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2
3 METHOD OF PRODUCING A FILM COATING BY MATRIX ASSISTED PULSED
4 LASER DEPOSITION

5
6 **Background of the Invention**

7 **1. Field of the Invention**

8 The invention relates generally to the production of film coatings and more specifically
9 to the production of film coatings of sorbent materials by matrix assisted pulsed laser deposition.

10 **2. Description of the Related Art**

11 Chemical sensors commonly use coatings of chemoselective materials to effect the
12 detection of chemical analytes. Chemoselective materials are substances that are chosen for their
13 ability to interact with specific chemical analytes. A typical chemical sensing device includes a
14 substrate transducer, a thin film coating of a chemoselective material on the substrate and a means
15 for detecting the interaction of the chemoselective material with a chemical analyte. In a surface
16 acoustic wave (SAW) device, the substrate is typically a piezoelectric material that is used to
17 propagate a surface acoustic wave between sets of interdigitated electrodes. In a SAW chemical
18 sensor, the chemoselective material is coated on the surface of the transducer. When a chemical
19 analyte interacts with a chemoselective material coated on the substrate, the interaction results in
20 a change in a physical characteristic of the coating which results in a detectable change in the
21 SAW properties such as the amplitude or velocity of the propagated wave. The detectable changes

1 in the characteristics of the wave indicates the presence of the chemical analyte. SAW devices
2 are described in numerous patents and publications including U.S. Patent 4,312,228 to Wohltjen
3 and U.S. 4,895,017 to Pyke, the disclosures of which are hereby incorporated by reference. Other
4 types of chemical sensors known in the art that use chemoselective coatings include bulk acoustic
5 wave (BAW) devices, plate acoustic wave devices, interdigitated microelectrode (IME) devices,
6 and optical waveguide (OW) devices, electrochemical sensors, and electrically conducting sensors.

7 The operating performance of a chemical sensor that uses a chemoselective film coating
8 is greatly affected by the thickness, uniformity and composition of the coating. For some
9 chemical sensor technologies, the sensitivity of the sensor to a chemical analyte increases with
10 increasingly thicker coatings. However, for some types of sensors, increasing the coating
11 thickness has a detrimental effect on the sensitivity. In these types of sensors, only the portion
12 of the coating immediately adjacent to the transducer substrate is sensed by the transducer. If the
13 coating thickness is too thick, the outer layers of the coating material, that is, the layers farthest
14 away from the substrate, are not sensed. These outer layers of coating material compete for the
15 analyte with the layers of coating being sensed and thus reduce the sensitivity of the chemical
16 sensor. Further, as the thickness of the chemoselective coating is increased, the time taken for
17 an analyte to diffuse into the coating and come to thermodynamic equilibrium is increased and
18 hence the time taken to reach an equilibrium sensing signal is increased. Thus, the thickness of
19 the coating is a critical factor in the performance of real time monitoring chemical sensors,
20 affecting the response time, recovery time and response magnitude of the sensor.

21 Uniformity of the coating is also a critical factor in the performance of a sensor that uses

Inventor's Name: R. Andrew McGill and Douglas B. Chrisey

1 a chemoselective coating. In this regard, it is important not only that the coating be uniform and
2 reproducible from one device to another, so that a set of devices will all operate with the same
3 sensitivity, but also that the coating on a single device be uniform across the active area of the
4 substrate. If a coating is non-uniform, the response time to analyte exposure and the recovery
5 time after analyte exposure are increased and the operating performance of the sensor is impaired.
6 The thin areas of the coating respond more rapidly to an analyte than the thick areas. As a result,
7 the sensor response signal takes longer to reach an equilibrium value, and the results are less
8 accurate than they would be with a uniform coating. Further, in a chemical sensing device that
9 uses acoustic wave energy in the detection of interactions between a chemoselective coating and
10 analyte molecules, a non-uniform coating causes a greater amount of insertion loss of the acoustic
11 signal than does a uniform coating. Insertion loss is caused by the loss of wave energy to the
12 coating, for example, in the form of heat. This loss is exacerbated by irregularities of the coating
13 surface. If insertion loss can be reduced by providing a more uniform coating, it would be
14 possible then to increase the thickness of the coating without significantly impairing the
15 operational ability of the device. Further, by reducing the insertion loss by producing a more
16 uniform coating, a device may functionally operate with a larger dynamic operating range. An
17 additional advantage to having a more uniform coating is that the coating is less likely than a
18 nonuniform coating to delaminate from the substrate surface.

19 Conventional methods to produce film coatings on substrates or chemical sensing devices
20 involve dissolving the coating material in a volatile solvent and applying the solution to the
21 substrate surface by pipetting or spray coating. The substrate surface may be rotated at high speed

Docket No.: N.C. 78,117

PATENT APPLICATION

Inventor's Name: R. Andrew McGill and Douglas B. Chrisey

1 in a technique called spin coating. These techniques have several disadvantages. It is difficult with
2 the spin coating or spray coating methods to control the coating thickness precisely, or to ensure
3 that the coating is uniform from one batch to another. Spray coating provides no control over the
4 uniformity of a coating over a substrate surface. Spin coating potentially provides a more uniform
5 coating surface than does spray coating, but nevertheless this method has the disadvantage that
6 the edges of the coating tend to be thicker than the interior. If a plurality of devices on a single
7 substrate are coated in a single batch, the devices closer to the outer edge of the substrate will
8 have a thicker coating than the devices closer to the center of the substrate. Further, the spin
9 coating method is difficult to scale up. The spin coating method is also awkward, unwieldy and
10 wasteful for coating large surfaces at one time because of the difficulty of spinning a large
11 substrate and because of the loss of material off the edges of the substrate during the spinning
12 process. Also, the spin coating method is poorly suited for coating discrete areas of a substrate
13 while leaving other areas uncoated, as might be desired when, for example, several devices are
14 to be coated in a single batch or when only the active area of a device is to be coated. Leaving
15 an area of a substrate uncoated in a spin coating process requires the use of tape, which can
16 introduce impurities on a substrate. Moreover, the spray coating and spin coating methods are not
17 useful to create coatings of materials that cannot dissolved in a solvent and are poorly suited for
18 creating multilayer coatings.

19 Thermal evaporation under a vacuum is another method of creating a film coating. This
20 method is usable only for compounds that do not decompose at the required operating
21 temperature.

Docket No.: N.C. 78,117

PATENT APPLICATION

Inventor's Name: R. Andrew McGill and Douglas B. Chrisey

1 More precise and accurate control over the thickness and uniformity of a film coating may
2 be achieved by using pulsed laser deposition (PLD), a physical vapor deposition technique that
3 has been developed recently for forming ceramic coatings on substrates. By this method, a target
4 comprising the stoichiometric chemical composition of the material to be used for the coating is
5 ablated by means of a pulsed laser, forming a plume of ablated material that becomes deposited
6 on the substrate. Although the method is used primarily to create coatings of oxide ceramics such
7 as ferroelectrics, ferrites and high T_c superconductors, it has also been used to create organic or
8 polymer coatings for various uses. U. S. Patent No. 4,604,294 to Tanaka et al, U.S. Pat. No.
9 5,192,580, to Blanchet-Fincher and U.S. Patent No. 5,288,528 to Blanchet-Fincher disclose
10 methods of making organic or polymeric thin films by laser vapor-deposition. In these methods,
11 certain bonds of the organic compound or polymer are photochemically broken, releasing low
12 molecular weight fragments that condense and repolymerize on a substrate. Similar methods are
13 also discussed in Ogale, S. B., "Deposition of Polymer Thin Films by Laser Ablation", in **Pulsed**
14 **Laser Deposition of Thin Films**, Chrisey, D. B. and Hubler, G.K., Eds. John Wiley & Sons,
15 New York, 1994, Chapter 25; Hansen S. G. and Robitaille, T. E., "Formation of Polymer Films
16 by Pulsed Laser Evaporation" Appl. Phys. Lett. **52** (1), January 4, 1988, 81-83; Kale et al.
17 "Deposition of Amorphous Fluoropolymers Thin Films by Laser Ablation" Appl. Phys Lett. **62**
18 (5), February 1, 1993, 479-481; Kale et al, "Deposition of Polyphenylene Sulphide (PPS) Polymer
19 by Pulsed Excimer Laser Ablation", Materials Letters 15 (1992) 260-263; and Kale et al
20 "Degradation of $Y_1Ba_2Cu_3O_{7-x}$ Thin Epitaxial Films in Aqueous Medium and Control of
21 Degradation Using Polymer Overlayers Deposited by Pulsed Excimer Laser" Thin Solid Films

Docket No.: N.C. 78,117

PATENT APPLICATION

Inventor's Name: R. Andrew McGill and Douglas B. Chrisey

1 206 (1991) 161-164. A method of producing collagen thin films by laser deposition is disclosed
2 in the commonly assigned U.S. Patent Application Serial No. 08/655,788. The disclosures of the
3 above patents, patent applications and publications are incorporated herein by reference.

4 Another factor that affects sensor performance is the chemical composition of the film
5 coating. For some applications, it is desirable that a film coating be created with a minimum of
6 fragmentation, rearrangement, degradation or damage to the material being transferred. This is
7 particularly true in the creation of chemoselective films for chemical sensing devices, since
8 chemical selectivity for a particular analyte often depends on the precise arrangement of
9 substituents on the chemoselective material. A drawback to using conventional pulsed laser
10 deposition in the creation of film coatings is that direct ablation of the target can be stressful and
11 damaging to fragile materials. Chemoselective polymers used as coatings in chemical sensing
12 devices commonly contain sensitive functional groups that can be easily destroyed by bond
13 scission processes or other unwanted reactions if they are exposed to too much energy or stress.

14 Methods of ablating and ionizing large molecules for mass spectral analysis have been
15 described. U.S. Patent No. 4,920,264 to Becker, the disclosure of which is incorporated herein
16 by reference, describes a method of desorbing large, nonvolatile, thermally labile molecules from
17 a substrate by laser ablation by combining the large molecule with a solvent and freezing the
18 mixture and then exposing the frozen mixture to laser radiation. The desorbed molecules are
19 ionized and introduced into a mass analysis zone or are introduced into a liquid chromatography
20 interface. U.S. Patent No. 5,118,937 to Hillencamp et al. the disclosure of which is incorporated
21 herein by reference, describes a method of laser desorption and ionization of large biomolecules

Docket No.: N.C. 78,117

PATENT APPLICATION

Inventor's Name: R. Andrew McGill and Douglas B. Chrisey

1 by combining the biomolecules with a matrix that absorbs laser light at a wavelength of 300 nm
2 or greater and irradiating the specimen with laser light in the range absorbed by the matrix. The
3 desorbed biomolecules are then ionized and introduced into a mass analyzer. U.S. Patent No.
4 5,135,870 to Williams et al, the disclosure of which is incorporated herein by reference, describes
5 a method of pulsed laser ablation and ionization of high molecular weight compounds by
6 combining the compounds with a solvent, freezing the solution, creating a thin film of the frozen
7 solution on a sample stage, and irradiating the sample stage to create a plume containing the high
8 molecular weight compound.

10 Summary of the Invention

11 Accordingly, it is an object of the present invention to provide a method of making a film
12 coating on a substrate wherein the method allows the thickness of the coating to be controlled
13 accurately and precisely.

14 It is a further object of the present invention to provide a method of making a film coating
15 on a substrate wherein the method produces a uniform coating.

16 It is a further object of the present invention to provide a method of making a film coating
17 on a substrate wherein the method allows a large area to be coated.

18 It is a further object of the present invention to provide a method of making a film coating
19 on a substrate wherein the method allows only selected areas of the substrate to be coated.

20 It is a further object of the present invention to provide a method of making a multilayer
21 film coating on a substrate.

1 It is a further object of the present invention to provide a method of making a film coating
2 of a chemoselective material by a modified pulsed laser deposition process in a manner so that
3 the chemical composition and chemoselective properties of the chemoselective material is not
4 destroyed or significantly damaged.

5 It is a further object of the present invention to provide an improved method of making
6 a chemical sensing device of a type that includes a film coating of chemoselective material,
7 whereby the performance of the chemical sensing device is improved.

8 These and other objects are accomplished by a method of producing a film of a coating
9 material on a substrate comprising the steps of combining a coating material with a matrix
10 material to form a target and exposing the target to a source of laser energy to desorb the matrix
11 material from the target and lift the coating material from the surface of the target. The target and
12 the substrate are oriented with respect to each other so that the lifted coating material is deposited
13 as a film upon said substrate. The matrix material used in the method of the invention is selected
14 to have the property of being more volatile than the coating material and less likely than the
15 coating material to adhere to the substrate in vacuum. The matrix material is further selected as
16 having the property such that when the target is exposed to a source of laser energy, the matrix
17 material desorbs from the target and lifts the coating material from the surface of the target.

18 The thickness of the film is accurately and precisely controlled by monitoring and
19 controlling the number of laser pulses to which the target is subjected and by adjusting other
20 operating parameters such as incident beam energy, pulsed laser rate, etc. The composition of
21 matrix material and the energy density of the laser may be controlled to minimize the damage

1 to functional groups of the coating material. Moreover, the process may be carried out in an
2 enclosed space and the composition, temperature and pressure of gases contained therein may be
3 controlled to minimize the damage to functional groups of the coating material in flight between
4 ablation and deposition.

5 A further aspect of the invention is an improved method of making a chemical or
6 biochemical sensing device of the type that is made by the steps of coating the substrate with a
7 film of a sorbent chemoselective or bioselective material and providing means to detect an
8 interaction of the film of the sorbent chemoselective or bioselective material with an analyte,
9 wherein the improvement is to carry out the step of coating the substrate by laser deposition of
10 the chemoselective or bioselective material onto the substrate.

11 12 **Brief Description of the Drawings**

13 A more complete appreciation of the invention will be readily obtained by reference to
14 the following Description of the Preferred Embodiments and the accompanying drawings, wherein

15 Figure 1 is a schematic depiction of an apparatus useful in connection with the practice
16 of the present invention.

17 Figure 2 is the Fourier Transform Infrared (FT-IR) spectrum of native SXFA.

18 Figure 3 is the Fourier Transform Infrared (FT-IR) spectrum of SXFA film prepared
19 according to the method of the present invention.

20 21 **Description of the Preferred Embodiments**

1 In one aspect, the method of the present invention can be used in any instance where it
2 is desired to form a film of coating material on a substrate. The method is particularly useful in
3 instances where it is desired to form a uniform and adherent film of a chemoselective or
4 bioselective material of controlled thickness on a substrate in a manner that minimizes damage
5 to the chemoselective or bioselective material.

6 The substrate of the present invention may be any solid surface of any shape, composition
7 and orientation.

8 The method of the present invention is particularly useful in instances where the substrate
9 is a component of a chemical or biochemical sensing device of the type that includes a substrate,
10 a film coating of a chemoselective or bioselective material on the substrate and a means for
11 detecting the interaction of the chemoselective or bioselective material with a chemical or
12 biochemical analyte. Examples of such devices include surface acoustic wave (SAW) devices,
13 bulk acoustic wave (BAW) devices, plate acoustic wave devices, interdigitated microelectrode
14 (IME) devices, optical waveguide (OW) devices and surface plasmon resonance devices. The
15 composition of the substrate depends upon the type of device. For example, when the substrate
16 is a component of a surface acoustic wave (SAW) device, the substrate typically includes a
17 piezoelectric material.

18 The coating material may be any material that one may wish to deposit onto a substrate.
19 In a chemical or biochemical sensing device, the coating material will be chosen for its ability
20 to interact selectively with a particular chemical or biological analyte. Criteria for selecting
21 coating materials for chemical sensing devices are described in detail in McGill et al, "Choosing

1 Polymer Coatings for Chemical Sensors", CHEMTECH, Vol 24, No. 9, pp 27-37 (1994), the
2 disclosure of which is incorporated herein by reference. Examples of chemoselective materials
3 include SXFA (poly(oxy{methyl[4-hydroxy-4,4,bis(trifluoromethyl)but-1-en-1-yl] silylene})),
4 P4V (poly(4-vinylhexafluorocumyl alcohol). In both of these polymers and in other similar
5 polymers, their chemoselectivity is derived from pendant functional groups that extend outward
6 from the polymer backbone. A purpose of the method of the present invention is to create
7 uniform, adherent coatings of these materials without disrupting or damaging the functional
8 groups. Other examples of chemoselective materials include perfluoro-polyethers terminated with
9 a variety of functional groups such as CF_3CH_2OH , polyethylene imines, polysiloxanes, alkylamino
10 pyridyl substituted polysiloxanes, polytetrafluoroethylene, polysilanes, polyesters,
11 polyvinylaldehydes, polyisobutylene, polyvinylesters, polyalkenes, zeolites, aerogels, porous
12 carbon, metals, silicalites, clay materials, cellulose materials, polyanilines, polythiophenes,
13 polypyrroles, fullerenes, cyclodextrins, cyclophanes, calixeranes, crown ethers, and organic dyes.
14 Examples of biochemical selective materials include antibodies, antigens, DNA, RNA, proteins,
15 oligopeptides, polypeptides, oligosaccharides, polysaccharides, and lipids..

16 The matrix material is selected to have the property that when it is combined with the
17 coating material to form a target and the target is exposed to a source of laser energy, the matrix
18 material absorbs some of the laser energy in such a manner so that the matrix material is
19 desorbed, thereby lifting or evaporating the coating material from the surface of the target.
20 Preferably, only a thin layer on the surface of the target desorbs at any one time. The matrix
21 material is also selected to be more volatile than the coating material and less likely than the

Docket No.: N.C. 78,117

PATENT APPLICATION

Inventor's Name: R. Andrew McGill and Douglas B. Chrisey

1 coating material to adhere to the substrate in vacuum. The choice of a particular matrix material
2 will depend on the choice of the coating material. Factors to be taken into consideration in
3 selecting the optimum matrix material for a particular coating material include its ability to
4 dissolve or form a colloidal or particulate suspension with the particular coating material, its
5 melting point, heat capacity, molecular size, chemical composition, spectral absorption
6 characteristics, heat of vaporization (factors that affect its ability to desorb and lift the coating
7 material from the target) and its reactivity or nonreactivity towards the coating material. Any
8 laser-produced decomposition products of the matrix material should be nonreactive. Another
9 consideration is any special ability a particular matrix material may have to impart protection to
10 a particular coating material from damage during the lasing, desorption and transfer to the
11 substrate. For example, a matrix material that absorbs laser energy at the same wavelength as an
12 important functional group on the coating material may serve to protect the coating material from
13 damage from exposure to the laser energy. Alternatively, a matrix material may be used that
14 absorbs at a wavelength in a spectral region substantially outside that of the coating material. In
15 this instance, the matrix material absorbs kinetic energy imparted from the laser to the coating
16 material. Preferred matrix materials include water, aryl solvents, especially toluene, acetophenone
17 and nicotinic acid, ketones, alcohols, ethers and esters. Examples of coating material-matrix
18 material combinations that work well are SXFA (poly(oxy{methyl[4-hydroxy-
19 4,4,bis(trifluoromethyl)but-1-en-1-yl] silylene})) (coating material) with *t*-butanol (matrix
20 material) and P4V (poly(4-vinylhexafluorocumyl alcohol)) (coating material) with acetophenone
21 (matrix material).

1 The coating material and the matrix material may be combined to form a target in any
2 manner that is sufficient to carry out the purpose of the invention. If the coating material is
3 soluble to some extent in the matrix material, the coating material may be dissolved in the matrix
4 material and then the solution may be frozen to form a solid target. The target may be kept
5 frozen while the surface is being exposed to a source of laser energy during the deposition
6 process. Alternatively, if the coating material is not soluble in a suitable solvent, the coating may
7 be mixed with a matrix material to form a colloidal suspension or condensed phase. The matrix
8 material can also include soluble or insoluble dopants, that is, additional compounds or materials
9 that one may wish to deposit onto the film.

10 The target may generally be in any shape suitable for being exposed to a laser beam (for
11 example, a pellet, disc, cylinder or parallelepiped). Preferably, the target is a dense, cylindrical
12 pellet. For substrates of a given size, the target should be about four times larger in area.

13 Apparatus for carrying out the steps of exposing the target to a source of laser energy to
14 desorb the coating material and matrix material and for depositing the coating material on a
15 substrate can be conventional apparatus for pulsed laser deposition as is described in *Pulsed Laser*
16 *Deposition of thin Films*, edited by D.B. Chrisey and G.K. Hubler (Wiley, New York, 1994) and
17 in Cotell, "Pulsed Laser Deposition and Processing of Biocompatible Hydroxylapatite Thin Films"
18 *Appl. Surf. Sci.* 69 (1993) pp140-148, the disclosures of which are incorporated herein by
19 reference.

20 The target may be mounted by any support means. The angle of incidence between the
21 source of laser energy and the target can be any angle used in the art and is typically about 45°.

Docket No.: N.C. 78,117

PATENT APPLICATION

Inventor's Name: R. Andrew McGill and Douglas B. Chrisey

1 Typically, the target is mounted on a moving support means, such as a rotating and/or translating
2 shaft, such that different portions of the target are in the center of the laser beam at different
3 times, thereby extending the useful lifetime of the target and providing enhanced film uniformity.
4 Typically, the target is rotated at a speed of about 0.05 - 0.5 revs/s. Such an arrangement allows
5 for greater uniformity of deposition on the substrate. In addition to (or instead of) moving the
6 target, the center of the laser beam can be moved to achieve similar effects. Larger substrate
7 areas may be coated by rastering the center of the laser beam across the target surface. In these
8 cases, targets having diameters >0.75 inch would be preferred.

9 Any suitable source of laser energy can be employed. In general, as discussed below, a
10 pulsed laser, particularly a short pulsed laser, is preferred in accordance with the present
11 invention. For example, an excimer laser (e.g., ArF, KrF, XeF or XeCl) can be used, an ArF
12 excimer laser being especially preferred. Other short pulsed lasers, e.g., Nd-YAG or CO₂, could
13 be used.

14 Lasers for use in accordance with the present invention generally emit light having a
15 wavelength in the range of about 193 nm - 1100 nm, an energy density of about 0.05 - 10 J/cm²
16 (typically about 0.1 - 2.0 J/cm²), a pulsewidth of about 10⁻¹² - 10⁻⁶ second and a pulse repetition
17 frequency of about 0 - 1000 Hz. In general, energy density (fluence) affects morphology; higher
18 energies tend to produce deposited films that have larger particles.

19 The distance between the target and the substrate is typically within the range of about
20 3 cm - 10 cm. More often, the distance between the target and the substrate is about 3 cm - 5
21 cm. A particularly preferred distance is about 4 cm. In general, larger distances are more

1 suitable for depositing on larger substrate areas. Distances of greater than 10 cm may be used
2 if desired, for example, for depositing on larger surface areas. However, the target-substrate
3 distance is also inversely related to the film thickness achieved for a given period of deposition.
4 The substrate may be manipulated, such as by rotation or translation, during deposition to allow
5 deposition on non-planar or irregularly shaped surfaces. If the coating material used in the
6 practice of the invention is a polymer, a more uniform coating may be created by heating the
7 substrate to a temperature above the glass transition or melting point of the polymer while the
8 coating material is being deposited on the substrate. .

9 The target and the substrate are preferably positioned within an enclosed space or
10 chamber, referred to as a "PLD chamber", having an environment whose temperature, pressure
11 and chemical composition are controlled to enhance the deposition process and to minimize the
12 likelihood of damage to the coating material. Suitable environments according to the present
13 invention may include argon, and argon/water, oxygen, alkanes, alkenes, alkynes, alcohols or a
14 mixture of these gases. A gas having the same chemical composition as the matrix material may
15 be used. Other non-reactive or inert gases may be substituted for argon. For creating a gas water
16 environment, there may be provided a gas inlet port which passes through a bubbler before
17 passing into a vacuum chamber. For creating a water-free environment, there may be provided
18 a gas inlet port which passes directly into a vacuum chamber. If desired, the chamber atmosphere
19 may be changed at the end of a deposition process to bring the substrate to atmospheric
20 conditions. Gases present before and during the deposition process may be referred to as "make-
21 up gases." The gases introduced into the chamber at the end of deposition may be referred to

1 as "quenching gases."

2 The background pressure within the chamber during deposition determines the rate at
3 which the film of coating material is deposited on the substrate. Generally, the lower the
4 pressure, the faster the deposition. As the pressure within the chamber increases, the number of
5 collisions between the ablated coating material and the gas increases. These collisions slow the
6 deposition process, resulting in thinner films. Generally, the background pressure within the
7 chamber during a deposition may be about 0 Torr - 760 Torr. Typically, deposition is performed
8 below atmospheric pressure. A preferred range for the total pressure within the chamber during
9 deposition is about 0.05 Torr - 50 Torr. A particularly preferred range is about 0.1 Torr to 1
10 Torr.

11 The thickness of the deposited film is proportional to the number of laser pulses to which
12 the target is exposed and, consequently, to the time of deposition for a given laser pulse rate.
13 The film thickness may be selected by controlling the number of laser pulses depending on the
14 purpose for which the finished article is to be used. A typical range of thicknesses for acoustic
15 wave devices is from about 1nm to about 10 microns. The thickness of the film may also be
16 controlled by selecting factors such as the laser energy density, the target temperature and the
17 distance of the substrate from the target.

18 In the manufacture of an acoustic wave device, the thickness of the coating material
19 during the deposition process may be monitored by operating an acoustic wave device having an
20 initial predetermined oscillating frequency. The change in the frequency of the acoustic wave as
21 the coating material is deposited on the substrate may be monitored in real time and the

1 deposition process halted when the frequency changes to a second predetermined level.

2 The method of the present invention is particularly suitable for making film coatings on
3 relatively large substrate areas (up to about six inches in diameter). To make numerous chemical
4 sensing devices at one time, a single large substrate can be coated at one time and then the coated
5 substrate can be subdivided into separate chemical or biochemical sensing device components.
6 The substrate may be masked so that only predetermined areas of the substrate are coated.

7 The method of the present invention may be used to make multi-layer devices by
8 repeating the steps of producing the film coating on a substrate using different coating materials.

9 Fig. 1 shows a typical apparatus 100 useful for carrying out the method of the present
10 invention. Vacuum chamber 10 with a base pressure of about 4×10^{-8} Torr encloses the
11 apparatus. Excimer laser 12 is focused through lens 14 onto target 16 made of the coating
12 material and the matrix material. Target 16 is affixed to rotating arm 18 which allows plume 20
13 to be precessed over substrate 22, thus covering a wider area than a fixed arm geometry would
14 allow. Substrate holder 24 is electrically isolated and may be heated by means of quartz lamp
15 26. The temperature is monitored by thermocouple 28. Gas inlet port 30 allows the introduction
16 of gases into chamber 10 in the direction of arrow 31. Bubbler 32 (optional) may be used when
17 a water vapor environment is desired.

18 In an alternative embodiment, the invention relates specifically to an improved method
19 of making a chemical or biochemical sensing device by the steps of (a) providing a substrate (b)
20 coating the substrate with a film of a chemoselective or bioselective material, the film having a
21 uniform thickness over a substantial portion of the substrate and (c) providing means to detect

1 an interaction of the film of the chemoselective or bioselective material with an analyte, wherein
2 the step of coating the substrate with a film of chemoselective or bioselective material is by the
3 technique of pulsed laser deposition as described above. The chemoselective or bioselective
4 material may be combined with a matrix material as described above, but if the chemoselective
5 or bioselective material is able to withstand the conditions for pulsed laser deposition, this step
6 may be omitted. Examples of chemoselective materials that can be used in the formation of a
7 chemical sensing device without combining the material with a matrix material include
8 polyolefins such as polyisobutylene, polyhalogenated olefins, polyhalogenated ethers, in particular,
9 polyepichlorohydrin, perfluorinated polymers, particularly polytetrafluoroethylene and porous
10 inorganic materials such as activated carbon, clays, zeolites and aerogels.

11 Having described the invention, the following examples are given to illustrate specific
12 embodiments of the invention including the best mode now known to perform the invention.
13 These specific examples are not intended to limit the scope of the invention described in this
14 application.

15 Example 1

16 A solution of SXFA (poly(oxy{methyl[4-hydroxy-4.4,bis(trifluoromethyl)but-1-en-1-yl]
17 silylene})) in t-BuOH (tertiary butyl alcohol) was prepared at a concentration of 0.005g of
18 polymer/g of matrix material. This solution was poured into a cylindrical teflon lined lid and
19 frozen in liquid nitrogen. The frozen SXFA(tBuOH) solution in the lid was transferred to the
20 PLD chamber as the target. The open end of the lid was secured in such a position to expose
21 the surface of the frozen SXFA(tBuOH) solution to the laser. The PLD conditions were as

Docket No.: N.C. 78,117

PATENT APPLICATION

Inventor's Name: R. Andrew McGill and Douglas B. Chrisey

1 follows:

2	Type of Laser	KrF, 248 nm
3	Laser Power(W) @ 10Hz	0.20
4	Energy Density (J/cm ²)	0.45
5	Repetition rate(Hz)	5
6	Spot Size(cm ²)	0.045
7	Laser Voltage(kV)	14.7 (Constant Energy Mode : 375mJ)
8	Substrate	NaCl Plate
9	Substrate Temperature (°C)	25°C
10	Make Up Gas	Water & Argon
11	Make Up Gas Pressure(torr)	0.050
12	Substrate-Target Distance	3 cm
13	Number of Shots	21,000

14
15 Water vapor was generated by bubbling argon through water maintained at about 25° C. The
16 argon stream was therefore nearly saturated with water vapor. The deposition was stopped at
17 20,000 shots and the repetition rate increased to 10Hz and an additional 1000 shots added. A
18 comparison of Fig. 2 (native SXFA) and Fig. 3 (PLD-deposited SXFA) shows that functional
19 groups of native SXFA are preserved in the PLD process.

20

21 **Example 2**

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1 A solution of poly(4-vinylhexafluorocumyl alcohol) (P4V) in acetophenone (ACPH) was
2 prepared at the concentration of 0.0056g/g. This solution was poured into a cylindrical teflon
3 lined lid and frozen in liquid nitrogen. The frozen P4V(ACPH) solution in the lid was
4 transferred to the PLD chamber as the target. The open end of the lid was secured in such a
5 position to expose the surface of the frozen P4V(ACPH) solution to the laser. The PLD
6 conditions were as follows:

7	Type of Laser	KrF, 248 nm
8	Laser Power(W) @ 10Hz	0.20
9	Energy Density (J/cm ²)	NA
10	Repetition rate(Hz)	5
11	Laser Voltage(kV)	16.2 (Constant Energy Mode : 375mJ)
12	Substrate	NaCl Plate
13	Substrate Temperature (°C)	25°C
14	Make Up Gas	Water & Argon
15	Make Up Gas Pressure(torr)	0.050
16	Substrate-Target Distance	3 cm
17	Number of Shots	21,000

18
19 Water vapor was generated by bubbling argon through water. The argon stream was therefore
20 nearly saturated with water vapor. The deposited coating appeared to add a tinted sheen to the
21 surface.

1 A comparison of the FT-IR spectra of native and PLD-deposited P4V showed that functional
2 groups of the P4V were preserved in the deposition process. (data not shown)
3

4 Example 3

5 A 2 port (launch and receive) 250MHz SAW resonator was coated with a film of SXFA
6 by the PLD method described above to create a coating having a thickness such that the
7 frequency of the device was shifted by 235 KHz during the deposition process. The insertion loss
8 of the device was determined to be 13db. The insertion loss of a similar device created using
9 conventional coating methods is determined to be between 16 to 20db. With no polymer coating
10 these SAW devices typically exhibit insertion loss values of between 8 to 10db. The theoretical
11 value is about 6db. The PLD coated device yields insertion loss values that are at about 50% less
12 than using conventional coating techniques. This is advantageous because the gain required to
13 operate the SAW device does not have to be as strong. More coating can be deposited without
14 significantly impairing the operational ability of the device.
15

16 Example 4

17 A flat clean 1 cm² Si (111) substrate wafer was coated with polyepichlorohydrin (PECH) under
18 the following conditions:

19 Type of Laser	KrF, 248 nm
20 Laser Power(W) @ 10Hz	0.20
21 Energy Density (J/cm ²)	0.5

Docket No.: N.C. 78,117

PATENT APPLICATION

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1 Repetition rate(Hz) 5
2 Laser Voltage(kV) 14.8 (Constant Energy Mode : 375mJ)
3 Substrate Temperature (°C) 25°C
4 Make Up Gas N₂/H₂
5 Make Up Gas Pressure(torr) .05
6 Substrate-Target Distance 3 cm
7 Number of Shots 29,000

8

9 The PECH Coated Si (111) wafer was analyzed with a J.A. Woolam Co. focused beam M-44™
10 ellipsometer and VASE® (variable angle spectroscopic ellipsometer). The thickness of the PECH
11 coating in a linear direction was sampled across the 1 cm² substrate. The coating thickness was
12 determined to be 2087+/-48Angstroms.

13

14 **Example 7**

15 An uncoated 250 MHz surface acoustic wave (SAW) device was placed in a vacuum
16 chamber at a pressure of about 50 millitorr at room temperature. A target of polyepichlorohydrin
17 (PECH) was exposed to a Kr-F pulsed laser (248nm) to transfer the PECH from the target to the
18 active area of the surface acoustic wave device, which was placed 4 cm from the target to create
19 a 32nm film of the PECH on the device. Performance of the SAW device when exposed to
20 dimethylmethylphosphate and bis-2-chloroethylether gases compared with the performance of
21 a SAW device created by the conventional means of spray coating with PECH in a solvent. The

Docket No.: N.C. 78,117

PATENT APPLICATION

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1 SAW device coated by pulsed laser deposition showed greater sensitivity, faster sensor signal
2 response, and a more rapid recovery of the sensor signal to a baseline value upon exposure to
3 clean air in comparison to the spray-coated SAW device.

4 Obviously, many modifications and variations of the present invention are possible in light
5 of the above teachings. It is therefore to be understood that

6 the invention may be practiced otherwise than as specifically described.

7

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ABSTRACT

A film of a coating material is produced on a substrate by a pulsed laser deposition method in which the material that forms the coating material is first combined with a matrix material to form a target. The target is then exposed to a source of laser energy to desorb the matrix material from the target and lift the coating material from the surface of the target. The target and the substrate are oriented with respect to each other so that the lifted coating material is deposited as a film upon said substrate. The matrix material is selected to have the property of being more volatile than the coating material and less likely than the coating material to adhere to the substrate. The matrix material is further selected as having the property such that when the target is exposed to a source of laser energy, the matrix material desorbs from the target and lifts the coating material from the surface of the target.

In another aspect of the invention, a method of making an improved chemical or biochemical sensing device that includes a chemoselective or bioselective coating on a substrate is carried out by coating the substrate by pulsed laser deposition.

100

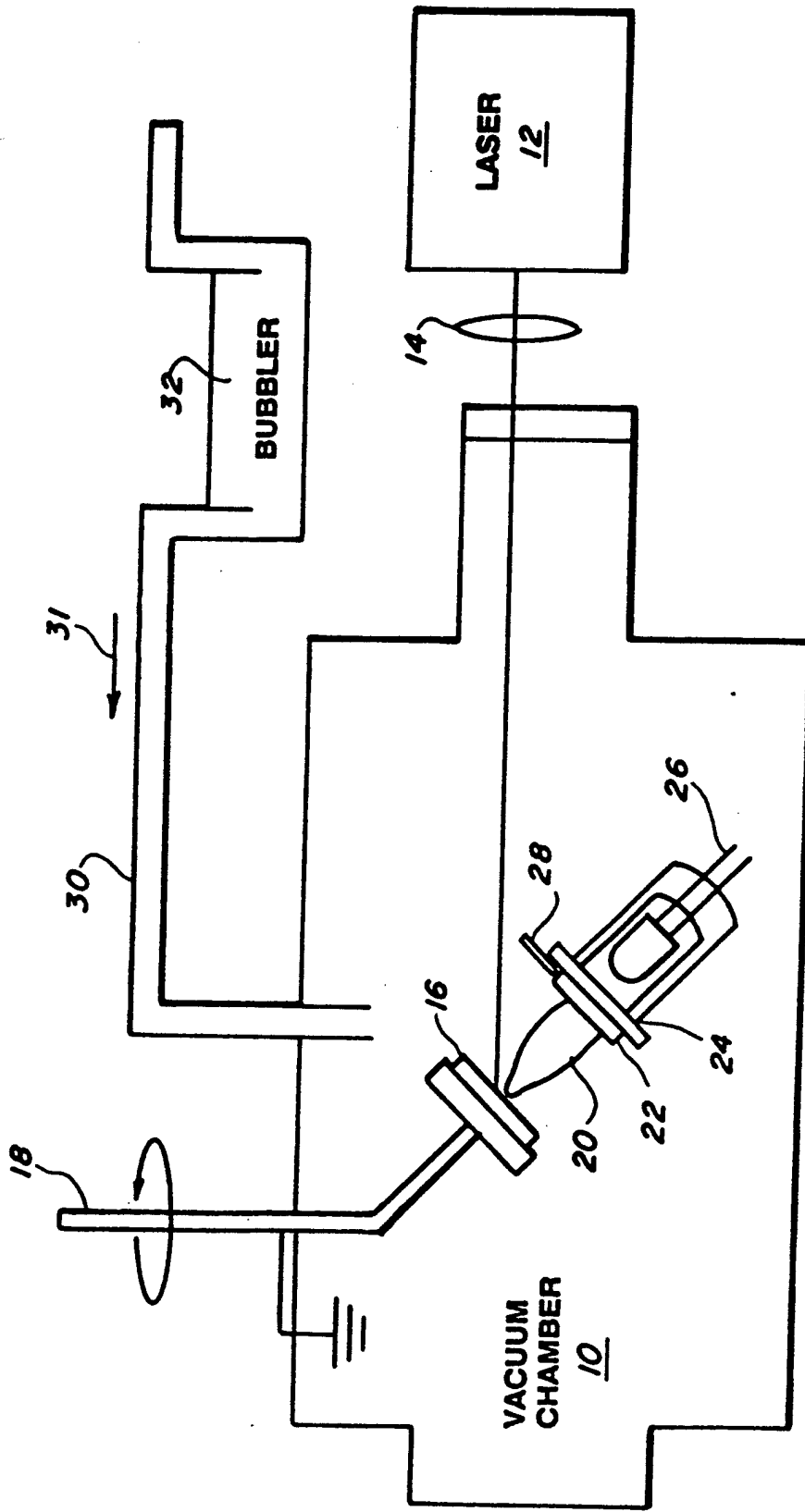


FIG. 1

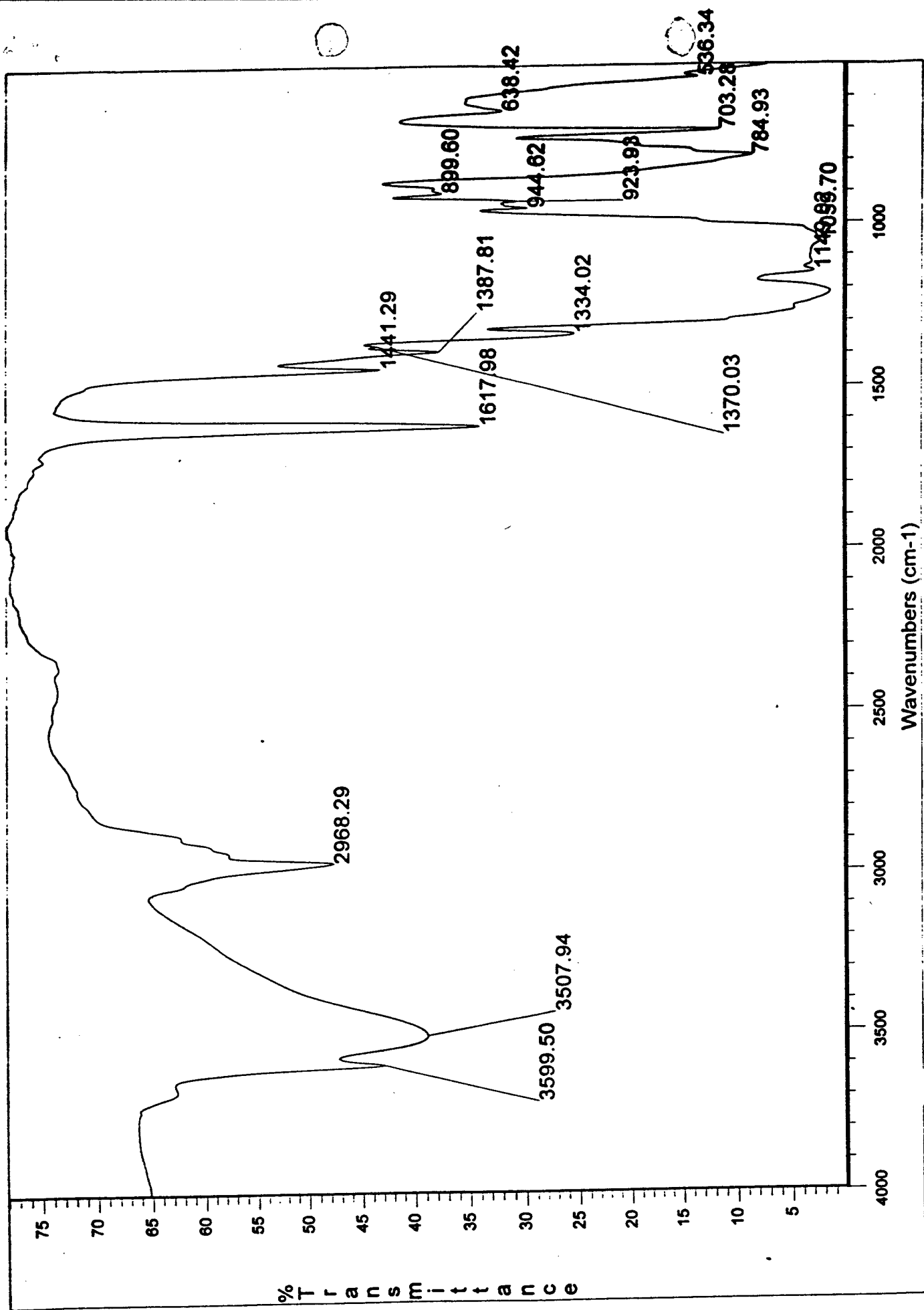


Fig. 2

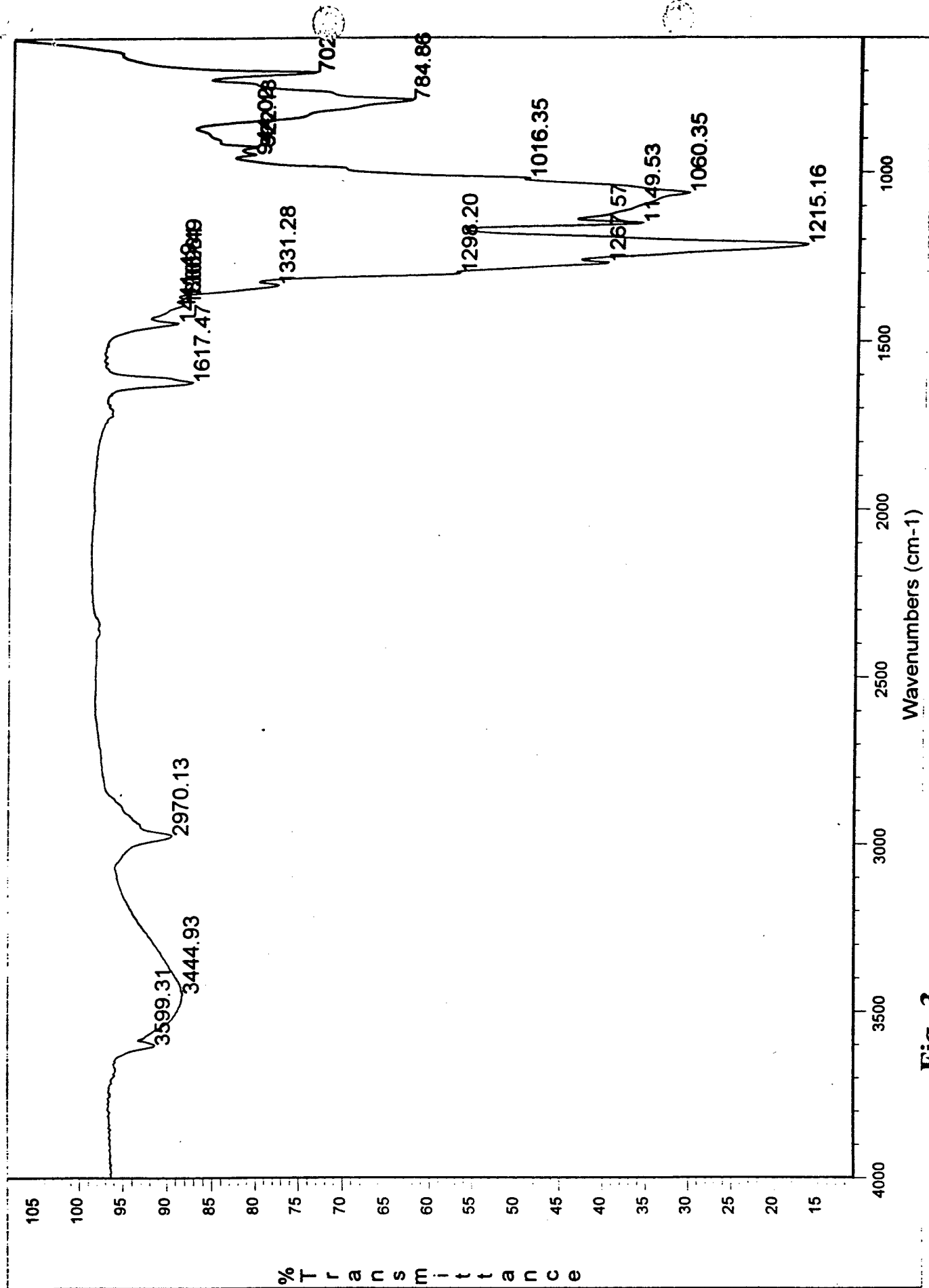


Fig. 3