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(54) **PROCESS FOR MAKING A POROUS  
SUBSTRATE OF GLASS POWDER FORMED  
THROUGH FLAME SPRAY PYROLYSIS**

**Related U.S. Application Data**

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(57) **ABSTRACT**

Inorganic porous substrates and methods of making inorganic porous substrates utilizing nanoparticles deposited onto a base substrate are described. The inorganic porous substrates are useful for biological applications, for example, biomolecule attachment such as DNA, RNA, protein and the like. The inorganic porous substrates are also useful for cell growth applications.

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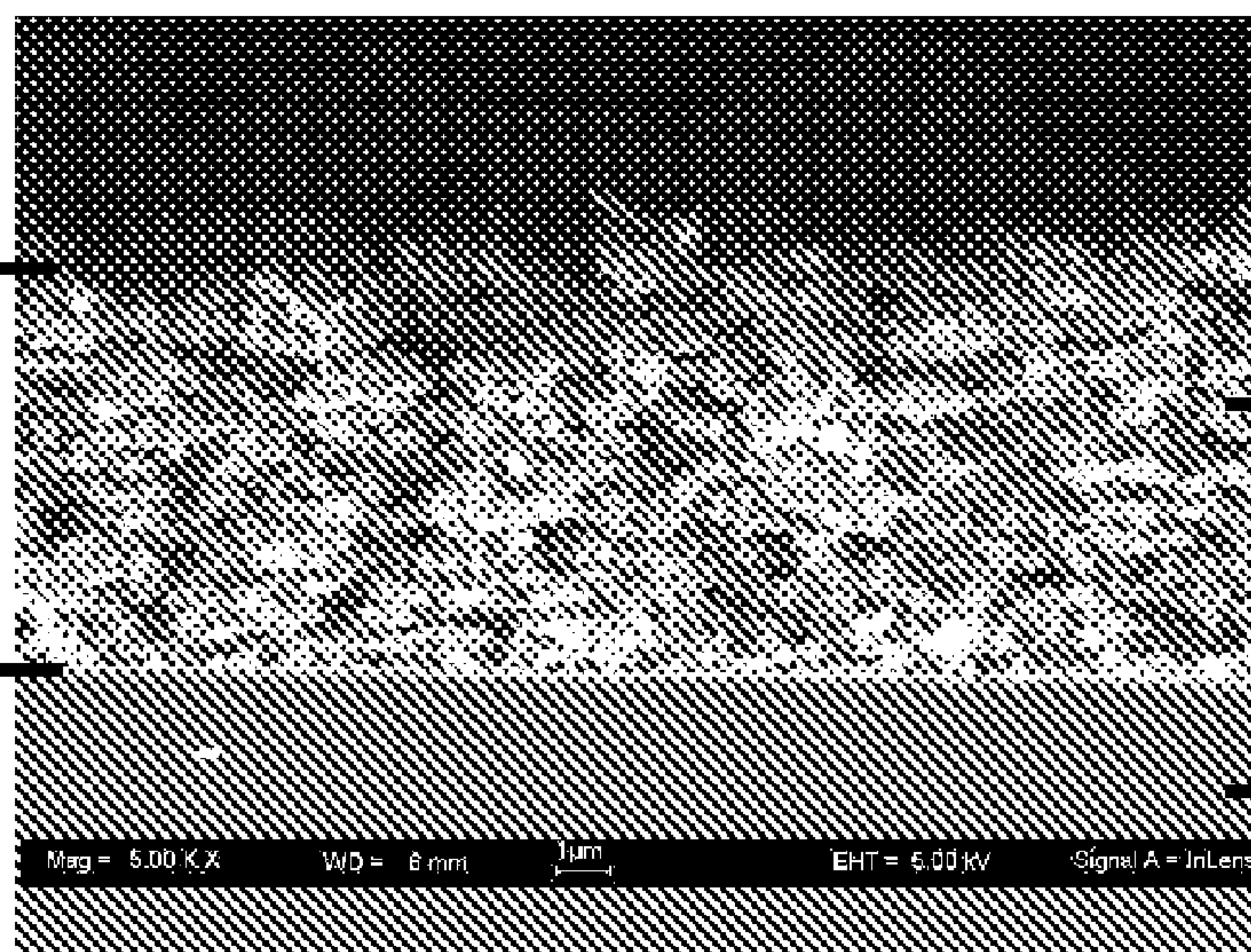
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**23**

**22**

**7**

**8**



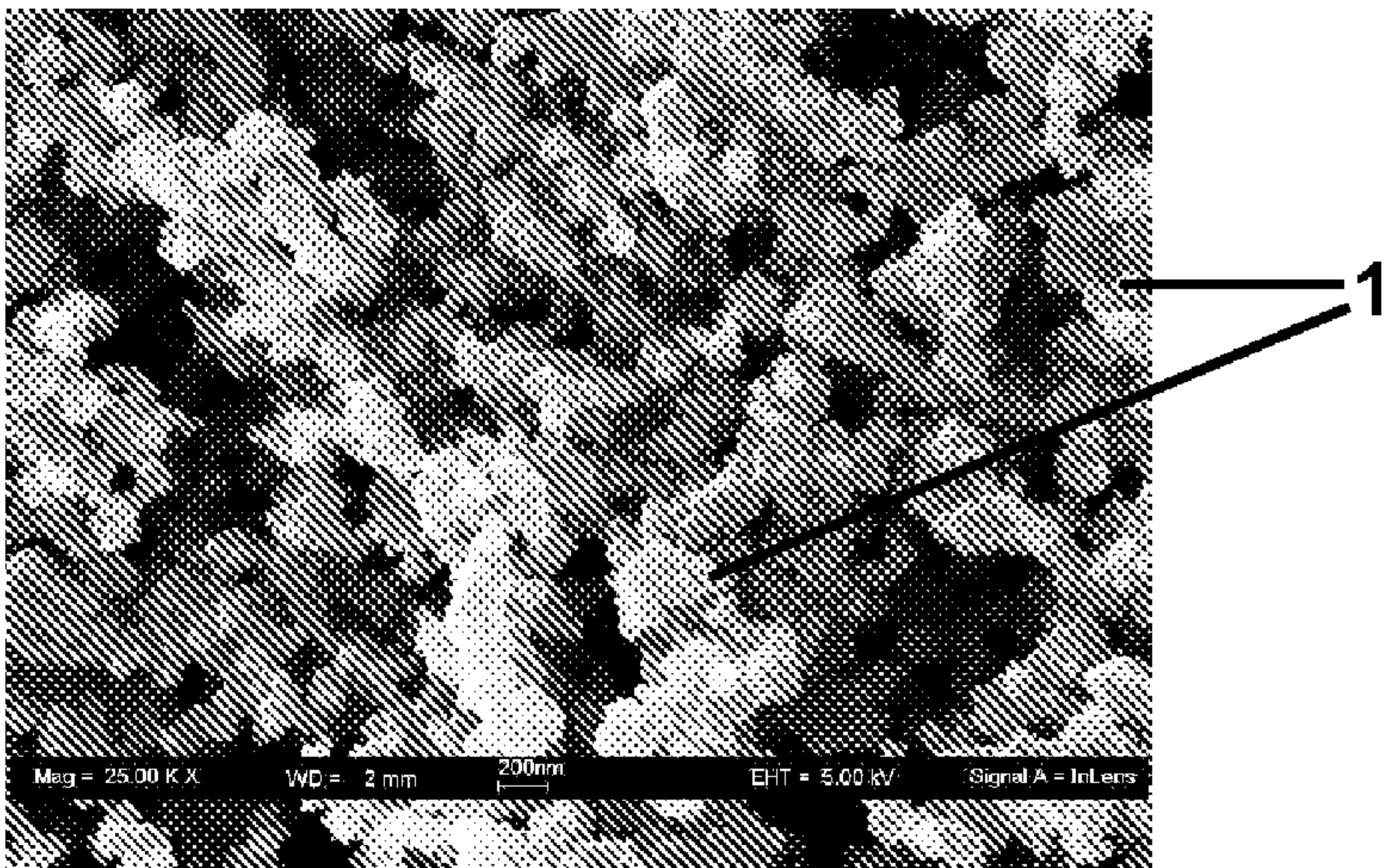


Figure 1

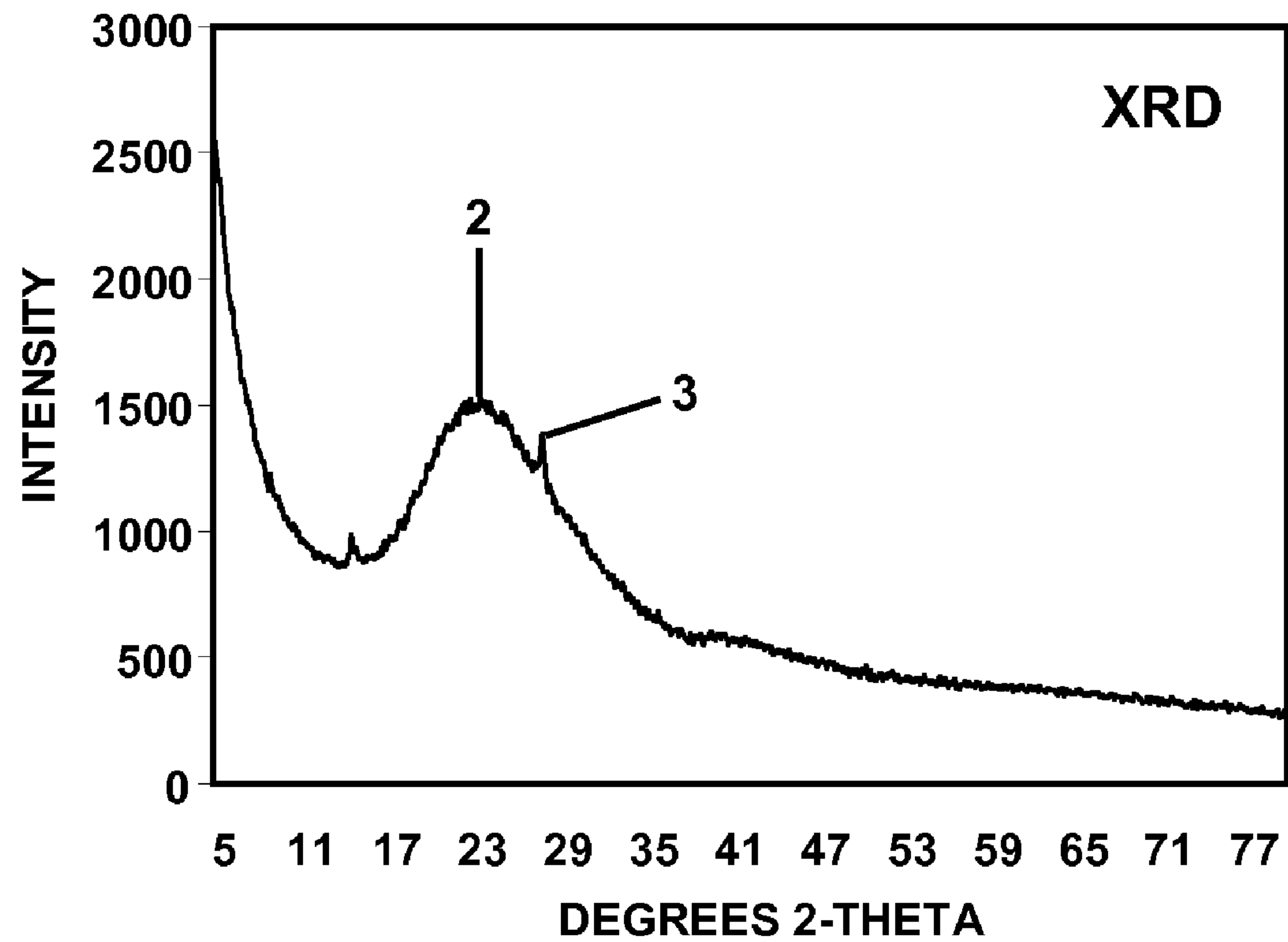
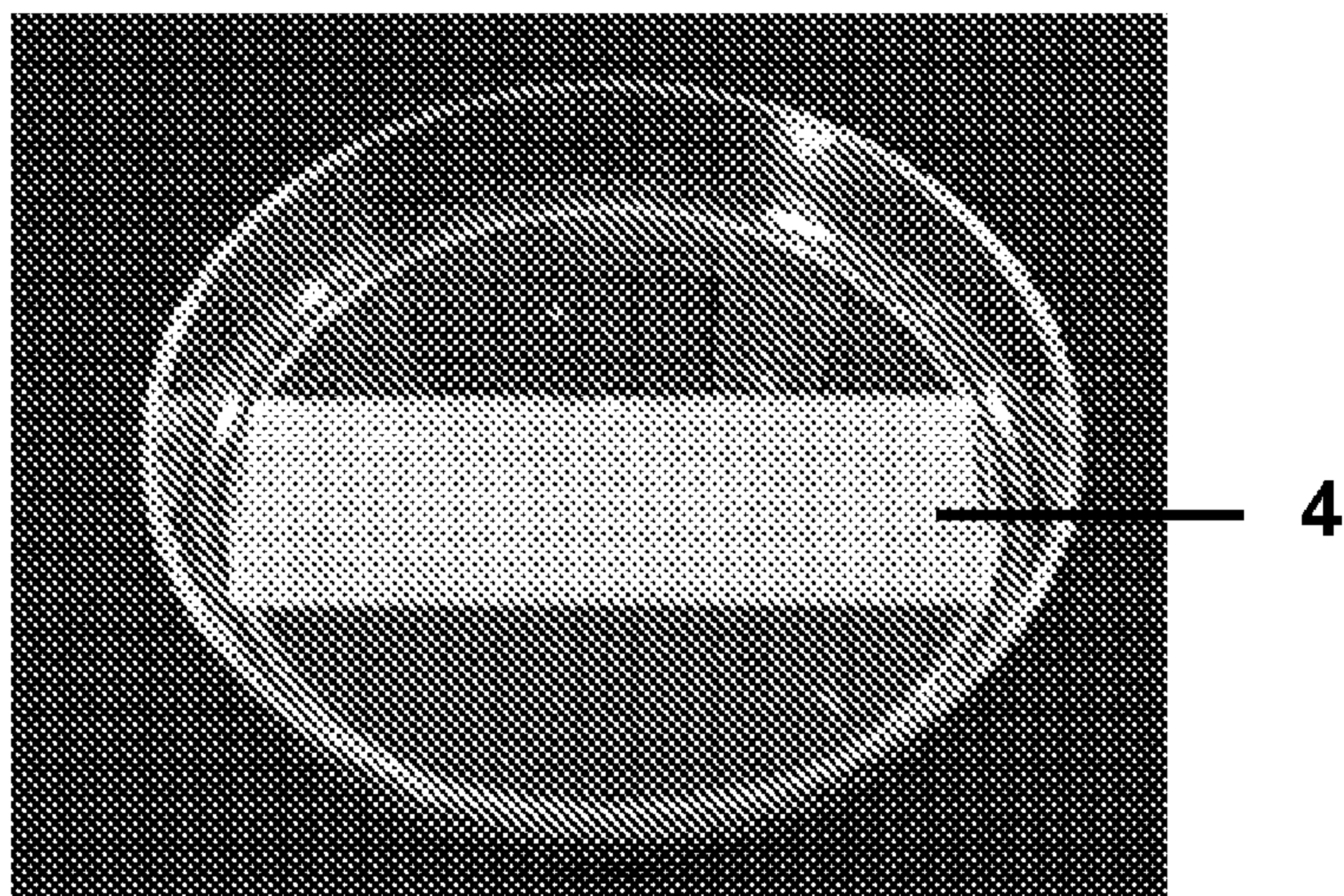
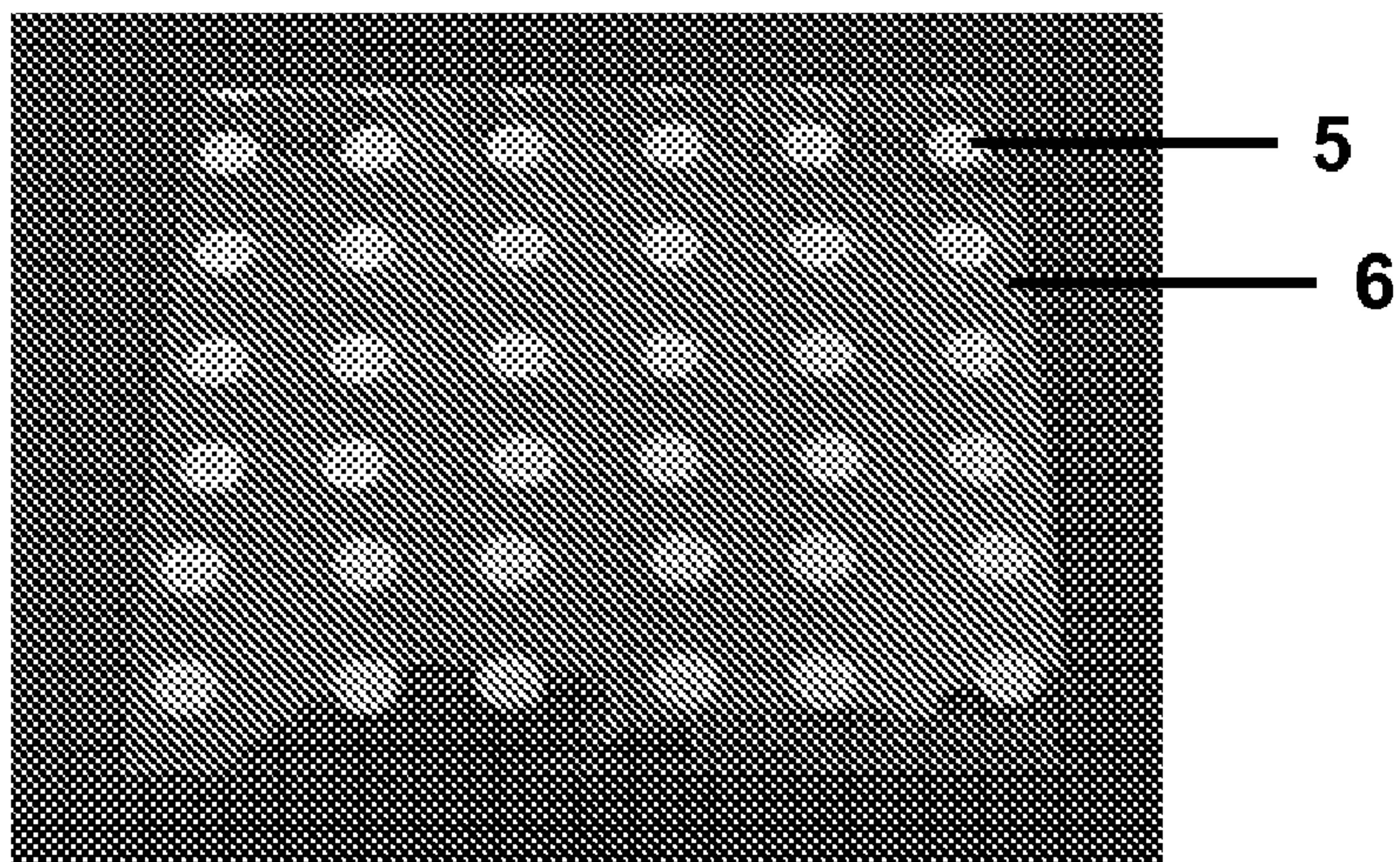


Figure 2





**Figure 3**



**Figure 4**



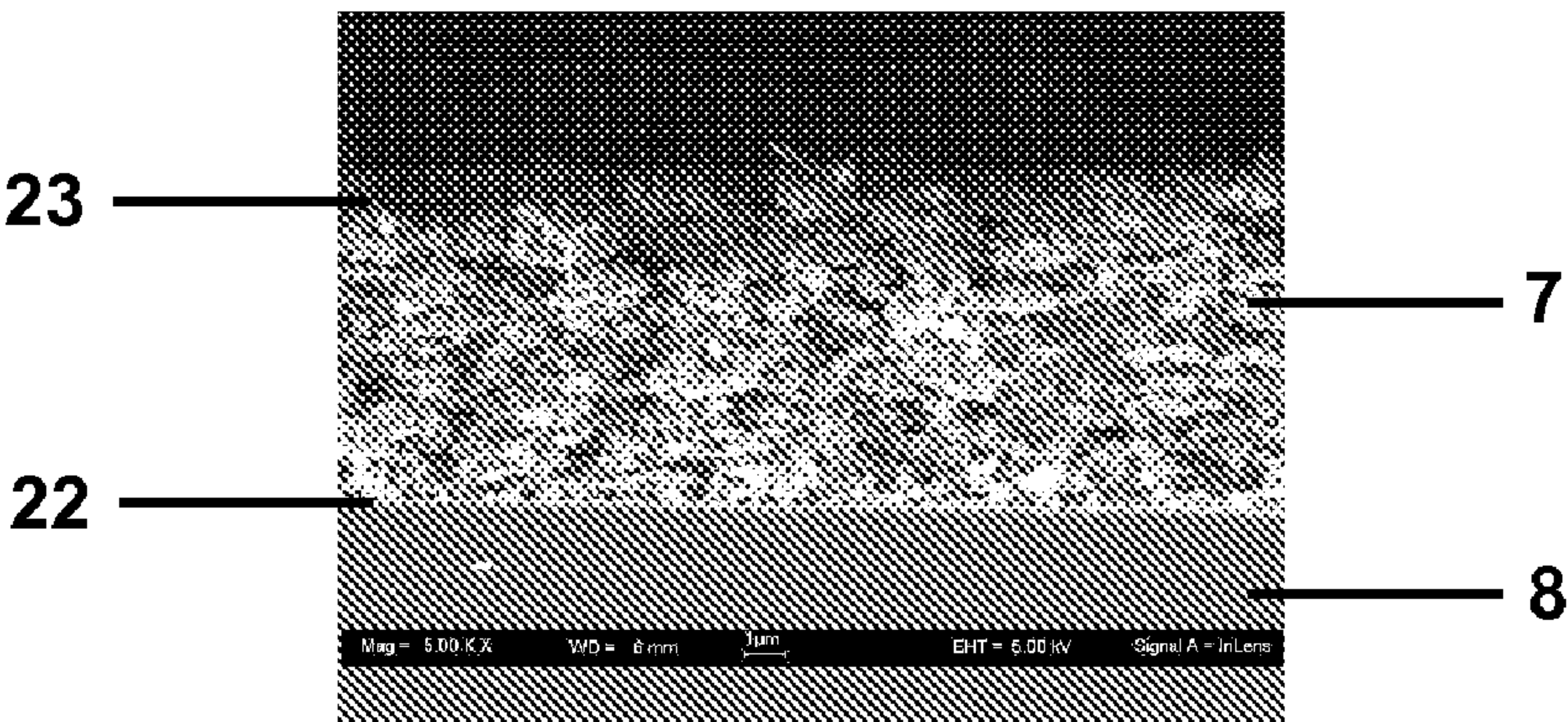


Figure 5

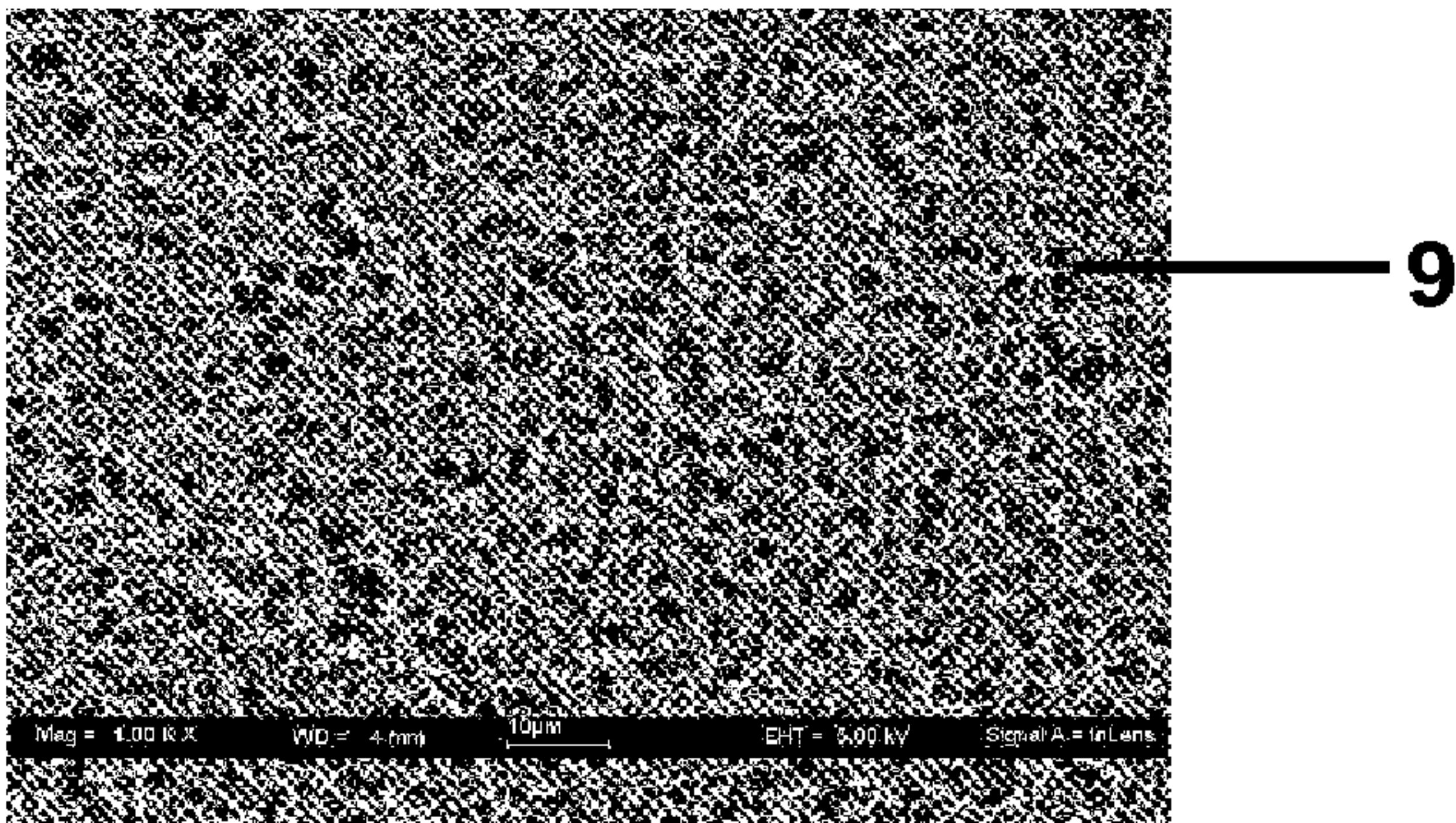


Figure 6

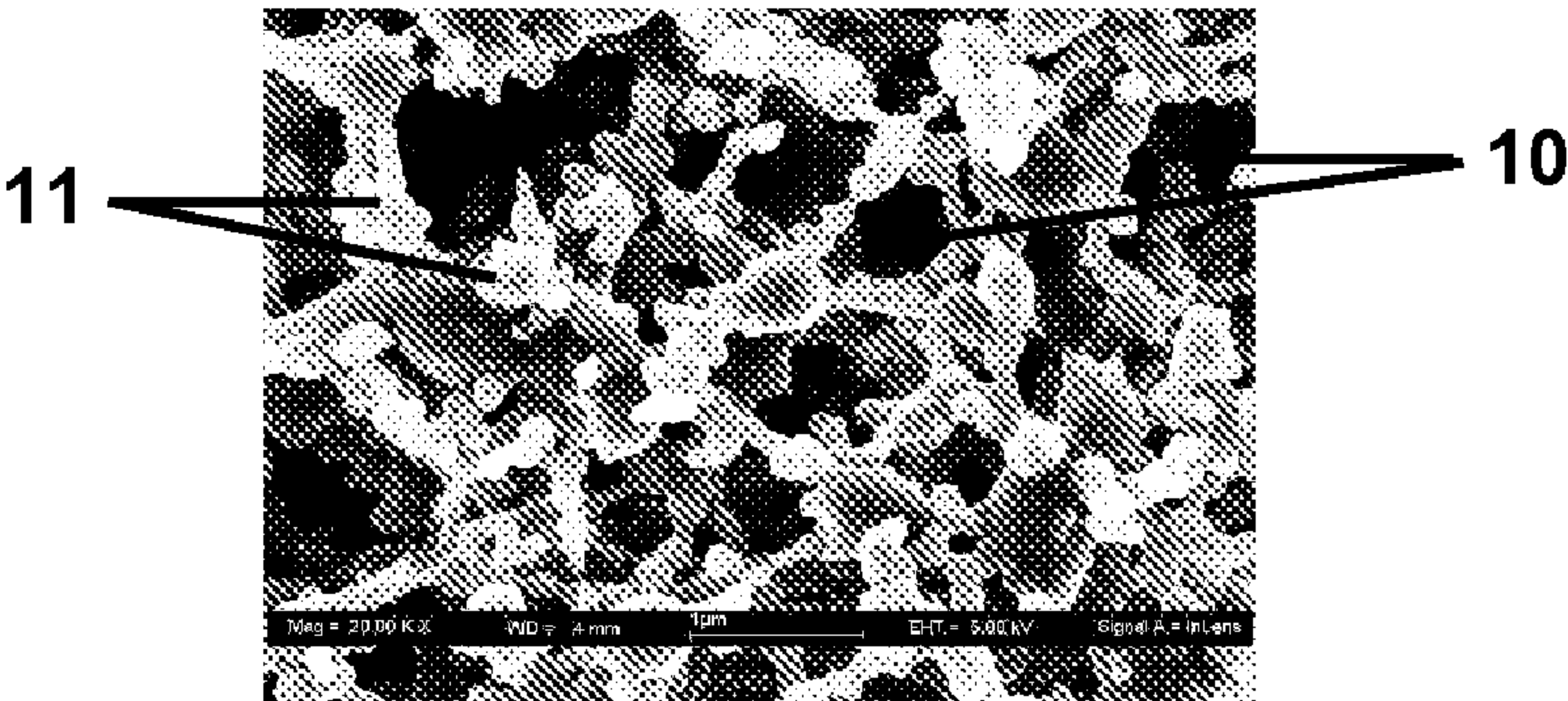


Figure 7



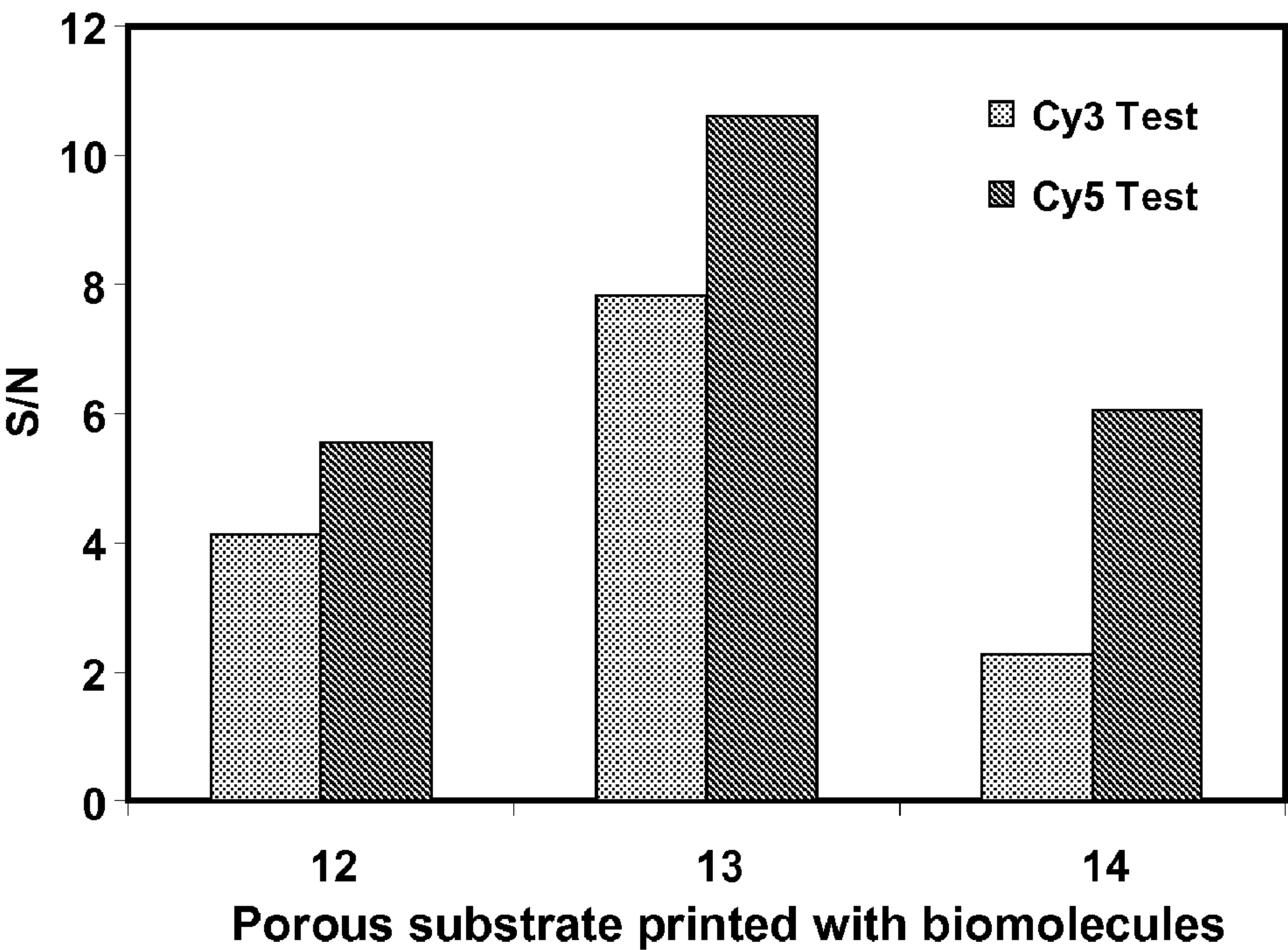


Figure 8

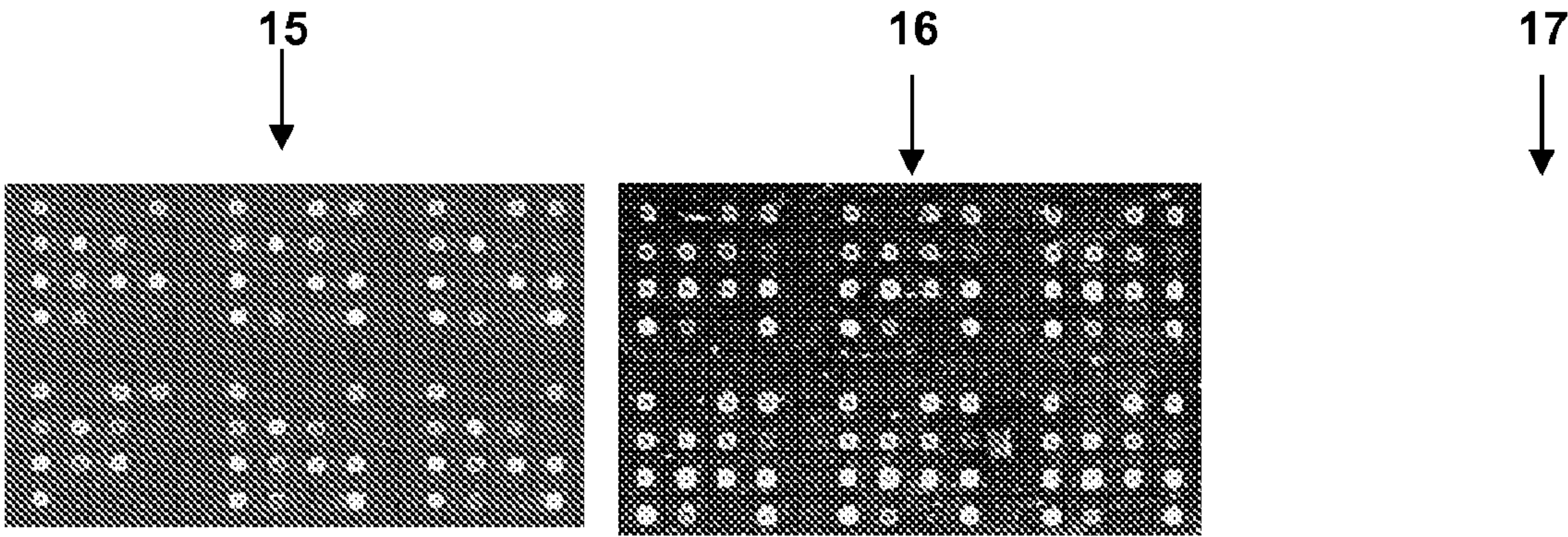


Figure 9



# PROCESS FOR MAKING A POROUS SUBSTRATE OF GLASS POWDER FORMED THROUGH FLAME SPRAY PYROLYSIS

**[0001]** This application claims the benefit of priority to provisional application No. 60/926,248, titled "Process for Making a Porous Substrate of Glass Powder Formed Through Flame Spray Pyrolysis," filed on Apr. 26, 2007, attorney docket no. SP07-073P, the contents of which are incorporated by reference herein in their entirety.

## BACKGROUND

**[0002]** 1. Field of the Invention

**[0003]** The present invention relates generally to inorganic porous substrates and more particularly to a method of making inorganic porous substrates utilizing nanoparticles deposited onto a substrate.

**[0004]** 2. Technical Background

**[0005]** Over the years, there has been rapid progress in the areas of electronics, materials science, and nanoscale technologies resulting in, for example, smaller devices in electronics, advances in fiber manufacturing and new applications in the biotechnology field. The ability to generate and collect increasingly smaller, cleaner and more uniform particles is necessary in order to foster technological advances in areas which utilize small particulate matter. The development of new, efficient and adaptable ways of producing small particulate matter and subsequently collecting or depositing the small particulate matter onto a substrate becomes more and more advantageous.

**[0006]** The size of a particle often affects the physical and chemical properties of the particle or material comprising the particle. For example, optical, mechanical, biochemical and catalytic properties often change when a particle has cross-sectional dimensions smaller than 200 nanometers (nm). When particle sizes are reduced to smaller than 200 nm, these smaller particles of an element or a compound often display properties that are quite different from those of larger particles of the same element or compound. For example, a material that is catalytically inactive in the macroscale can behave as a very efficient catalyst when in the form of nanoparticles.

**[0007]** The aforementioned particle properties are valuable in many technology areas. For example, in optical fiber manufacturing, the generation of substantially pure silica and germanium soot particles from impure precursors in a particular size range (about 5-300 nm) has been key in providing optical preforms capable of producing high purity optical fiber. Also, in the field of pharmaceuticals, the generation of particles having certain predetermined properties is advantageous in order to optimize, for example, in vivo delivery, bioavailability, stability of the pharmaceutical and physiological compatibility. The optical, mechanical, biochemical and catalytic properties of particles are closely related to the size of the particles and the size of the compounds comprising the particles.

**[0008]** Porous microstructures are of great interest to many research and commercial areas. Three-dimensional structures made from nanoparticles provide optimum surface area. Enhanced surface area is an enabling physical property for many applications, such as custom spotted microarrays, high display of surface area for catalysis, high display of luminescent elements and the like. Conventional methods of produc-

ing enhanced surface area, such as the method described in PCT Publication No. WO0116376A1 and commonly owned US Patent Application Publication Nos. 2003/0003474 and 2002/0142339, the disclosures of which are incorporated herein by reference in their entirety, use ball milled Corning 1737™ glass particles of size range from 0.5  $\mu$ m to 2  $\mu$ m. These ball milled particles are sintered onto Corning 1737™ glass substrates.

**[0009]** The conventional ball milling processes for manufacturing slides for use in the manufacture of microarrays have the following disadvantages: lot to lot variability between ball milled preparations of 1737™ microparticles, broad heterogeneous particle size distributions, requirement for post processing deposition of the ball milled microparticles by either tape casting or screen printing, particle sizes are especially large and do not yield ultimate nanoparticle surface areas, screen printing has been shown to yield missing spot effects on microarrays due to irregular surface patterns and limitation of the process to 1737™ glasses.

**[0010]** It would be advantageous to have methods for producing particles in the nanometer size range (average particle sizes 500 nm or less) thus minimizing the size variation and composition variation evident in conventional ball milling processes for making inorganic porous substrates.

## SUMMARY

**[0011]** Methods for making porous substrates of the present invention are described herein. The methods address one or more of the above-mentioned disadvantages of conventional ball milling methods and conventional aerosol particle generating methods, in particular, when the desired particles are dimensionally in the nanometer range (average particle size of 500 nm or less).

**[0012]** Methods for producing a porous substrate comprising average particle sizes of 500 nanometers or less using flame spray pyrolysis are described herein. In some embodiments, the average particle sizes are, for example, 400 nm or less, 300 nm or less, 200 nm or less, 100 nm or less or 80 nm or less.

**[0013]** In one embodiment, a method of depositing nanoparticles onto a base substrate to produce an inorganic porous substrate using flame spray pyrolysis is described. The method comprises providing a solution comprising glass precursors and a solvent, atomizing the solution to form aerosol droplets, synthesizing nanoparticles from the aerosol particles using a flame and either subsequently or simultaneously sintering the nanoparticles onto the base substrate.

**[0014]** According to another embodiment, a method of making a coated inorganic porous substrate is described. The method comprises providing a solution comprising glass precursors and a solvent, atomizing the solution to form aerosol droplets, passing the aerosol droplets through a flame under conditions sufficient to generate nanoparticles, depositing the nanoparticles onto a base substrate to form the inorganic porous substrate, and coating the inorganic porous substrate with a material selected from a silane, a polymer and combinations thereof.

**[0015]** Another embodiment is a method comprising providing a solution comprising glass precursors and a solvent, atomizing the solution to form aerosol droplets, passing the aerosol droplets through a flame under conditions sufficient to generate nanoparticles, depositing the nanoparticles onto a base substrate to form an inorganic porous substrate, coating the inorganic porous substrate with a material selected from a



silane, a polymer and combinations thereof, and depositing a biomolecule onto the coated inorganic porous substrate.

**[0016]** Additional features and advantages of the invention will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from the description or recognized by practicing the invention as described in the written description and claims hereof, as well as the appended drawings.

**[0017]** It is to be understood that both the foregoing general description and the following detailed description are merely exemplary of the invention, and are intended to provide an overview or framework to understanding the nature and character of the invention as it is claimed.

**[0018]** The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate one or more embodiment(s) of the invention and together with the description serve to explain the principles and operation of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0019]** The invention can be understood from the following detailed description either alone or together with the accompanying drawing figures.

**[0020]** FIG. 1 is a scanning electron microscope (SEM) photomicrograph of nanoparticles deposited onto a substrate comprising surface area of 176 m<sup>2</sup>/g.

**[0021]** FIG. 2 is an X-ray diffraction plot of the nanoparticles of FIG. 1.

**[0022]** FIG. 3 is a photograph of nanoparticles deposited onto a base substrate that is a glass microscope slide.

**[0023]** FIG. 4 is a photograph of nanoparticles deposited onto a base substrate that is a microwell format.

**[0024]** FIG. 5 is an SEM photomicrograph of the morphology of an inorganic porous substrate on a 1737™ slide in cross-section after being sintered at 800° C. for 2 hours in air atmosphere.

**[0025]** FIG. 6 is an SEM photomicrograph of the morphology of an inorganic porous substrate on a 1737™ slide after being sintered at 800° C. for 2 hours in air atmosphere.

**[0026]** FIG. 7 is an SEM photomicrograph of the morphology of an inorganic porous substrate on a 1737™ slide after being sintered at 800° C. for 2 hours in air atmosphere.

**[0027]** FIG. 8 shows Cy3/Cy5 signal-to-noise bioassay data for two porous substrates made according to the present invention on slides.

**[0028]** FIG. 9 shows an image of hybridized microarrays printed on two porous substrates made according to the present invention on slides as compared to a control porous substrate (left) made according to a conventional attrition ball milled and screen printing process on a slide.

#### DETAILED DESCRIPTION

**[0029]** Reference will now be made in detail to various embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

**[0030]** According to one embodiment, a solution is provided, for example, at room temperature, comprising glass precursors such as components of a multicomponent glass, for example, Si, Al, B, Ca, Mg, Sr, K, Ba, Ni and Co. The glass precursors are organic derivatives that will pyrolyze to their

corresponding oxides. The glass precursors are dissolved in a flammable solvent, such as an alcohol. Organic solvents that could be used include methanol, ethanol, propanol, higher alcohols (including all possible isomers of carbon chains), methoxy-alcohols, alkoxy-alcohols, hydrocarbon solvents (e.g. mineral spirits), ketones (e.g. acetone), ethers (e.g. dimethyl ether, methyl-ethyl ether) or mixtures thereof.

**[0031]** The solution is converted by atomizing into a spray of aerosol droplets. Atomizing can be achieved by a variety of methods, for example, through an external mixing air-assisted nozzle. The spray of aerosol droplets is converted into oxide nanoparticles using flame spray pyrolysis, wherein the composition of each particle is determined by the composition of the liquid which is atomized.

**[0032]** The conversion to oxide nanoparticles is facilitated through the addition of heat. A source of flammable gas can also be used in conjunction with the heat in some applications. For example, a source of oxygen, methane, propane or combinations thereof, or any flammable gas. Sources of heat comprise combustion by ignition of the flammable spray with a flame or a spark. The oxide nanoparticles are then deposited onto a substrate to form an inorganic porous substrate.

**[0033]** Table 1 shows examples of liquid compositions of the solution used to generate nanoparticles according to one embodiment. The solutions were prepared in a nitrogen filled drybox to minimize particulate formation during mixing due to hydrolysis of the glass nanoparticle precursors upon exposure to moist air. The order of mixing of the composition glass nanoparticle precursors can affect the properties of the resulting solution and thus the glass nanoparticle precursors were mixed as presented in Table 1 (top to bottom). Glass precursors for SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, B<sub>2</sub>O<sub>3</sub>, CaO, MgO, SrO, K<sub>2</sub>O and BaO can include tetraethylorthosilicate, aluminum tri-sec-butoxide, boron-tri-ethoxide, calcium 2-methoxyethoxide in 2-methoxyethanol, magnesium 2-methoxyethoxide in 2-methoxyethanol, strontium iso-propoxide, potassium tert-butoxide and barium methoxypropoxide in methoxypropanol respectively. The solution according to the embodiment illustrated in Table 1 also comprises anhydrous ethanol, 18 MΩ/cm water (as an alternative, other purity of water can be used either more pure or less pure) and 2 M HCl. In another embodiment, glass precursors for NiO, Co<sub>3</sub>O<sub>4</sub> were added to the solution. These precursors were Nickel(II) acetylacetonate and Cobalt(III) acetylacetonate respectively. The solution comprising the glass nanoparticle precursors and the solvent was stirred until the solid glass nanoparticle precursors were dissolved, in order to minimize plugging of the atomizer.

**[0034]** A commercial external air-assisted atomizer (Schlick Atomizing Technologies model 970 S4) was used in conjunction with a flame spray burner and incorporated into a nanoparticulate generating apparatus. The flame spray burner was used to generate a pilot flame that ignites the flammable spray comprising the solution and combustible gases. The burner conditions used were as follows: a flow of methane at a rate of 3.6 L/min, a flow of oxygen at a rate of 3.4 L/min, a flow of nitrogen shield gas at a rate of 10 L/min. The conditions at the nozzle of the atomizer were as follows: a flow of atomizing oxygen at a rate of 25 L/min, a differential pressure across the nozzle of 1 Bar and a liquid flow rate of solution at a rate of 7.5 mL/min. Oxide nanoparticles were deposited directly onto 1737™ substrates in either 96-well format or 1"×3" slide format.



**[0035]** The 1737™ substrates were placed in a chamber and exposed to the air-borne soot (oxide nanoparticles) generated by the burner before venting to a wet scrubber particle pollution abatement system. After deposition, the slides were heated in an air atmosphere furnace for 2 hours at 750° C. to fix the oxide nanoparticles to the substrate by partial sintering.

**[0036]** According to other embodiments, the deposited oxide nanoparticles can be sintered onto the substrates at temperatures of 700° C. or more, or at temperatures of 750° C. or more, or at temperatures of 800° C. or more, or at temperatures of 850° C. or more or at temperatures of 900° C. or more depending on the composition of the oxide nanoparticles and the intended application.

TABLE 1

Chemical	Composition			
	1		2	
	Mass or Volume	Moles	Mass or Volume	Moles
Tetraethylorthosilicate (99.95%, Chemat Technology)	64.4 g	0.3092	64.4 g	0.3092
Anhydrous ethanol (Pharmco Products, Inc.)	480 g	10.42	480 g	10.42
18 MΩ/cm water	4.0 g	0.222	4.0 g	0.222
2 M HCl (Fisher Scientific)	2.2 mL	—	2.2 mL	—
Aluminum tri-sec-butoxide ((97%, Aldrich Chemicals)	10.6 g	0.043	10.6 g	0.043
Boron-tri-ethoxide (Avocado Research Products)	57.2 g	0.3918	57.2 g	0.3918
20 wt % calcium 2-methoxyethoxide in 2-methoxyethanol (Geleste, Inc.)	8.14 g	0.00856 Ca	8.14 g	0.00856 Ca
25 wt % magnesium 2-methoxyethoxide in 2-methoxyethanol (Geleste, Inc.)	1.8 g	0.00258 Mg	1.8 g	0.00258 Mg
Potassium tert-butoxide (95-99%, Strem Chemicals)	1.7 g	0.0151	1.7 g	0.0151
Strontium iso-propoxide (Geleste, Inc.)	1.4 g	0.0068	N/A	N/A
Barium iso-propoxide (Strem Chemicals)	1.8 g	0.00704	N/A	N/A
19 wt % strontium methoxypropoxide in methoxypropanol (Geleste, Inc.)	N/A	N/A	9.52 g	0.0068
25 wt % barium methoxypropoxide in methoxypropanol (Geleste, Inc.)	N/A	N/A	8.88 g	0.00704

**[0037]** Table 2 shows normalized oxide nanoparticle compositions (analysis was done on bulk powders comprising the nanoparticles which are commensurate with the compositions deposited on the porous substrate by ICP Mass Spectroscopy) resulting from the flame spray pyrolysis method of the solutions described in Table 1 according to one embodiment.

TABLE 2

Wt %	(Target)	1	2
SiO <sub>2</sub>	64.88	66.68	63.06
Al <sub>2</sub> O <sub>3</sub>	7.68	7.68	7.36

TABLE 2-continued

Wt %	(Target)	1	2
B <sub>2</sub> O <sub>3</sub>	18.19	16.62	19.83
CaO	1.53	1.34	1.45
MgO	0.36	0.34	0.39
SrO	0.94	1.05	2.27
K <sub>2</sub> O	2.74	2.58	2.09
BaO	3.68	3.68	3.51

**[0038]** Table 3 shows the experimentally determined wt % of compositions 3, 4, 5 and 6 of oxide nanoparticles produced by the combustion of the solution and flammable spray utilizing flame spray pyrolysis according to another embodiment. The oxide nanoparticle compositions include adsorbed combustion products, which comprise approximately 7 to 9 weight percentages (wt %). When the oxide nanoparticle compositions are heated at a temperature of 700° C. or more, the combustion products are minimized as shown by differential thermal analysis. Therefore, the weight percentages of components are normalized to 100% to represent elemental ratios in the bulk oxide nanoparticle compositions.

TABLE 3

wt %	Target	Experimental			
		Data 3	Normalized 4	5	Normalized 6
SiO <sub>2</sub>	63.95	61.8	66.23724	59.1	64.830927
Al <sub>2</sub> O <sub>3</sub>	7.57	7.07	7.577626	6.96	7.6349112
B <sub>2</sub> O <sub>3</sub>	17.93	13.8	14.79084	14.8	16.235156
CaO	1.51	1.52	1.629136	1.45	1.5906065
MgO	0.35	0.35	0.37513	0.34	0.3729698
SrO	0.93	0.88	0.943184	0.85	0.9324245
K <sub>2</sub> O	2.7	2.81	3.011758	2.79	3.0605463
BaO	3.63	3.66	3.922788	3.53	3.8723041
NiO	1.01	1	1.0718	0.95	1.0421215
Co <sub>3</sub> O <sub>4</sub>	0.4	0.41	0.439438	0.39	0.4278183
sum	99.98	93.3	99.99894	91.16	99.9997852

**[0039]** Nanoparticles were generated and deposited onto a substrate using the methods described above. FIGS. 1 and 2 illustrate that the exemplified porous substrate comprising nanoparticles (analysis was done on bulk powders comprising the nanoparticles which are commensurate with the compositions deposited on the porous substrate) is amorphous and glassy, as shown by the first peak 2 of the X-ray diffraction plot. The second peak 3 shows a minor component B(OH)<sub>3</sub> which is a crystalline phase of boric acid. This minor component is removed upon sintering of the inorganic porous substrate. The deposited nanoparticles 1 are approximately 80 nm in mean diameter and have a surface area of approximately 170 m<sup>2</sup>/g.

**[0040]** According to another embodiment, increased control over particle collection efficiency and particle packing density can be achieved by heating the substrates during deposition and/or can be facilitated through electrostatic deposition methods. For example, a charge can be provided on the base substrate by placement of the base substrate between two oppositely charged electrodes and/or a charge can be induced on the nanoparticles by charging the particles using a corona charger or other charging techniques known in the art. Exemplary electrostatic methods and apparatuses are described in commonly owned U.S. patent application Ser.



No. 11/712,149, the disclosure of which is incorporated herein by reference in its entirety.

**[0041]** According to another embodiment, the base substrate can be heated during the deposition process at temperatures of 400° C. to 800° C. during deposition in order to increase the deposition of the nanoparticles or to increase the particle packing or densification of the porous substrate.

**[0042]** The deposited oxide nanoparticles can be thermally adhered (sintered) onto the base substrate either by heating during the deposition process or as a subsequent and separate step. Further densification of the surface can be subsequently done for certain applications through additional heat treatments of the inorganic porous substrate.

**[0043]** The sintering process is achieved by heating the inorganic porous substrates under appropriate conditions such as temperature, duration of heating and rate of cooling. These conditions are selected for the appropriate oxide being sintered. Local heat generation for sintering can be achieved by oven bake, CO<sub>2</sub> LASER sinter and microwave sinter. Other methods for forming interparticle connections may include wet methods as are known in the art, such sol-gel methods.

**[0044]** The base substrate can comprise a slide **4** or a microplate **6** format as shown in FIG. **3** and FIG. **4** respectively. Slides are typically 1 inch by 3 inches. Nanoparticles can be deposited onto substrates which comprise a microplate insert format. Typical microplate insert formats are 3 inches by 4.5 inches.

**[0045]** According to another embodiment, prior to depositing the nanoparticles onto the base substrate, a portion of the base substrate can be masked such that a pattern of inorganic porous substrate is formed on the base substrate.

**[0046]** A mask, for example, a stainless steel plate can have holes drilled in a microplate format, for example, 96 or 384 well formats. The mask with holes can be positioned between the base substrate and the airborne nanoparticles such that the nanoparticles are deposited only on the unmasked areas. After deposition, the mask can be removed and the porous substrate comprising areas of deposited nanoparticles **5** can be sintered and/or coated. A holey plate can then be adhered to the base substrate forming a microwell plate such that the deposited nanoparticles are located at the bottom of some or all of the wells of the microwell plate.

**[0047]** FIG. **5**, FIG. **6** and FIG. **7** illustrate the morphology of the porous substrate **7** comprising oxide nanoparticles deposited onto a microscope slide substrate **8** and sintered at 800° C. for 2 hours in an air atmosphere furnace. The structure of the sintered nanoparticles is web-like, resulting from the viscous flow and/or surface diffusion of the nanoparticles during heat treatment (e.g. sintering). In this embodiment, the sintering process causes the nanoparticles to form a series of interconnected webs **11** defining interconnected pores **10** located between the webs. The interconnected pores defined by the interconnected webs transverse the width of the porous substrate from a first surface **23** of the porous substrate to a first surface **22** of the substrate.

**[0048]** The interconnected webs range in size from 0.1 to 1 microns. The interconnected pores defined by the webs are 25 microns or less and the thickness of the porous substrate is from 8 to 10 microns. FIG. **5** shows the porous substrate in cross-section comprising interconnected pores. FIG. **6** shows the porous substrate (topical view) comprising interconnected pores **9** which are 20 microns or less in size. In some embodiments, the interconnected pores are 5 microns or less

in size. FIG. **7** shows the porous substrate comprising interconnected webs **11** and interconnected pores **10** which are 1 micron or less in size.

**[0049]** This interconnected web and interconnected pore microstructure is advantageous in that it provides a more uniform distribution of material, for example, biological material, silane, cells and the like when the material is coated onto the porous substrate.

**[0050]** Nanoparticles which are deposited onto the surface of a base substrate by the above-mentioned methods can undergo subsequent processing steps depending on the intended application.

**[0051]** According to another embodiment, after sintering, the inorganic porous substrates can be subsequently coated with a number of materials, for example, polymers and silanes to form a coated porous substrate. The coated porous substrates are useful for covalent or non-covalent attachment of biomolecules.

**[0052]** Silanes have been shown to modify the surface characteristics of glass and to subsequently affect the interaction of the surface with biological molecules (e.g. DNA, proteins, and even cells). Silanes can be used to provide either covalent attachment chemistry for the retention of DNA or a non-covalent retention of DNA by charge attraction. In some cases, multiple characteristics of the silane molecules can be used to provide a hydrophobic, as well as charged surface, which can also be used to attach DNA either covalently or non-covalently. Examples of silane molecules which can provide the hydrophobic charged surface are (but not limited to) amine functionalized silanes (e.g. GAPST<sup>™</sup> 3-aminopropyltrimethoxy silane (trademark of Corning Incorporated), N-(2-aminoethyl)-3-aminopropyltrimethoxy silane) or thio functionalized silanes (3-mercaptopropyltrimethoxysilane). These silanes can be used alone or in combination to coat the inorganic porous substrates of the present invention.

**[0053]** Silane coating can be performed either by solution phase coating or CVD coating. The solution coating process involves either dip coating or immersing the inorganic porous substrate into an organic carrier solvent such as isopropyl alcohol (IPA) and a percentage by volume of silane. The silane is allowed time to coat and then the process is stopped by removal of the inorganic porous substrate from the coating bath and is followed by subsequent wash steps. The CVD process involves placing the dry nanoparticle surface into a sealed coating chamber and then allowing exposure of a silane vapor that is generated by either heat or vacuum.

**[0054]** One example of a non-covalent attachment of plasmid DNA to nanoparticles is shown in FIG. **8** and FIG. **9**. FIG. **8** shows Cy3/Cy5 signal-to-noise bioassay data for two inorganic porous substrate microarrays **12** and **13** made according to another embodiment of the present invention as compared to a control porous substrate microarrays **14** made according to a conventional attrition ball milled and screen printing process. FIG. **9** shows the image of the hybridized microarrays printed on two inorganic porous substrates **16** and **17** made according to the present invention as compared to a control porous substrate **15** made according to a conventional attrition ball milled and screen printing process.

**[0055]** Biomolecules can be deposited onto the inorganic porous substrates according to the present invention by a number of deposition techniques as are known to one skilled in the art of microarray manufacturing, for example, printing with pins, quills or printing from a reservoir comprising biomolecules. For example, biomolecules can be suspended in a



bioassay solution. The pins are introduced into the bioassay solution. When the pins are withdrawn from the bioassay solution, some of the biomolecules are adhered to the pins. The pins then contact the coated inorganic porous substrate and the biomolecules are transferred to the coated inorganic porous substrate. This process is repeated multiple times and a microarray format of printed spots of biomolecules is produced.

**[0056]** The defect “missing spots” can occur on a microarray for a number of reasons such as the inability to distinguish the printed spot for the background noise of the coated inorganic porous substrate (referred to as signal-to-noise), the lack of biomolecules transferring to the coated inorganic porous substrate during printing due to the surface roughness of the coated inorganic porous substrate or due to a lack of uniformity in the coating of the coated inorganic porous substrate or a combination thereof.

**[0057]** Preliminary data as evident in FIG. 8 and FIG. 9 indicates that the inorganic porous substrates made according to the present invention result in minimizing the “missing spots” problem inherent in the conventionally manufactured inorganic porous substrates. The signal-to-noise is also higher (lower background) in Cy3/Cy5 tests compared to conventional screen-printed attrition ball milled porous substrates. Porous substrates according to the present invention can be used for binding and functional assays, for example, of G-protein coupled receptors (GPCR).

**[0058]** It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A method of depositing nanoparticles onto a base substrate to form an inorganic porous substrate, the method comprising: providing a solution comprising glass precursors and a solvent; atomizing the solution to form aerosol droplets; passing the aerosol droplets through a flame under conditions sufficient to generate oxide nanoparticles; and depositing the oxide nanoparticles onto a base substrate to form the inorganic porous substrate.

2. The method according to claim 1, further comprising masking a portion of the base substrate such that a pattern of inorganic porous substrate is formed on the base substrate.

3. The method according to claim 2, wherein the pattern of inorganic porous substrate is a 96 well or 384 well pattern.

4. The method according to claim 1, wherein the solvent is selected from methanol, ethanol, propanol, alcohols, meth-

oxy-alcohols, alkoxy-alcohols, hydrocarbon solvents, ketones, ethers, methyl-ethyl ether and combinations thereof.

5. The method according to claim 1, further comprising heating the base substrate at a temperature of 400° C. to 800° C. during deposition.

6. The method according to claim 1, further comprising providing a charge on the base substrate.

7. The method according to claim 1, further comprising heating the base substrate at a temperature of 700° C. or more such that the oxide nanoparticles are simultaneously deposited and sintered onto the base substrate.

8. The method according to claim 1, further comprising sintering the inorganic porous substrate at a temperature of 700° C. or more.

9. The method according to claim 8, comprising sintering the inorganic porous substrate at a temperature of 750° C. or more.

10. The method according to claim 9, comprising sintering the inorganic porous substrate at a temperature of 800° C. or more.

11. A method of making a coated inorganic porous substrate, the method comprising: providing a solution comprising glass precursors and a solvent; atomizing the solution to form aerosol droplets; passing the aerosol droplets through a flame under conditions sufficient to generate oxide nanoparticles; depositing the oxide nanoparticles onto a base substrate to form the inorganic porous substrate; and coating the inorganic porous substrate with a material selected from a silane, a polymer and combinations thereof.

12. A method comprising: providing a solution comprising glass precursors and a solvent; atomizing the solution to form aerosol droplets; passing the aerosol droplets through a flame under conditions sufficient to generate oxide nanoparticles; depositing the oxide nanoparticles onto a base substrate to form an inorganic porous substrate; coating the inorganic porous substrate with a material selected from a silane, a polymer and combinations thereof; and depositing a biomolecule onto the coated inorganic porous substrate.

13. The method according to claim 12, wherein the depositing a biomolecule onto the coated porous substrate comprises printing of the biomolecule.

14. The method according to claim 13, wherein the printing of the biomolecule is selected from pin printing, quill printing and reservoir printing.

15. The method according to claim 12, wherein the biomolecule is selected from DNA, RNA, protein and combinations thereof.

16. The method according to claim 15, wherein the biomolecule comprises a G-protein coupled receptor.

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