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**Colella et al.**

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(54) **CUVETTE-BASED APPARATUS FOR BLOOD COAGULATION MEASUREMENT AND TESTING**

(58) **Field of Classification Search**  
CPC ..... Y10T 436/10; Y10T 436/101666; Y10T 436/108331; Y10T 436/11; Y10T 436/25;  
(Continued)

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(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(57) **ABSTRACT**

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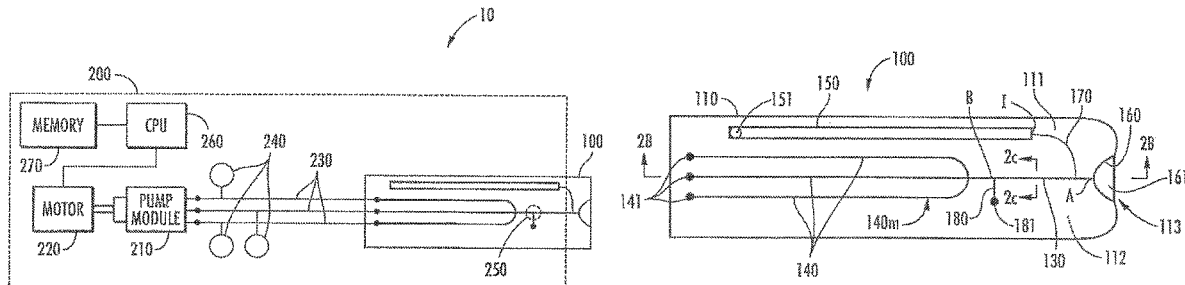
An apparatus for measuring blood clotting time includes a blood clot detection instrument and a cuvette for use with the blood clot detection instrument. The cuvette includes a blood sample receptor-inlet; a channel arrangement including at least one test channel for performing a blood clotting time measurement, a sampling channel having at least one surface portion that is hydrophilic, communicating with the blood sample receptor-inlet and the at least one test channel, and a waste channel having at least one surface portion that is hydrophilic, communicating with the sampling channel; and a vent opening communicating with the sampling channel. The sampling channel, the vent opening and the waste channel, coact to automatically draw a requisite volume of a blood sample deposited at the blood receptor-inlet, into the sampling channel. More specifically, air compressed within the blood clot detection instrument, the at least one test channel of the cuvette, and the section of the sampling channel  
(Continued)

**Related U.S. Application Data**

(63) Continuation of application No. 13/959,007, filed on Aug. 5, 2013, now Pat. No. 10,180,419, which is a (Continued)

(51) **Int. Cl.**  
**G01N 33/49** (2006.01)  
**B01L 3/00** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **G01N 33/4905** (2013.01); **B01L 3/50273** (2013.01); **B01L 3/502715** (2013.01);  
(Continued)



channel extending beyond the vent opening of the cuvette, coacts with the waste channel to cause a leading edge of the blood sample drawn into the sampling channel from the blood receptor-inlet, to pull back within the sampling channel and uncover an optical sensor in of the blood clot detection instrument. The uncovering of the optical sensor activates a pump module of the blood clot detection instrument, which draws the requisite volume of the blood sample into the at least one test channel.

2300/0816; B01L 2300/165; B01L 2400/086; B01L 3/502715; B01L 3/502723; B01L 3/50273; B01L 3/502746; B01L 2200/026; B01L 2300/0825; B01L 3/5023; B01L 2400/0406; B01L 2400/0622; B01L 3/502  
 USPC ..... 422/73, 500-504, 507  
 See application file for complete search history.

**31 Claims, 6 Drawing Sheets**

**Related U.S. Application Data**

continuation of application No. 13/474,243, filed on May 17, 2012, now abandoned, which is a continuation of application No. 12/503,665, filed on Jul. 15, 2009, now abandoned.

(60) Provisional application No. 61/081,290, filed on Jul. 16, 2008.

**(52) U.S. Cl.**

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**(58) Field of Classification Search**

CPC ..... Y10T 436/2575; G01N 33/4905; G01N 15/1459; G01N 33/86; G01N 15/12; G01N 2015/1486; G01N 21/03; B01L 2200/146; B01L 2200/16; B01L

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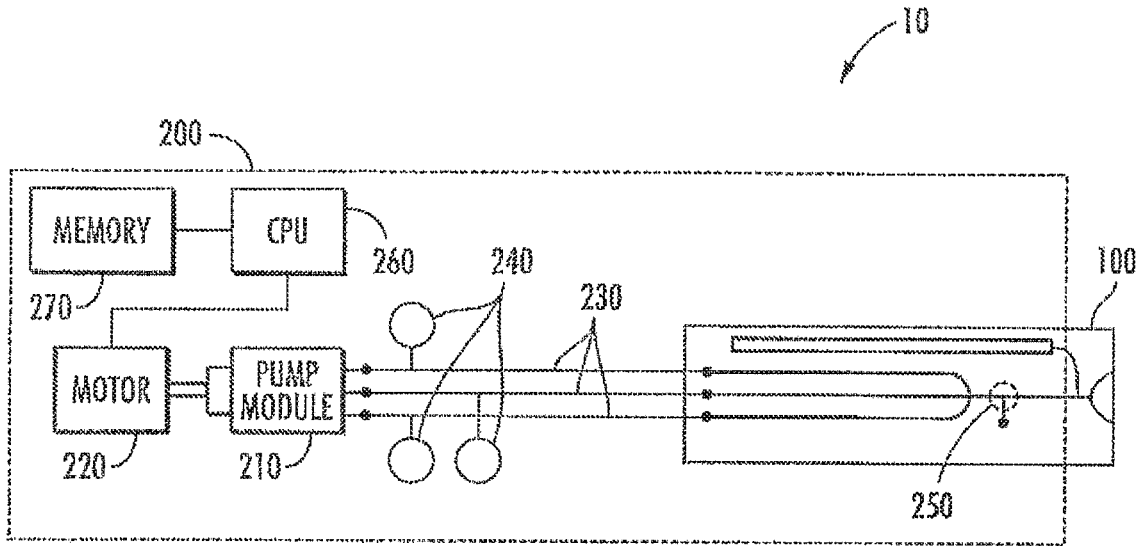


FIG. 1

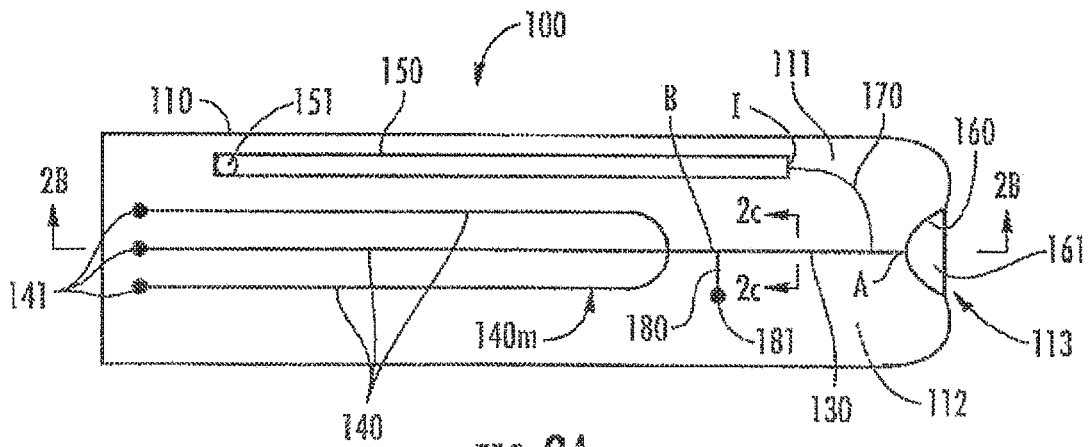
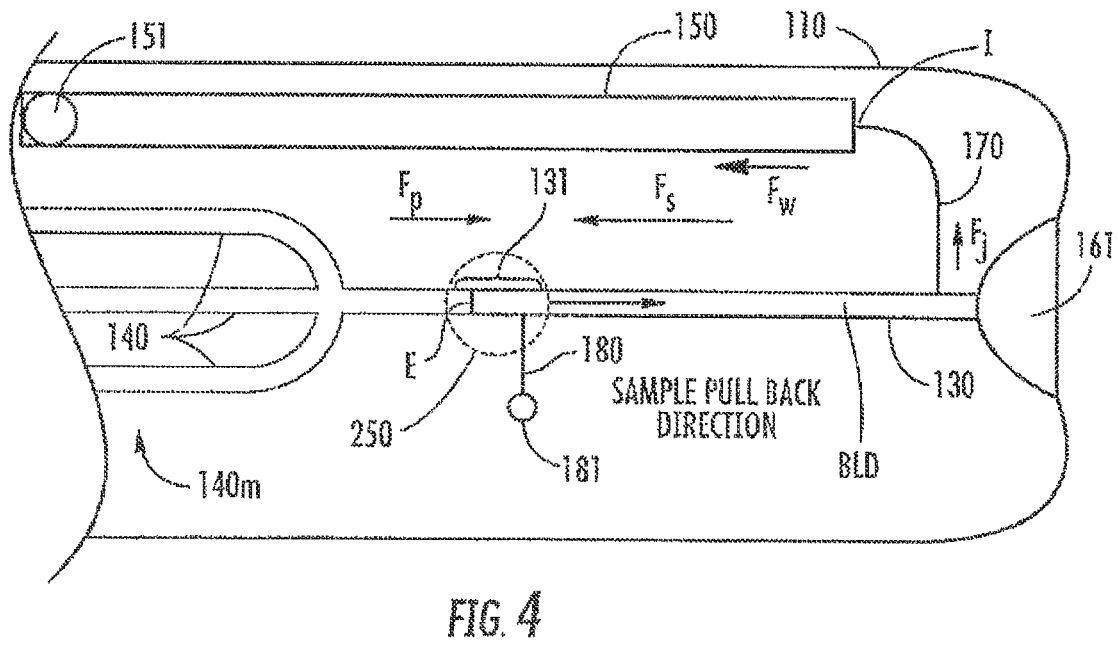
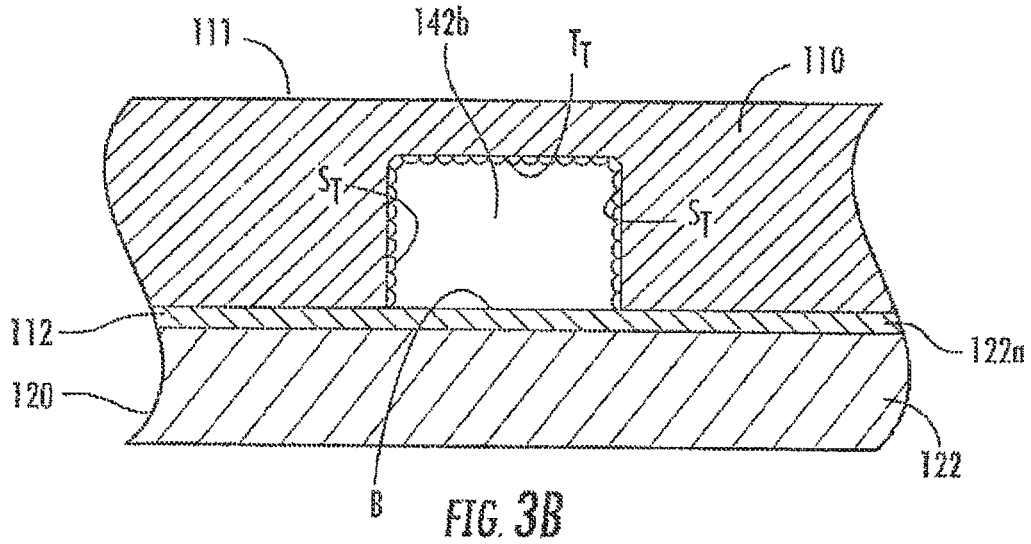


FIG. 2A





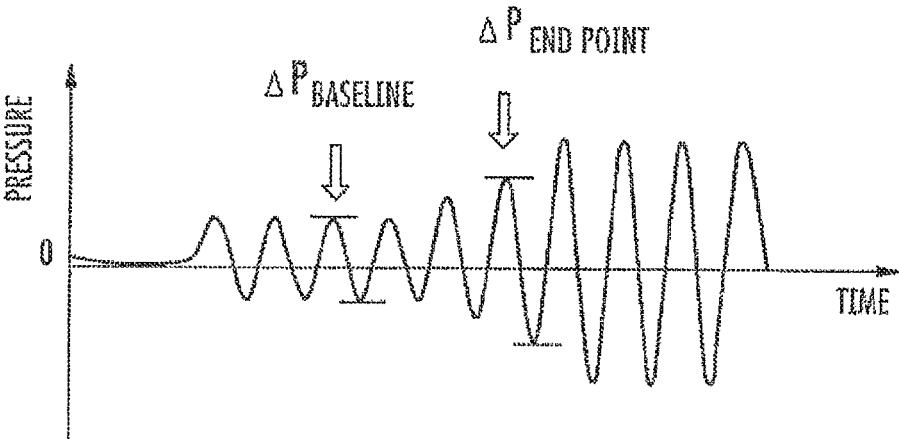


FIG. 5

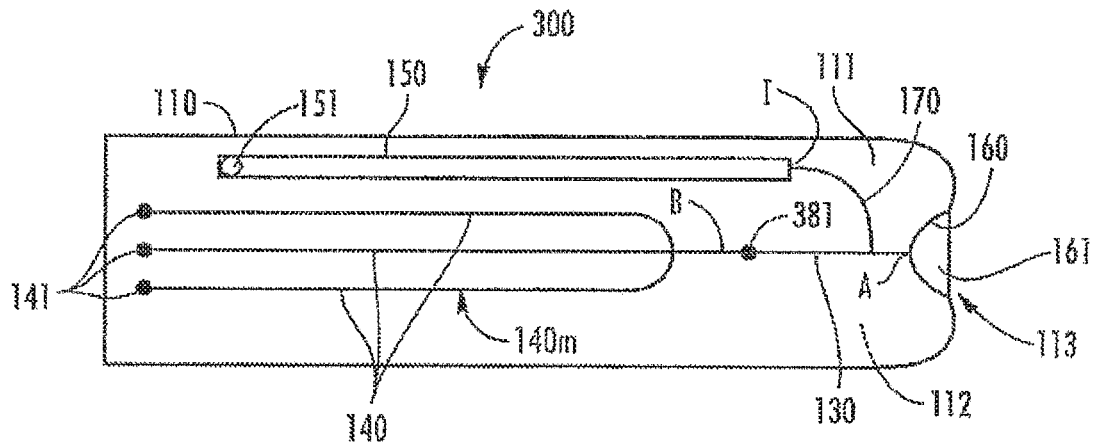


FIG. 6A

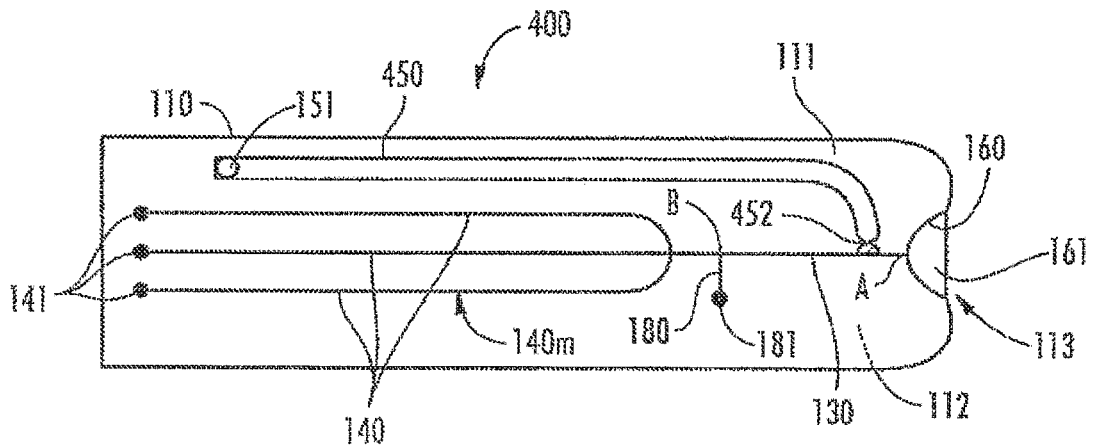
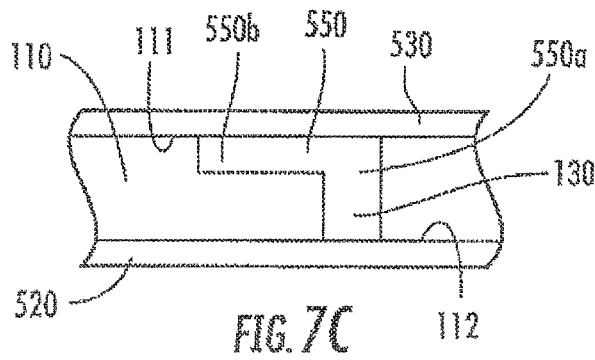
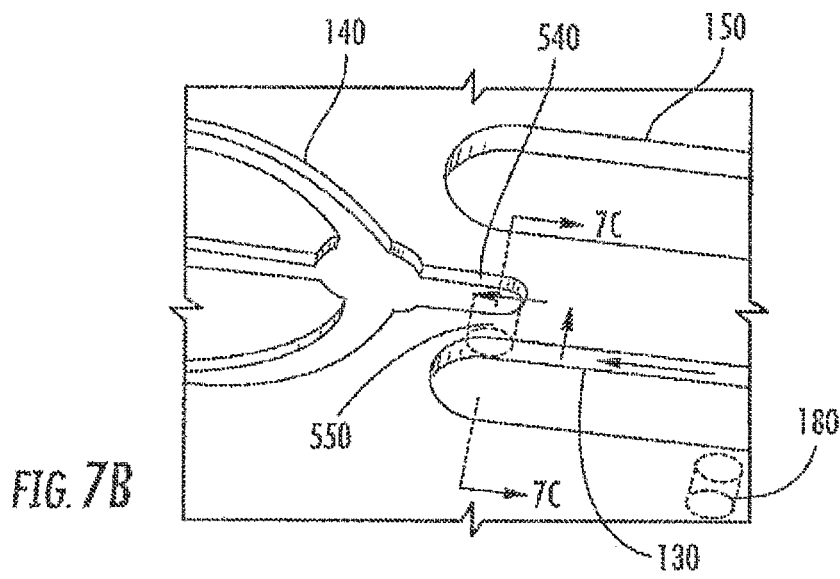
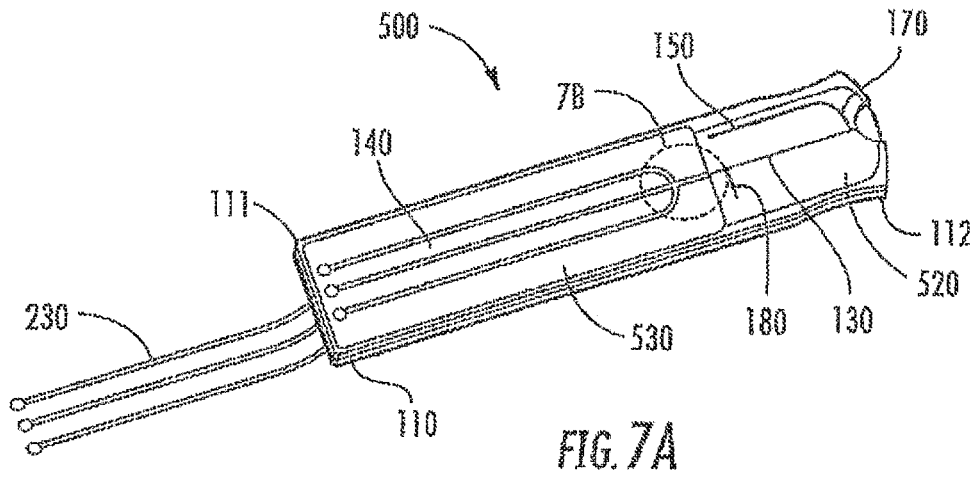


FIG. 6B





## CUVETTE-BASED APPARATUS FOR BLOOD COAGULATION MEASUREMENT AND TESTING

### CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. application Ser. No. 13/959,007 filed Aug. 5, 2013, which is a continuation application and claims the benefit of U.S. application Ser. No. 13/474,243 filed May 17, 2012, now U.S. Patent Application No. 2013/0017126, issued on Jan. 17, 2013, which is a continuation application and claims the benefit of U.S. application Ser. No. 12/503,665 filed on Jul. 15, 2009, now U.S. Patent Application No. 2010/0028207, issued on Feb. 4, 2010, which claims priority to and benefit of U.S. Provisional Application No. 61/081,290 filed on Jul. 16, 2008. The entire contents of each of the above patents and applications are incorporated herein in their entirety by reference for all purposes.

### FIELD

The invention relates to apparatus and methods for measuring and testing blood coagulation. More particularly, the invention relates to a cuvette-based apparatus for blood coagulation measurement and testing having automatic volumetric blood sample filling capability.

### BACKGROUND

Many people take anticoagulants to maintain the therapeutic coagulation time of their blood. Depending upon the person, the peak anticoagulant effect of the anticoagulant may be delayed by many hours and/or days, and the duration of the effect may persist after the peak for another four to five days. Accordingly, it is critical that the people who take anticoagulants closely monitor the coagulation time of their blood, so that they can monitor and adjust the amount of the anticoagulant they are taking.

A common manner of determining the effective amount of anticoagulant in a person's blood is to perform a prothrombin time (PT) test. A PT test measures how long a sample of blood takes to clot. As a result, the anticoagulation or hemostasis level in the blood is directly proportional to the length of time required to form clots.

Many devices and apparatus exist for performing coagulation time measurements and tests. Some of these apparatus are portable and simple enough to operate by a person in his or her home. An example of such an apparatus is describe in U.S. Pat. No. 5,534,226, entitled PORTABLE TEST APPARATUS AND ASSOCIATED METHOD OF PERFORMING A BLOOD COAGULATION TEST, issued to Gavin et al. and assigned to International Technidyne Corporation, the assignee herein. The apparatus described in this patent includes a disposable cuvette and a testing device. In operation, a sample of blood is placed into a cup-like supply reservoir of the cuvette, the blood sample is drawn into the cuvette, and the coagulation time of the blood sample is measured.

A problem associated with such apparatus, is that the volume of the blood sample drawn into the cuvette for measurement and testing is controlled by both the testing device and the sample cup removal techniques. Moreover, the cup-like supply reservoir can be messy to use.

Accordingly, a need exists for an improved apparatus for measuring and testing blood coagulation.

### SUMMARY

A cuvette is described herein for use with a blood clot detection instrument. The cuvette comprises a blood sample receptor-inlet and a channel arrangement comprising: at least one test channel for performing a blood clotting time measurement; a sampling channel communicating with the blood sample receptor-inlet and the at least one test channel; a waste channel communicating with the sampling channel; and a vent opening communicating with the sampling channel. At least the sampling channel and the waste channel each has at least one surface portion, a coating, an insert or liner, and any combination thereof, that is hydrophilic. The sampling channel with its at least one surface portion that is hydrophilic, the vent opening and the waste channel with its at least one surface portion that is hydrophilic, coact to automatically draw a requisite volume of a blood sample deposited at the blood receptor-inlet, into the sampling channel. More specifically, air compressed within the blood clot detection instrument, the at least one test channel of the cuvette, and the section of the sampling channel extending beyond the vent opening of the cuvette, coacts with the waste channel to cause the a leading edge of the blood sample drawn into the sampling channel from the blood receptor-inlet, to pull back within the sampling channel and uncover an optical sensor of the blood clot detection instrument. The volume of the blood sample in the sampling channel at the time when the blood sample is pulled back to uncover the optical sensor, equals the requisite volume. The uncovering of the optical sensor activates a pump module of the blood clot detection instrument, which draws the requisite volume of the blood sample into the at least one test channel.

An apparatus is described herein for measuring blood clotting time. The apparatus comprises: a blood clot detection instrument and a cuvette for use with the blood clot detection instrument. The blood clot detection instrument comprises: a pump module and at least one pressure sensor. The cuvette comprises a blood sample receptor-inlet; a channel arrangement comprising: at least one test channel for performing a blood clotting time measurement; a sampling channel communicating with the blood sample receptor-inlet and the at least one test channel; and a waste channel communicating with the sampling channel; and a vent opening communicating with the sampling channel. At least the sampling channel has at least one surface portion, a coating, an insert or liner, and any combination thereof, that is hydrophilic. The sampling channel with its at least one surface portion that is hydrophilic, the vent opening and the waste channel coact to automatically draw a requisite volume of a blood sample deposited at the blood receptor-inlet, into the sampling channel, the requisite volume of blood sample being drawn into the at least one test channel when the pump module of the blood clot detection instrument is activated. The at least one test channel of the cuvette, and the pump module and the at least one pressure sensor of the clot detection instrument, coact to perform a blood clotting time measurement on the requisite volume of the blood sample.

Also described herein is a blood clot detection instrument for automatically measuring blood clotting time of a blood sample contained in a test channel of a cuvette. The blood clot detection instrument comprises a pump module for communicating with the test channel of the cuvette; a

pressure sensor, and a central processing unit. The central processing unit executes instructions for operating the pump module in a pressure alternating mode that pumps the blood sample back and forth in a test channel of a cuvette. During clot formation, the viscosity of the blood sample increases and causes a pumping pressure of the pump module to increase over time. The central processing unit executes further instructions for obtaining a baseline pumping pressure from the pressure sensor upon initial operation of the pump module in the pressure alternating mode; obtaining additional pumping pressures over time from the pressure sensor, determining a pumping pressure difference value between each additional pumping pressure and the baseline pumping pressure; comparing each pumping pressure difference value to a predetermined threshold value; and indicating the blood clotting time of the blood sample when the pumping pressure difference value exceeds the predetermined threshold value, the indicated blood clotting time comprising a duration of time extending between the measurement of the additional pumping pressure used for determining the pumping pressure difference value that exceeded the predetermined threshold value and the measurement of the baseline pumping pressure.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an embodiment of a cuvette-based apparatus for measuring blood coagulation or clotting time.

FIG. 2A is a schematic plan view of an embodiment of the disposable cuvette.

FIG. 2B is a sectional view through line 2B-2B of FIG. 2A.

FIG. 2C is a sectional view through line 2C-2C of FIG. 2A.

FIG. 3A is an enlarged view of a blood sample testing portion of the disposable cuvette shown in FIG. 2A.

FIG. 3B is a section view through line 3B-3B of FIG. 3A.

FIG. 4 is an enlarged view of a volumetric blood sampling portion of the disposable cuvette shown in FIG. 2A.

FIG. 5 is a pressure profile and clot detection graph.

FIG. 6A is a schematic plan view of another embodiment of the disposable cuvette.

FIG. 6B is a schematic plan view of a further embodiment of the disposable cuvette.

FIG. 7A is a perspective view of a further embodiment of the disposable cuvette.

FIG. 7B is an enlarged view of encircled area 7B in FIG. 7A.

FIG. 7C is a sectional view through line 7C-7C in FIG. 7B.

Like reference numbers and designations in the various drawings indicate like elements.

#### DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, there is shown a schematic view of an embodiment of a cuvette-based apparatus 10 for measuring blood coagulation or clotting time. The apparatus 10 generally comprises a disposable cuvette 100 and a blood clot detection instrument 200. The apparatus 10 may be used for measuring blood coagulation time by depositing a sample of blood (whole blood or plasma) onto a specified location of the disposable cuvette 100 and operatively coupling the disposable cuvette 100 to the clot detection instrument 200. The cuvette 100 automatically selects or fills

itself with a requisite volume of the blood sample (to be tested) deposited at the specified location of the cuvette 100. The clot detection instrument 200 facilitates automatic mixing of the blood sample with a clotting reagent within the cuvette 100 and automatically measures the clotting time of the selected volume of the blood sample mixed with the clotting reagent within the disposable cuvette 100, without contacting the blood sample. After completion of the measurement, the cuvette 100 may be uncoupled or removed from the clot detection instrument 200 and disposed of. Because the clot detection instrument 200 does not contact the blood sample, another cuvette 100 may be operatively coupled to the clot detection instrument 200 for measuring another blood sample without sterilization or other cleaning of the clot detection instrument 200.

Referring still to FIG. 1, the clot detection instrument 200 comprises a pneumatic pump module 210, a motor 220 for driving the pump module 210, a plurality of tubes 230 extending from the pump module 210 for pneumatically coupling with the cuvette 100, a pressure sensor 240 associated with each tube 230 for measuring the pneumatic pressure within the tube 230, and an optical sensor 250 for optically sensing a sampling channel in the cuvette 100. In one embodiment, the optical sensor 250 comprises, but is not limited, to a LED/photo sensor. The clot detection instrument 200 also comprises, without limitation, a central processing unit 260 (CPU) executing instructions for controlling the operation of the motor 220 and thus the pump module 220 via signals received from the optical sensor 250, and determining clotting time based on the pressures sensed by the pressure sensors 240, a display (not shown) for displaying the measured clotting time or other data related to the measurement, a memory 270 for storing previously performed measurements, and buttons, knobs, and/or switches (not shown) for operating the clot detection instrument 200, controlling the display and/or accessing stored data from the memory 270.

Referring now to FIGS. 2A-2C, there is collectively shown a schematic plan view of an embodiment of the disposable cuvette 100. The cuvette 100 comprises a substantially planar main body 110 defining generally planar top and bottom surfaces 111, 112. The cuvette main body 110 is typically made from a rigid, transparent hydrophobic or hydrophilic plastic material, using any suitable forming method, such molding. The plastic hydrophobic materials may include, without limitation polystyrene and polytetrafluoroethylene and the plastic hydrophilic materials may include, without limitation, styrene acrylonitrile, acrylonitrile styrene acrylate. The cuvette main body 110 may also be made from other types of rigid, transparent hydrophobic or hydrophilic materials. The cuvette main body 110 includes an arrangement of open channels formed in its bottom surface 112. The open channels are covered and sealed by a thin, substrate 120 that is non-removably attached to the bottom surface 112 of the cuvette body 110. When the cuvette main body 110 is not made from a hydrophilic material or is made from a hydrophobic material, the channels of the channel arrangement each have at least one surface that is hydrophilic, and/or has a hydrophilic coating, and/or has a hydrophilic insert disposed therein (formed, for example, as a tube or liner, thereby fully or partially lining the channel(s)), that facilitates the automatic filling function of the cuvette 100.

In one embodiment, at least a top surface 121 of the thin substrate 120, i.e., the surface in contact with the bottom surface 112 of the cuvette body 110, is hydrophilic or has hydrophilic properties. The hydrophilic properties of the top

surface **121** of the substrate **120**, facilitates the requisite volumetric selection of the blood sample deposited on the cuvette **100**, for coagulation time measurement by the clot detection instrument **200**. In other embodiments, requisite volumetric selection of the blood sample is accomplished by forming the cuvette body **110** from a hydrophilic material.

The thin substrate **120**, in one embodiment, is a transparent film **122** coated on one side with a layer **122a** of clear pressure sensitive hydrophilic adhesive. The layer **122a** of hydrophilic adhesive forms the top surface **121** of the substrate **120** and non-removably attaches the substrate **120** to the bottom surface **112** of the cuvette body **110**. The transparent film **122** may comprise, in one embodiment, a transparent polyester material.

In an alternative embodiment the transparent film **122** is made from a hydrophilic material. Such a substrate may be attached to the bottom surface **112** of the cuvette body **110** (with the top surface **121** of the substrate **120** mated with the bottom surface **112** of the cuvette body **110**) with a layer of adhesive applied to the bottom surface **112** of cuvette body **110**. Alternatively, such a substrate may be attached to the bottom surface **112** of the cuvette body **110** using heat sealing methods.

Referring still to FIGS. 2A-2C, the channel arrangement formed in the bottom surface of the cuvette body **110** generally comprises a sampling channel **130**, one or more test channels **140** and at least one waste channel **150**. A first end **131** of the sampling channel **130** communicates with a sample depositing area **160** formed in a first or front end **113** of the cuvette body **110**. The sample depositing area **160** in the front end **113** of the cuvette body **110** and the exposed underlying portion of the substrate **120** form a blood sample receptor and inlet **161** (receptor-inlet **161**) on which the entire blood sample is deposited. The sampling channel **130** extends longitudinally in the bottom surface of the cuvette body **110**, from the receptor-inlet **161**, and merges at its second end with the one or more test channels **140** formed in the bottom surface of the cuvette body **110**.

The channel arrangement shown in FIGS. 2A-2C further includes a jumper channel **170** that branches off from the sampling channel **130** just downstream of the receptor-inlet **161** and fluidly connects the waste channel **150** with the sampling channel **130**. The terminal end of the waste channel **150** communicates with a waste channel venting aperture **151** formed transversely through the cuvette body **110**, which allows "dead" air displaced from within the waste and jumper channels **150**, **170** by incoming blood, to be vented to the external environment. The waste channel venting aperture **151** is open to the external environment at the top surface **111** of the cuvette body **110** and closed by the substrate **120** at the bottom surface of the cuvette body **110**.

The channel arrangement shown in FIGS. 2A-2C further includes a vent channel **180** that branches off from the sampling channel **130** downstream of the jumper channel **170**. The vent channel **180** communicates with a vent opening **181** formed transversely through the cuvette body **110** which allows "dead" air displaced from within the sampling and vent channels **130**, **180** by incoming blood to be vented to the external environment. The vent opening **181** is open to the external environment at the top surface **111** of the cuvette body **110** and closed by the substrate **120** at the bottom surface of the cuvette body **110**.

As shown in FIG. 2C, the sampling channel **130** (and the jumper, waste and vent channels **170**, **150**, **180**) formed in the bottom surface **112** of the cuvette main body **110** has a smooth top T surface and smooth side surfaces S. The bottom surface B of the sampling channel **130** (and the

jumper, waste and vent channels **170**, **150**, **180**) is formed by the top surface **121** (e.g., hydrophilic adhesive layer **122a** or the top surface of the hydrophilic film **122**) of the substrate **120**, which is also smooth.

The cuvette main body **110**, in some embodiments, is made from a hydrophobic material. In such embodiments, the sampling, vent, jumper, and waste channels **130**, **180**, **170**, and **150**, respectively, each includes at least one surface that is hydrophilic, and/or has a hydrophilic coating, and/or has a hydrophilic insert disposed therein, that facilitates the automatic sample sizing function of the cuvette **100**.

In other embodiments, the cuvette main body **110** is made from a hydrophilic material. The one or more test channels **140** in such embodiments, each includes at least one surface that is hydrophobic, and/or has a hydrophobic coating, and/or has a hydrophobic insert disposed therein, where no automatic filling or sample sizing function is required to be performed by the cuvette **100**.

The requisite volume of blood sample selected by the cuvette **100** for measurement by the clot detection instrument **200**, is obtained from the blood sample deposited on the receptor-inlet **161**. The size of this volume is determined by the effective volume of the sampling channel **130**. The effective volume of the sampling channel **130** is determined by the width of the sampling channel **130**, the height of the sampling channel **130**, and length of the sampling channel **130** as measured from point A, which is adjacent to the receptor-inlet **161**, to point B, which is adjacent to the vent channel **180**. The jumper channel **170**, connecting the sampling channel **130** to waste channel **150**, delays the filling of the waste channel **150** until the sampling channel **130** is completely filled. The duration of the delay is controlled by an intersection I of the jumper channel **170** and the waste channel **150** and the length and cross-sectional area (CSA) of jumper channel **170** relative to the CSA of the waste channel **150**, which insure that blood from the blood sample deposited on the receptor-inlet **161**, is drawn into the sampling channel **130** prior to being drawn into the waste channel **150**. The delay time is determined by the cross section area and length of the jumper channel **170**. The duration of the delay may be increased by lengthening the jumper channel **170**, and/or decreasing the cross-sectional area (width and height) of the jumper channel **170** relative to the CSA of the waste channel to increase flow resistant through the jumper channel **170**. Thus, during automatic blood sample volume sizing, the intersection I of the jumper channel **170** and the waste channel **150** acts like a resistor. Once a blood sample is applied or deposited in the cuvette's receptor-inlet **161**, the blood sample enters the sampling channel **130** and the jumper channel **170** substantially simultaneously. While the blood sample moves forward in the sampling channel **130**, it also fills the jumper channel **170**, then stops at the intersection I of the jumper channel **170** and the waste channel **150**. The sampling channel **130** continues to fill until an equilibrium state is reached. The remaining sample in the receptor-inlet **161** then forces the blood sample into the waste channel **150** from the jumper channel **170**. The hydrophilic force of the waste channel **150** picks up and draws off the remaining blood sample in the receptor-inlet **161**.

In one embodiment where the cuvette comprises three test channels **140**, the sampling channel **130** has a width of about 0.055 inches, a height of about 0.014 inches, and a length of about 0.9 inches; the vent channel **180** has a width of about 0.010 inches, a height of about 0.012 inches, and a length of about 0.140 inches; the jumper channel **170** has a width of about 0.010 inches, a height of about 0.012 inches, and a

length of about 0.25 inches; and the waste channel **150** has a width of about 0.066 inches, a height of about 0.014 inches, and length of about 2.24 inches. The three test channels **140** of such a cuvette each has a width of about 0.030 inches and a height of about 0.010 inches. The length of each of the outer two test channels is about 1.69 inches and the inner test channel is about 1.634 inches. The sampling, jumper, waste, and test channel(s) in other embodiments of the cuvette may have other suitable dimensions.

FIG. 6A shows another embodiment of the cuvette, denoted by reference number **300**. The cuvette **300** is substantially identical to the cuvette **100** shown in FIG. 2A, except that the vent channel extending between the sampling channel and the vent opening is replaced by a vent opening **381** that directly opens into the sampling channel **130**.

FIG. 6B shows a further embodiment of the cuvette, denoted by reference number **400**. The cuvette **400** is substantially identical to the cuvette **100** shown in FIG. 2A, except that the waste channel **450** communicates directly with the sampling channel **130** thereby omitting the jumper channel. In addition, the waste channel **450** includes one or more restrictions **452** located just after the entrance to the waste channel **450** that function to delay filing of the waste channel **450**.

FIGS. 7A-7C collectively show a further embodiment of a cuvette, denoted by reference number **500**. The cuvette **500** is substantially identical to the cuvette **100** shown in FIG. 2A, except that the one or more open test channels **140** are formed in the top surface **111** of the main body **110** instead of in the bottom surface **112** of the main body **110** where the open sampling, vent, jumper, and waste channels **130**, **180**, **170**, **150** are formed. In addition, the open one or more test channels **140** in the top surface **111** of the cuvette main body **110** are covered and sealed by a thin substrate **530** with hydrophobic properties (e.g., the substrate **530** includes a hydrophobic adhesive coating or is a hydrophobic film) that is non-removably attached to the top surface **111** of the cuvette main body **110**, and the open sampling, vent, jumper, and waste channels **130**, **180**, **170**, **150** in the bottom surface **112** of the cuvette main body **110** are covered and sealed by a thin, substrate **520** with hydrophilic properties (e.g., the substrate **520** includes a hydrophilic adhesive coating or is a hydrophilic film) that is non-removably attached to the bottom surface **112** of the cuvette body **110**. As can be seen in FIGS. 7B and 7C, the sampling channel **103** and an inlet **540** to the one or more test channels **140** are laterally offset from one another. A connecting channel **550** formed in the top surface **111** of the cuvette main body **110**, has a first end **550a** that communicates with a terminal end of the sampling channel **103** and a second end **550b** that communicates with an inlet **540** to the one or more test channels **140**. The first end **550a** of the connecting channel **550** is covered and sealed by the hydrophilic substrate **520**. The remainder of the connecting channel **550** including the second end **550b** thereof, is covered and sealed by the hydrophobic substrate **530**. The connecting channel **550** transfers the volume of the blood sample precisely collected by the sampling channel **130**, to the one or more test channels **140**.

In one embodiment, the one or more test channels **140** comprises a branched array of three test channels **140** in a menorah-shaped configuration **140<sub>m</sub>** (visible in FIGS. 2A, 3A, 4, 6A and 6B). The menorah-shaped array of test channels **140<sub>m</sub>** evenly divides the selected volume of blood into three separate blood samples, thereby allowing the cuvette **100** to be used for performing up to three different blood tests. For examples of the blood tests that may be

performed in the cuvette, see U.S. Pat. No. 5,534,226, entitled, PORTABLE TEST APPARATUS AND ASSOCIATED METHOD OF PERFORMING A BLOOD COAGULATION TEST, assigned to the International Technidyne Corporation, the assignee herein. The entire disclosure of U.S. Pat. No. 5,534,226 is incorporated herein by reference. The branched array in other embodiments of the cuvette **100** may include two test channels **140** or more than three test channels **140**.

Referring still to FIGS. 2A, 3A, 4, 6A and 6B, the terminal or marginal terminal end of each test channel **140** communicates with a drive aperture **141** formed through the cuvette body **110**. The drive aperture **141** is open to the external environment at the top surface **112** of the cuvette body **110** and closed by the substrate **120** at the bottom surface of the cuvette body **110**. When the cuvette **100** is operatively coupled to the clot detection instrument **200**, as shown in FIG. 1, the plurality of tubes **230** extending from the pump module **210** sealingly engage the one or more drive apertures **141** of the cuvette body **110**, so that the arrangement of channels and the pneumatic pump module **210** of the clot detection instrument **200** form a pneumatic system when the cuvette **100** is operatively coupled to the clot detection instrument **200**.

Referring now to FIGS. 3A and 3B, each of the test channels **140** formed in the bottom surface of the cuvette body **110** includes end sections **142a** with smooth top, side and bottom walls (the bottom wall of each test channel **140** being formed by the smooth top surface **121** of the substrate **120**) similar to the top, side and bottom walls of the sampling, jumper and waste channels **130**, **170**, and **150**, and an intermediate section **142b** where the top wall  $T_T$  and side walls  $S_T$  are textured. In one non-limiting embodiment, the texturing may comprise a flat knurl cross-hatch. In other embodiments, the texturing in the intermediate section **142b** of one or more of test channels **140** may only be on the top wall or on one or both of the side walls. The length of the textured section is selected so that the blood sample BLD always remains within this section of the test channel **140** during testing. A dehydrated clot promoting reagent (not shown) for triggering and accelerating blood clotting, is disposed in each test channel **140** where the texturing is located. The reagent in each test channel **140** may be the same or different. Therefore, in one embodiment, reagent A may be in each of the test channels. In another embodiment, reagent A may be in two of the test channels and reagent B may be in one of the test channels. In still another embodiment, reagent A may be in one of the test channels, reagent B may be in one of the test channels and reagent C may be in one of the test channels. When the blood sample is drawn into the test channels **140**, the reagent rehydrates and mixes with the blood. The textured wall(s) of each test channel **140** improve reagent deposition thereon during manufacture of the cuvette, and increase clotting measurement sensitivity, as the blood sample is reciprocally moved or oscillated therein when measuring of the clotting time of the blood sample, as will be explained further on. In an alternate embodiment, the textured intermediate section of one or more the test channels **140** may be replaced by a restricted area (not shown) where the test channel **140** is narrowed.

The automatic volumetric filling function of the cuvette **100** will now be described in greater detail with reference to FIG. 4. Prior to volumetric filling, the cuvette **100** must be operatively coupled to the clot detection instrument **200** such that the plurality of tubes **230** extending from the pump module **210** of the clot detection instrument **200** sealingly engage the one or more drive apertures **141** of the cuvette

body **110**, thereby creating a pneumatic system formed by the arrangement of channels of the cuvette **100** and the pneumatic pump module **210** of the clot detection instrument **200**, as shown in FIG. 1. The automatic volumetric filling function commences when a blood sample is deposited onto the receptor-inlet **161** of the cuvette **100**. The blood sample may be deposited on the receptor-inlet **161** by finger after a fingerstick, a needle, a dropper, a pipette, a capillary tube, or any other suitable depositing device. Since at least a portion of the sampling channel **130** is hydrophilic, a force  $F_s$  is generated by the hydrophilicity of this portion, which initially draws the blood sample deposited on the receptor-inlet **161** into the sampling channel **130** until the entire vent channel **180** becomes filled. The dead air in the vent channel **180** and the section of the sampling channel **130** extending between the receptor-inlet **161** and the vent channel **180**, is vented through the vent opening **181** of the vent channel **180** as the blood BLD fills this section of the sampling channel **130**, and the vent channel **180**. The blood drawn into the vent channel **180** seals the vent opening **181**. At the same time the jumper channel hydrophilicity force  $F_j$  draws blood into the jumper channel. Once the vent channel **180** has been filled, the force  $F_s$  continues to draw more blood from the blood sample deposited on the receptor-inlet **161** into the sampling channel **130** such that the blood BLD in the sampling channel **130** overshoots the vent channel **180** and covers the optical sensor **250** of the clot detection instrument **200**, which lies under or over section or area **131** of the sampling channel **130**. The blood BLD which overshoots the vent channel **180** compresses the dead air volume contained within the section of the sampling channel **130** extending beyond the vent channel **180**, the test channels **140**, and the tubes **230** of the clot detection instrument **200**, and the pump module **210**, because  $F_s > F_p$  and  $F_w < F_s$ , where  $F_p$  is the pressure of the compressed dead air volume, and  $F_w$  is the hydrophilicity force generated by at least a portion of the waste channel **150** that is hydrophilic. Blood stops flowing in the sampling channel **130** towards the test channels **140** when an equilibrium state  $F_s = F_p + F_w$  is achieved therein.

After the equilibrium state has been reached, blood that has been delayed by the the jumper channel/waste channel intersection I and the jumper channel **170**, reaches the waste channel **150**. The waste channel **150** generates a force  $F_w$ , that increases to a value proportional to the line of contact between the blood and the hydrophilic surface, which first pulls additional blood remaining in the receptor-inlet **161** into the waste channel **150**. As the waste channel **150** fills with excess blood sample BLD, dead air disposed therein and displaced by the incoming blood BLD is vented to the external environment through the waste channel venting aperture **151**. Once the remaining blood sample drawn off from the receptor-inlet **161**, force  $F_w + F_p$  becomes greater than  $F_s$ , and therefore, the leading edge E of the blood BLD in the sampling channel **130** starts pulling back towards the vent channel **180**.

The leading edge E of the blood BLD in the sampling channel **130** continues to be pulled back by force  $F_w + F_p$ , and uncovers the optical sensor **250**. The volume of the blood sample BLD disposed in the sampling channel **130** at the moment the optical sensor **250** is uncovered, is the requisite volume. Consequently, the pump module **210** of the clot detection instrument **200** is immediately activated by the uncovered optical sensor **250** and draws this requisite volume of blood sample BLD into the test channels **140** such that the blood sample BLD is disposed in the sections of the test channels **140** that are textured. The ratio of force  $F_w$  to force  $F_s$  determines the sample pull back speed. Generally,

a wider waste channel **150** has stronger pull back. In one, non-limiting embodiment, the ratio of force  $F_w$  to force  $F_s$  equals 1.2. One of ordinary skill in the art will recognize that the forces described above may be adjusted by the material properties of the cuvette body **110**, substrate **120**, size and/or geometry of the plurality of channels. The blood sample over shoot and pull back functions of the sampling channel **130** may also be adjusted and controlled by the volume of dead air in the tubes **230** and pump module **210** of the clot detection instrument **200**.

The automatic blood clot testing function of the cuvette **100** will now be described in greater detail with reference to FIGS. 3A and 5. After the pump module **210** has drawn the blood sample into one or more test channels **140** of the cuvette **100**, the pump module **210** automatically switches into a pumping mode where it alternately creates positive and negative pressures in the test channels **140** of the cuvette **100**. The alternating positive and negative pressures (pumping pressure) reciprocally moves the blood samples BLD back and forth across textured sections (or restricted areas) of the one or more test channels **140**, thereby mixing the blood sample with dehydrated reagent, as shown in FIG. 3A. As the reagent rehydrates and mixes with the blood sample BLD, it triggers and accelerates the blood clotting cascade. Fibrin formation within the blood sample BLD causes the viscosity of the blood sample BLD to increase with time. The viscosity increase may be detected, in one embodiment, by measuring the pumping pressure within each test channel **140** over time. As shown in the graph of FIG. 5, the pumping pressure starts at an initial pumping pressure value (pumping pressure baseline  $\Delta P_{baseline}$ ) and increases with time, as the viscosity of the blood increases during clotting. The pressure sensors **240** of the blood clot detection instrument **200**, measure the pump pressure over time and the CPU **260** of the clot detection instrument **200** compares this data to the initial pressure baseline  $\Delta P_{baseline}$ . The clotting time of the blood sample may be determined when pressure value is greater than or equal to a preset threshold. In one embodiment, the clotting time is,

$$\Delta P_{end\ point} - \Delta P_{baseline} \geq \text{threshold},$$

where  $\Delta P_{end\ point}$  is the clotting end point peak to peak pressure.

The preset threshold may be fixed or dynamic. In one embodiment, a dynamic threshold may be,

$$\Delta P_{baseline} + (0.3 \times \Delta P_{baseline}).$$

In general, the hydrophilicity of the one or more test channels **140** will aid the robust automatic volumetric blood sample filling function of the cuvette **100**, while impeding the clotting performance of the cuvette **100**. Appropriately balancing the test channel **140** dimensions, geometry, degree of texturing/restriction size, and the hydrophilic properties of the cuvette body **110** and substrate **120**, will provide the cuvette **100** with requisite blood clotting performance.

The pump profile of the pump module **210**, i.e., pumping speed and stroke, may also affect clotting performance. For example, a pump speed greater than 20 millisecond (ms) per pump step, equivalent to 20 ul per sec in test channel or a pump stroke greater than 55 steps, equivalent to 0.044, may increase the chance of deforming a weak clot (International Normalized Ratio > 4.0), which may in turn, result in lower clot detection precision. In one embodiment, the pump profile is 40 ms per pump step and 36 steps per pump direction (generates positive and negative pressures).

While exemplary drawings and specific embodiments have been described and illustrated, it is to be understood

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that that the scope of the present invention is not to be limited to the particular embodiments discussed. Thus, the embodiments shall be regarded as illustrative rather than restrictive, and it should be understood that variations may be made in those embodiments by workers skilled in the art without departing from the scope of the present invention as set forth in the claims that follow and their structural and functional equivalents.

What is claimed is:

1. An apparatus for measuring blood clotting time, the apparatus comprising:

A) a blood clot detection instrument, the blood clot detection instrument comprising:

a pump module; and

at least one pressure sensor; and

B) a cuvette for use with the blood clot detection instrument, the cuvette comprising: a main body including:

i) a blood sample receptor-inlet;

ii) a channel arrangement comprising:

a) at least one test channel for communicating with the pump module when the cuvette is operatively coupled to the clot detection instrument;

b) a sample channel fluidically coupled to the at least one test channel and to a sample deposit area at the blood sample receptor-inlet, at least a portion of the sample channel having a hydrophilic surface such that blood is automatically drawn from the sample-receptor inlet; and

c) a vent opening fluidically coupled to the sample channel, the vent opening configured to vent air from the sample channel as the sample channel fills with blood, a predetermined sample volume defined by a volume of the sample channel between the sample-receptor inlet and the vent opening;

d) a waste channel fluidically coupled to the sample channel between the blood sample receptor-inlet and the vent opening, a flow restriction at an intersection of the waste channel and the sample channel impeding blood from flowing into the waste channel until the sample channel is filled to the vent opening such that the sample channel automatically fills with the predetermined sample volume.

2. The apparatus of claim 1, wherein compressed air within the blood clot detection instrument, the at least one test channel, the sample channel, the vent opening and waste channel, is configured to automatically draw a requisite volume of a blood sample deposited at the blood receptor-inlet, into the sample channel, and

wherein the at least one test channel, the pump module and the at least one pressure sensor, coact to perform a blood clotting time measurement on the requisite volume of the blood sample.

3. The apparatus of claim 2, wherein the coaction between the sample channel and the vent opening includes a force generated by the at least one surface portion of the sample channel that is hydrophilic and which draws the blood from the blood sample deposited at the blood sample receptor-inlet into the sample channel and venting of air through the vent opening which is displaced from the sample channel by the incoming blood.

4. The apparatus of claim 1, wherein the channel arrangement further comprises a member associated with the waste channel for delaying the filling of the waste channel until the sample channel is filled.

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5. The apparatus of claim 4 wherein the member associated with the waste channel comprises a jumper channel or a restriction.

6. The apparatus of claim 5, wherein the jumper channel or restriction has at least one surface portion, a coating, an insert or liner, and any combination thereof, that is hydrophilic.

7. The apparatus of claim 1, wherein the channel arrangement is formed in a surface of the main body.

8. The apparatus of claim 7, further comprising a substrate for closing and sealing at least a portion of the channel arrangement formed in the surface of the main body.

9. The apparatus of claim 8, wherein the substrate forms the at least one surface portion of the sample channel that is hydrophilic.

10. The apparatus of claim 8, wherein the substrate comprises a film with a hydrophilic surface, the hydrophilic surface of the substrate forming the at least one surface portion of the sample channel that is hydrophilic.

11. The apparatus of claim 8, wherein the substrate comprises a film and a layer of hydrophilic material disposed on the film, the hydrophilic material forming the at least one surface portion of the sample channel that is hydrophilic.

12. The apparatus of claim 11, wherein the hydrophilic material is an adhesive which attaches the substrate to the main body.

13. The apparatus of claim 1, further comprising a blood clotting reagent disposed in the at least one test channel.

14. The apparatus of claim 1, wherein the at least one test channel includes a section having at least one textured surface.

15. The apparatus of claim 1, wherein the at least one test channel includes a restriction.

16. The apparatus of claim 1, wherein the main body is made of one of a hydrophobic material, a hydrophilic material, or a combination of a hydrophobic material and a hydrophilic material.

17. The apparatus of claim 1, wherein the waste channel has at least one surface portion, a coating, an insert or liner, and any combination thereof, that is hydrophilic.

18. The apparatus of claim 1, wherein the at least one test channel has at least one surface portion, a coating, an insert or liner and any combination thereof, that is hydrophilic or hydrophobic.

19. The apparatus of claim 1, wherein the channel arrangement further comprises a vent channel connecting the vent opening with the sample channel and wherein the vent channel has at least one surface portion, a coating, an insert or liner, and any combination thereof, that is hydrophilic.

20. The apparatus of claim 1; wherein the channel arrangement further comprises a jumper channel connecting the waste channel with the sample channel, the jumper channel for delaying the filling of the waste channel until the sample channel is filled.

21. The apparatus of claim 1 wherein the blood clot detection instrument comprises:

a pump module for communicating with the test channel of the cuvette; a pressure sensor; and

a central processing unit executing instructions for:

operating the pump module in a pressure alternating mode that causes a viscosity of the blood sample to increase over time; the increase in viscosity of the blood causing a pumping pressure of the pump module to increase over time;

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obtaining a baseline pumping pressure from the pressure sensor upon initial operation of the pump module in the pressure alternating mode;  
 obtaining additional pumping pressures over time from the pressure sensor;  
 determining a pumping pressure difference value between each additional pumping pressure and the baseline pumping pressure;  
 comparing the pumping pressure difference value to a predetermined threshold value; and  
 indicating the blood clotting time of the blood sample when the pumping pressure difference value equals or exceeds the predetermined threshold value, the indicated blood clotting time comprising a duration of time extending between the measurement of the additional pumping pressure used for determining the pumping pressure difference value that exceeded the predetermined threshold value and the measurement of the baseline pumping pressure.

22. The apparatus of claim 21, wherein the predetermined threshold may be fixed or dynamic.

23. The apparatus of claim 21, wherein the pump module, in the pressure alternating mode, creates positive and negative pressures in the test channel of the cuvette.

24. The apparatus of claim 21, wherein the pump module, in the pressure alternating mode, reciprocally moves the blood sample back and forth across a textured section or restricted area of the test channel, thereby mixing the blood sample with a reagent disposed in the test channel that triggers and accelerates clotting of the blood sample.

25. The apparatus of claim 1, wherein the at least one test channel comprises three test channels and further comprising a reagent in each of the test channels.

26. The apparatus of claim 25, wherein the reagents are all the same, different, or combinations thereof.

27. The apparatus of claim 1, wherein air compressed within the blood clot detection instrument, the at least one

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test channel of the cuvette, and the section of the sample channel extending beyond the vent opening of the cuvette, coacts with the waste channel to cause a leading edge of the blood sample draw-n into the sample channel from the blood receptor-inlet, to pull back within the sample channel and uncover an optical sensor of the blood dot detection instrument, the volume of the blood sample in the sample channel at the time when the blood sample is pulled back to uncover the optical sensor, equaling the requisite volume, the uncovering of the optical sensor activating the pump module of the blood clot detection instrument, which draws the requisite volume of the blood sample into the at least one test channel.

28. The apparatus of claim 1 further comprising;  
 a first substrate with hydrophilic properties for closing and sealing the sample channel and the waste channel; and  
 a second substrate with hydrophobic properties for closing and sealing the at least one test channel.

29. The apparatus of claim 28, wherein the sample channel and the waste channel are formed in a first surface of the cuvette and the first substrate is affixed to the first surface, and the at least one test channel is formed in second surface of the cuvette and the second substrate is affixed to the second surface.

30. The apparatus of claim 29, wherein the first and second surfaces are opposed to one another.

31. The apparatus of claim 28, wherein the channel arrangement further comprises: a vent channel connecting the vent opening with sample channel; and  
 a jumper channel connecting the waste channel to the sample channel, for delaying the filling of the waste channel until the sample channel is filled,  
 wherein the first substrate closes and seals the vent channel and the jumper channel.

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