least one of the properties selected from the group consisting of quality, age and hardness of the Chinese herb housed in packaging by comparing and matching the collected set of spectral data and the absorption spectra to
5 a predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

In one embodiment, the step of shifting the focal point is carried out by auto-aligning the terahertz beam using a digital optical phase conjugation system to defocus the terahertz
10 beam onto the Chinese herb/package interface.

BRIEF DESCRIPTION OF THE DRAWINGS

The above advantages and features of a system and method in accordance with this
15 invention are described in the following detailed description and are shown in the drawings:

Figure 1 is a block diagram of a system for non-destructively determining the quality of a Chinese herb housed in packaging according to an embodiment of the present invention.
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Figure 2 is a flow chart exemplifying the method of non-destructively determining the quality of a Chinese herb housed in packaging using the system in accordance with the present invention.

25 Figure 3 is a block diagram of a THz-TDS system for non-destructively determining the quality of a Chinese herb housed in packaging according to a variation of the system of the present invention.

Figure 4 is a diagram depicting defocusing of THz reflection onto and into sub-interfaces
30 of the Chinese herb housed in packaging.

Figure 5 is a picture showing an example of a Chinese herb, Lurong housed in packaging.

Figure 6 shows a THz spectral of the Chinese herb, Lurong housed in packaging
35 according to Figure 5.

Figure 7 shows a time domain spectral of the THz signal obtained from the surface of the packaging of the Chinese herb and from the defocused area.

Figure 8 shows the integration area from frequency domain for the detection peaks of the surface and the defocused area of the THz signal shown in Figure 7.

DETAILED DESCRIPTION

The present invention relates to a rapid, non-destructive, and non-contact technology for quality assessment of Chinese herbs. Embodiments of systems and methods of the present invention operate in the terahertz ("THz") range in the electromagnetic spectrum which lies between microwave and infrared frequencies and generally defines frequencies ranging from 100 GHz (10¹¹ Hz, 3 mm wavelength) to 10 THz (10¹³ Hz, 3.3 μm wavelength). Electromagnetic radiation in the THz range may also be referred to as THz light, THz radiation, or THz waveforms. In particular, the present invention relates to a system and a method for non-destructively determining the quality of Chinese herb housed in packaging, more particularly, using terahertz time-domain spectroscopy and/or designed terahertz portable system.

- In a first aspect of the present invention, a system for non-destructively determining the quality of a Chinese herb housed in packaging is provided. The system comprising:
- (a) a femtosecond laser source for generating terahertz pulses;
 - (b) a transmitter coupled to the femtosecond laser source for emitting terahertz radiation in response to the terahertz pulses;
 - (c) an optical system configured to illuminate terahertz radiation from the transmitter onto at least one surface of the Chinese herb housed in packaging and to receive the terahertz radiation reflected by or transmitted through the Chinese herb housed in packaging to provide a return beam of terahertz radiation, and wherein the optical system further comprises a digital optical phase conjugation system configured to defocus the terahertz radiation to at least one sub-interface of the Chinese herb housed in packaging;
 - (d) a detector configured to detect and receive the return beam of terahertz radiation and generate an electrical signal in response to the return beam of terahertz radiation;
 - (e) a signal processing system coupled to the detector, the signal processing system configured to process the generated signal into spectral data for determining the quality of the Chinese herb housed in packaging by comparing and matching the

collected spectral data to a predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

5 The transmitter is coupled to the femtosecond laser source for emitting THz radiation in response to the THz pulses. Any suitable type of transmitter can be used without departing from the scope of the present invention. Such transmitter includes terahertz antenna or a non-linear crystal. In the present invention, the transmitter is configured to emit THz radiation having a frequency range of 100 GHz to 10 THz.

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The optical system comprises a first lens and a second lens arranged in a spaced apart manner to define a first optical path, within which the Chinese herb housed in packaging is placed. The first lens is configured to illuminate THz radiation from the transmitter onto the Chinese herb housed in packaging. The second lens is configured to receive the THz radiation reflected by or transmitted through the Chinese herb housed in packaging to provide a return beam of THz radiation.

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The optical system further comprises an illuminating optical system configured to provide a second optical path between the transmitter and the first lens of the optical system.

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The illuminating optical system comprises a pair of off-axis parabolic mirrors arranged to provide an oblique-angle illumination of THz radiation from the transmitter to the first lens of the optical system, for illuminating the THz radiation onto the Chinese herb housed in packaging. The optical system further comprises a pick-up optical system configured to provide a third optical path between the detector and the second lens of the optical system. The pick-up optical system comprises a pair of off-axis parabolic mirrors arranged to provide an oblique-angle optical path for the return beam of THz radiation to travel from the second lens of the optical system to the detector. The optical system can be an open space optical system or a fiber connected optical system.

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30 The digital optical phase conjugation system is configured to defocus the THz radiation to at least one sub-interface of the Chinese herb housed in packaging to do the THz-time domain signal sampling so as to obtain the information about the Chinese herb. The term "sub-interface" as used herein refers to the Chinese herb/packaging interface **320** and an interface within the Chinese herb **322**.

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The digital optical phase conjugation system is used to focus on highly scattered media and therefore, capable of auto-aligning the THz radiation onto the Chinese herb housed

in the packaging. The time domain signal is used for self-correcting the frequency domain absorption peak intensity. The method of the present invention uses auto-defocus and auto-aligning to correct the package background.

- 5 The detector is coupled to the optical system. The detector is configured to detect the return beam of THz radiation within a frequency band of 0.1 THz to 10 THz. Once the return beam of THz radiation is received by the detector, the detector generates an electrical signal in response to the return beam of THz radiation which can be interpreted, scaled and/or digitized by a signal processing system. The signal processing system is
- 10 generally electrically coupled to the detector so as to receive the electrical signals from the detector. Any suitable type of detector can be used without departing from the scope of the present invention. Such detector includes terahertz antenna or a non-linear crystal.

- Either or both of the transmitter and the detector can be a terahertz antenna or a non-
- 15 linear crystal.

- The signal processing system comprises data storage means and processing means. In one embodiment, the data storage means stores database consisting of THz reflectance spectra information of different types of Chinese herbs with different profiles. The
- 20 processing means processes the signals generated from the detector into spectral data and determines the type and quality of the Chinese herb housed in packaging by comparing and matching the collected spectral data in response to the database consisting of THz reflectance spectra information of different types of Chinese herbs with different profiles. In other embodiments, the database may further include one or more
- 25 of the other predetermined parameters relating to the different types of Chinese herbs with different profiles. Such parameters include dielectric constants, absorption coefficient, refractive index and hydration absorption peaks.

- Inn one embodiment, the signal processing system comprises an algorithm for correlating the quality of the Chinese herb housed in packaging with respect to the predetermined database of THz reflectance spectra information of different types of Chinese herbs with different profiles. The quality of Chinese herbs that is to be determined by the system of the present invention includes, but not limited to, age, composition and purity. The algorithm can be further configured to identify the type of
- 30 Chinese herb housed in the packaging or to determine the authenticity of the Chinese herb. The algorithm can also be configured to detect dubious cases associated with abnormal components present in the Chinese herb, or abnormal quality elasticity or
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rigidity based on the THz signal differences of the Chinese herb with and without stress. More precisely, the detection of abnormal elasticity is performed by evaluating if the THz signal differences identity metrics as devised fall outside $\pm 10\%$ of an acceptable range.

- 5 The algorithm can be configured for determining other properties of the Chinese herbs using the terahertz spectral results and/or the terahertz parameters of the Chinese herbs derived from the method of the present invention. The identification of the type of Chinese herb and its quality is carried out by comparing and matching the information about the Chinese herb in response to the database consisting of THz reflectance spectra
10 information of different types of Chinese herbs with different profiles.

- In another aspect of the analysis, the detector seeks to pick up the THz signal difference between the Chinese herb with and without light source stress measured by the detector. The algorithm seeks to derive the Chinese herb parameters. More specifically, the
15 measurements on the elastic parameters are based on a set of calibrated equations relating to the THz signal difference between the Chinese herb with and without stress. The calibrated equation may be modelled by means of data-fitting the THz signal difference against the actual Chinese herb elastic.

- 20 In another embodiment, the signal processing system is configured to collate spectral data about Chinese herbs from the signals obtained from the system and method of the present invention. This allows database related to the Chinese herbs THz spectral to be built up. This in turns, allows auto-identification of the Chinese herbs to be realised.

- 25 In a second aspect of the present invention, a method of non-destructively determining the quality of a Chinese herb housed in a packaging using terahertz time-domain spectroscopy is provided. The method comprising illuminating terahertz radiation onto the Chinese herb housed in packaging; measuring a terahertz signal reflected from at least one surface of the packaging of the Chinese herb to obtain a first reading; shifting
30 a focal point of the terahertz radiation onto a Chinese herb/packaging interface of the Chinese herb housed in packaging; measuring a terahertz signal reflected from the Chinese herb/packaging interface to obtain a second reading; defocusing the terahertz radiation into the Chinese herb housed in packaging and measuring a terahertz signal reflected from the Chinese herb to obtain a third reading; carrying out Fast Fourier
35 transform of the first, the second and the third readings, and auto-correcting the data collected using time domain delay to obtain a set of spectral data; calculating an absorption spectra based on the first, the second and the third readings; and determining

the quality of the Chinese herb housed in packaging by comparing and matching the collected set of spectral data and/or absorption spectra to a predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

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In one embodiment, the THz radiation is reflected off the sample and sent as it is to the detector. However, it should be understood that the system and method disclosed in the present invention are equally applicable to transmitted radiation. In the latter embodiment, the transmitter sends THz radiation through the sample. Additionally, it should be understood that a system may incorporate the use of both transmitted and reflected radiation in a single system.

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The THz radiation illuminated onto the sample is a stress induced visible light beam. The stress induced light beam can be of any wavelength that falls within the visible light range for the purpose of introducing elastic stress over the surface of the Chinese herb housed in packaging. Preferably, the visible light beam is a collimated beam including laser or any other kinds of light beam. The incident and reflected THz signals are performed at an angle to Chinese herb surface. The visible light beam is preferred to incident at an angle perpendicular to the Chinese herb surface.

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In one embodiment, the step of determining the quality of the Chinese herb housed in packaging includes determining at least one of the properties selected from the group consisting of type, purity, authenticity and composition of Chinese herb. The step includes using the collected spectral data to obtain THz fingerprint and calibrated peak intensity of the sample, and correlating the data to the predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles to determine the selected property of the Chinese herbs.

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In another embodiment, the step of determining the quality of the Chinese herb housed in packaging includes determining at least one of the properties of the Chinese herb selected from the group consisting of quality, age and hardness of Chinese herb. The step includes using the collected spectral data and absorption spectra to derive parameters such as dielectric constants, absorption coefficient, refractive index, etc. of the sample and correlating the parameters to the predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles to determine the selected property of the Chinese herbs.

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In yet another embodiment, the step of determining includes identifying an abnormal Chinese herb by matching the profile of the sample of packaged Chinese herb with the profiles in the predetermined database. In a further embodiment, the step of determining may include identifying other quality indicators, including elastic, porosity, etc. of the Chinese herbs. In a further embodiment, hydration absorption peaks (typically between 1 THz to 2 THz) of the sample may be obtained, which can be used for hydration analysis of the Chinese herb.

In a further embodiment, the step of determining may include using cluster analysis to identify the Chinese herb housed in the packaging and assign the THz radiation reflectance spectra of the Chinese herb to the database of THz reflectance spectra information. This can be done by cluster analysis of the THz reflectance spectra information corresponding to the THz radiation reflected from the sample in respect to THz reflectance spectra information of the database of THz reflectance spectra information.

In one embodiment, the step of shifting the focal point includes auto-aligning the THz beam using a digital optical phase conjugation system to defocus the THz radiation onto the Chinese herb/package interface **320**. The terahertz signal reflected from the Chinese herb/package interface is then measured to obtain the second reading. The step of defocusing the THz radiation also includes auto-aligning the THz beam using the digital optical phase conjugation system to defocus the THz radiation to provide a focal point **322** within the Chinese herb. Depending on the hydration level of the Chinese herb, the THz radiation can penetrate deep into the Chinese herb or even transmit through the Chinese herb. One such example includes, but not limited to, dry ginseng. With the advanced THz technology, the THz source could be further enhanced to facilitate deeper penetration into the sample. For samples with high humidity, reflection subsurface THz propagation will be used for analysis. With time domain signal corrections, the THz transport parameters can be precisely calculated. Such parameters can be used for analysing the various properties of the Chinese herbs.

The method of the present invention is a self-correction method that uses time domain time-of-flight to precisely correct and calculate the distance X of THz beam passing through the sample. The data obtained is further used for calibration of absorption intensity. The data can also be used for calculation of absorption spectral, absorption coefficient, refractive index and dielectric constants.

The time domain signal is the distance of THz beam passing through the sample of Chinese herb. The time domain signal is used for correcting the frequency domain absorption peak intensity. The time domain signal is measured and the reading is used to calculate the parameters of the sample of Chinese herb, particularly the refractive index n and extinction coefficient k as shown below:

$$\tilde{\epsilon}(\omega) = \frac{\tilde{E}_{sam}(\omega)}{\tilde{E}_{ref}(\omega)} = \frac{2\tilde{n}(n_s + 1)\exp[i\omega(\tilde{n} - 1)d/c]\exp[i\omega(\tilde{n}_s - 1)d/c]}{(1 + \tilde{n})(\tilde{n} + n_s) + (1 - \tilde{n})(\tilde{n} - n_s)\exp(2i\omega\tilde{n}d/c)}$$

wherein $\tilde{n} = n + ik$ and d are the complex refractive index and thickness of nanonets, respectively. $\tilde{n}_s$ is the refractive index of substrate.

Based on the refractive index n , real optical path l of the THz wave propagated inside the sample can be extracted.

$$l = \frac{c\delta t}{n}$$

The absorption of the peak intensity can be correlated to the real optical path of the THz wave propagated inside the sample.

$$\frac{I}{I_0} = kl$$

Figure 1 shows an exemplary embodiment of the system according to present invention.

The system **100** comprises a femtosecond laser source **102**, a transmitter **104**, an optical system **106**, a digital optical phase conjugation system **108**, a detector **110** and a signal processing system **112**.

The optical system **106** comprises a first lens **114** and a second lens **116** arranged in a spaced-apart manner to define a first optical path **118**. A second optical path **120** is provided between the transmitter and the first lens and a first pair of off-axis parabolic mirrors (**122'**, **122''**) is arranged between the transmitter and the first lens to provide an oblique-angle illumination of THz radiation from the transmitter to the first lens. A third optical path **124** is provided between the detector and the second lens, and a second pair of off-axis parabolic mirrors (**126'**, **126''**) is also arranged between the detector and the second lens to provide an oblique-angle optical path for the return beam of THz radiation to travel from the second lens to the detector.

In one embodiment, the quality of Chinese herb housed in packaging is determined by first placing a sample of Chinese herb housed in packaging **128** in the first optical path of the system of the present invention. The system is activated by using the femtosecond laser source **102** to generate terahertz pulses to the transmitter **104**. The transmitter **104** receives the THz pulses and emits THz radiation in response to the THz pulses. The THz radiation travels through the second optical path **120** towards the first lens **114** of the optical system **106**. The first lens converges the THz radiation toward a point, called a focal point **130** on the sample of Chinese herb housed in packaging. The THz radiation is then reflected from the sample and received by the second lens **116**. The reflected THz radiation passes through the second lens **116** to provide a return beam of THz radiation. The return beam of THz radiation passes through a third optical path **124** towards the detector. The detector detects and receives the return beam of THz radiation and generates a signal indicative of the received THz radiation which is amplified and digitized by circuitry **132**. The signal processing system **112** that is coupled to the detector is configured to process the generated signal and may further be configured to create a visual imaging of the THz response from the sample of Chinese herb housed in packaging. The visual image can be reconstructed series of 2D images at different depth based on the spectral data.

Referring to Figure 2, a flow chart depicting an exemplary method for non-destructively determining the quality of a Chinese herb housed in a packaging using the system of the present invention is provided. The method comprises illuminating THz radiation onto a surface of the Chinese herb housed in packaging **202**, and collecting and measuring the THz radiation reflected from the surface of the Chinese herb **204**. A visible light beam is then shone onto the sample of Chinese herb. The THz radiation is defocused onto at least one sub-interface of the Chinese herb housed in packaging and the THz radiation reflected from the sub-interface is collected and measured **206**. The signals measured are subjected to Fast Fourier Transform and the data obtained is corrected by time domain delay. Spectral analysis is performed according to different frequency range **208**. In another aspect of the analysis, an absorption spectra of the measured signals is calculated. Dielectric and absorption spectral analysis is performed using algorithms to correlate the results obtained to the age and quality of the Chinese herb **210**.

The system of the present invention is portable. The system and method of the present invention is suitable for use in determining the quality and other properties of the Chinese herb including, but not limited to, age, composition, authenticity, purity, hydration, etc. of the Chinese herb. The system and method of the present invention can be applied to

Chinese herbs housed in any non-electrically conductive types of packaging including, but not limited to, plastic, paper, wool, cotton, ceramic, etc. ...

The system and method of the present invention provides a very effective and useful way of determining the quality of Chinese herb housed in packaging. The present invention is technologically significant in that it allows one to obtain the Chinese herb information rapidly, almost instantly, reliably, non-invasively on a simple platform with no external damages to the Chinese herb. Accurate measurement, detection and identification of the Chinese herb can be made without the need to open the packaging. No pre-treatment of the Chinese herb is required. This reduces costs and time in determining the quality or other attributes of the Chinese herbs. The system and method of the present invention also allows collation of data relating to various types of Chinese herbs. This allows the building up of data relating to Chinese herbs which is currently lacking in the industry. The collation of data helps to reduce the lack of information by adding analysis and data of reported as non-reported substances from the medical and nutritional sectors. At the same time, it is intended to prove the efficiency of the first commercially available THz spectrometer featuring portability and real-time data acquisition. Both objectives should bring evidence on the capabilities of this emerging technology. The present invention provides a more reliable system and method for determining the cultivation ages of Chinese herbs. It can be used to detect Chinese herbs of various shapes and sizes, and with irregular packaging.

To facilitate a better understanding of the present invention, the following examples of specific embodiments are given. In no way should the following examples be read to limit or define the entire scope of the invention. One skilled in the art will recognize that the examples set out below are not an exhaustive list of the embodiments of this invention.

EXAMPLE

Example 1

In this example, an embodiment of a system for non-destructive inspection of Chinese herb housed in packaging in accordance with the present invention which uses a THz time-domain system (THz-TDS) **300**, a computer or a system processing system **302** and an XYZ stage **304** is used, as shown in Figure 3.

The THz-TDS system **300** was configured to reflect electromagnetic radiation in terahertz range from the transmitter **306** towards a surface of the sample **308**. The THz radiation **310** reflected by the sample **308** was received by a detector **312**, and a signal indicative of the received radiation was generated by the detector and amplified by a lock-in amplifier **318**. In this example, the THz radiation was generated from a 1560-nm fs laser **314**. The computer **302**, which communicates with the THz-TDS system **300**, was configured to process the generated signal and the computer was further configured to create a visual imaging of the terahertz response from the sample. The XYZ stage **304** was configured to hold the sample **308** for scanning the sample **308** using the THz-TDS system **300** of the present invention and moving the terahertz focal point **316** to different areas of the sample.

Results:

In reflection configuration under a normal incidence, the incoming terahertz wave was reflected at the surface of the tested sample. In the frequency domain, the ratio between the sample and the reference spectra is then

$$\tilde{R} = |r| \exp(i\phi) = \frac{\tilde{n} - 1}{\tilde{n} + 1} = \frac{n + i\kappa - 1}{n + i\kappa + 1}$$

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The above equation can be inverted, and simple expression for the index of refractive and absorption coefficient can be found:

$$n = \frac{1 - |r|^2}{1 + |r|^2 - 2|r|\cos\phi},$$

$$\alpha = \frac{4\pi\nu}{c} \frac{2|r|\sin\phi}{1 + |r|^2 - 2|r|\cos\phi}$$

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Absorption peaks analysis and dielectric parameters analysis can be used to precisely determine the quality of the Chinese herbs.

In this example, Chinese herbs such as Lurong, Ginseng, Wu Weizi, Lingzhi were tested. The components and uniformity of the overall samples have been analysed. The results have been benchmarked with current literature and other available reports.

Figure 6 shows the frequency domain spectral obtained from a sample of packaged Chinese herb consisting of Lurong. The curves 402, 404 and 406 were obtained from the surface of the package, the Chinese herb/package interface and within the Chinese herb housed in the package, respectively. Lurong characterization peaks were identified and the intensity was calibrated. The results obtained were used for purity analysis. The characterization peaks can be selectively enhanced using meta-material patterns.

Figure 7 shows the time domain spectral of the THz signal taken from the surface of the sample and the defocused area within the sample. The chart shows that the peak shifted and intensity decreased from the detection of the surface of the sample to the defocused area.

Figure 8 shows integration area from frequency domain for the detection peaks of the surface and the defocused area of the THz signal shown in Figure 7. The integration area was corrected using the time domain peak shift, thereafter the integration area difference at different frequency range can be used for correlation to the quality of the Chinese herb. For example, the Chinese herb characterization peaks integration corrected by focus shift can be used for the purity analysis, while the hydration absorption is most likely to be focused at the 0.04THz to 0.8THz range, therefore the integration for this frequency range can be used to characterize the hydration level of the samples.

Although an embodiment of the present invention have been shown and described, the present invention is not limited to the described embodiments. Instead, it would be appreciated by those skilled in the art that changes may be made to the embodiments without departing from the scope of the invention, the scope of which is set forth in the following claims.

Claims:

1. A system for non-destructively determining the quality of a Chinese herb housed in packaging, the system comprising:

5 a femtosecond laser source for generating terahertz pulses;

a transmitter coupled to the femtosecond laser source for emitting terahertz radiation in response to the terahertz pulses;

an optical system configured to illuminate terahertz radiation from the transmitter onto at least one surface of the Chinese herb housed in packaging and to receive the terahertz radiation reflected by or transmitted through the Chinese herb housed in packaging to provide a return beam of terahertz radiation, and wherein the optical system further comprises a digital optical phase conjugation system configured to auto-aligning the terahertz radiation to defocus the terahertz radiation to at least one sub-interface of the Chinese herb housed in packaging;

15 a detector configured to detect and receive the return beam of terahertz radiation and generate an electrical signal in response to the return beam of terahertz radiation;

a signal processing system coupled to the detector, the signal processing system configured to process the generated signal into spectral data for determining the quality of the Chinese herb housed in packaging by comparing and matching the collected spectral data to a predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles, wherein the signal processing system comprises an algorithm for correlating the quality of the Chinese herb housed in packaging with respect to the predetermined database of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

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2. The system of claim 1, wherein the algorithm is configured to calculate an absorption spectra based on collected data and to determine at least one of the properties selected from the group consisting of quality, age and hardness of the Chinese herb housed in packaging by comparing and matching the collected spectral data and the absorption spectra to the predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

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3. The system of claim 1, wherein the algorithm is configured to determine at least one of the properties selected from the group consisting of type, purity, authenticity and composition of the Chinese herb housed in packaging by comparing and matching the collected spectral data of the Chinese herb housed in packaging to the predetermined

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database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

4. The system of claim 1, wherein the optical system further comprises a first lens and a second lens arranged spaced apart along the optical path, wherein the first lens is configured to illuminate terahertz radiation from the transmitter onto the Chinese herb housed in packaging and the second lens is configured to receive the terahertz radiation reflected by or transmitted through the Chinese herb housed in packaging to provide the return beam of terahertz signal.

5. The system of claim 4, wherein the optical system further comprises:
a first pair of off-axis parabolic mirrors coupled to the transmitter to focus the terahertz radiation onto the Chinese herb housed in packaging; and
a second pair of off-axis parabolic mirrors coupled to the detector to pick up the terahertz radiation reflected from the Chinese herb housed in packaging.

6. The system of claim 1, wherein the optical system is an open space optical system or a fiber connected optical system.

7. The system of claim 1, wherein the digital optical phase conjugation system is configured to defocus the terahertz radiation to at least one sub-interface of the Chinese herb housed in packaging to do a THz-time domain system sampling to obtain information about the Chinese herb.

8. The system of claim 1, wherein either or both of the transmitter and the detector comprise a terahertz antenna.

9. The system of claim 1, wherein either or both of the transmitter and the detector is a non-linear crystal.

10. The system of claim 1, wherein the detector is configured to detect and receive return beam of terahertz radiation within a frequency of 0.1 to 10 THz.

11. The system of claim 1, wherein the signal processing system is configured to detect abnormal components in the Chinese herb housed in packaging in response to the predetermined database consisting of terahertz reflectance spectra information of

different types of Chinese herbs with different profiles by evaluating if the differences in the terahertz signal identity metrics fall outside an acceptable predetermined range.

12. A method of non-destructively determining the quality of a Chinese herb housed in packaging using terahertz time-domain spectroscopy, the method comprising:

illuminating terahertz radiation onto the Chinese herb housed in packaging;
measuring a terahertz signal reflected from at least one surface of the packaging of the Chinese herb to obtain a first reading;

shifting a focal point of the terahertz radiation onto a Chinese herb/packaging interface of the Chinese herb housed in packaging;

measuring a terahertz signal reflected from the Chinese herb/packaging interface to obtain a second reading;

defocusing the terahertz radiation into the Chinese herb housed in packaging and measuring a terahertz signal reflected from the Chinese herb to obtain a third reading;

carrying out Fast Fourier transform of the first, the second and the third readings and auto-correct the data using time domain delay to obtain a set of spectral data;

calculating an absorption spectra based on the first, the second and the third readings; and

determining the quality of the Chinese herb housed in packaging by comparing and matching the collected set of spectral data and/or the absorption spectra to a predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles,

wherein the step of defocusing the terahertz radiation into the Chinese herb housed in packaging includes auto-aligning the terahertz radiation using a digital optical phase conjugation system to defocus the terahertz radiation into the Chinese herb housed in packaging.

13. The method of claim 12, wherein the step of determining the quality of the Chinese herb housed in packaging includes determining at least one of the properties selected from the group consisting of type, purity, authenticity and composition of the Chinese herb housed in packaging by comparing and matching the collected set of spectral data to the predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

14. The method of claim 12, wherein the step of determining the quality of the Chinese herb housed in packaging includes determining at least one of the properties selected from the group consisting of quality, age and hardness of the Chinese herb

housed in packaging by comparing and matching the collected set of spectral data and the absorption spectra to a predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

5 15. The method of claim 12, wherein the step of determining the quality of the Chinese herb housed in packaging further includes using the collected set of spectral data and absorption spectra to derive parameters selected from the group consisting of dielectric constants, absorption coefficient and refractive index and correlating the parameters to the predetermined database consisting of terahertz reflectance spectra
10 information of different types of Chinese herbs with different profiles to determine the selected property of the Chinese herb.

16. The method of claim 12, wherein the step of determining includes identifying an abnormal Chinese herb by matching the collected set of spectral data to the
15 predetermined database consisting of terahertz reflectance spectra information of different types of Chinese herbs with different profiles.

17. The method of claim 12, wherein the step of shifting the focal point is carried out by auto-aligning the terahertz beam using a digital optical phase conjugation system to
20 defocus the terahertz beam onto the Chinese herb/package interface.