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(54) **SOLID FORMS OF BERBERINE URSODEOXYCHOLATE AND COMPOSITIONS AND METHODS THEREOF**

FESTE FORMEN VON BERBERINURSODEOXYCHOLAT SOWIE ZUSAMMENSETZUNGEN UND VERFAHREN DAFÜR

FORMES SOLIDES DE BERBÉRINE URSODÉSOXYCHOLATE, COMPOSITIONS ET PROCÉDÉS ASSOCIÉS

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<b>WO-A1-2016/015634</b>	<b>WO-A1-2016/015634</b>
<b>CN-A- 102 229 636</b>	<b>CN-A- 105 693 805</b>
<b>CN-A- 105 693 805</b>	<b>US-A1- 2016 199 391</b>

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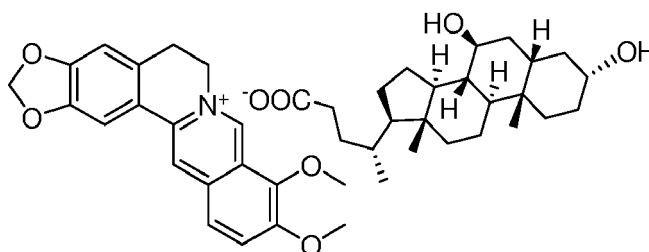
**[0001]** This application claims the benefit of priority to Chinese Application No. 201710335467.5, filed May 12, 2017.

**Technical Field of the Invention**

**[0002]** The invention generally relates to solid forms of berberine ursodeoxycholate, and to pharmaceutical compositions and methods of preparation and therapeutic uses thereof. In particular, the invention relates to solid forms (e.g., crystalline or amorphous forms) of berberine ursodeoxycholate and pharmaceutical compositions thereof useful in treating and/or preventing various diseases or disorders, including metabolic disorders, heart diseases, neurodegenerative diseases and liver diseases.

**Background of the Invention**

**[0003]** The compound berberine ursodeoxycholate "BBR-UDCA", represented by



Berberine ursodeoxycholate (BBR-UDCA)

was disclosed in WO 2016/015634A1 (PCT/CN2015/085350, filed July 28, 2015, priority date July 29, 2014).

**[0004]** Preparation of the compound was disclosed therein as were certain beneficial biological activities of the compound.

**[0005]** Solid forms are of particular interest in the development of suitable dosage forms of pharmaceuticals. It is desirable to have processes for producing a compound with the selected solid form in high purity when the compound is used in clinical studies or commercial products since impurities present may produce undesired toxicological effects. If a solid form is not held constant during clinical or stability studies, the exact dosage form used or studied may not be comparable from one lot to another.

**[0006]** Certain solid forms may also exhibit enhanced thermodynamic stability or may be more readily manufactured in high purity in large quantities, and thus are more suitable for inclusion in pharmaceutical formulations. Different solid forms of an active pharmaceutical ingredient can lead to changes in the drug's solubility, dissolution rate, pharmacokinetics and ultimately its bioavailability and efficacy in patients. Certain solid forms may display other advantageous physical properties such as lack of hygroscopic tendencies, filterability, improved solubility, and enhanced rates of dissolution due to different lattice energies.

**[0007]** Thus, finding which solid form is the most stable under each condition of interest and the processes that lead to changes in a solid form is crucial to the design of the drug manufacturing process in order to ensure that the final product is in its preferred solid form. There remains an ongoing need to identify novel solid forms having desirable physicochemical properties suitable for preparation and therapeutic use.

**Summary of the Invention**

**[0008]** The present invention provides novel solid form A of BBR-UDCA as defined in claims 1-10, having one or more desirable properties, such as high stability, high crystallinity, high purity, low hygroscopicity, favorable dissolution and/or favorable mechanical properties. In particular, solid forms of BBR-UDCA disclosed herein provide improved physical stability and/or physicochemical properties suitable for clinical studies, product manufacture and therapeutic use.

**[0009]** The solid forms disclosed herein can be utilized to treat various diseases or disorders, such as diabetes, diabetic complications, dyslipidemia, dyslipidemia in statin-intolerance patients, hyperlipidemia, hypercholesterolemia, hypertriglyceridemia, diabetic dyslipidemia, obesity, metabolic syndromes, pre-diabetes, heart diseases, neurodegenerative diseases, sarcopenia, muscle atrophy, inflammation, and cancers as well as various liver diseases or disorders, such

as fatty liver, non-alcoholic fatty liver disease, non-alcoholic steatohepatitis, cholestatic liver diseases or graft-versus-host disease of the liver. The compounds of this invention are also useful in improving liver functions in chronic viral associated liver diseases and alcohol-related liver diseases.

**[0010]** The invention relates to a solid form, which is Form A of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern as defined in claims 1-10.

**[0011]** Disclosed herein, but not forming part of the present invention is Form B of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 7.39, 9.31, 12.41, 13.14, 14.37, 14.76, 15.53, 18.65, 21.79, 22.87, 25.27, 25.53 and  $28.12^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0012]** Disclosed herein, but not forming part of the present invention is Form C of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 7.23, 10.42, 12.10, 13.37, 14.24, 14.48, 15.28, 15.95, 17.00, 18.17, 20.12, 21.77 and  $25.47^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0013]** Disclosed herein, but not forming part of the present invention is Form D of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 4.24, 6.79, 8.50, 10.25, 11.50, 13.62, 14.74, 15.20, 17.92, 18.39, 22.91 and  $25.73^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0014]** Disclosed herein, but not forming part of the present invention is Form E of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 8.59, 10.55, 11.36, 11.86, 12.46, 13.08, 13.38, 14.34, 15.57, 17.24, 17.72, 18.43, 19.66, 19.84, 20.35, 20.91, 21.36, 21.95, 23.21, 24.67, 25.04, 25.82, 26.12, 27.01, 27.84, 28.97, 30.35, 33.33, 34.54 and  $36.06^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0015]** Disclosed herein, but not forming part of the present invention is Form H of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 13.05, 14.63 and  $25.46^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0016]** Disclosed herein, but not forming part of the present invention is Form I of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 4.19, 7.64, 10.03, 13.32, 13.84, 14.83, 16.73, 22.73, 25.61 and  $28.57^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0017]** Disclosed herein, but not forming part of the present invention is Form J of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 4.61, 6.32, 7.38, 8.22, 9.21, 10.57, 11.73, 12.13, 12.62, 12.96, 13.87, 14.55, 14.78, 15.81, 16.48, 17.69, 18.39, 19.01, 20.06, 21.25, 22.13, 23.20, 24.47, 24.89, 26.31, 27.98, 30.25 and  $33.35^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0018]** Disclosed herein, but not forming part of the present invention is Form P of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 3.11, 5.01, 5.78, 7.26, 9.20, 10.10, 10.79, 11.65, 13.70, 14.59, 15.22, 16.19, 16.54, 17.05, 18.06, 18.68, 20.52, 21.09, 21.73, 22.49, 24.73, 25.42, 25.94 and  $30.11^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0019]** Disclosed herein, but not forming part of the present invention is Form W of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 6.49, 7.16, 8.51, 10.21, 12.01, 13.13, 13.90, 14.42, 15.18, 15.57, 16.03, 16.45, 16.74, 17.08, 17.85, 18.39, 19.61, 20.43, 21.39, 21.70, 23.51 and  $25.21^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0020]** Disclosed herein, but not forming part of the present invention is Form X of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 3.63, 6.61, 7.24, 10.49, 11.95, 13.51, 14.26, 14.54, 15.14, 16.01, 16.82, 18.28, 20.26, 21.08, 21.49, 21.90, 25.60, 26.40, 27.31, 29.34, 30.59, 31.01, 34.04, 34.68 and  $36.91^\circ (\pm 0.2^\circ)$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0021]** Form A of the invention relates to a solid form of hemi-nonahydrate of BBR-UDCA.

**[0022]** In yet another aspect, the invention generally relates to a composition comprising the solid form A of the invention.

**[0023]** In yet another aspect, the invention generally relates to a composition comprising two or more solid forms disclosed herein (i.e. Form A and one or more of or more of Forms B, C, D, E, H, I, J, P, W, and X).

**[0024]** In yet another aspect, the invention generally relates to a pharmaceutical composition comprising Form A of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0025]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form B of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0026]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising

Form C of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0027]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form D of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0028]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form E of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0029]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form H of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0030]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form I of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0031]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form J of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0032]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form P of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0033]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form W of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0034]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form X of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0035]** In yet another aspect, the invention generally relates to a unit dosage form comprising a pharmaceutical composition of the invention.

**[0036]** In yet another aspect, the invention generally relates to Form A for use in a method for treating, reducing, or preventing a metabolic disorder, a heart disease, a neurodegenerative disease, or a liver disease, comprising administering to a subject in need thereof a therapeutically effective amount of a pharmaceutical composition of the invention.

**[0037]** In yet another aspect, the invention generally relates to form A for use in a method for treating, reducing, or preventing a disease or disorder, comprising administering to a subject in need thereof a therapeutically effective amount of a pharmaceutical composition of the invention or a unit dosage form of the invention, effective to treat, prevent, or reduce one or more diseases or disorders selected from fatty liver, non-alcoholic fatty liver disease (NAFLD) and non-alcoholic steatohepatitis (NASH), cholestatic liver diseases, graft-versus-host disease of the liver, primary sclerosing cholangitis, chronic viral associated liver diseases, alcohol-related liver diseases, metabolic diseases or disorders such as pre-diabetes, diabetes, hyperlipidemia, hypercholesterolemia, diabetic dyslipidemia, dyslipidemia in statin-intolerant patients, obesity, or a related disease or disorder thereof in a mammal, including a human.

**[0038]** In yet another aspect, the invention generally relates to a method for preparing Form A of berberine ursodeoxycholate. The method includes: forming a mixture of a crystalline and/or amorphous form of berberine ursodeoxycholate with co-solvents of an organic solvent and H<sub>2</sub>O, wherein the water activity is greater than about 0.4; stirring the mixture at room temperature; filtering the mixture to obtain a filter cake; washing the filter cake with distilled water; and removing water to obtain Form A of berberine ursodeoxycholate.

**[0039]** Disclosed herein, but not forming part of the present invention is a method for preparing Form B of berberine ursodeoxycholate. The method includes: forming a mixture of a crystalline and/or amorphous form of berberine ursodeoxycholate with acetonitrile/H<sub>2</sub>O, wherein the acetonitrile : H<sub>2</sub>O (v/v) is from about 1:2 to about 2:1; and slowly evaporating to remove acetonitrile /H<sub>2</sub>O to obtain Form B of berberine ursodeoxycholate.

**[0040]** Disclosed herein, but not forming part of the present invention is a method for preparing Form C of berberine ursodeoxycholate. The method includes: forming a mixture of a crystalline and/or amorphous form of berberine ursodeoxycholate with isopropyl alcohol / isopropyl acetate, wherein the isopropyl alcohol: isopropyl acetate (v/v) is from about 1:2 to about 2:1; and slowly evaporating to remove isopropyl alcohol / isopropyl acetate to obtain Form C of berberine ursodeoxycholate.

**[0041]** Disclosed herein, but not forming part of the present invention is a method for preparing Form D of berberine ursodeoxycholate. The method includes: forming a mixture of crystalline and/or amorphous form of berberine ursodeoxycholate with an organic solvent or an organic solvent/water co-solvents having a water activity less than about 0.2; stirring the mixture at room temperature; and filtering the mixture to obtain Form D of berberine ursodeoxycholate.

**[0042]** Disclosed herein, but not forming part of the present invention is a method for preparing Form E of berberine ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; and performing solid vapor diffusion in a dichloromethane atmosphere to obtain Form E of berberine ursodeoxycholate.

**[0043]** Disclosed herein, but not forming part of the present invention is a method for preparing Form H of berberine ursodeoxycholate. The method includes: dissolving a crystalline and/or amorphous form of berberine ursodeoxycholate in acetonitrile/H<sub>2</sub>O, wherein the acetonitrile : H<sub>2</sub>O (v/v) is from about 1:2 to about 2:1; slowly evaporating acetonitrile/H<sub>2</sub>O; collecting precipitate by filtration; heating the obtained precipitate to about 100°C; and cooling heated precipitate to room temperature to obtain Form H of berberine ursodeoxycholate.

**[0044]** Disclosed herein, but not forming part of the present invention is a method for preparing Form I of berberine ursodeoxycholate. The method includes: dissolving a crystalline and/or amorphous form of berberine ursodeoxycholate

in tetrahydrofuran/H<sub>2</sub>O, wherein the tetrahydrofuran : H<sub>2</sub>O (v/v) is from about 1:2 to about 2:1; slowly evaporating tetrahydrofuran/H<sub>2</sub>O; and collecting the precipitate by filtration to obtain Form I of berberine ursodeoxycholate.

[0045] Disclosed herein, but not forming part of the present invention is a method for preparing Form J of berberine ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; heating Form A of berberine ursodeoxycholate to about 100°C in N<sub>2</sub>; and cooling the heated berberine ursodeoxycholate under N<sub>2</sub> to room temperature to obtain Form J of berberine ursodeoxycholate.

[0046] Disclosed herein, but not forming part of the present invention is a method for preparing Form P of berberine ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; slurring Form A of berberine ursodeoxycholate in MeOH / methyl ethyl ketone or MeOH/methyl tert-butyl ether, wherein the MeOH : methyl ethyl ketone (v/v) is from about 1:8 to about 1:10 or MeOH : methyl tert-butyl ether (v/v) is from about 1:8 to about 1:10 at about 50°C; and collecting the solid to obtain Form P of berberine ursodeoxycholate.

[0047] Disclosed herein, but not forming part of the present invention is a method for preparing Form W of berberine ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; slurring Form A of berberine ursodeoxycholate in cyclohexanone/n-butylacetate, wherein the cyclohexanone : n-butylacetate (v/v) is from about 1:3 to about 1:5 at room temperature; and collecting the solid to obtain Form W of berberine ursodeoxycholate.

[0048] Disclosed herein, but not forming part of the present invention is a method for preparing Form X of berberine ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; dissolving Form A of berberine ursodeoxycholate in n-butanol; slowly evaporating n-butanol at room temperature; and collecting the precipitate by filtration to obtain Form X of berberine ursodeoxycholate.

## Brief Description of the Drawings

[0049]

FIG. 1 shows an embodiment of XRPD pattern of Form A of BBR-UDCA.

FIG. 2 shows an embodiment of XRPD pattern of Form B of BBR-UDCA.

FIG. 3 shows an embodiment of XRPD pattern of Form C of BBR-UDCA.

FIG. 4 shows an embodiment of XRPD pattern of Form D of BBR-UDCA.

FIG. 5 shows an embodiment of XRPD pattern of Form E of BBR-UDCA.

FIG. 6 shows an embodiment of XRPD pattern of Form H of BBR-UDCA.

FIG. 7 shows an embodiment of XRPD pattern of Form I of BBR-UDCA.

FIG. 8 shows an embodiment of XRPD pattern of Form J of BBR-UDCA.

FIG. 9 shows an embodiment of XRPD pattern of Form P of BBR-UDCA.

FIG. 10 shows an embodiment of XRPD pattern of Form W of BBR-UDCA.

FIG. 11 shows an embodiment of XRPD pattern of Form X of BBR-UDCA.

FIG. 12 shows an overlay of XRPD patterns of Form A of BBR-UDCA and hemi-nonahydrate single crystal of BBR-UDCA.

FIG. 13 shows an overlay of XRPD patterns of Form A of BBR-UDCA after stability evaluation.

FIG. 14 shows an overlay of XRPD patterns of Form D of BBR-UDCA after stability evaluation.

FIG. 15 shows an embodiment of a DVS graph of Form A of BBR-UDCA.

FIG. 16 shows an embodiment of an overlay of XRPD patterns of Form A of BBR-UDCA before and after DVS testing.

FIG. 17 shows an embodiment of a DVS graph of Form D of BBR-UDCA.

FIG. 18 shows an overlay of XRPD patterns of residual solid after solubility tests.

FIG. 19 depicts a unit cell of single crystalline Form A of BBR-UDCA.

FIG. 20 shows an embodiment of a TGA/DSC graph of Form B of BBR-UDCA.

FIG. 21 shows an embodiment of a TGA/DSC graph of Form C of BBR-UDCA.

FIG. 22 shows an embodiment of a TGA/DSC graph of Form D of BBR-UDCA.

FIG. 23 shows an embodiment of a TGA/DSC graph of Form H of BBR-UDCA.

FIG. 24 shows an embodiment of a TGA/DSC graph of Form I of BBR-UDCA.

FIG. 25 shows an embodiment of a TGA/DSC graph of Form P of BBR-UDCA.

FIG. 26 shows an embodiment of a TGA/DSC graph of Form W of BBR-UDCA.

FIG. 27 shows an embodiment of a TGA/DSC graph of Form X of BBR-UDCA.

FIG. 28 shows an embodiment of a TGA graph of Form A of BBR-UDCA.

FIG. 29 shows an embodiment of microscopic photo of single crystalline Form A of BBR-UDCA.

FIG. 30 shows an embodiment of <sup>1</sup>H NMR spectra of Form A of BBR-UDCA (bottom) and Form B of BBR-UDCA (top).

FIG. 31 shows an embodiment of <sup>1</sup>H NMR spectra of Form A of BBR-UDCA (bottom) and Form C of BBR-UDCA (top).

FIG. 32 shows an embodiment of <sup>1</sup>H NMR spectra of Form A of BBR-UDCA (bottom) and Form H of BBR-UDCA (top).

FIG. 33 shows an embodiment of <sup>1</sup>H NMR spectra of Form A of BBR-UDCA (bottom) and Form I of BBR-UDCA (top).

FIG. 34 shows an embodiment of  $^1\text{H}$  NMR spectra of Form W of BBR-UDCA.

FIG. 35 shows an embodiment of  $^1\text{H}$  NMR spectra of Form X of BBR-UDCA.

## Definitions

[0050] The terms used herein have their ordinary meaning and the meaning of such terms is independent at each occurrence thereof. That notwithstanding and except where stated otherwise, the following definitions apply throughout the specification and claims.

[0051] As used herein, the term "essentially the same" with reference to X-ray diffraction peak positions means that typical peak position and intensity variability are taken into account. For example, one skilled in the art will appreciate that the peak positions ( $2\theta$ ) will show some variability, typically as much as 0.1 to 0.2 degrees, as well as on the apparatus being used to measure the diffraction. Further, one skilled in the art will appreciate that relative peak intensities will show inter-apparatus variability as well as variability due to degree of crystallinity, preferred orientation, prepared sample surface, and other factors known to those skilled in the art, and should be taken as qualitative measures only. Similarly, as used herein, "essentially the same" with reference to differential scanning calorimetry (DSC) is intended to also encompass the variability associated with these analytical techniques, which are known to those of skill in the art.

[0052] As used herein, the term "stable" refers to a compound that is not substantially altered when subjected to conditions to allow for its production, detection, recovery, purification, and use for one or more of the purposes disclosed herein. In some embodiments, a stable compound or chemically feasible compound is one that is not substantially altered when kept at a temperature of 40 °C or less, in the absence of moisture or other chemically reactive conditions, for at least a week, preferably for at least a month, more preferably for at least six months, even more preferably for at least one year.

[0053] As used herein, the term "solvate" refers to a crystalline solid adduct containing either stoichiometric or non-stoichiometric amounts of a solvent incorporated within the crystal structure. When the solvent is tightly bound to the drug the resulting complex will have a well-defined stoichiometry that is independent of humidity. When, however, the solvent is weakly bound, as in channel solvates and hygroscopic compounds, the solvent content will be dependent on humidity and drying conditions. In such cases, the complex will often be non-stoichiometric. If the incorporated solvent is water, such adduct is referred to as a "hydrate". Thus, the term "hydrate" describes a solvate comprising the drug substance and a stoichiometric or non-stoichiometric amount of water.

[0054] A compound of the present invention is, subsequent to its preparation, preferably isolated and purified to obtain a composition containing an amount by weight equal to or greater than 95%, which is then used or formulated as described herein. In certain embodiments, a compound of the invention is more than 99% pure. As used herein, the term "substantially pure" with reference to a particular crystalline or amorphous form means that the crystalline or amorphous form includes less than 10%, preferably less than 5%, more preferably less than 3%, even more preferably less than 1% by weight of any other physical forms of the compound.

[0055] As used herein, the term "crystalline" refers to any solid substance exhibiting three-dimensional order, which in contrast to an amorphous solid substance, gives a distinctive X-ray powder diffraction (XRPD) pattern with sharply defined peaks.

[0056] As used herein, the term "amorphous" refers to any solid substance that lacks order in three dimensions. In some instances, amorphous solids may be characterized by known techniques, including X-ray powder diffraction (XRPD) crystallography, solid-state nuclear magnet resonance (ssNMR) spectroscopy, differential scanning calorimetry (DSC), or some combination of these techniques. Amorphous solids give diffuse XRPD patterns, typically comprised of one or two broad peaks (*i.e.*, peaks having base widths of about  $5^\circ 2\theta$  or greater).

[0057] As used herein, the term "polymorph" refers to different crystalline forms of the same compound and includes, but is not limited to, other solid state molecular forms including hydrates (*e.g.*, bound water present in the crystalline structure) and solvates (*e.g.*, bound solvents other than water) of the same compound.

[0058] As used herein, the term "X-ray powder diffraction pattern" or "XRPD pattern" refers to the experimentally observed diffractogram or parameters derived therefrom. X-Ray powder diffraction patterns are characterized by peak position (abscissa) and peak intensities (ordinate).

[0059] As used herein, the term "2 theta value" or " $2\theta$ " refers to the peak position in degrees based on the experimental setup of the X-ray diffraction experiment and is a common abscissa unit in diffraction patterns. The experimental setup requires that if a reflection is diffracted when the incoming beam forms an angle theta ( $\theta$ ) with a certain lattice plane, the reflected beam is recorded at an angle 2 theta ( $2\theta$ ). It should be understood that reference herein to specific  $2\theta$  values for a specific solid form is intended to mean the  $2\theta$  values (in degrees) as measured using the X-ray diffraction experimental conditions as described herein. For example, as described herein,  $\text{CuK}\alpha$  (wavelength :  $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ) was used as the source of radiation.

[0060] As used herein, the term "effective amount" of an active agent refers to an amount sufficient to elicit the desired biological response. As will be appreciated by those of ordinary skill in this art, the effective amount of a compound of

the invention may vary depending on such factors as the desired biological endpoint, the pharmacokinetics of the compound, the disease being treated, the mode of administration, and the patient.

**[0061]** As used herein, the term "treating, reducing, or preventing a disease or disorder" refers to ameliorating such a condition before or after it has occurred. As compared with an equivalent untreated control, such reduction or degree of prevention is at least 5%, 10%, 20%, 40%, 50%, 60%, 80%, 90%, 95%, or 100% as measured by any standard technique.

**[0062]** As used herein, the term "pharmaceutically acceptable excipient, carrier, or diluent" refers to a pharmaceutically acceptable material, composition or vehicle, such as a liquid or solid filler, diluent, excipient, solvent or encapsulating material, involved in carrying or transporting the subject pharmaceutical agent from one organ, or portion of the body, to another organ, or portion of the body. Each carrier must be "acceptable" in the sense of being compatible with the other ingredients of the formulation and not injurious to the patient. Some examples of materials which can serve as pharmaceutically-acceptable carriers include: sugars, such as lactose, glucose and sucrose; starches, such as corn starch and potato starch; cellulose, and its derivatives, such as sodium carboxymethyl cellulose, ethyl cellulose and cellulose acetate; powdered tragacanth; malt; gelatin; talc; excipients, such as cocoa butter and suppository waxes; oils, such as peanut oil, cottonseed oil, safflower oil, sesame oil, olive oil, corn oil and soybean oil; glycols, such as propylene glycol; polyols, such as glycerin, sorbitol, mannitol and polyethylene glycol; esters, such as ethyl oleate and ethyl laurate; agar; buffering agents, such as magnesium hydroxide and aluminum hydroxide; alginic acid; pyrogen-free water; isotonic saline; Ringer's solution; ethyl alcohol; phosphate buffer solutions; and other non-toxic compatible substances employed in pharmaceutical formulations. Wetting agents, emulsifiers and lubricants, such as sodium lauryl sulfate, magnesium stearate, and polyethylene oxide-polypropylene oxide copolymer as well as coloring agents, release agents, coating agents, sweetening, flavoring and perfuming agents, preservatives and antioxidants can also be present in the compositions.

**[0063]** As used herein, the "an amount sufficient" refers to the amount of a compound, alone or in combination with another therapeutic regimen, required to treat, prevent, or reduce a metabolic disorder such as diabetes in a clinically relevant manner. A sufficient amount of an active compound used to practice the present invention for therapeutic treatment of conditions varies depending upon the manner of administration, the age, body weight, and general health of the mammal or patient. Ultimately, the prescribers will decide the appropriate amount and dosage regimen. Additionally, an effective amount may be an amount of compound that is safe and efficacious in the treatment of a patient as determined and approved by a regulatory authority (such as the U.S. Food and Drug Administration).

**[0064]** As used herein, the "low dosage" refers to at least 5% less (*e.g.*, at least 10%, 20%, 50%, 80%, 90%, or even 95%) than the lowest standard recommended dosage of a particular compound formulated for a given route of administration for treatment of any human disease or condition. For example, a low dosage of an agent that reduces glucose levels and that is formulated for administration by inhalation will differ from a low dosage of the same agent formulated for oral administration.

**[0065]** As used herein, the "high dosage" is meant at least 5% (*e.g.*, at least 10%, 20%, 50%, 100%, 200%, or even 300%) more than the highest standard recommended dosage of a particular compound for treatment of any human disease or condition.

**[0066]** As used herein, the term "subject" refers to any animal (*e.g.*, a mammal), including, but not limited to humans, non-human primates, rodents, and the like, which is to be the recipient of a particular treatment. Typically, the terms "subject" and "patient" are used interchangeably herein in reference to a human subject.

**[0067]** When using the term "solid form" with reference to form A, this is synonymous with "crystalline form".

### Detailed Description of the Invention

**[0068]** The present invention is based in part on the unexpected discovery of novel solid form A of berberine ursodeoxycholate (BBR-UDCA) having one or more desirable properties, such as high stability, high crystallinity, high purity, low hygroscopicity, favorable dissolution and/or favorable mechanical properties. In particular, solid forms of BBR-UDCA disclosed herein provide improved physical stability and/or physicochemical properties suitable for clinical studies, product manufacture and therapeutic use.

**[0069]** While multiple solid forms of BBR-UDCA have been identified, each solid form can be uniquely identified by different analytical parameters, alone or in combination, such as, but not limited to: X-ray powder diffraction pattern (XRPD) peaks or combinations of two or more peaks; thermo gravimetric analysis (TGA); differential scanning calorimetry (DSC); dynamic vapor sorption (DVS); polarized light microscope (PLM); high-performance liquid chromatography (HPLC); and nuclear magnetic resonance (NMR).

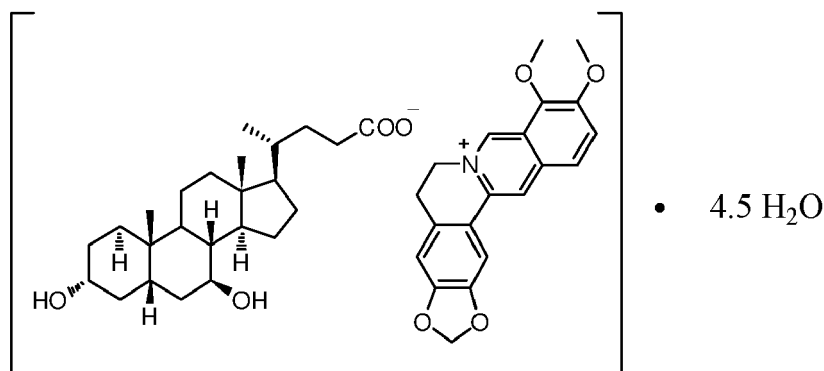
**[0070]** Diseases and disorders that may be treated and/or prevented by the compounds, pharmaceutical compositions and methods disclosed herein include such as diabetes, diabetic complications, dyslipidemia, dyslipidemia in statin-intolerance patients, hyperlipidemia, hypercholesterolemia, hypertriglyceridemia, diabetic dyslipidemia, obesity, metabolic syndromes, pre-diabetes, atherosclerosis, heart diseases, neurodegenerative diseases, sarcopenia, muscle atro-



phy, inflammation, cancer and liver diseases and conditions such as fatty liver, non-alcoholic fatty liver disease, non-alcoholic steatohepatitis, cholestatic liver diseases or graft-versus-host disease of the liver. The compounds of this invention are also useful in improving liver functions in chronic viral associated liver diseases and alcohol-related liver diseases.

**[0071]** The invention generally relates to a solid form, which is Form A of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern as defined in claims 1-10.

**[0072]** The solid form (Form A of BBR-UDCA) is a hemi-nonahydrate of BBR-UDCA.



Hemi-nonahydrate of berberine ursodeoxycholate (BBR-UDCA)

**[0073]** The solid form (Form A of BBR-UDCA) is crystalline. In certain embodiments, the crystalline form is characterized in a monoclinic crystal system and  $P2_1$  space group. In certain embodiments of the crystalline form, each unit cell contains two asymmetric units and there are two BBR cations, two UDCA anions and nine  $H_2O$  molecules per asymmetric unit, and four BBR cations, four UDCA anions and eighteen  $H_2O$  molecules per unit cell. (**FIG. 19.**)

**[0074]** In certain embodiments, the solid form (Form A of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 1.**

**[0075]** In certain embodiments, the solid form (Form A of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0076]** In certain embodiments, the solid form (Form A of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0077]** Disclosed herein, but not forming part of the present invention is a solid form, which is Form B of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 7.39, 9.31, 12.41, 13.14, 14.37, 14.76, 15.53, 18.65, 21.79, 22.87, 25.27, 25.53 and  $28.12^\circ (\pm 0.2^\circ)$  obtained using Cu  $K\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0078]** In certain embodiments, the solid form (Form B of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 9.31, 12.41, 15.53, 18.65, 21.79, 22.87, and  $25.53^\circ (\pm 0.2^\circ)$ .

**[0079]** In certain embodiments, the solid form (Form B of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 7.39, 9.31, 12.41, 13.14, 14.37, 14.76, 15.53, 18.65, 21.79, 22.87, 25.27, 25.53 and  $28.12^\circ (\pm 0.2^\circ)$ .

**[0080]** In certain embodiments, the solid form (Form B of BBR-UDCA) is a hydrate of berberine ursodeoxycholate.

**[0081]** In certain embodiments, the solid form (Form B of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 2.**

**[0082]** In certain embodiments, the solid form (Form B of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve comprising an endotherm at about  $78.1^\circ \text{C}$  (onset temperature) and an endotherm at about  $91.2^\circ \text{C}$  (onset temperature).

**[0083]** In certain embodiments, the solid form (Form B of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve essentially the same as the one presented in **FIG. 20.**

**[0084]** In certain embodiments, the solid form (Form B of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0085]** In certain embodiments, the solid form (Form B of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0086]** Disclosed herein, but not forming part of the present invention is a solid form, which is Form C of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 7.23, 10.42, 12.10, 13.37, 14.24, 14.48, 15.28, 15.95, 17.00, 18.17, 20.12, 21.77 and  $25.47^\circ (\pm 0.2^\circ)$  obtained using Cu  $K\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0087]** In certain embodiments, the solid form (Form C of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 7.23, 12.10, 13.37, 15.28, 18.17 and  $21.77^\circ (\pm 0.2^\circ)$ .

**[0088]** In certain embodiments, the solid form (Form C of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 7.23, 10.42, 12.10, 13.37, 14.24, 14.48, 15.28, 15.95, 17.00, 18.17, 20.12, 21.77 and

25.47 ° ( $\pm 0.2$  °).

**[0089]** In certain embodiments, the solid form (Form C of BBR-UDCA) is a hydrate of berberine ursodeoxycholate.

**[0090]** In certain embodiments, the solid form (Form C of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 3**.

**[0091]** In certain embodiments, the solid form (Form C of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve comprising an endotherm at about 68.4 °C (onset temperature) and an endotherm at about 183.3 °C (onset temperature).

**[0092]** In certain embodiments, the solid form (Form C of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve essentially the same as the one presented in **FIG. 21**.

**[0093]** In certain embodiments, the solid form (Form C of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0094]** In certain embodiments, the solid form (Form C of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0095]** Disclosed herein, but not forming part of the present invention is Form D of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 4.24, 6.79, 8.50, 10.25, 11.50, 13.62, 14.74, 15.20, 17.92, 18.39, 22.91 and 25.73 ° ( $\pm 0.2$  °) obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598$  Å,  $\lambda_2 = 1.544426$  Å, intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0096]** In certain embodiments, the solid form (Form D of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 4.24, 6.79, 8.50, 13.62 and 15.20 ° ( $\pm 0.2$  °).

**[0097]** In certain embodiments, the solid form (Form D of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 4.24, 6.79, 8.50, 10.25, 11.50, 13.62, 14.74, 15.20, 17.92 and 25.73 ° ( $\pm 0.2$  °).

**[0098]** In certain embodiments, the solid form (Form D of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 4.24, 6.79, 8.50, 10.25, 11.50, 13.62, 14.74, 15.20, 17.92, 18.39, 22.91 and 25.73 ° ( $\pm 0.2$  °).

**[0099]** In certain embodiments, the solid form (Form D of BBR-UDCA) is an anhydrous berberine ursodeoxycholate.

**[0100]** In certain embodiments, the solid form (Form D of BBR-UDCA) is crystalline.

**[0101]** In certain embodiments, the solid form (Form D of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 4**.

**[0102]** In certain embodiments, the solid form (Form D of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve comprising an endotherm at about 185.2 °C (onset temperature).

**[0103]** In certain embodiments, the solid form (Form D of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve essentially the same as the one presented in **FIG. 22**.

**[0104]** In certain embodiments, the solid form (Form D of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0105]** In certain embodiments, the solid form (Form D of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0106]** Disclosed herein, but not forming part of the present invention is a solid form, which is Form E of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 8.59, 10.55, 11.36, 11.86, 12.46, 13.08, 13.38, 14.34, 15.57, 17.24, 17.72, 18.43, 19.66, 19.84, 20.35, 20.91, 21.36, 21.95, 23.21, 24.67, 25.04, 25.82, 26.12, 27.01, 27.84, 28.97, 30.35, 33.33, 34.54 and 36.06 ° ( $\pm 0.2$  °) obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598$  Å,  $\lambda_2 = 1.544426$  Å, intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0107]** In certain embodiments, the solid form (Form E of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 11.36, 17.24, 17.72 and 20.91 ° ( $\pm 0.2$  °).

**[0108]** In certain embodiments, the solid form (Form E of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 10.55, 11.36, 12.46, 13.08, 13.38, 14.34, 17.24, 17.72, 19.66, 19.84, 20.35, 20.91, 21.36 and 21.95 ° ( $\pm 0.2$  °).

**[0109]** In certain embodiments, the solid form (Form E of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of: 8.59, 10.55, 11.36, 11.86, 12.46, 13.08, 13.38, 14.34, 15.57, 17.24, 17.72, 18.43, 19.66, 19.84, 20.35, 20.91, 21.36, 21.95, 23.21, 24.67, 25.04, 25.82, 26.12, 27.01, 27.84, 28.97, 30.35, 33.33, 34.54 and 36.06 ° ( $\pm 0.2$  °) obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598$  Å,  $\lambda_2 = 1.544426$  Å, intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0110]** In certain embodiments, the solid form (Form E of BBR-UDCA) is crystalline.

**[0111]** In certain embodiments, the solid form (Form E of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 5**.

**[0112]** In certain embodiments, the solid form (Form E of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0113]** In certain embodiments, the solid form (Form E of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0114]** Disclosed herein, but not forming part of the present invention is a solid form, which is Form H of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 13.05, 14.63 and 25.46 ° ( $\pm 0.2$  °) obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598$  Å,  $\lambda_2 = 1.544426$  Å, intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0115]** In certain embodiments, the solid form (Form H of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 13.05, 14.63 and 25.46 ° ( $\pm 0.2$  °).

**[0116]** In certain embodiments, the solid form (Form H of BBR-UDCA) is a hydrate of berberine ursodeoxycholate.

**[0117]** In certain embodiments, the solid form (Form H of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 6**.

**[0118]** In certain embodiments, the solid form (Form H of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve comprising an endotherm at about 97.1 °C (peak temperature) and an endotherm at about 138.3 °C (onset temperature).

**[0119]** In certain embodiments, the solid form (Form H of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve essentially the same as the one presented in **FIG. 23**.

**[0120]** In certain embodiments, the solid form (Form H of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0121]** In certain embodiments, the solid form (Form H of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0122]** Disclosed herein, but not forming part of the present invention is a solid form, which is Form I of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 4.19, 7.64, 10.03, 13.32, 13.84, 14.83, 16.73, 22.73, 25.61 and 28.57 ° ( $\pm 0.2^\circ$ ) obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0123]** In certain embodiments, the solid form (Form I of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 7.64, 10.03, 13.32, 16.73 and 22.73° ( $\pm 0.2^\circ$ ).

**[0124]** In certain embodiments, the solid form (Form I of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 4.19, 7.64, 10.03, 13.32, 13.84, 14.83, 16.73, 22.73, 25.61 and 28.57 ° ( $\pm 0.2^\circ$ ).

**[0125]** In certain embodiments, the solid form (Form I of BBR-UDCA) is a hydrate of berberine ursodeoxycholate.

**[0126]** In certain embodiments, the solid form (Form I of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 7**.

**[0127]** In certain embodiments, the solid form (Form I of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve comprising an endotherm at about 56.2 °C (onset temperature) and an endotherm at about 79.6 °C (onset temperature).

**[0128]** In certain embodiments, the solid form (Form I of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve essentially the same as the one presented in **FIG. 24**.

**[0129]** In certain embodiments, the solid form (Form I of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0130]** In certain embodiments, the solid form (Form I of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0131]** Disclosed herein, but not forming part of the present invention is a solid form, which is Form J of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 4.61, 6.32, 7.38, 8.22, 9.21, 10.57, 11.73, 12.13, 12.62, 12.96, 13.87, 14.55, 14.78, 15.81, 16.48, 17.69, 18.39, 19.01, 20.06, 21.25, 22.13, 23.20, 24.47, 24.89, 26.31, 27.98, 30.25 and 33.35 ° ( $\pm 0.2^\circ$ ) obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0132]** In certain embodiments, the solid form (Form J of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 4.61, 10.57, 14.78, 19.01 and 26.31 ° ( $\pm 0.2^\circ$ ).

**[0133]** In certain embodiments, the solid form (Form J of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 4.61, 7.38, 8.22, 9.21, 10.57, 14.55, 14.78, 16.48, 17.69, 19.01, 20.06, 24.47 and 26.31 ° ( $\pm 0.2^\circ$ ).

**[0134]** In certain embodiments, the solid form (Form J of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 4.61, 6.32, 7.38, 8.22, 9.21, 10.57, 11.73, 12.13, 12.62, 12.96, 13.87, 14.55, 14.78, 15.81, 16.48, 17.69, 18.39, 19.01, 20.06, 21.25, 22.13, 23.20, 24.47, 24.89, 26.31, 27.98, 30.25 and 33.35 ° ( $\pm 0.2^\circ$ ).

**[0135]** In certain embodiments, the solid form (Form J of BBR-UDCA) is an anhydrous berberine ursodeoxycholate.

**[0136]** In certain embodiments, the solid form (Form J of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 8**.

**[0137]** In certain embodiments, the solid form (Form J of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0138]** In certain embodiments, the solid form (Form J of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0139]** Disclosed herein, but not forming part of the present invention is Form P of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 3.11, 5.01, 5.78, 7.26, 9.20, 10.10, 10.79, 11.65, 13.70, 14.59, 15.22, 16.19, 16.54, 17.05, 18.06, 18.68, 20.52, 21.09, 21.73, 22.49, 24.73, 25.42, 25.94 and 30.11 ° ( $\pm 0.2^\circ$ ) obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0140]** In certain embodiments, the solid form (Form P of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 5.01, 5.78, 11.65, 17.05, 18.68 and 20.52 ° ( $\pm 0.2^\circ$ ).

**[0141]** In certain embodiments, the solid form (Form P of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 5.01, 5.78, 7.26, 9.20, 10.10, 10.79, 11.65, 13.70, 14.59, 15.22, 16.19, 16.54, 17.05, 18.68, 20.52 and 25.94 ° ( $\pm 0.2^\circ$ ).

**[0142]** In certain embodiments, the solid form (Form P of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 3.11, 5.01, 5.78, 7.26, 9.20, 10.10, 10.79, 11.65, 13.70, 14.59, 15.22, 16.19, 16.54, 17.05, 18.06, 18.68, 20.52, 21.09, 21.73, 22.49, 24.73, 25.42, 25.94 and 30.11° ( $\pm 0.2^\circ$ ).

**[0143]** In certain embodiments, the solid form (Form P of BBR-UDCA) is a hydrate of berberine ursodeoxycholate.

**[0144]** In certain embodiments, the solid form (Form P of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 9**.

**[0145]** In certain embodiments, the solid form (Form P of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve comprising an endotherm at about 100.3 °C (peak temperature), an endotherm at about 122.5 °C (peak temperature) and an endotherm at about 168.7 °C (peak temperature).

**[0146]** In certain embodiments, the solid form (Form P of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve essentially the same as the one presented in **FIG. 25**.

**[0147]** In certain embodiments, the solid form (Form P of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0148]** In certain embodiments, the solid form (Form P of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0149]** Disclosed herein, but not forming part of the present invention is a solid form, which is Form W of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 6.49, 7.16, 8.51, 10.21, 12.01, 13.13, 13.90, 14.42, 15.18, 15.57, 16.03, 16.45, 16.74, 17.08, 17.85, 18.39, 19.61, 20.43, 21.39, 21.70, 23.51 and 25.21° ( $\pm 0.2^\circ$ ) obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0150]** In certain embodiments, the solid form (Form W of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 6.49, 7.16, 12.01, 13.13, 15.18, 16.45, 17.85, 21.39 and 25.21° ( $\pm 0.2^\circ$ ).

**[0151]** In certain embodiments, the solid form (Form W of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 6.49, 7.16, 8.51, 10.21, 12.01, 13.13, 13.90, 14.42, 15.18, 15.57, 16.03, 16.45, 16.74, 17.08, 17.85, 18.39, 19.61, 20.43, 21.39, 21.70, 23.51 and 25.21° ( $\pm 0.2^\circ$ ).

**[0152]** In certain embodiments, the solid form (Form W of BBR-UDCA) is a hydrate of berberine ursodeoxycholate.

**[0153]** In certain embodiments, the solid form (Form W of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 10**.

**[0154]** In certain embodiments, the solid form (Form W of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve comprising an endotherm at about 82.1 °C (peak temperature) and an endotherm at about 106.4 °C (peak temperature).

**[0155]** In certain embodiments, the solid form (Form W of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve essentially the same as the one presented in **FIG. 26**.

**[0156]** In certain embodiments, the solid form (Form W of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0157]** In certain embodiments, the solid form (Form W of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0158]** Disclosed herein, but not forming part of the present invention is a solid form, which is Form X of BBR-UDCA, having an X-ray powder diffraction (XRPD) pattern comprising one or more peaks at  $2\theta$  values selected from the group consisting of: 3.63, 6.61, 7.24, 10.49, 11.95, 13.51, 14.26, 14.54, 15.14, 16.01, 16.82, 18.28, 20.26, 21.08, 21.49, 21.90, 25.60, 26.40, 27.31, 29.34, 30.59, 31.01, 34.04, 34.68 and 36.91° ( $\pm 0.2^\circ$ ) obtained using Cu K $\alpha$  radiation of ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ).

**[0159]** In certain embodiments, the solid form (Form X of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 3.63, 7.24, 11.95, 13.51, 14.54, 15.14, 18.28, 21.90 and 25.60° ( $\pm 0.2^\circ$ ).

**[0160]** In certain embodiments, the solid form (Form X of BBR-UDCA) has an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 3.63, 6.61, 7.24, 10.49, 11.95, 13.51, 14.26, 14.54, 15.14, 16.01, 16.82, 18.28, 20.26, 21.08, 21.49, 21.90, 25.60, 26.40, 27.31, 29.34, 30.59, 31.01, 34.04, 34.68 and 36.91° ( $\pm 0.2^\circ$ ).

**[0161]** In certain embodiments, the solid form (Form X of BBR-UDCA) is a hydrate of berberine ursodeoxycholate.

**[0162]** In certain embodiments, the solid form (Form X of BBR-UDCA) is characterized by an X-ray powder diffraction (XRPD) pattern comprising peaks at diffraction angles  $2\theta$  essentially the same as the one presented in **FIG. 11**.

**[0163]** In certain embodiments, the solid form (Form X of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve comprising an endotherm at about 86.7 °C (peak temperature) and an endotherm at about 189.1 °C (peak temperature).

**[0164]** In certain embodiments, the solid form (Form X of BBR-UDCA) is characterized by a differential scanning calorimetry (DSC) curve essentially the same as the one presented in **FIG. 27**.

**[0165]** In certain embodiments, the solid form (Form X of BBR-UDCA) is characterized by a purity of 70% or higher.

**[0166]** In certain embodiments, the solid form (Form X of BBR-UDCA) is characterized by a purity of 95% or higher.

**[0167]** In yet another aspect, the invention generally relates to a composition comprising the solid form of the invention.

**[0168]** In yet another aspect, the invention generally relates to a composition comprising two or more solid forms disclosed herein (i.e. Form A and one or more of Forms B, C, D, E, H, I, J, P, W, and X).

**[0169]** The composition of comprising one or more (or two or more) solid forms disclosed herein may include further agents as needed.

**[0170]** In certain embodiments, the composition further includes, in addition to berberine ursodeoxycholate, one or more other therapeutically effective agents.

**[0171]** In certain embodiments, the composition further includes one or more agents selected from the group consisting

of vitamin D, vitamin C, vitamin E, vitamin B12, vitamin A, benfotiamine, chromium picolinate and vanadium.

**[0172]** In certain embodiments, the composition further includes one or more agents selected from the group consisting of omega-3 fatty acids, S-adenosylmethionine, N-acetyl cysteine, silymarin, polyenylphosphatidylcholine, and resveratrol.

**[0173]** In yet another aspect, the invention generally relates to a pharmaceutical composition comprising Form A of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0174]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form B of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0175]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form C of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0176]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form D of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0177]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form E of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0178]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form H of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0179]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form I of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0180]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form J of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0181]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form P of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0182]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form W of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0183]** Disclosed herein, but not forming part of the present invention is a pharmaceutical composition comprising Form X of BBR-UDCA and a pharmaceutically acceptable excipient, carrier, or diluent.

**[0184]** In certain embodiments, the pharmaceutical composition further includes, in addition to berberine ursodeoxycholate, one or more other therapeutically effective agents.

**[0185]** In certain embodiments, the pharmaceutical composition of the invention further includes one or more agents selected from the group consisting of vitamin D, vitamin C, vitamin E, vitamin B12, vitamin A, benfotiamine, chromium picolinate and vanadium.

**[0186]** In certain embodiments, the pharmaceutical composition of the invention further includes one or more agents selected from the group consisting of omega-3 fatty acids, S-adenosylmethionine, N-acetyl cysteine, silymarin, polyenylphosphatidylcholine, and resveratrol.

**[0187]** In yet another aspect, the invention generally relates to a unit dosage form comprising a pharmaceutical composition disclosed herein.

**[0188]** In certain embodiments, the unit dosage form is an oral dosage form.

**[0189]** Any suitable dosage forms may be utilized. In certain embodiments, the unit dosage form is a tablet. In certain embodiments, the unit dosage form is a capsule. In certain embodiments, the unit dosage form is a certain volume of suspension.

**[0190]** In certain embodiments, the invention provides a tablet comprising solid form A of BBR-UDCA or pharmaceutical compositions disclosed herein. For example, in one embodiment the tablet comprises from about 1 to about 1,000 mg of solid form A of BBR-UDCA. Further, for example, the tablet comprises from about 50 to about 500 mg of solid form A of BBR-UDCA. Even further, for example, the tablet comprises about 500 to 1,000 mg of solid form A of BBR-UDCA. Even further, for example, the tablet comprises about 50 mg, about 100 mg, about 150 mg, about 200 mg, about 250 mg, about 300 mg, about 350 mg, or about 400 mg, about 450 mg, about 500 mg, about 550 mg, about 600 mg, about 650 mg, about 700 mg, about 750 mg, about 800 mg, about 850 mg, about 900 mg, about 950 mg, about 1,000 mg of solid form A of BBR-UDCA.

**[0191]** In certain embodiments, the invention provides a soft gelatin capsule comprising solid form A of BBR-UDCA or pharmaceutical compositions disclosed herein. For example, in one embodiment the soft gelatin capsule comprises from about 1 to about 1,000 mg of solid form A of BBR-UDCA. Further, for example, the soft gelatin capsule comprises from about 50 to about 500 mg of solid form A of BBR-UDCA. Even further, for example, the soft gelatin capsule comprises about 500 to 1,000 mg of solid form A of BBR-UDCA. Even further, for example, the soft gelatin capsule comprises about 50 mg, about 100 mg, about 150 mg, about 200 mg, about 250 mg, about 300 mg, about 350 mg, or about 400 mg, about 450 mg, about 500 mg, about 550 mg, about 600 mg, about 650 mg, about 700 mg, about 750 mg, about 800 mg, about 850 mg, about 900 mg, about 950 mg, about 1,000 mg of solid form A of BBR-UDCA.

**[0192]** In yet another aspect, the invention generally relates to the claimed solid form A for use in a method for treating, reducing, or preventing a metabolic disorder, a heart disease, a neurodegenerative disease, or a liver disease, comprising

administering to a subject in need thereof a therapeutically effective amount of a pharmaceutical composition of the invention.

**[0193]** In yet another aspect, the invention generally relates to the claimed solid form A for use in method for treating, reducing, or preventing a disease or disorder, comprising administering to a subject in need thereof a therapeutically effective amount of a pharmaceutical composition disclosed herein or a unit dosage form disclosed herein, effective to treat, prevent, or reduce one or more diseases or disorders selected from fatty liver, non-alcoholic fatty liver disease (NAFLD) and non-alcoholic steatohepatitis (NASH), cholestatic liver diseases, graft-versus-host disease of the liver, primary sclerosing cholangitis, chronic viral associated liver diseases, alcohol-related liver diseases, metabolic diseases or disorders such as pre-diabetes, diabetes, hyperlipidemia, hypercholesterolemia, diabetic dyslipidemia, dyslipidemia in statin-intolerant patients, obesity, or a related disease or disorder thereof in a mammal, including a human.

**[0194]** In certain embodiments, the disease or disorder is cholestatic liver diseases, graft-versus-host disease of the liver, chronic viral associated liver diseases or alcohol-related liver diseases, or a related disease or disorder.

**[0195]** In certain embodiments, the disease or disorder is fatty liver, NAFLD or NASH, or a related disease or disorder.

**[0196]** In certain embodiments, the disease or disorder is NAFLD, or a related disease or disorder.

**[0197]** In certain embodiments, the disease or disorder is NASH, or a related disease or disorder.

**[0198]** In certain embodiments, the disease or disorder is primary sclerosing cholangitis, or a related disease or disorder.

**[0199]** In certain embodiments, the disease or disorder is hypercholesterolemia, or a related disease or disorder.

**[0200]** In certain embodiments, the disease or disorder is pre-diabetes, diabetes or hyperlipidemia, diabetic dyslipidemia, or dyslipidemia, or a related disease or disorder, in statin-intolerant patients.

**[0201]** In certain embodiments, the disease or disorder is obesity, or a related disease or disorder.

**[0202]** In certain embodiments, the subject is administered, in addition to berberine ursodeoxycholate, one or more other therapeutically effective agents.

**[0203]** In certain embodiments, the invention relates to a solid form of BBR-UDCA, wherein the solid form is non-hygroscopic.

**[0204]** In certain embodiments, the invention relates to a solid form of BBR-UDCA, wherein the solid form comprises a plurality of small crystallites of BBR-UDCA.

**[0205]** In yet another aspect, the invention generally relates to a method for preparing Form A of berberine ursodeoxycholate. The method includes: forming a mixture of a crystalline and/or amorphous form of berberine ursodeoxycholate with co-solvents of an organic solvent and H<sub>2</sub>O, wherein the water activity is greater than about 0.4; stirring the mixture at room temperature, filtering the mixture to obtain a filter cake; washing the filter cake with distilled water; and removing water to obtain Form A of berberine ursodeoxycholate.

**[0206]** The organic solvent is EtOH.

**[0207]** The EtOH : H<sub>2</sub>O (v/v) is from about 1:5 to about 1: 30. In certain embodiments, the EtOH : H<sub>2</sub>O (v/v) is from about 1:10 to about 1: 20. In certain embodiments, the EtOH : H<sub>2</sub>O (v/v) is about 1:10.

**[0208]** The mixture is stirred at room temperature for about 3 to about 7 hours.

**[0209]** Removing water is performed until the water content is about 10% or less to obtain Form A of berberine ursodeoxycholate..

**[0210]** Disclosed herein, but not forming part of the present invention is a method for preparing Form B of berberine ursodeoxycholate. The method includes: forming a mixture of a crystalline and/or amorphous form of berberine ursodeoxycholate with acetonitrile/H<sub>2</sub>O, wherein the acetonitrile : H<sub>2</sub>O (v/v) is from about 1:2 to about 2:1; and slowly evaporating to remove acetonitrile /H<sub>2</sub>O to obtain Form B of berberine ursodeoxycholate.

**[0211]** In certain embodiments, the acetonitrile: H<sub>2</sub>O (v/v) is about 1:1.

**[0212]** Disclosed herein, but not forming part of the present invention is a method for preparing Form C of berberine ursodeoxycholate. The method includes: forming a mixture of a crystalline and/or amorphous form of berberine ursodeoxycholate with isopropyl alcohol / isopropyl acetate, wherein the isopropyl alcohol: isopropyl acetate (v/v) is from about 1:2 to about 2:1; and slowly evaporating to remove isopropyl alcohol / isopropyl acetate to obtain Form C of berberine ursodeoxycholate.

**[0213]** In certain embodiments, the isopropyl alcohol: isopropyl acetate (v/v) is about 1:1.

**[0214]** Disclosed herein, but not forming part of the present invention is a method for preparing Form D of berberine ursodeoxycholate. The method includes: forming a mixture of crystalline and/or amorphous form of berberine ursodeoxycholate with an organic solvent or an organic solvent/water co-solvents having a water activity less than about 0.2; stirring the mixture at room temperature; and filtering the mixture to obtain Form D of berberine ursodeoxycholate.

**[0215]** In certain embodiments, a mixture of crystalline and/or amorphous form of berberine ursodeoxycholate with ethyl acetate is formed.

**[0216]** In certain embodiments, the mixture is stirred at room temperature for about 1 to about 24 hours. In certain embodiments, the mixture is stirred at room temperature for about 2 to about 7 hours. In certain embodiments, the mixture is stirred at room temperature for about 3 to about 5 hours.

**[0217]** Disclosed herein, but not forming part of the present invention is a method for preparing Form E of berberine

ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; and performing solid vapor diffusion in a dichloromethane atmosphere to obtain Form E of berberine ursodeoxycholate.

**[0218]** Disclosed herein, but not forming part of the present invention is a method for preparing Form H of berberine ursodeoxycholate. The method includes: dissolving a crystalline and/or amorphous form of berberine ursodeoxycholate in acetonitrile/H<sub>2</sub>O, wherein the acetonitrile : H<sub>2</sub>O (v/v) is from about 1:2 to about 2:1; slowly evaporating acetonitrile/H<sub>2</sub>O; collecting precipitate by filtration; heating the obtained precipitate to about 100°C; and cooling heated precipitate to room temperature to obtain Form H of berberine ursodeoxycholate.

**[0219]** In certain embodiments, the acetonitrile: H<sub>2</sub>O (v/v) is about 1:1.

**[0220]** In certain embodiments, the obtained precipitate is heated for about 0.5 to about 2 hours.

**[0221]** Disclosed herein, but not forming part of the present invention is a method for preparing Form I of berberine ursodeoxycholate. The method includes: dissolving a crystalline and/or amorphous form of berberine ursodeoxycholate in tetrahydrofuran/H<sub>2</sub>O, wherein the tetrahydrofuran : H<sub>2</sub>O (v/v) is from about 1:2 to about 2:1; slowly evaporating tetrahydrofuran/H<sub>2</sub>O; and collecting the precipitate by filtration to obtain Form I of berberine ursodeoxycholate.

**[0222]** In certain embodiments, the tetrahydrofuran: H<sub>2</sub>O (v/v) is about 1:1.

**[0223]** Disclosed herein, but not forming part of the present invention is a method for preparing Form J of berberine ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; heating Form A of berberine ursodeoxycholate to about 100°C in N<sub>2</sub>; and cooling the heated berberine ursodeoxycholate under N<sub>2</sub> to room temperature to obtain Form J of berberine ursodeoxycholate.

**[0224]** In certain embodiments, the Form A of berberine ursodeoxycholate is heated in N<sub>2</sub> for about 0.5 to about 2 hours.

**[0225]** Disclosed herein, but not forming part of the present invention is a method for preparing Form P of berberine ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; slurring Form A of berberine ursodeoxycholate in MeOH / methyl ethyl ketone or MeOH/methyl tert-butyl ether, wherein the MeOH : methyl ethyl ketone (v/v) is from about 1:8 to about 1:10 or MeOH: methyl tert-butyl ether (v/v) is from about 1:8 to about 1:10 at about 50°C; and collecting the solid to obtain Form P of berberine ursodeoxycholate.

**[0226]** In certain embodiments, the slurring is performed for about 6 to about 36 hours.

**[0227]** In certain embodiments, the MeOH: methyl tert-butyl ether (v/v) is 1:9.

**[0228]** In certain embodiments, the MeOH : methyl ethyl ketone (v/v) is 1:9.

**[0229]** Disclosed herein, but not forming part of the present invention is a method for preparing Form W of berberine ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; slurring Form A of berberine ursodeoxycholate in cyclohexanone/n-butylacetate, wherein the cyclohexanone : n-butylacetate (v/v) is from about 1:3 to about 1:5 at room temperature; and collecting the solid to obtain Form W of berberine ursodeoxycholate.

**[0230]** In certain embodiments, the cyclohexanone : n-butylacetate (v/v) is about 1:4.

**[0231]** In certain embodiments, the slurring is performed for about 6 to about 36 hours.

**[0232]** Disclosed herein, but not forming part of the present invention is a method for preparing Form X of berberine ursodeoxycholate. The method includes: providing Form A of berberine ursodeoxycholate; dissolving Form A of berberine ursodeoxycholate in n-butanol; slowly evaporating n-butanol at room temperature; and collecting the precipitate by filtration to obtain Form X of berberine ursodeoxycholate.

**[0233]** In certain embodiments, evaporating n-butanol at room temperature is performed for about 6 to about 36 hours.

**[0234]** It is contemplated that any one of the solid forms of BBR-UDCA as disclosed herein can exist in the presence of the any other of the physical forms or mixtures thereof. Accordingly, there is provided the crystalline form or the amorphous form of BBR-UDCA or a pharmaceutical composition comprising the crystalline form or the amorphous form of BBR-UDCA as described herein, wherein the crystalline or amorphous form is present in a solid form that includes less than 95%, less than 90%, less than 80%, less than 70%, less than 60%, less than 50%, less than 40%, less than 30%, less than 20%, less than 10%, less than 5%, less than 3%, or less than 1% by weight of any other physical forms of BBR-UDCA. For example, there is disclosed a solid form of BBR-UDCA comprising a crystalline form of BBR-UDCA that has any one of the powder X-ray diffraction patterns disclosed herein, wherein the solid form includes less than 95%, less than 90%, less than 80%, less than 70%, less than 60%, less than 50%, less than 40%, less than 30%, less than 20%, less than 10%, less than 5%, less than 3%, or less than 1% by weight of any other physical forms of BBR-UDCA.

**[0235]** In certain embodiments, the invention relates to form A of BBR-UDCA, wherein the form is substantially pure.

**[0236]** A further aspect of the invention provides a pharmaceutical composition comprising the crystalline form A of BBR-UDCA as disclosed herein. In a further aspect, the invention provides a pharmaceutical composition comprising crystalline form A of BBR-UDCA as disclosed herein wherein the crystalline form is substantially pure. In a further aspect, the invention provides a method of preparing a pharmaceutical composition comprising combining crystalline form A of BBR-UDCA as disclosed herein and a pharmaceutically acceptable excipient, carrier, or diluent. In a further aspect, the invention provides a method of preparing a pharmaceutical composition comprising combining crystalline form A of BBR-UDCA as disclosed herein and a pharmaceutically acceptable excipient, carrier, or diluent, wherein the crystalline form is substantially pure. In a further aspect, the invention provides a pharmaceutical composition prepared by combining crystalline form A of BBR-UDCA as disclosed herein and a pharmaceutically acceptable excipient, carrier, or diluent. In

a further aspect, the invention provides a pharmaceutical composition prepared by combining crystalline form A of BBR-UDCA as disclosed herein and a pharmaceutically acceptable excipient, carrier, or diluent wherein the crystalline form is substantially pure. In a further aspect, the invention provides an oral dosage form comprising the crystalline form A of BBR-UDCA or pharmaceutical compositions disclosed herein. For example, in one embodiment, the oral dosage form is a tablet or capsule.

**[0237]** Isotopically-labeled compounds are also within the scope of the present disclosure. As used herein, an "isotopically-labeled compound" refers to a presently disclosed compound in which one or more atoms are replaced by an atom having an atomic mass or mass number different from the atomic mass or mass number usually found in nature. Examples of isotopes that can be incorporated into compounds presently disclosed include isotopes of hydrogen, carbon, nitrogen, oxygen, phosphorous, fluorine and chlorine, such as  $^2\text{H}$ ,  $^3\text{H}$ ,  $^{13}\text{C}$ ,  $^{14}\text{C}$ ,  $^{15}\text{N}$ ,  $^{18}\text{O}$ ,  $^{17}\text{O}$ ,  $^{31}\text{P}$ ,  $^{32}\text{P}$ ,  $^{35}\text{S}$ ,  $^{18}\text{F}$ , and  $^{36}\text{Cl}$ , respectively.

**[0238]** By isotopically-labeling the presently disclosed compounds, the compounds may be useful in drug and/or substrate tissue distribution assays. Tritiated ( $^3\text{H}$ ) and carbon-14 ( $^{14}\text{C}$ ) labeled compounds are particularly preferred for their ease of preparation and detectability. Further, substitution with heavier isotopes such as deuterium ( $^2\text{H}$ ) can afford certain therapeutic advantages resulting from greater metabolic stability, for example increased *in vivo* half-life or reduced dosage requirements and, hence, may be preferred in some circumstances. Isotopically labeled compounds presently disclosed, including pharmaceutical salts, esters, and prodrugs thereof, can be prepared by any means known in the art.

**[0239]** Further, substitution of normally abundant hydrogen ( $^1\text{H}$ ) with heavier isotopes such as deuterium can afford certain therapeutic advantages, e.g., resulting from improved absorption, distribution, metabolism and/or excretion (ADME) properties, creating drugs with improved efficacy, safety, and/or tolerability. Benefits may also be obtained from replacement of normally abundant  $^{12}\text{C}$  with  $^{13}\text{C}$ . See, WO 2007/005643, WO 2007/005644, WO 2007/016361, and WO 2007/016431.

**[0240]** Possible formulations include those suitable for oral, sublingual, buccal, parenteral (for example subcutaneous, intramuscular, or intravenous), rectal, topical including transdermal, intranasal and inhalation administration. Most suitable means of administration for a particular patient will depend on the nature and severity of the disease or condition being treated or the nature of the therapy being used and on the nature of the active compound.

**[0241]** The following examples are meant to be illustrative of the practice of the invention, and not limiting in any way.

## Examples

**[0242]** The examples below, including preparation and analysis, further illustrate and exemplify particular aspects and embodiments of the invention. The following examples are only examples of the present invention in as far as they relate to crystalline Form A as defined in claims 1-10.

## General Method 1. X-ray Powder Diffraction (XRPD)

**[0243]** The XRPD data were collected according to the following general protocol.

### Instrument Method

**[0244]** XRPD patterns were collected on a PANalytical X-ray powder diffractometer fitted with an automatic sample changer, a theta-theta goniometer, automatic beam divergence slit and a PSD Vantec-1 detector. The X-ray tube voltage and amperage were set to 45 kV and 40 mA respectively. The diffractometer was aligned and a calibration check performed using a corundum reference material on the day of data collection. XRPD parameters used are listed in **Table 1**. Data were collected and analyzed by the software Data Viewer.

**Table 1. Parameters for XRPD Tests**

Parameters	Model	
	Empyrean	X' Pert <sup>3</sup>
Mode	Reflection	Reflection
X-Ray wavelength	Cu, $\kappa\alpha$	
	$\text{K}\alpha 1$ (Å): 1.540598,	
	$\text{K}\alpha 2$ (Å): 1.544426,	
X-Ray tube setting	$\text{K}\alpha 2/\text{K}\alpha 1$ intensity ratio: 0.50	
	45 kV, 40 mA	



(continued)

Divergence slit	Automatic	Fixed 1/8°
Scan mode	Continuous	
Scan range (° 2Theta)	3-40	
Scan step time (s)	17.8	46.7
Step size (° 2Theta)	0.0167	0.0263
Test Time	~5min 30s	~5min 4s

## General Method 2. Single-crystal X-ray Diffraction (SCXRD)

**[0245]** The SCXRD data were collected at 153 K using BRUKER D8 VENTURE diffractometer (Mo/K $\alpha$  radiation,  $\lambda$  = 0.710Å). The polarized light microscopic picture was captured using Shanghai Cewei PXS9-T stereomicroscope.

## General Method 3. Differential Scanning Calorimetry (DSC)

**[0246]** DSC was performed using a TA Q200/Q2000 from TA Instruments. Detailed parameters used are listed in Table 2.

**Table 2. Parameters for DSC Tests**

Parameters	DSC
Method	Ramp
Sample pan	Aluminum, sealed/open
Temperature	25 °C - Setting temperature
Heating rate	10 °C/min
Purge gas	N <sub>2</sub>

## General Method 4. Thermo Gravimetric Analysis (TGA)

**[0247]** The TGA data were collected using a TA Q500/Q5000 TGA from TA Instruments. Detailed parameters used are listed in Table 3.

**Table 3. Parameters for TGA Tests**

Parameters	TGA
Method	Ramp
Sample pan	Aluminum, open
Temperature	Room temperature - Setting temperature
Heating rate	10 °C/min
Purge gas	N <sub>2</sub>

## General Method 5. Dynamic Vapor Sorption (DVS)

**[0248]** DVS was measured via a SMS (Surface Measurement Systems) DVS Intrinsic. Parameters for DVS test are listed in Table 4.

**Table 4. Parameters for DVS Tests**

Parameters	Values
Temperature	25°C
Sample size	10-20 mg
Gas and flow rate	N <sub>2</sub> , 200 mL/min
dm/dt	0.002%/min
Min.dm/dt stability duration	10 min

(continued)

Parameters	Values
Max. equilibrium time	360 min
RH range	0%RH-95%RH-0%RH for anhydrous forms 60%RH-95%RH-0%RH-95%RH for hydrous forms
RH step size	10% for 90%RH-0%RH and 0%RH-90%RH 5% for 95%RH-90%RH and 90%RH-95%RH

**General Method 6. Solution Nuclear Magnetic Resonance (NMR)**

**[0249]** Solution NMR was collected on Bruker 400M NMR Spectrometer using DMSO- $d_6$ .

**General Method 7. High Performance Liquid Chromatography (HPLC)**

**[0250]** Agilent 1260/1100 HPLC was utilized and detailed chromatographic conditions for purity and solubility measurement are listed in **Table 5**.

**Table 5. HPLC-DAD Methods for Purity and Solubility Tests**

Parameters	Agilent 1260/1100 DAD Detector			
Column	Cosmosil C18 5um 150×4.6mm			
Mobile phase	A: 10 mM NaH <sub>2</sub> PO <sub>4</sub> in H <sub>2</sub> O (pH 2.2)			
	B: Acetonitrile			
	Purity		Solubility	
Gradient table	Time (min)	%B	Time (min)	%B
	0.0	20	0.0	20
	15.0	45	6.0	60
	25.0	90	7.0	60
	30.0	90	7.1	20
Parameters	Agilent 1260/1100 DAD Detector			
	30.1	20	10.0	20
	35.0	20	-	-
Run time	35.0 min		10.0 min	
Post time	0.0 min			
Flow rate	1.0 mL/min			
Injection volume	5 µL			
Detector wavelength	UV at 220 nm, reference 500 nm			
Column temperature	30 °C			
Sampler temperature	RT			
Diluent	Acetonitrile : H <sub>2</sub> O (1:1, v/v)			

**Table 6. HPLC-ELSD Methods for Solubility Tests**

Parameters	Agilent 1100 ELSD Detector	
Column	Waters symmetry shield RP18 3.5um 150×4.6mm A: 0.1%TFA in H <sub>2</sub> O	
Mobile phase	B: 0.1%TFA in acetonitrile	
	Time (min)	%B
	0.0	25

(continued)

	Time (min)	%B
Gradient table	10.0	90
	11.0	90
	11.1	25
	15.0	25
Run time	15.0 min	
Flow rate	1.0 mL/min	
Injection volume	5 µL	
Detector	ELSD	
Column temperature	40 °C	
Sampler temperature	RT	
Parameters	Agilent 1100 ELSD Detector	
Diluent	Acetonitrile:H <sub>2</sub> O (1:1, v/v)	
ELSD	Alltech 3300	
Temperature	50 °C	
Gain	2	
gas flow	3.0 L/min	

**Form A of Berberine Ursodeoxycholate**Preparation and Characterization of Form A

**[0251]** 5 g BBR-UDCA (mixed crystal or amorphous form) was added into 20 mL EtOH/H<sub>2</sub>O (1:10, v/v). The mixture was stirred at room temperature for 5 hours, and then the mixture was filtered. The filter cake was washed with distilled water. Form A (4.3 g) was obtained.

XRPD and TGA analysis of Form A

**[0252]** The XRPD (**FIG. 1**) pattern comprised peaks at 2θ values of 3.98, 7.06, 7.34, 7.93, 8.79, 9.47, 11.70, 11.94, 12.34, 12.55, 13.90, 14.17, 15.14, 15.50, 16.16, 16.54, 16.78, 17.53, 17.67, 18.23, 19.03, 19.98, 20.87, 21.13, 21.96, 23.49, 24.24, 24.97, 25.50, 26.63, 27.60, 28.06, 28.63, 29.40 and 30.49 °. The XRPD overlay (**FIG. 12**) showed the experimental XRPD pattern of this sample matched well with the calculate pattern derived from the single crystal structure, indicating the sample was a hemi-nonahydrate. The TGA data was shown in **FIG. 28**. A weight loss of 9.4% was observed (theoretical weight loss of hemi-nonahydrate was 10.0%) up to 100°C.

**Form B of Berberine Ursodeoxycholate**Preparation and Characterization of Form B

**[0253]** 5 g BBR-UDCA was dissolved in ACN/H<sub>2</sub>O (1:1, v/v) solution. Type B (1.6 g) was obtained via slow evaporation from ACN/H<sub>2</sub>O (1:1, v/v) solution.

XRPD, DSC and TGA analysis of Form B

**[0254]** The XRPD (**FIG. 2**) pattern comprised peaks at 2θ values of 7.39, 9.31, 12.41, 13.14, 14.37, 14.76, 15.53, 18.65, 21.79, 22.87, 25.27, 25.53 and 28.12 °. TGA/DSC data was shown in **FIG. 20**. A weight loss of 12.2% was found when heated up to 150°C. Two endotherms at 78.1°C and 91.2°C (onset temperatures) were observed.

**Form C of Berberine Ursodeoxycholate**Preparation of Form C

**[0255]** Type C of BBR-UDCA (1.8 g) was obtained via slow evaporation from isopropyl alcohol / isopropyl acetate

(IPA/IPAc) (1:1, v/v) solution of 5 g BBR-UDCA.

XRPD, DSC and TGA analysis of Form C

[0256] The XRPD (FIG. 3) pattern comprised peaks at  $2\theta$  values of 7.23, 10.42, 12.10, 13.37, 14.24, 14.48, 15.28, 15.95, 17.00, 18.17, 20.12, 21.77 and 25.47 °. TGA/DSC data (FIG. 21) showed a weight loss of 11.6% when being heated up to 150°C with two endotherms at 68.4°C and 183.3°C (onset temperatures).

**Form D of Berberine Ursodeoxycholate**

Preparation of Form D

[0257] 5 g Form A of BBR-UDCA was added into ethyl acetate ( $aw \leq 0.2$ ). The obtained suspension was stirred at room temperature for 5 hours, and then the mixture was filtered. Form D of BBR-UDCA (4.3 g) was obtained.

XRPD, DSC and TGA analysis of Form D

[0258] The XRPD (FIG. 4) pattern comprised peaks at  $2\theta$  values of 4.24, 6.79, 8.50, 10.25, 11.50, 13.62, 14.74, 15.20, 17.92, 18.39, 22.91 and 25.73 °. TGA/DSC data (FIG. 22) showed a weight loss of 2.2% after heating to 150°C and an endotherm at 185.2°C (onset temperature).

**Form E of Berberine Ursodeoxycholate**

Preparation of Form E

[0259] 5 g Form A of BBR-UDCA was added into dichloromethane (DCM) atmosphere. Type E (4.5 g) was obtained via solid vapor diffusion in DCM after 24 hours.

XRPD, DSC and TGA analysis of Form E

[0260] The XRPD (FIG. 5) pattern comprised peaks at  $2\theta$  values of 8.59, 10.55, 11.36, 11.86, 12.46, 13.08, 13.38, 14.34, 15.57, 17.24, 17.72, 18.43, 19.66, 19.84, 20.35, 20.91, 21.36, 21.95, 23.21, 24.67, 25.04, 25.82, 26.12, 27.01, 27.84, 28.97, 30.35, 33.33, 34.54 and 36.06 °.

**Form H of Berberine Ursodeoxycholate**

Preparation of Form H

[0261] 5 g BBR-UDCA was dissolved into acetonitrile/H<sub>2</sub>O (1:1, v/v). After slow evaporation of the solvents, the precipitate was collected by filtration. The obtained solid was heated to 100°C for 0.5-2 hours, and then it was cooled to room temperature. Form H of BBR-UDCA (0.8 g) was obtained.

XRPD, DSC and TGA analysis of Form H

[0262] The XRPD (FIG. 6) pattern comprised peaks at  $2\theta$  values of 13.05, 14.63 and 25.46 °. TGA/DSC data (FIG. 23) showed a weight loss of 7.9% after heating to 150°C, with an endotherm at 97.1°C (peak temperature) and an endotherm at 138.3°C (onset temperature).

**Form I of Berberine Ursodeoxycholate**

Preparation of Form I

[0263] 5 g BBR-UDCA was dissolved into tetrahydrofuran/H<sub>2</sub>O (1:1, v/v). After slow evaporation of the solvents for 24 hours, the precipitate was collected by filtration. Form I of BBR-UDCA (0.9 g) was obtained.

XRPD, DSC and TGA analysis of Form I

[0264] The XRPD (FIG. 7) pattern comprised peaks at  $2\theta$  values of 4.19, 7.64, 10.03, 13.32, 13.84, 14.83, 16.73,

22.73, 25.61 and 28.57 °. TGA/DSC data (**FIG. 24**) showed a weight loss of 10.7% after heating to 150°C, with an endotherm at 56.2°C (onset temperature) and an endotherm at 79.6°C (onset temperature).

#### Form J of Berberine Ursodeoxycholate

##### Preparation of Form J

**[0265]** 5 g Form A of BBR-UDCA was heated to 100°C in N<sub>2</sub> for 0.5-2 hours, and then it was cooled to room temperature with N<sub>2</sub> protection. Form J of BBR-UDCA (4.4 g) was obtained.

##### XRPD, DSC and TGA analysis of Form J

**[0266]** The XRPD (**FIG. 8**) pattern comprised peaks at 2θ values of 4.61, 6.32, 7.38, 8.22, 9.21, 10.57, 11.73, 12.13, 12.62, 12.96, 13.87, 14.55, 14.78, 15.81, 16.48, 17.69, 18.39, 19.01, 20.06, 21.25, 22.13, 23.20, 24.47, 24.89, 26.31, 27.98, 30.25 and 33.35 °.

**[0267]** Form J converts to Form A with air exposure.

#### Form P of Berberine Ursodeoxycholate

##### Preparation of Form P

**[0268]** Form P of BBR-UDCA (3.8 g) was obtained via slurring 5 g Form A of BBR-UDCA in MeOH/methyl ethyl ketone (1:9, v/v) at 50 °C for one day.

##### XRPD, DSC and TGA analysis of Form P

**[0269]** The XRPD (**FIG. 9**) pattern comprised peaks at 2θ values of 3.11, 5.01, 5.78, 7.26, 9.20, 10.10, 10.79, 11.65, 13.70, 14.59, 15.22, 16.19, 16.54, 17.05, 18.06, 18.68, 20.52, 21.09, 21.73, 22.49, 24.73, 25.42, 25.94 and 30.11 °. TGA/DSC data (**FIG. 25**) showed a weight loss of 8.8% after heating to 150°C, with an endotherm at 100.3°C (peak temperature), an endotherm at 122.5°C (peak temperature), and 168.7°C (peak temperature).

#### Form W of Berberine Ursodeoxycholate

##### Preparation of Form W

**[0270]** Form W of BBR-UDCA (4.0 g) was obtained via slurring 5.0 g Form A of BBR-UDCA in cyclohexanone/n-butylacetate (1:4, v/v) at room temperature for one day.

##### XRPD, DSC and TGA analysis of Form W

**[0271]** The XRPD (**FIG. 10**) pattern comprised peaks at 2θ values of 6.49, 7.16, 8.51, 10.21, 12.01, 13.13, 13.90, 14.42, 15.18, 15.57, 16.03, 16.45, 16.74, 17.08, 17.85, 18.39, 19.61, 20.43, 21.39, 21.70, 23.51 and 25.21 °. TGA/DSC data (**FIG. 26**) showed a weight loss of 7.2% after heating to 110°C, with an endotherm at 82.1 °C (peak temperature) and an endotherm at 106.4°C (peak temperature).

#### Form X of Berberine Ursodeoxycholate

##### Preparation of Form X

**[0272]** 5 g Form A of BBR-UDCA was dissolved in n-butanol. After slow evaporation of the solvent at room temperature for 24 hours, the precipitate was collected by filtration. Form X of BBR-UDCA (0.8 g) was obtained.

##### XRPD, DSC and TGA analysis of Form X

**[0273]** The XRPD (**FIG. 11**) pattern comprised peaks at 2θ values of 3.63, 6.61, 7.24, 10.49, 11.95, 13.51, 14.26, 14.54, 15.14, 16.01, 16.82, 18.28, 20.26, 21.08, 21.49, 21.90, 25.60, 26.40, 27.31, 29.34, 30.59, 31.01, 34.04, 34.68 and 36.91°. TGA/DSC data (**FIG. 27**) showed a weight loss of 17.0% after heating to 140°C, and an endotherm at 86.7°C (peak temperature) and an endotherm at 189.1°C (peak temperature) were observed.

## Stability Evaluation

**[0274]** To evaluate the physical and chemical stability of Form A of BBR-UDCA and Form D of BBR-UDCA, samples were stored at 80°C (sealed) for 24 hours, 25°C/60% RH (open) and 40°C/75%RH (open) for one week. Both the samples were characterized using XRPD and HPLC, with the results summarized in the following table. XRPD results in **FIG. 13** and **FIG. 14** showed no crystal-form change for both Form A and D under all three conditions. The physical stability of Form A was better than Form D based on the 1-week stability results at 25°C/60%RH (open) and 40°C/75%RH (open).

**[0275]** With the HPLC-DAD result, no HPLC purity decrease was observed for Form A and a decrease of purity (0.5-1.7 area%) was observed for Form D under all three conditions, which indicated the slight degradation of Form D.

**Table 7. Accelerated Stability Evaluation Summary of Form A and D**

Starting Material	Time point	Condition	Form	Purity (Area%)	Purity/ Initial purity(%)
Form A	Initial	-	Form A	99.5	-
	24 hours	80°C	Form A	99.3	99.8
	1 week	25°C/60%RH	Form A	99.4	99.9
	1 week	40°C/75%RH	Form A	99.4	99.8
Form D	Initial	-	Form D	99.6	-
	24 hours	80°C	Form D	99.0	99.5
	1 week	25°C/60%RH	Form D*	98.9	99.3
	1 week	40°C/75%RH	Form D*	97.9	98.3

\*According to **FIG. 14**, degree of crystallinity decreased.

**[0276]** Samples of Form A of BBR-UDCA, Form D of BBR-UDCA and BBR-UDCA (mixed crystals without quality control on crystal forms) were stored 25°C/60%RH (sealed) and 40°C/75%RH (sealed) for one month. All the samples were characterized using XRPD and HPLC, with the results summarized in the following table. No crystal-form change for both Form A and D under all three conditions. Both Form A and Form D showed better chemical stability compared to the mixed crystals of BBR-UDCA

**Table 8. 1-Month Stability Evaluation Summary**

Starting Material	Time Point	Condition	Crystal Form	Purity (Area%)	Purity/ Initial Purity(%)
Form A	Initial	-	Form A	99.5	-
	1 Month	25°C/60%RH	Form A	99.3	99.8
	1 Month	40°C/75%RH	Form A	99.4	99.9
Form D	Initial	-	Form D	99.6	-
	1 Month	25°C/60%RH	Form D	97.2	97.6
	1 Month	40°C/75%RH	Form D	94.7	95.1
Mixed crystal	Initial	-	Mixed	99.0	-
	1 Month	25°C/60%RH	Mixed	90.8	91.7
	1 Month	40°C/75%RH	Mixed	88.7	89.6

## Hygroscopicity Evaluation

**[0277]** Dynamic Vapor Sorption (DVS) isotherm plot of Form A of BBR-UDCA was collected at 25°C with the various humidity, 60%RH-95%RH-0%RH-95%RH (60%RH was the ambient humidity). The result is shown in **FIG. 15**. As the DVS plot shown, a step-like weight loss was observed between 10%RH and 20%RH. A water uptake of 9.9% was observed at 25°C/80%RH, which matched to the TGA weight loss. The XRPD overlay shown in **FIG. 16** indicated that there was no crystal-form change after DVS, which indicated the good physical stability of Form A.

**[0278]** To investigate the hygroscopicity of Form D of BBR-UDCA, DVS isotherm plot of Form D was collected at 25°C between 0 and 95%RH. The result is shown in **FIG. 17**. A water uptake of 4.1% was observed at 25°C/80%RH, while obvious increase was observed over 90% RH and 24.5% water uptake at 95%RH. The result of DVS test indicated Form D was deliquesced in high humidity.

### Polarized Light Microscopy (PLM)

[0279] PLM characterizations of Form A of BBR-UDCA and Form D of BBR-UDCA were performed for observation of the morphology of the samples. Needle-like particles were observed in Form A sample and the particle size was 20  $\mu\text{m}$  to 50  $\mu\text{m}$ . For Type D sample, the particle size was approximately 10  $\mu\text{m}$ .

### Equilibrium Aqueous Solubility

[0280] About 5 mg of each crystal type of solid (Form A of BBR-UDCA and Form D of BBR-UDCA, respectively) was weighed in separate 3-mL bottle, suspended into 1 mL of water, slurried (1000 rpm) at RT for 24 hours, and then centrifuged at 10000 rpm for 3 minutes. The resulting residual solids were characterized by XRPD and supernatant was measured by HPLC-DAD/ELSD. Due to the poor UV absorption of UDCA, DAD was used as the detector only for BBR and ELSD was used for both BBR and UDCA. As shown in **FIG. 18**, no matter the initial crystal types, the crystal type of both residual solids after solubility test was Form A, indicating that Form D converted to Form A during solubility experiment. With Form A as the starting material, the solubility of BBR was 0.35 mg/mL or 0.33 mg/mL using DAD or ELSD as detectors, respectively. The solubility of UDCA was 0.42 mg/mL, indicating the molar ratio was 0.94:1 (BBR: UDCA). With Form D as the starting material, the solubility of BBR was 0.42 mg/mL or 0.41 mg/mL using DAD or ELSD as detectors, respectively. The solubility of UDCA was 0.52 mg/mL, indicating the molar ratio was 0.93:1 (BBR: UDCA). The reason of the deviation from 1: 1 may be that after HTD 1801 dissolving in water, a small amount of disproportionation occurred and it was hardly detected by XRPD due to its limited amount.

[0281] According to the results, Form D gave a better solubility in water than Form A.

**Table 9. Summary of Solubility Evaluation**

Starting material	Form of residual solid	Solubility of BBR (mg/mL)*	Solubility of BBR (mg/mL)#	Solubility of UDCA (mg/mL)#
Type A	Type A	0.35	0.33	0.42
Type D	Type A	0.42	0.41	0.52

\*: using DAD as detector;

#: using ELSD as detector.

### Single Crystal Growth and Structure Analysis

[0282] Single crystals of compound HTD1801 hemi-nonahydrate were obtained by liquid vapor diffusion in ACN/H<sub>2</sub>O (1:5, v:v)/MTBE mixture solvent system. The SCXRD characterization and structure analysis of the single crystal confirmed that it is in monoclinic crystal system and  $P2_1$  space group. There are two BBR cations, two UDCA anions and nine H<sub>2</sub>O molecules per asymmetric unit while each unit cell contains two asymmetric units, which means that there are four BBR cations, four UDCA anions and eighteen H<sub>2</sub>O molecules per unit cell. Adjacent UDCA anions and H<sub>2</sub>O molecules are connected to each other to form the 3-D supramolecular framework structure with 1-D linear channels by intermolecular hydrogen bonding (O-H $\cdots$ O) while the BBR cations are stacked orderly in the channels by  $\pi$ - $\pi$  interaction to form the 3-D crystal structure of the crystal eventually.

**Table\_10. Structural Information and Refinement Parameters for HTD1801 Hemi-nonahydrate Single Crystal**

Identification code	CP2276
Empirical formula	C <sub>44</sub> H <sub>66</sub> NO <sub>12.5</sub>
Formula weight	808.97
Temperature	153.15K
Wavelength	Mo K $\alpha$ (0.71073Å)
Crystal system, space group	Monoclinic, $P2_1$

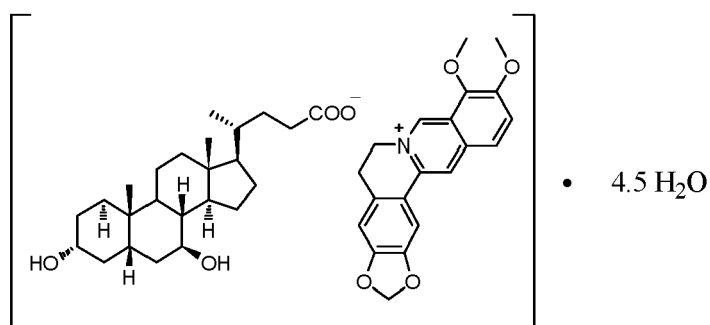
(continued)

5	<b>Unit cell dimensions</b>	$a = 23.5456(12) \text{ \AA}$ $b = 7.4294(4) \text{ \AA}$ $c = 25.3314(13) \text{ \AA}$ $\alpha = 90^\circ$ $\beta = 109.860(2)^\circ$ $\gamma = 90^\circ$
10	<b>Volume</b>	$4167.7(4) \text{ \AA}^3$
	<b>Z, Calculated density</b>	4, 1.289 g/cm <sup>3</sup>
	<b>Absorption coefficient</b>	0.093 mm <sup>-1</sup>
15	<b><i>F</i>(000)</b>	1748.0
	<b>Crystal size</b>	$0.1 \times 0.025 \times 0.01 \text{ mm}$
	<b>2 Theta range for data collection</b>	4.826° to 55.266°
20	<b>Limiting indices</b>	$-30 \leq h \leq 30$ $-9 \leq k \leq 9$ $-33 \leq l \leq 32$
	<b>Reflections collected / unique</b>	89416 / 19234 [R(int) = 0.2125]
	<b>Completeness</b>	99.00 %
25	<b>Refinement method</b>	Full-matrix least-squares on $F^2$
	<b>Data / restraints / parameters</b>	19234 / 19 / 1097
	<b>Goodness-of-fit on <math>F^2</math></b>	1.006
30	<b>Final R indices [<math>I &gt; 2\sigma(I)</math>]</b>	$R_1 = 0.0881$ , $wR_2 = 0.1238$
	<b>Largest diff. peak and hole</b>	0.28 and $-0.30 \text{ e. \AA}^{-3}$

[0283] The XRPD overlay (FIG. 12) showed that the XRPD pattern of Form A matched well with the XRPD pattern of the obtained single crystal. In addition, the TGA data of Form A showed that a weight loss of 9.4% was observed, while the theoretical weight loss of hemi-nonahydrate was 10.0%. All these results indicated that Form A was a hemi-nonahydrate of BBR-UDCA.

## Claims

1. A crystalline form, which is Form A of berberine ursodeoxycholate, having an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of the group consisting of: 7.06, 7.34, 8.79, 9.47, 11.94, 14.17, 15.50, 16.54 and 16.78, 17.53, 17.67, 18.23, 19.03, 19.98, 20.87, 21.13, 21.96, 23.49, 24.24, 24.97, 25.50, 26.63, 27.60, 28.06, 28.63, 29.40 and  $30.49^\circ \pm 0.2^\circ$  obtained using Cu K $\alpha$  radiation ( $\lambda_1 = 1.540598 \text{ \AA}$ ,  $\lambda_2 = 1.544426 \text{ \AA}$ , intensity ratio  $\lambda_2/\lambda_1 = 0.50$ ), wherein the Form A of berberine ursodeoxycholate has the formula:





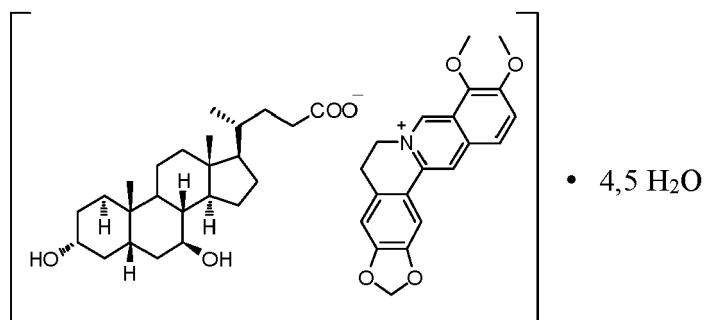
2. The crystalline form of claim 1, having an X-ray powder diffraction (XRPD) pattern that further comprises one or more peaks at  $2\theta$  values of 3.98, 7.93, 11.70, 12.34, 12.55, 13.90, 15.14 and  $16.16^\circ \pm 0.2^\circ$ .
3. The crystalline form of claim 1 or 2, having an X-ray powder diffraction (XRPD) pattern comprising peaks at  $2\theta$  values of 3.98, 7.06, 7.34, 7.93, 8.79, 9.47, 11.70, 11.94, 12.34, 12.55, 13.90, 14.17, 15.14, 15.50, 16.16, 16.54, 16.78, 17.53, 17.67, 18.23, 19.03, 19.98, 20.87, 21.13, 21.96, 23.49, 24.24, 24.97, 25.50, 26.63, 27.60, 28.06, 28.63, 29.40 and  $30.49^\circ \pm 0.2^\circ$ .
4. The crystalline form of any of claims 1 to 3, wherein the crystalline form is **characterized by** a monoclinic crystal system and  $P2_1$  space group.
5. The crystalline form of any of claims 1 to 4, wherein each unit cell contains two asymmetric units and there are two BBR cations, two UDCA anions and nine  $H_2O$  molecules per asymmetric unit, and four BBR cations, four UDCA anions and eighteen  $H_2O$  molecules per unit cell.
6. The crystalline form of any of claims 1-5, wherein the solid form is **characterized by** a purity of 70% or higher.
7. A pharmaceutical composition comprising Form A of berberine ursodeoxycholate according to any of claims 1-6 and a pharmaceutically acceptable excipient, carrier, or diluent.
8. A crystalline form of any of claims 1-6 or the pharmaceutical composition of claim 7 for use in treating a disease or disorder selected from fatty liver, non-alcoholic fatty liver disease (NAFLD) and non-alcoholic steatohepatitis (NASH), cholestatic liver diseases, graft-versus-host disease of the liver, primary sclerosing cholangitis, chronic viral associated liver diseases, alcohol-related liver diseases, metabolic diseases or disorders such as pre-diabetes, diabetes, hyperlipidemia, hypercholesterolemia, diabetic dyslipidemia, dyslipidemia in statin-intolerant patients, obesity, or a related disease or disorder thereof in a mammal, including a human.
9. A crystalline form of any of claims 1 to 6 or the pharmaceutical composition according to claim 7 for use according to claim 8, wherein the disease or disorder is fatty liver, NAFLD or NASH.
10. A crystalline form of any of claims 1 to 6 or the pharmaceutical composition according to claim 7 for use according to claim 8, wherein the disease or disorder is cholestatic liver diseases, graft-versus-host disease of the liver, chronic viral associated liver diseases or alcohol-related liver diseases.
11. A method for preparing Form A of any of claims 1-6, comprising:
  - forming a mixture of a crystalline and/or amorphous form of berberine ursodeoxycholate with a co-solvent of EtOH and  $H_2O$ , wherein the water activity is greater than about 0.4;
  - stirring the mixture at room temperature for about 3 to about 7 hours;
  - filtering the mixture to obtain a filter cake;
  - washing the filter cake with distilled water; and
  - removing water to until the water content is about 10% or less to obtain Form A of berberine ursodeoxycholate,
 wherein EtOH :  $H_2O$  v/v is from about 1:5 to about 1: 30.

## Patentansprüche

1. Kristalline Form, bei der es sich um Form A von Berberin-Ursodeoxycholat handelt, mit einem Röntgenpulverbeugungsmuster (XRPD), das Peaks bei  $2\theta$ -Werten, aus der Gruppe bestehend aus: 7,06, 7,34, 8,79, 9,47, 11,94, 14,17, 15,50, 16,54 und 16,78, 17,53, 17,67, 18,23, 19,03, 19,98, 20,87, 21,13, 21,96, 23,49, 24,24, 24,97, 25,50, 26,63, 27,60, 28,06, 28,63, 29,40 und  $30,49^\circ \pm 0,2^\circ$ , umfasst, erhalten unter Verwendung von Cu  $K\alpha$ -Strahlung ( $\lambda_1 = 1,540598 \text{ \AA}$ ,  $\lambda_2 = 1,544426 \text{ \AA}$ , Intensitätsverhältnis  $\lambda_2/\lambda_1 = 0,50$ ), wobei die Form A von Berberin-Ursodeoxycholat die Formel:

5

10



hat.

15 **2.** Kristalline Form nach Anspruch 1 mit einem Röntgenpulverbeugungsmuster (XRPD), das außerdem einen oder mehrere Peaks bei 2 $\theta$ -Werten von 3,98, 7,93, 11,70, 12,34, 12,55, 13,90, 15,14 und 16,16°  $\pm$  0,2° umfasst.

20 **3.** Kristalline Form nach Anspruch 1 oder 2 mit einem Röntgenpulverbeugungsmuster (XRPD), das Peaks bei 2 $\theta$ -Werten von 3,98, 7,06, 7,34, 7,93, 8,79, 9,47, 11,70, 11,94, 12,34, 12,55, 13,90, 14,17, 15,14, 15,50, 16,16, 16,54, 16,78, 17,53, 17,67, 18,23, 19,03, 19,98, 20,87, 21,13, 21,96, 23,49, 24,24, 24,97, 25,50, 26,63, 27,60, 28,06, 28,63, 29,40 und 30,49°  $\pm$  0,2° umfasst.

25 **4.** Kristalline Form nach einem der Ansprüche 1 bis 3, wobei die kristalline Form durch ein monoklines Kristallsystem und die Raumgruppe P2<sub>1</sub> gekennzeichnet ist.

**5.** Kristalline Form nach einem der Ansprüche 1 bis 4, wobei jede Elementarzelle zwei asymmetrische Einheiten enthält und es zwei BBR-Kationen, zwei UDCA-Anionen und neun H<sub>2</sub>O-Moleküle pro asymmetrischer Einheit sowie vier BBR-Kationen, vier UDCA-Anionen und achtzehn H<sub>2</sub>O-Moleküle pro Elementarzelle gibt.

30 **6.** Kristalline Form nach einem der Ansprüche 1-5, wobei die feste Form durch eine Reinheit von 70% oder mehr gekennzeichnet ist.

**7.** Pharmazeutische Zusammensetzung, umfassend die Form A von Berberin-Ursodeoxycholat nach einem der Ansprüche 1-6 und einen pharmazeutisch annehmbaren Hilfsstoff, Träger oder Verdünnungsmittel.

35 **8.** Kristalline Form nach einem der Ansprüche 1-6 oder pharmazeutische Zusammensetzung nach Anspruch 7 zur Verwendung bei der Behandlung einer Krankheit oder Störung, ausgewählt aus Fettleber, nicht-alkoholischer Fettlebererkrankung (NAFLD) und nicht-alkoholischer Steatohepatitis (NASH), cholestatischen Lebererkrankungen, Graft-versus-Host-Krankheit der Leber, primär sklerosierender Cholangitis, chronischen virusbedingten Leberkrankheiten, alkoholbedingten Leberkrankheiten, Stoffwechselkrankheiten oder -störungen wie Prädiabetes, Diabetes, Hyperlipidämie, Hypercholesterinämie, diabetischer Dyslipidämie, Dyslipidämie bei Statin-intoleranten Patienten, Fettleibigkeit oder einer damit zusammenhängenden Krankheit oder Störung bei einem Säugetier, einschließlich eines Menschen.

45 **9.** Kristalline Form nach einem der Ansprüche 1 bis 6 oder pharmazeutische Zusammensetzung nach Anspruch 7 zur Verwendung nach Anspruch 8, wobei die Krankheit oder Störung eine Fettleber, NAFLD oder NASH ist.

50 **10.** Kristalline Form nach einem der Ansprüche 1 bis 6 oder pharmazeutische Zusammensetzung nach Anspruch 7 zur Verwendung nach Anspruch 8, wobei es sich bei der Krankheit oder Störung um cholestatische Lebererkrankungen, Graft-versus-Host-Krankheit der Leber, chronische virusbedingte Leberkrankheiten oder alkoholbedingte Lebererkrankungen handelt.

**11.** Verfahren zur Herstellung der Form A nach einem der Ansprüche 1-6, umfassend:

55 **Bilden einer Mischung aus einer kristallinen und/oder amorphen Form von Berberin-Ursodeoxycholat mit einem Co-Lösungsmittel aus EtOH und H<sub>2</sub>O, wobei die Wasseraktivität größer als etwa 0,4 ist;**  
**Rühren der Mischung bei Raumtemperatur für etwa 3 bis etwa 7 Stunden;**  
**Filtern des Gemisches, um einen Filterkuchen zu erhalten;**

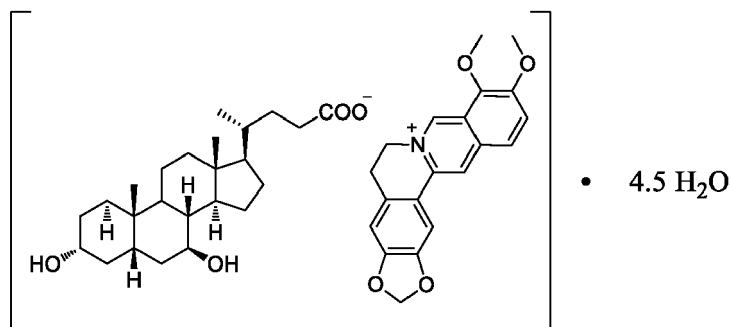
Waschen des Filterkuchens mit destilliertem Wasser; und

Entfernen von Wasser, bis der Wassergehalt etwa 10% oder weniger beträgt, um die Form A von Berberin-Ursodeoxycholat zu erhalten,

worin EtOH : H<sub>2</sub>O v/v von etwa 1:5 bis etwa 1:30 ist.

## Revendications

1. Forme cristalline, qui est la Forme A de l'ursodésoxycholate de berbérine, ayant un motif de diffraction de rayons X sur poudres (XRPD) comportant des pics à des valeurs  $2\theta$  du groupe constitué de : 7,06 ; 7,34 ; 8,79 ; 9,47 ; 11,94 ; 14,17 ; 15,50 ; 16,54 et 16,78 ; 17,53 ; 17,67 ; 18,23 ; 19,03 ; 19,98 ; 20,87 ; 21,13 ; 21,96 ; 23,49 ; 24,24 ; 24,97 ; 25,50 ; 26,63 ; 27,60 ; 28,06 ; 28,63 ; 29,40 et 30,49 ° ( $\pm 0,2^\circ$ ) obtenus en utilisant un rayonnement Cu K $\alpha$  ( $\lambda_1 = 1,540598 \text{ \AA}$ ,  $\lambda_2 = 1,544426 \text{ \AA}$ , rapport d'intensité  $\lambda_2/\lambda_1 = 0,50$ ), dans laquelle la Forme A de l'ursodésoxycholate de berbérine a la formule :



2. Forme cristalline selon la revendication 1, ayant un motif de diffraction de rayons X sur poudres (XRPD) qui comporte en outre un ou plusieurs pics à des valeurs  $2\theta$  de 3,98 ; 7,93 ; 11,70 ; 12,34 ; 12,55 ; 13,90 ; 15,14 et  $16,16^\circ \pm 0,2^\circ$ .
3. Forme cristalline selon la revendication 1 ou 2, ayant un motif de diffraction de rayons X sur poudres (XRPD) comportant des pics à des valeurs  $2\theta$  de 3,98 ; 7,06 ; 7,34 ; 7,93 ; 8,79 ; 9,47 ; 11,70 ; 11,94 ; 12,34 ; 12,55 ; 13,90 ; 14,17 ; 15,14 ; 15,50 ; 16,16 ; 16,54 ; 16,78 ; 17,53 ; 17,67 ; 18,23 ; 19,03 ; 19,98 ; 20,87 ; 21,13 ; 21,96 ; 23,49 ; 24,24 ; 24,97 ; 25,50 ; 26,63 ; 27,60 ; 28,06 ; 28,63 ; 29,40 et  $30,49^\circ \pm 0,2^\circ$ .
4. Forme cristalline selon l'une quelconque des revendications 1 à 3, dans laquelle la forme cristalline est **caractérisée par** un système cristallin monoclinique et un groupe spatial P2<sub>1</sub>.
5. Forme cristalline selon l'une quelconque des revendications 1 à 4, dans laquelle chaque cellule unitaire contient deux unités asymétriques et il y a deux cations BBR, deux anions UDCA et neuf molécules H<sub>2</sub>O par unité asymétrique, et quatre cations BBR, quatre anions UDCA et dix-huit molécules H<sub>2</sub>O par cellule unitaire.
6. Forme cristalline selon l'une quelconque des revendications 1 à 5, dans laquelle la forme solide est **caractérisée par** une pureté de 70 % ou plus.
7. Composition pharmaceutique comportant la Forme A de l'ursodésoxycholate de berbérine selon l'une quelconque des revendications 1 à 6 et un excipient, un vecteur ou un diluant acceptable du point de vue pharmaceutique.
8. Forme cristalline selon l'une quelconque des revendications 1 à 6 ou composition pharmaceutique selon la revendication 7 pour une utilisation dans le traitement d'une maladie ou d'un trouble choisi parmi une stéatose hépatique, une stéatose hépatique non alcoolique (NAFLD) et une stéatohépatite non alcoolique (NASH), des maladies hépatiques cholestatiques, une maladie du greffon contre l'hôte du foie, une cholangite sclérosante primitive, des maladies hépatiques virales chroniques associées, des maladies hépatiques liées à l'alcool, des maladies ou des troubles métaboliques tels que des pré-diabètes, des diabètes, des hyperlipidémies, des hypercholestérolémies, des dyslipidémies diabétiques, des dyslipidémies chez des patients intolérants à la statine, de l'obésité, ou une maladie ou un trouble lié à ceux-ci chez un mammifère, incluant chez un être humain.
9. Forme cristalline selon l'une quelconque des revendications 1 à 6 ou composition pharmaceutique selon la reven-

dication 7 pour une utilisation selon la revendication 8, dans laquelle la maladie ou le trouble est une stéatose hépatique, une NAFLD ou une NASH.

5 10. Forme cristalline selon l'une quelconque des revendications 1 à 6 ou composition pharmaceutique selon la revendication 7 pour une utilisation selon la revendication 8, dans laquelle la maladie ou le trouble est une maladie hépatique cholestatique, une maladie du greffon contre l'hôte du foie, des maladies hépatiques virales chroniques associées ou des maladies hépatiques liées à l'alcool.

10 11. Procédé de préparation de la Forme A selon l'une quelconque des revendications 1 à 6, comportant les étapes consistant à :

former un mélange d'une forme cristalline et/ou amorphe de l'ursodésoxycholate de berbérine avec un co-solvant d'EtOH et de H<sub>2</sub>O, dans lequel l'activité de l'eau est supérieure à environ 0,4 ;  
 agiter le mélange à température ambiante pendant environ 3 à environ 7 heures ;  
 15 filtrer le mélange pour obtenir un gâteau de filtration ;  
 laver le gâteau de filtration à l'eau distillée ; et  
 éliminer l'eau jusqu'à ce que la teneur en eau soit d'environ 10 % ou moins pour obtenir la Forme A de l'ursodésoxycholate de berbérine,  
 dans lequel EtOH:H<sub>2</sub>O est d'environ 1:5 à environ 1:30.

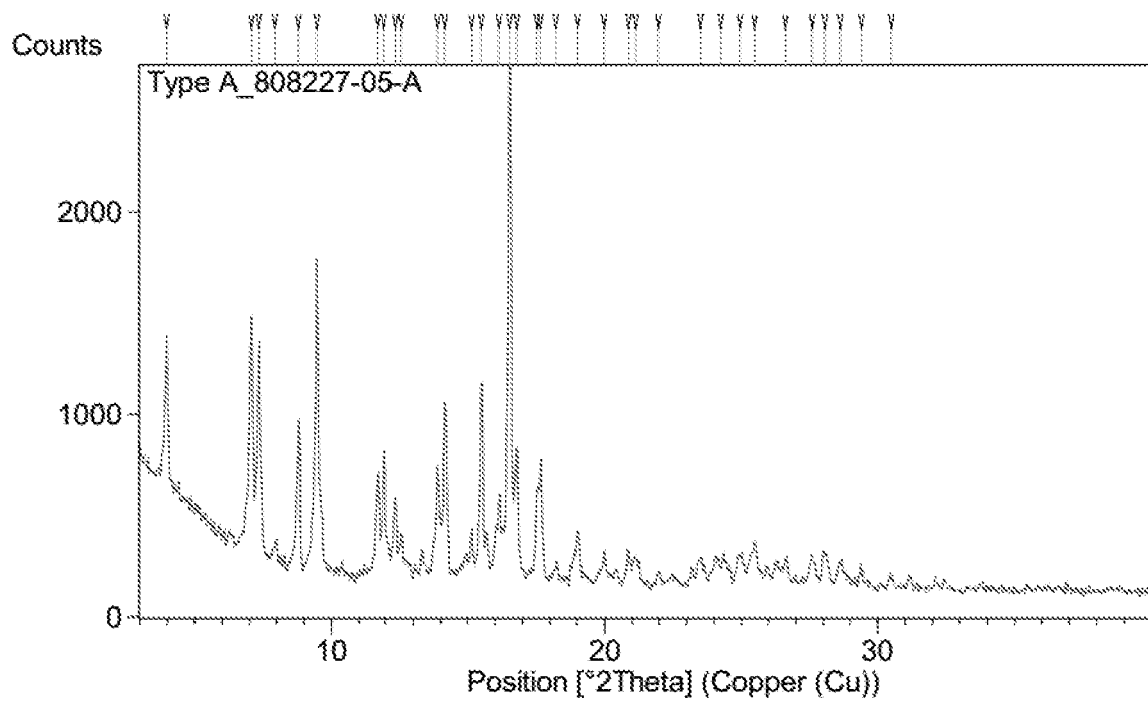


FIG.1

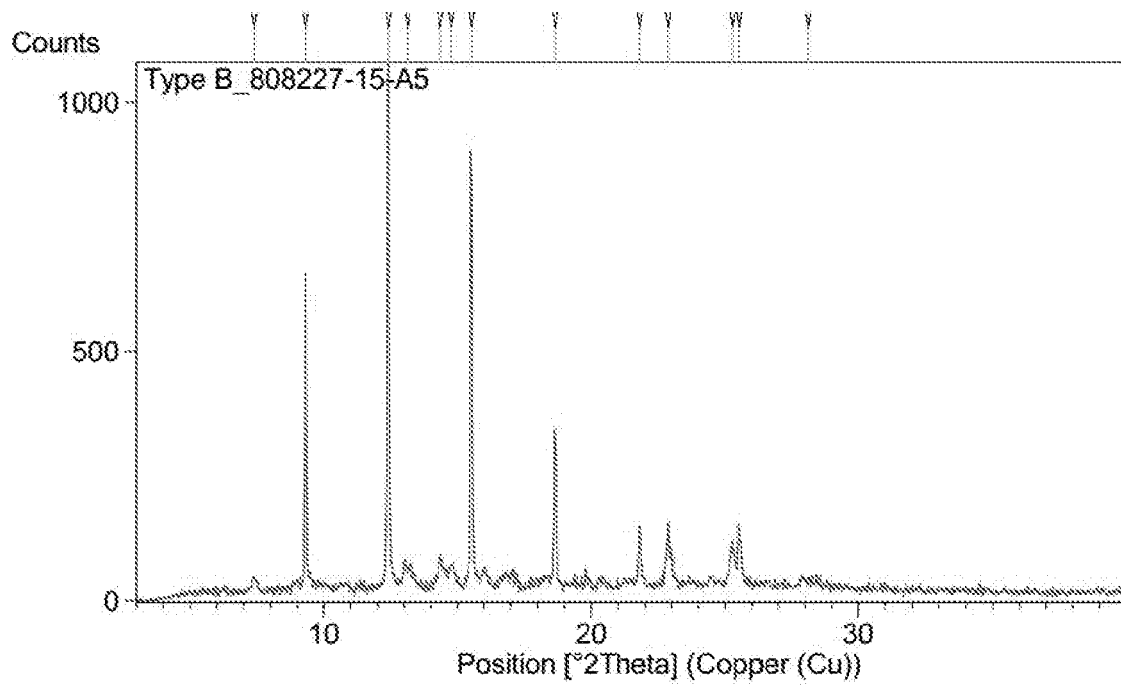


FIG.2

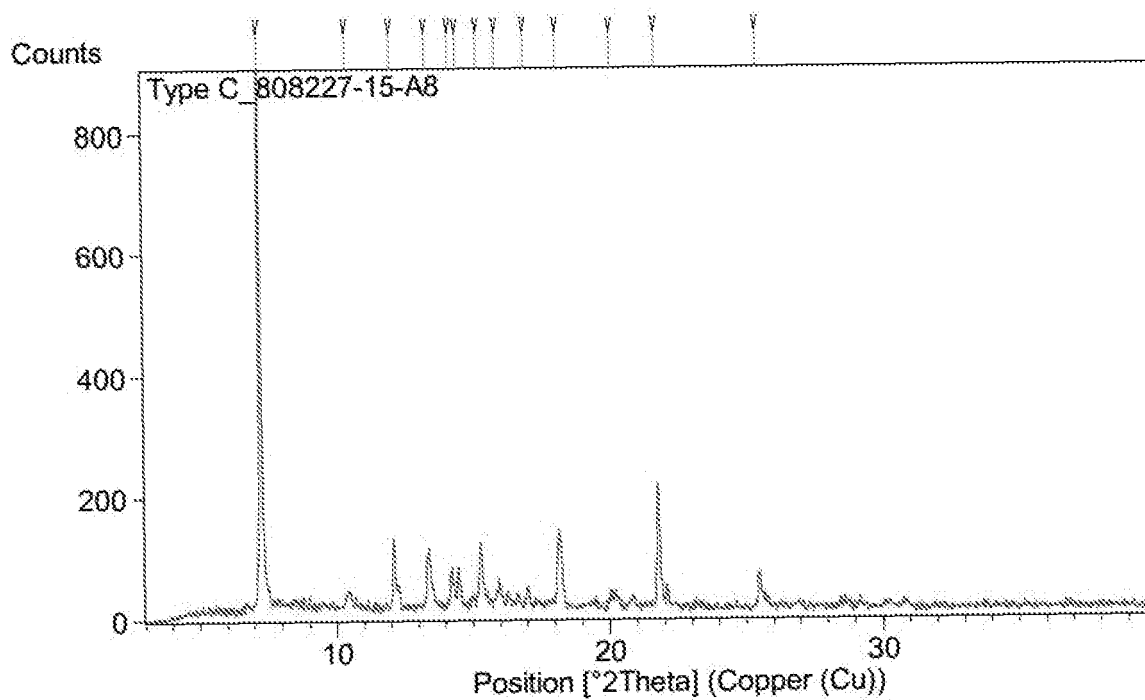


FIG.3

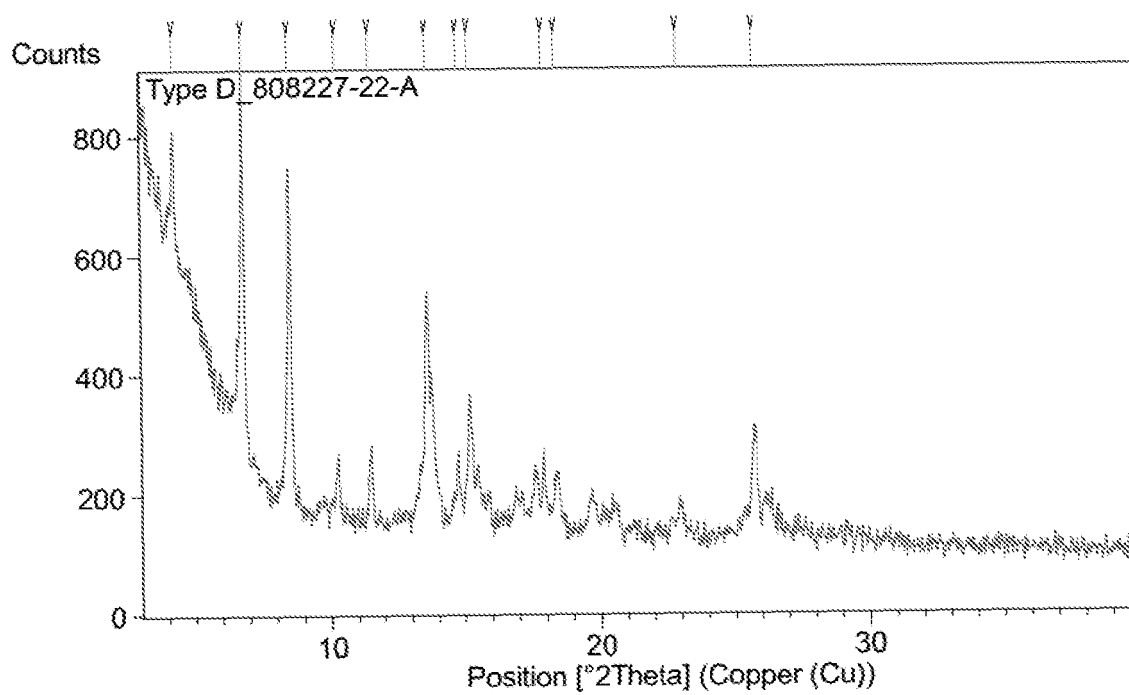


FIG.4

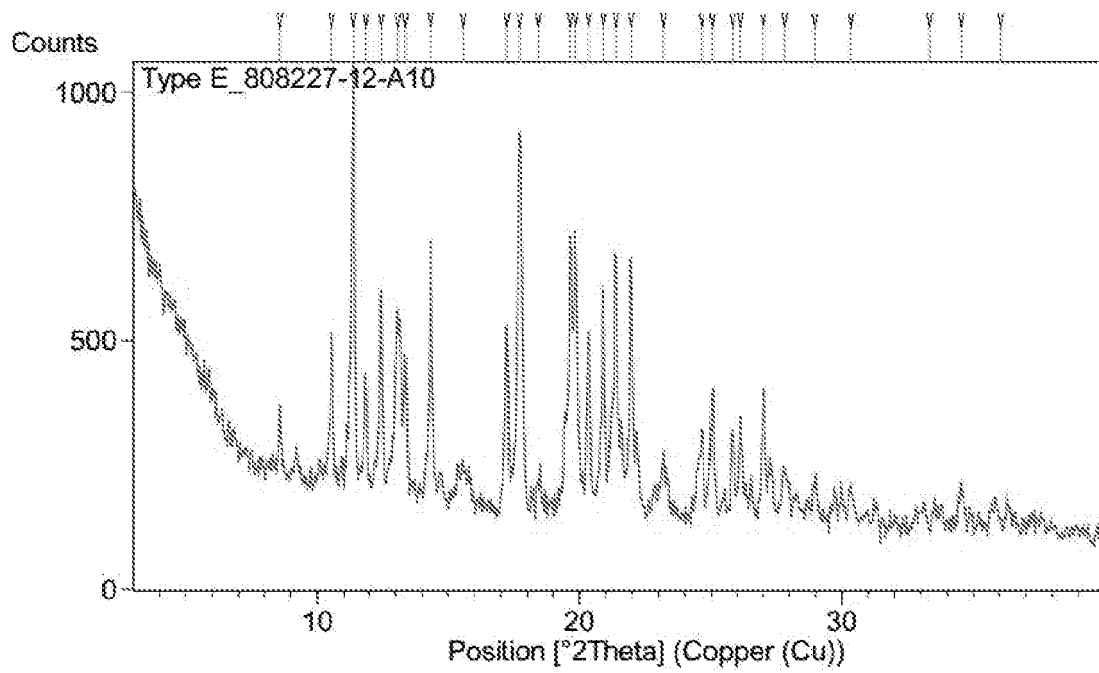


FIG.5

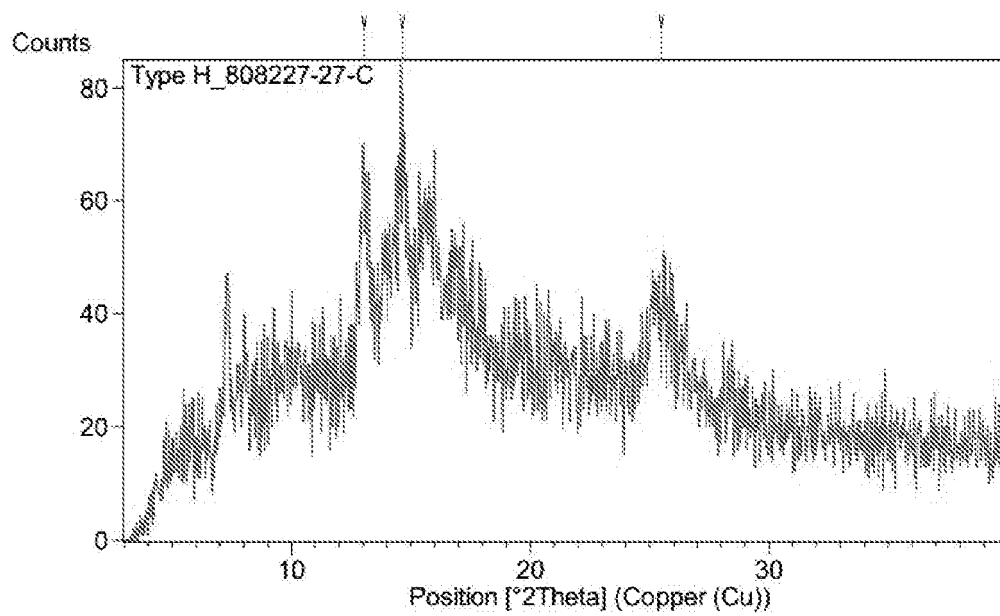


FIG.6

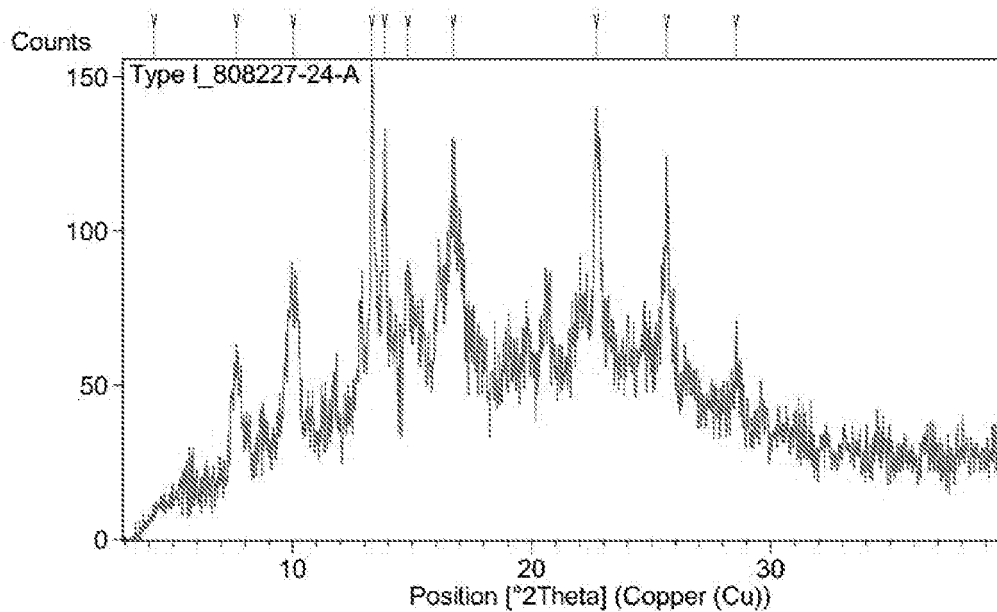


FIG.7

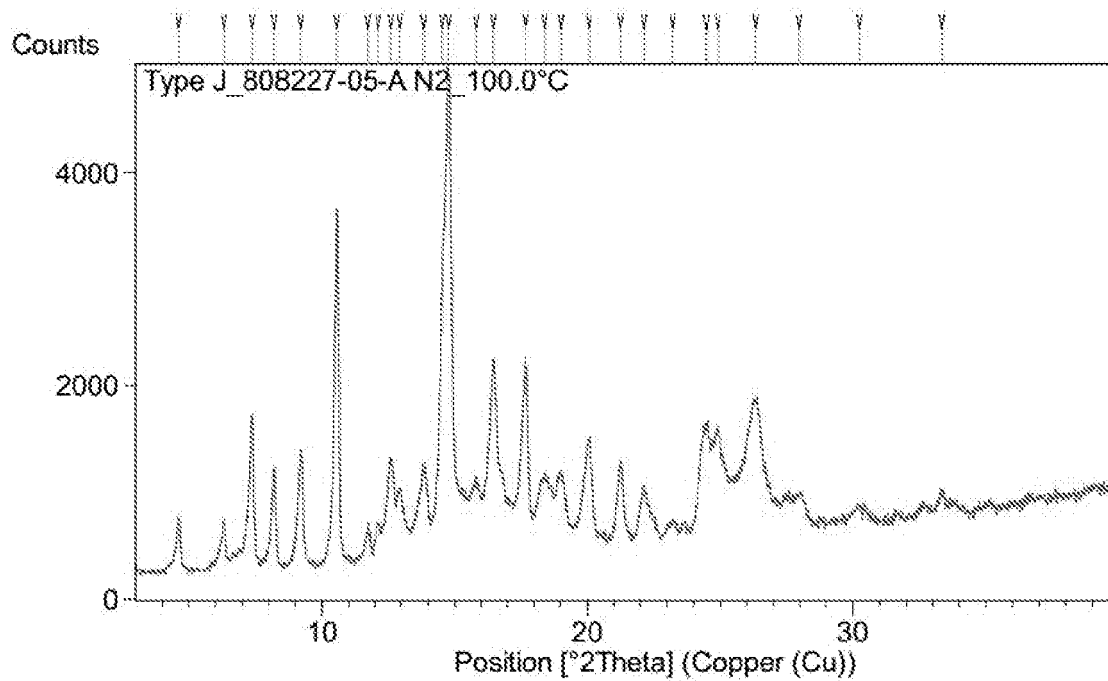


FIG.8



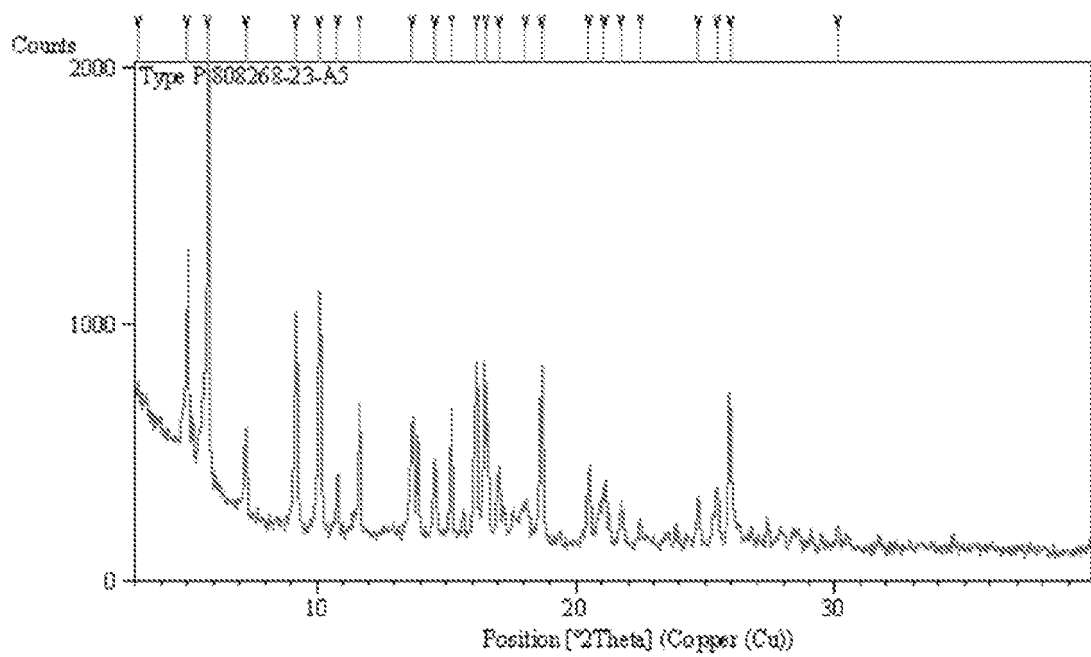


FIG.9

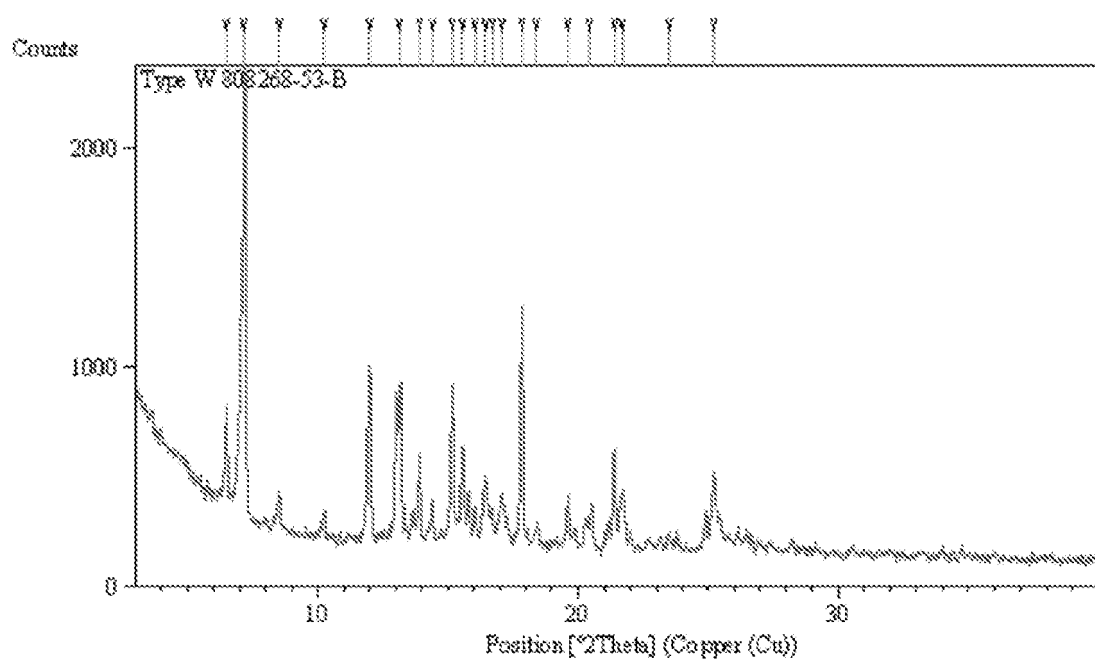


FIG.10

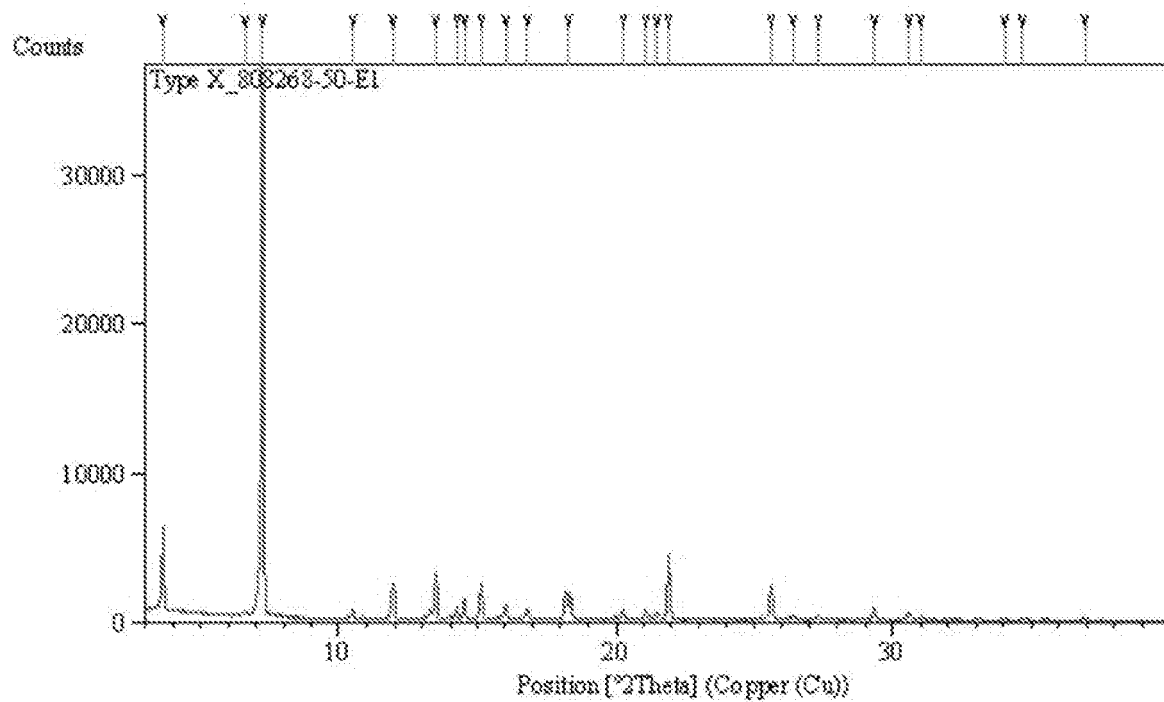


FIG.11

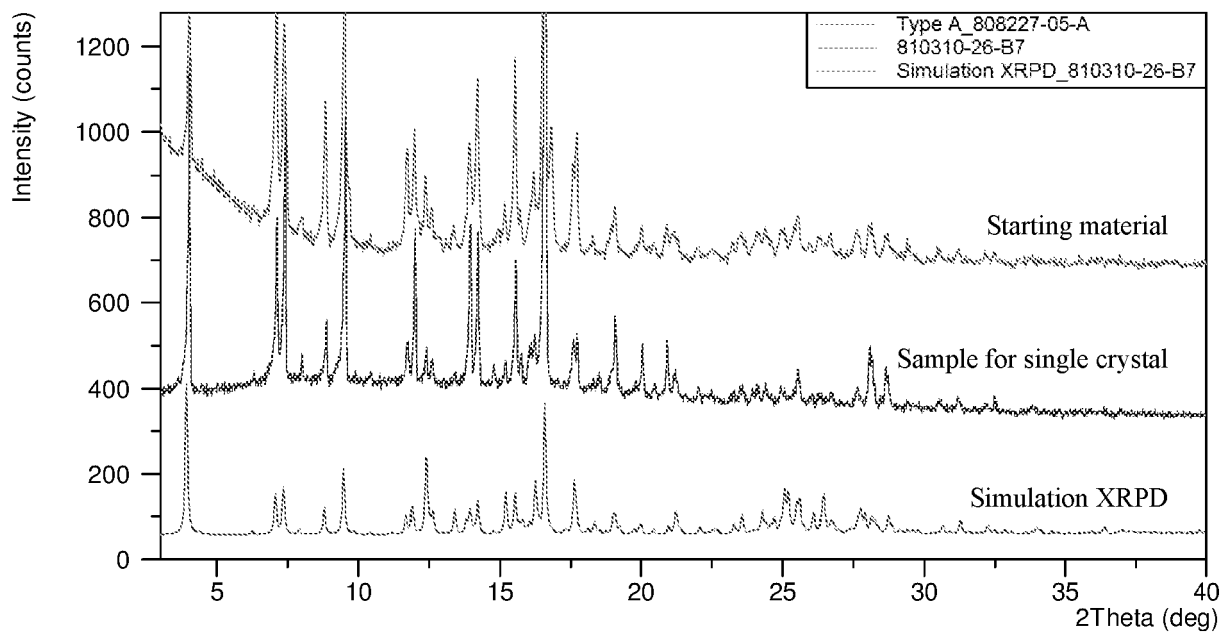


FIG.12

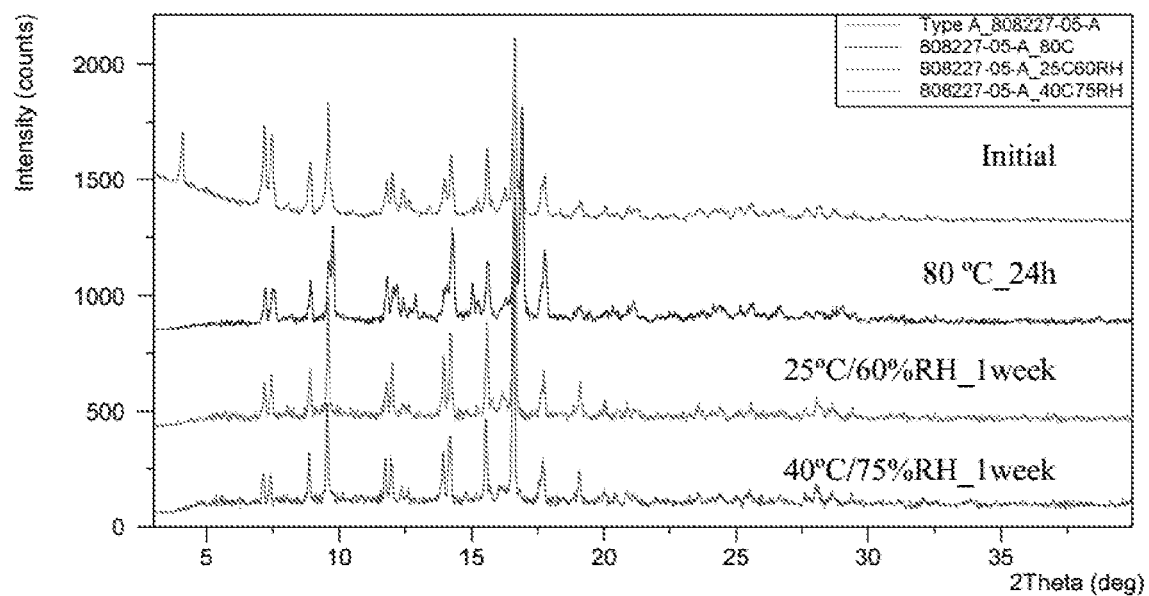


FIG.13

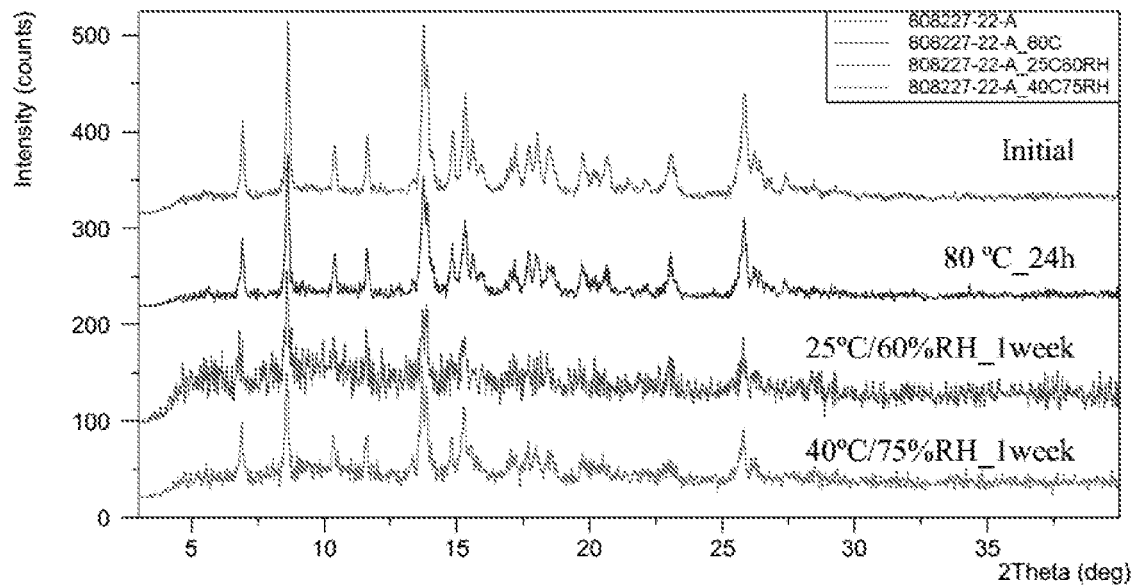


FIG.14

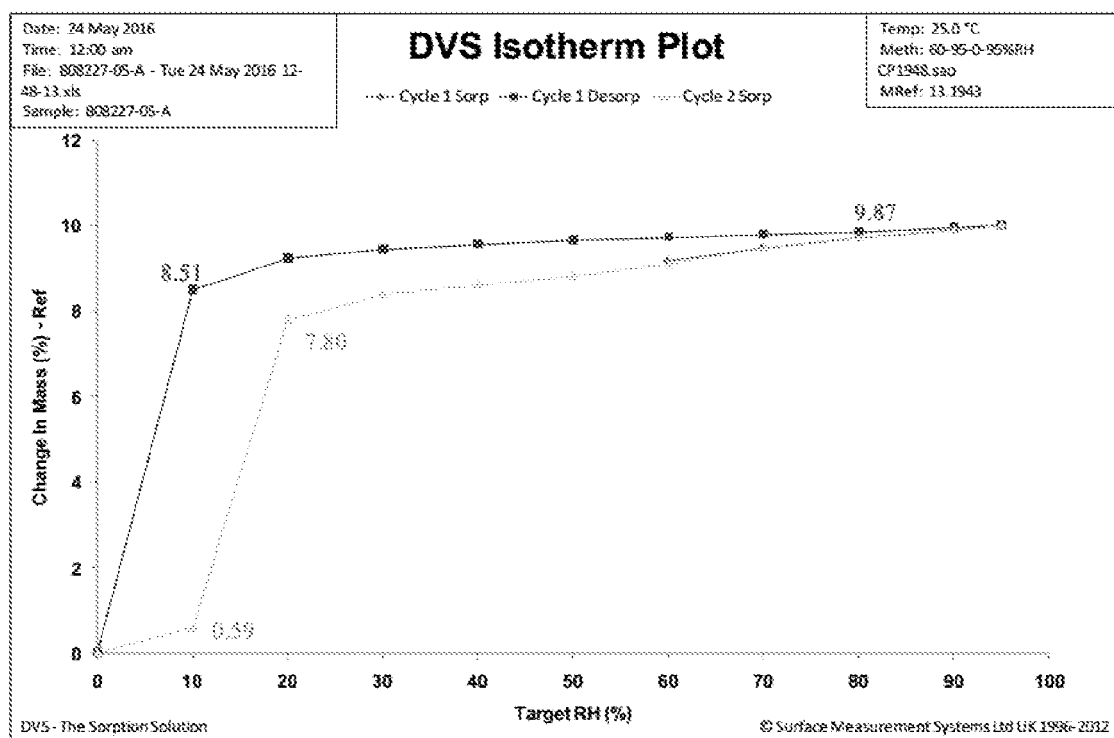


FIG.15

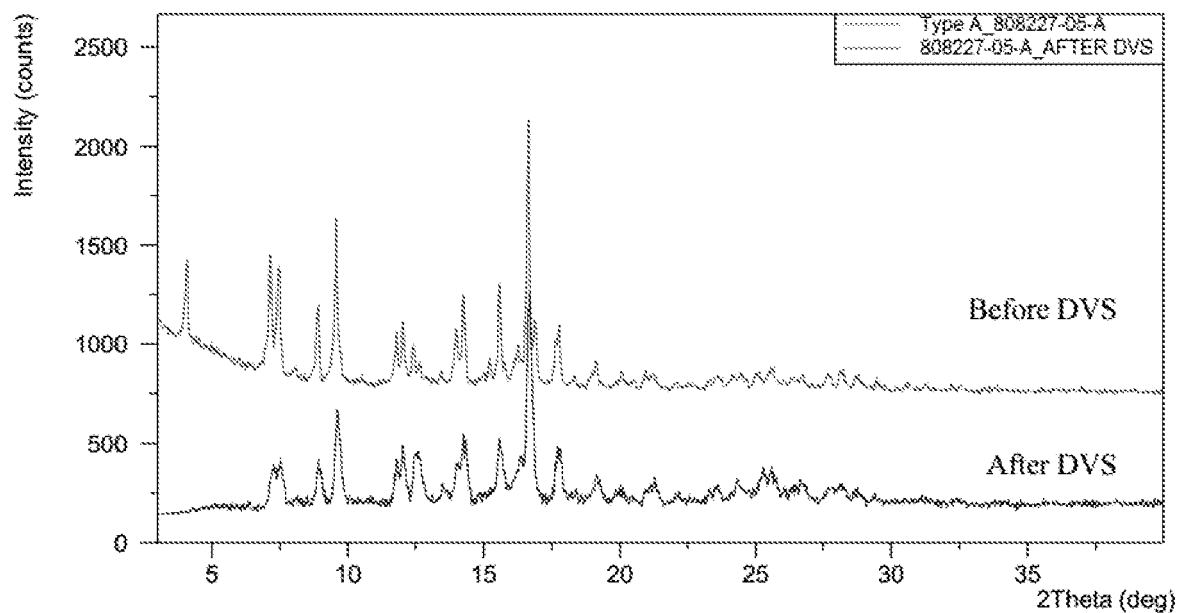


FIG.16

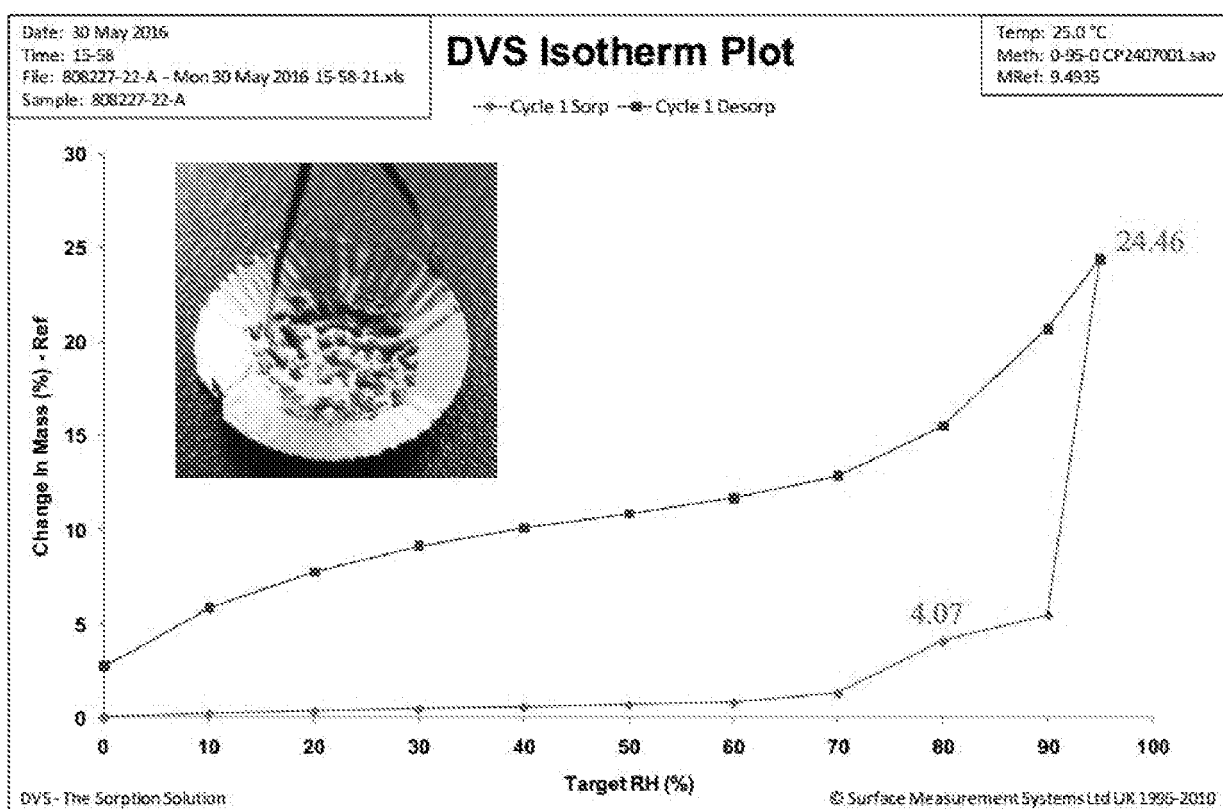


FIG.17

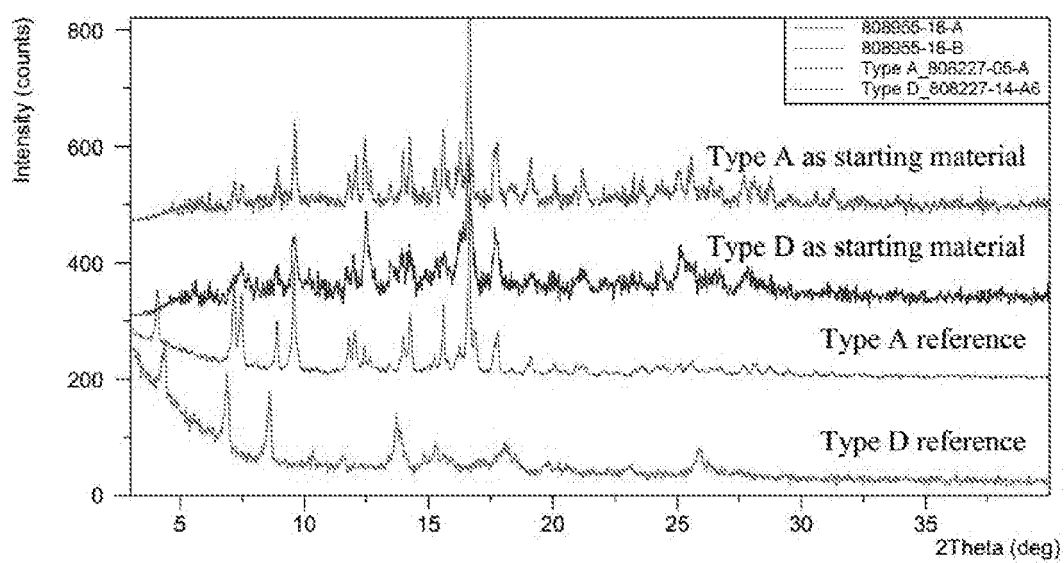


FIG.18

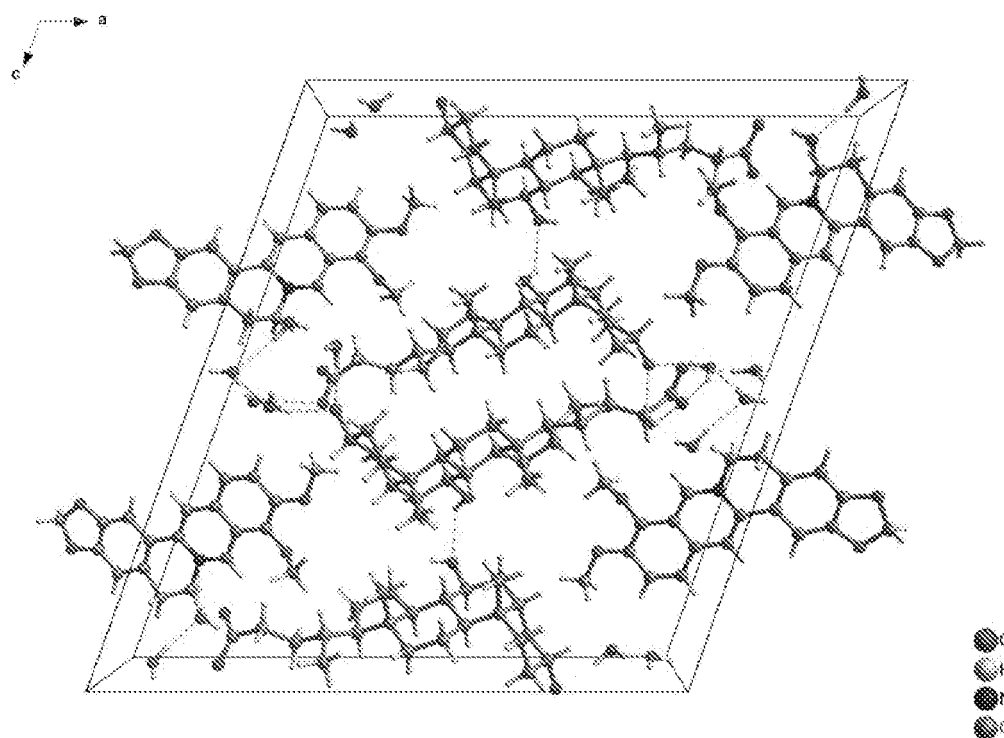


FIG.19

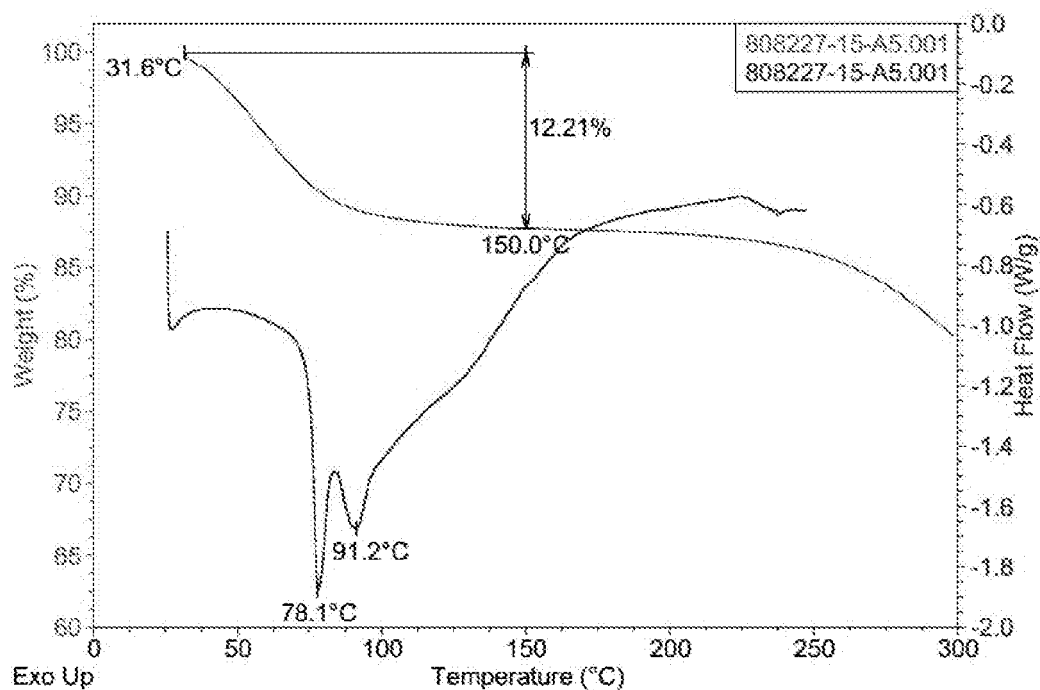


FIG.20

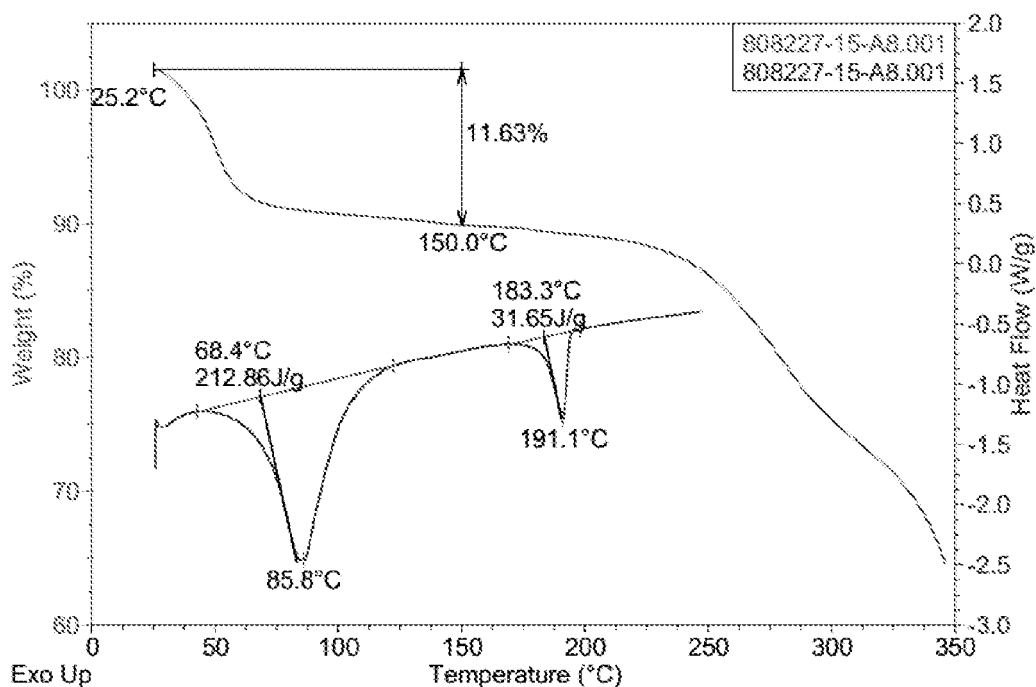


FIG.21

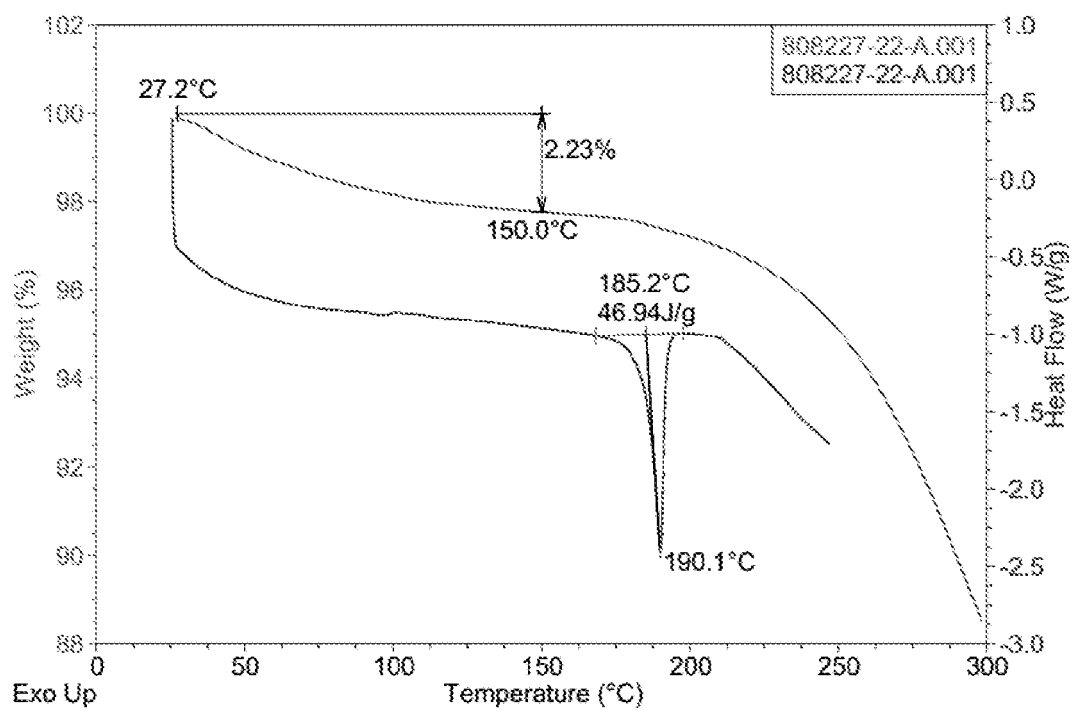


FIG.22

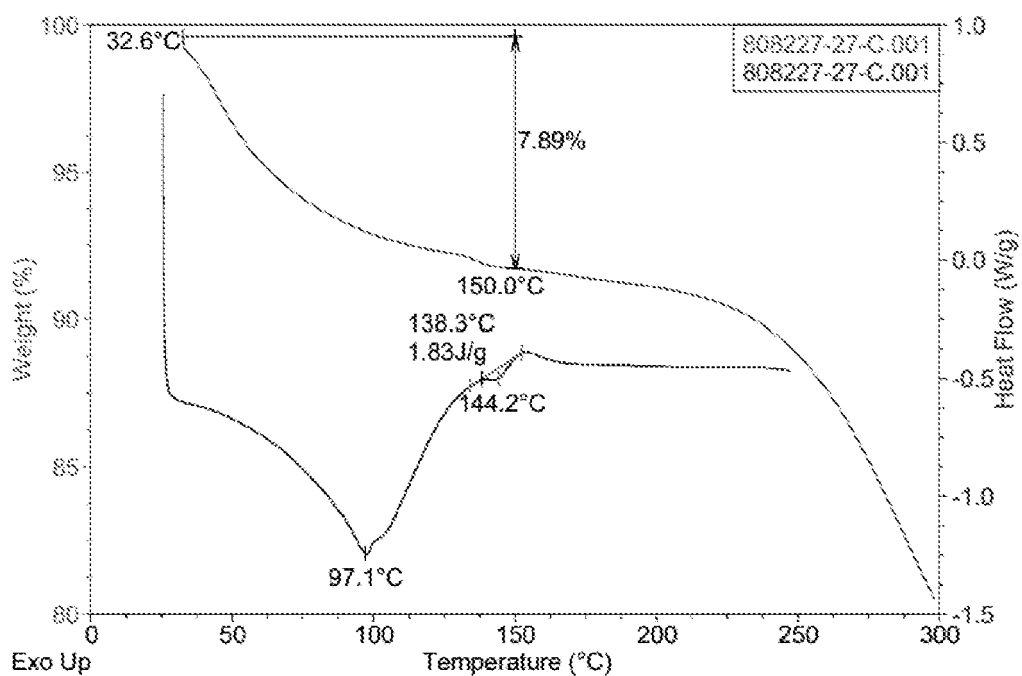


FIG.23



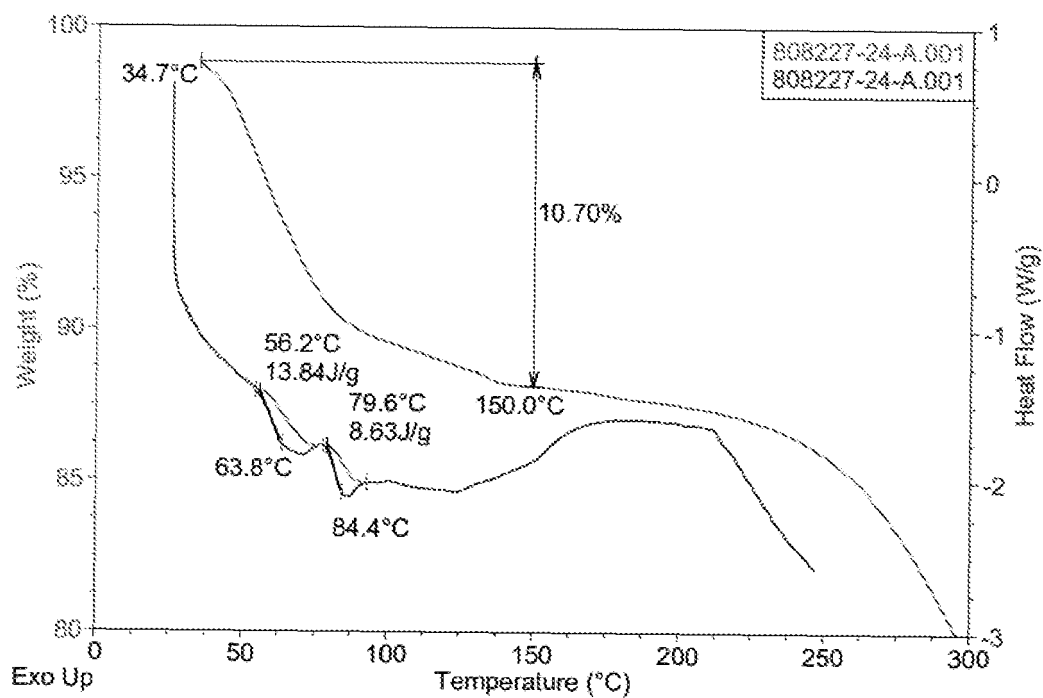


FIG.24

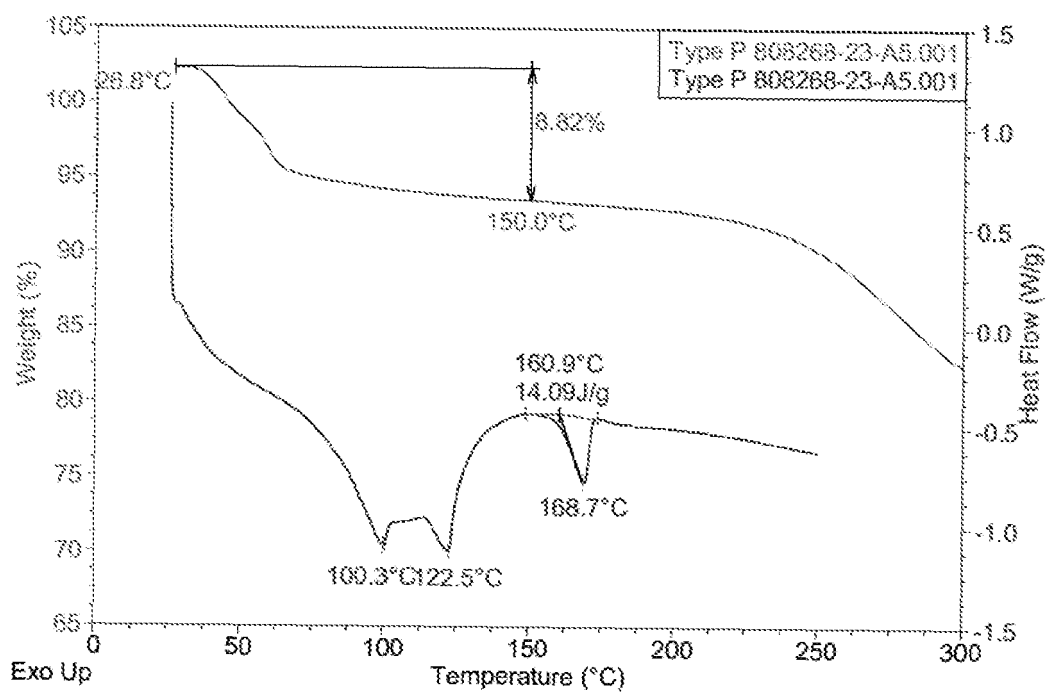


FIG.25

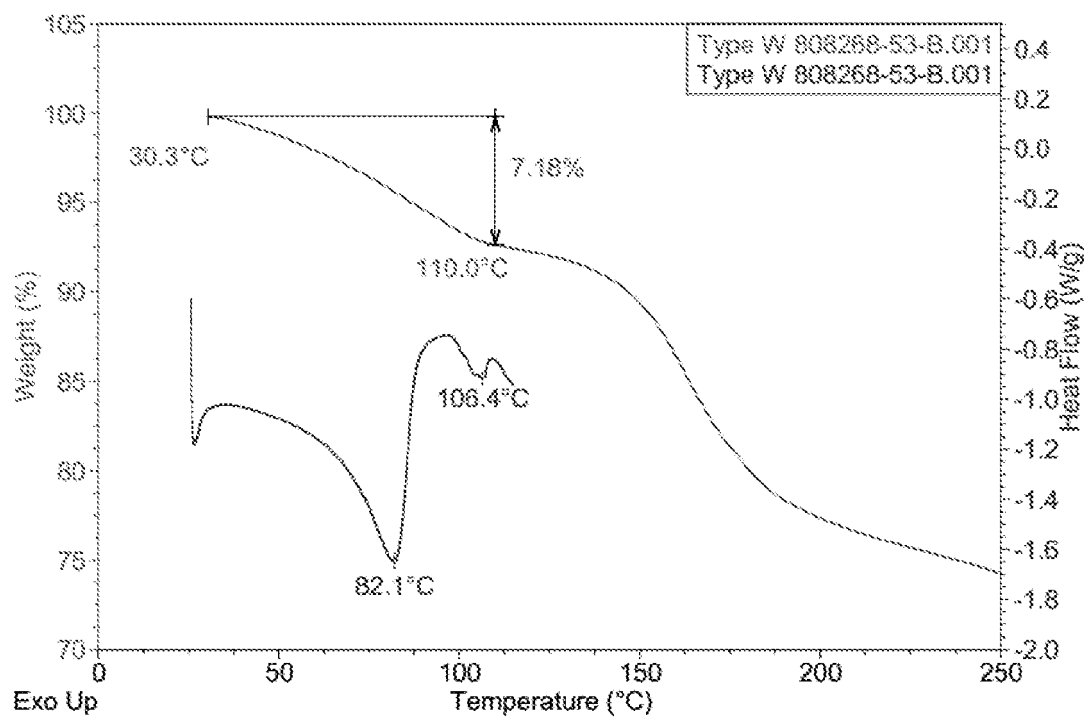


FIG.26

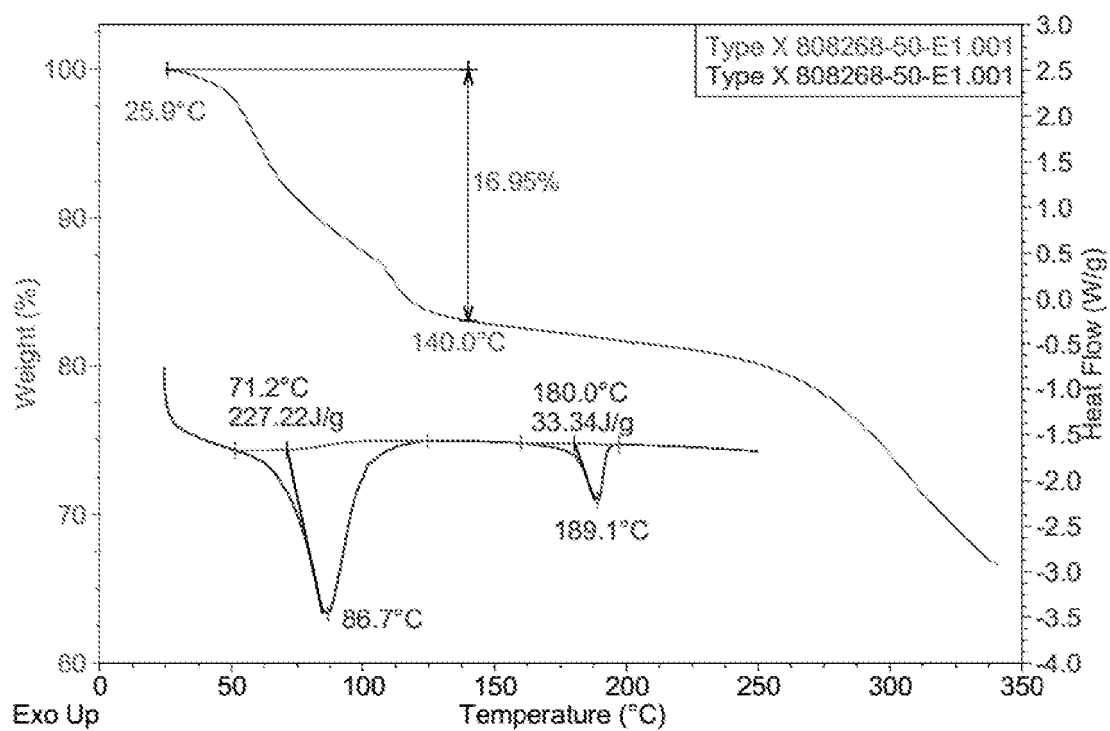


FIG.27

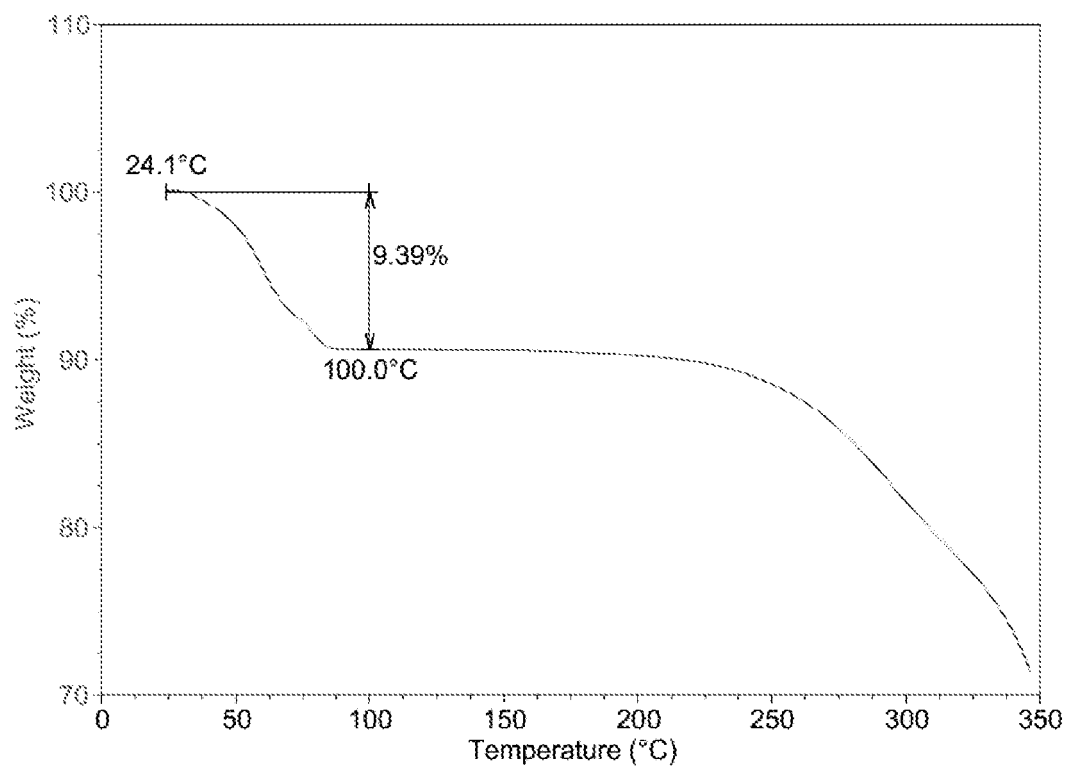


FIG.28

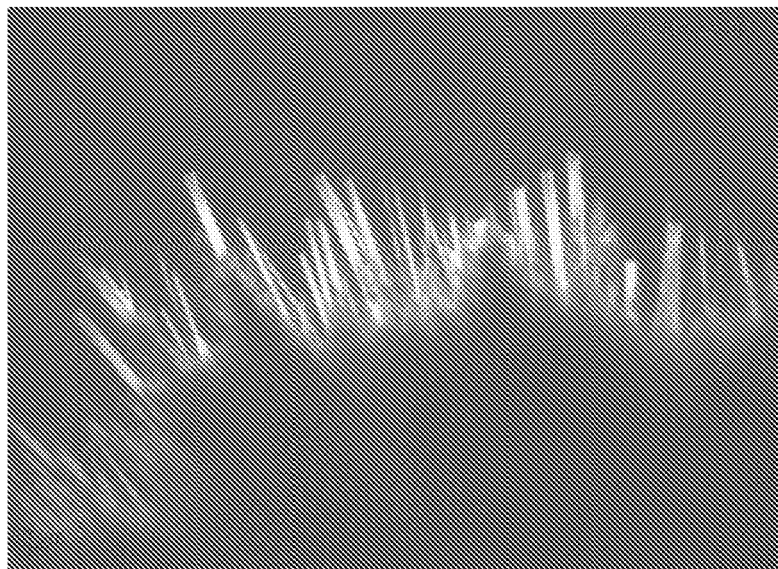


FIG.29

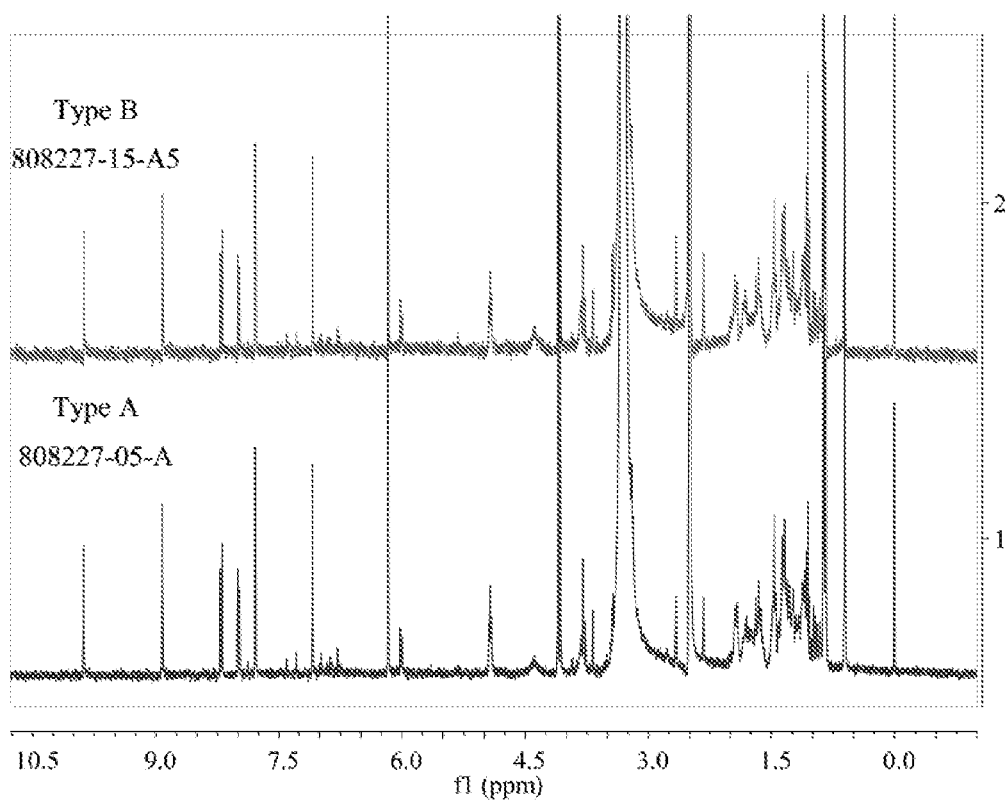


FIG.30

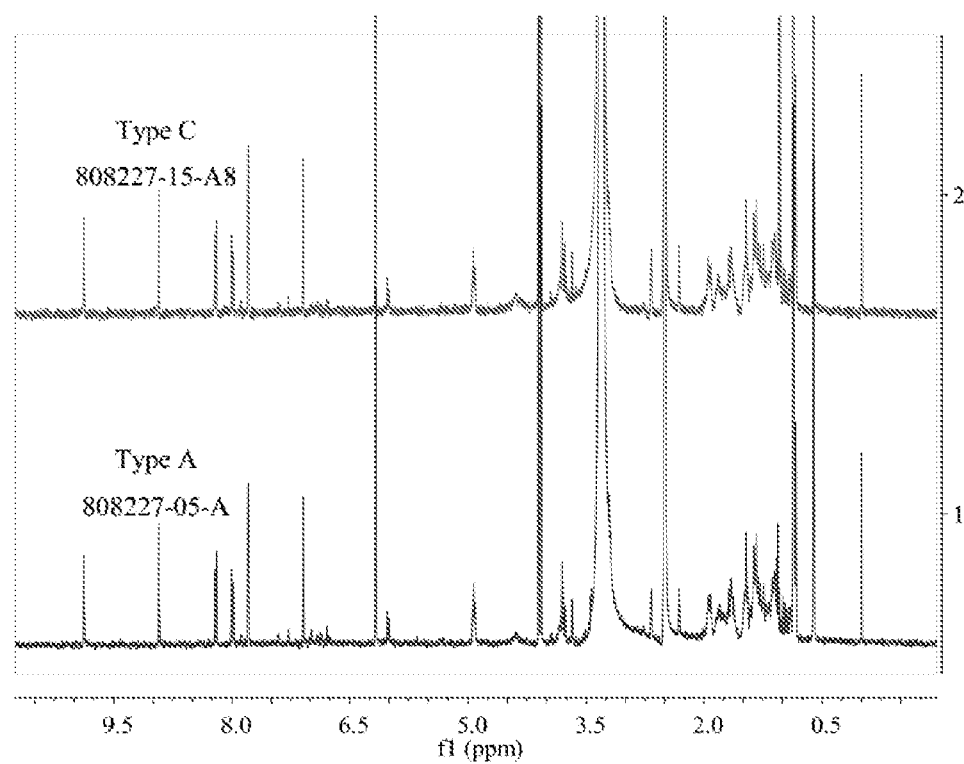


FIG.31

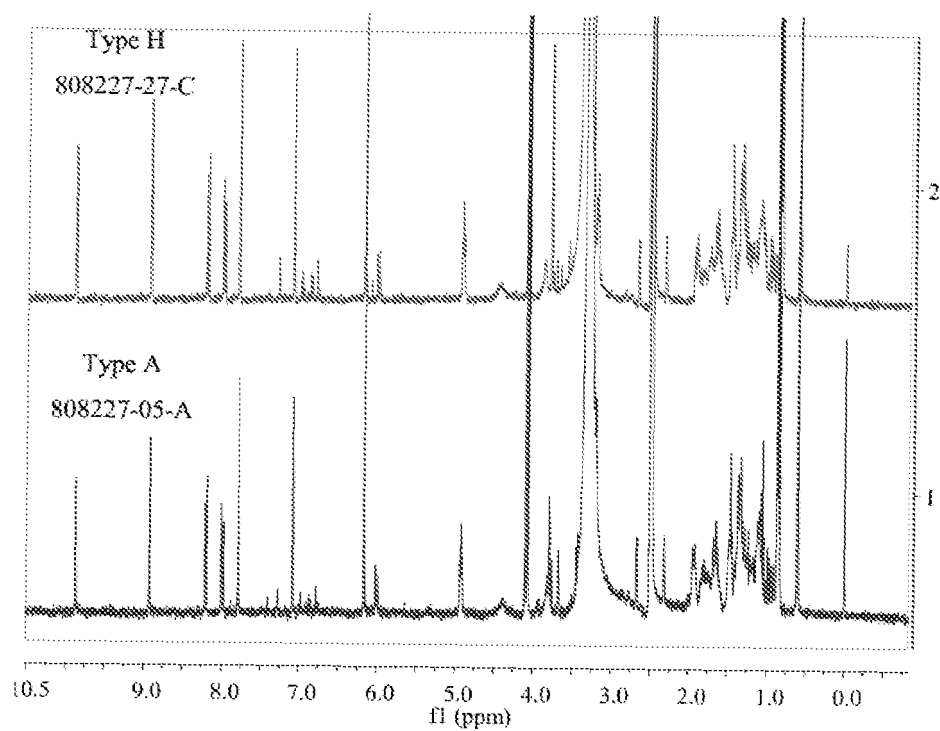


FIG.32

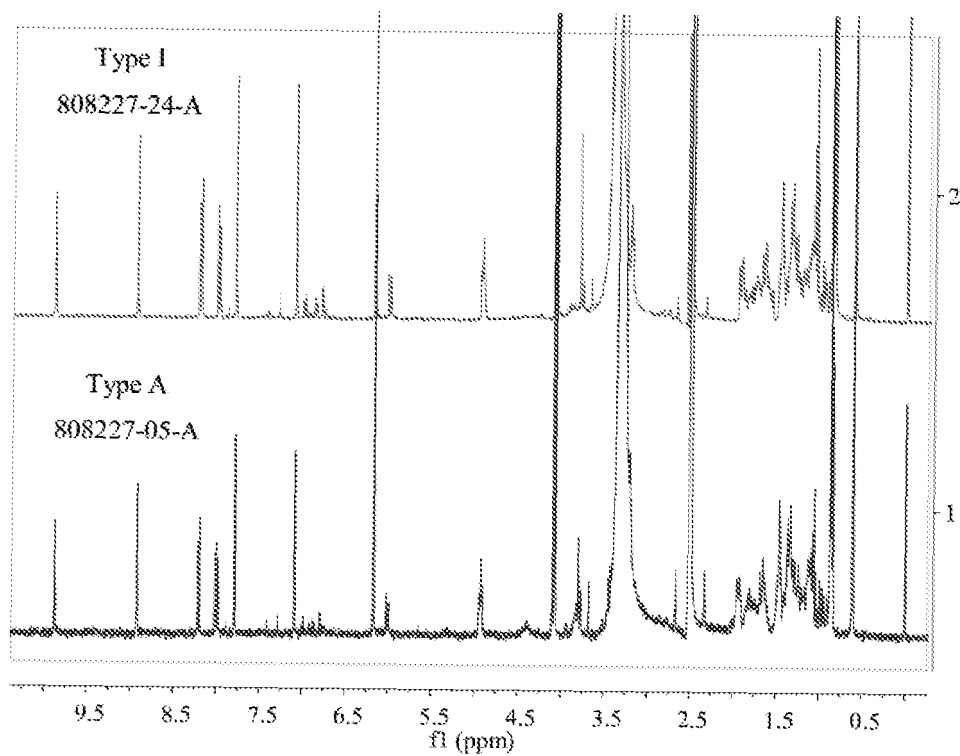


FIG.33

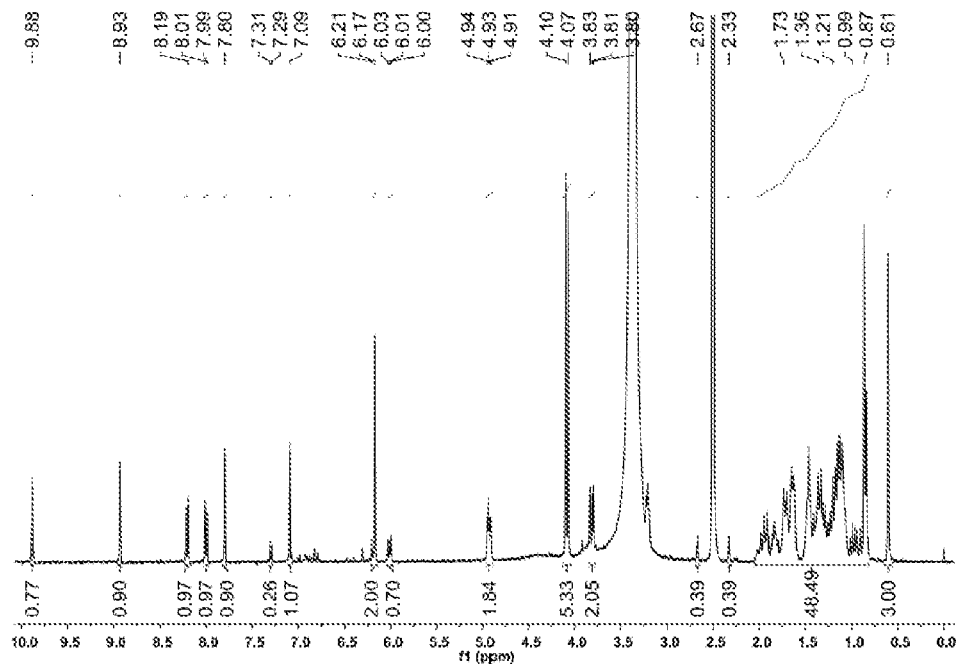


FIG.34

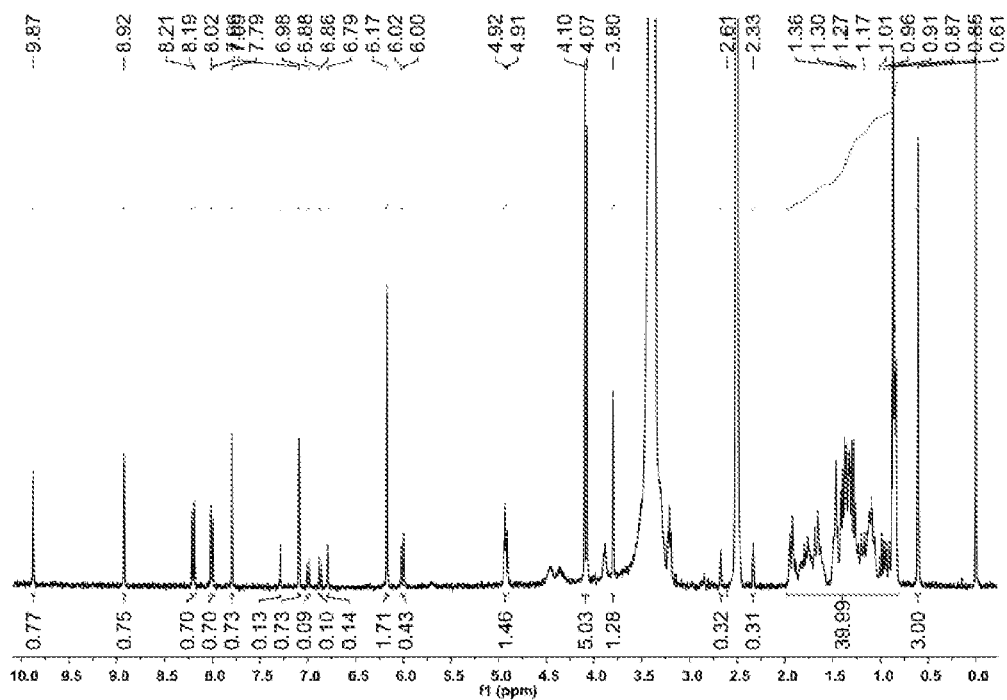


FIG.35

**REFERENCES CITED IN THE DESCRIPTION**

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