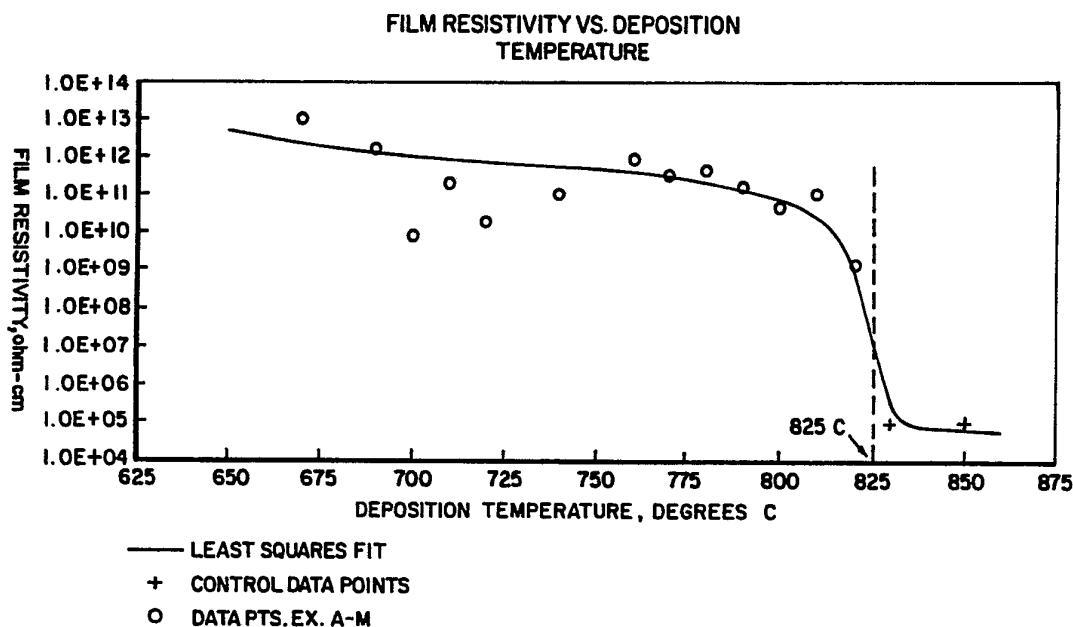




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<p>(21) International Application Number: PCT/US91/01828 (22) International Filing Date: 18 March 1991 (18.03.91) (30) Priority data: 497,161 20 March 1990 (20.03.90) US (71) Applicant: DIAMONEX, INCORPORATED [US/US]; Iron Run Corporate Center, 90 Windsor Drive, Allentown, PA 18106 (US). (72) Inventors: GARG, Diwakar ; 2815 Whitemarsh Place, Macungie, PA 18062 (US). TSAI, Wilman ; 740 Stendhal Lane, Cupertino, CA 95014 (US). DYER, Paul, Nigel ; 3920 Pleasant Avenue, Allentown, PA 18103 (US). KI-MOCK, Fred, M. ; 2961 Magnolia Circle, Macungie, PA 18062 (US). IAMPIETRO, Robert, L. ; 210 South Fourth Street, Emmaus, PA 18049 (US).</p>	<p>(74) Agents: McCUBBREY, J., Bruce et al. ; McCubrey, Bartels, Meyer & Ward, Suite 2700, One Post Street, San Francisco, CA 94104-5231 (US). (81) Designated States: AT (European patent), BE (European patent), CA, CH (European patent), DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB (European patent), GR (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent). Published <i>With international search report.</i> <i>With amended claims.</i></p>	

(54) Title: DIAMOND-ON-A-SUBSTRATE FOR ELECTRONIC APPLICATIONS



(57) Abstract

A coated substrate product is disclosed which comprises a substrate and a polycrystalline diamond layer having a smooth surface finish, enhanced crystal orientation in comparison to industrial grade diamond powder particularly in the (220) and (400) directions, and excellent electrical and thermal properties. Also disclosed is a method for fabricating such a coated substrate in which the polycrystalline diamond layer is chemically vapor deposited onto the substrate at substrate temperatures in the range of 650° to 825° C.

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DIAMOND-ON-A-SUBSTRATE
FOR ELECTRONIC APPLICATIONS

FIELD OF THE INVENTION

5 This invention relates generally to the
manufacture of integrated circuit devices. More
particularly, the invention relates to a coated substrate
product comprised of a substrate and a polycrystalline
diamond (PCD) layer with an enhanced crystal orientation
and high electrical resistivity, and to a method for
10 producing same.

BACKGROUND OF THE INVENTION

Very Large Scale Integrated (VLSI) circuit
devices have become so dense that, for example,
semiconductor circuits smaller than 1.0 micrometers are
15 now being employed. One of the drawbacks of increasing
the density of an integrated circuit device is the
difficulty of maintaining electrical isolation of one
circuit from another. When one circuit inadvertently
couples electrically with another circuit, the device
20 will malfunction and a fault will be recorded. This type
of failure occurs in normal operation and to a greater
degree when radiation is also present, such as in
communication satellites. The other drawback of
increasing the density of an integrated circuit is
25 insufficient dissipation of heat generated by the chip,
resulting in a rise of junction temperature. This rise
in junction temperature reduces efficiency and
reliability, and sometimes causes the chip to short
circuit.

30 In an effort to improve electrical isolation
between circuits and heat dissipation efficiency of the
chip, the electronics industry has been experimenting
with multi-layer composite structures coated with one or
more layers of PCD. These PCD films have been
35 successfully deposited using a number of chemical vapor
deposition (CVD) techniques including hot filament CVD

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(HFCVD), RF plasma-assisted CVD, microwave plasma-assisted CVD, DC plasma assisted CVD, DC plasma jet, and laser-assisted CVD. The electrical properties such as resistivity and breakdown voltage of PCD layers deposited by the above techniques have generally been low and therefore unacceptable to the electronics industry.

A number of technical papers and patents have been published which describe the deposition and properties of polycrystalline diamond (PCD) produced by various techniques. For example, technical papers by B. V. Spitsyn, et al., entitled, "Vapor Growth of Diamond on Diamond and Other Surfaces", published in Journal of Crystal Growth, Vol. 52, pp. 219-226 (1981), D. V. Fedoseev, et al., entitled "Synthesis of Diamond in Its Thermodynamic Metastability Region", published in Russian Chemical Reviews, Vol. 53(5), pp. 435-444 (1984), and B. V. Derjaguin and D. B. Fedoseev entitled "The Synthesis of Diamond at Low Pressure", Scientific American, Vol. 233(5), pp. 102-9 (1975), discussed diamond deposition on a number of substrates. These papers neither disclose nor suggest a process of depositing diamond film with enhanced crystal orientation and consequently the authors of these papers had no concept of the advantages of such a process.

M. W. Geis has described deposition of (111) textured diamond films on smooth substrates using diamond seeds in a paper entitled "Growth of Textured Diamond Films on Foreign Substrates from Attached Seed Crystals," published in Appl. Phys. Lett, Vol. 55(6), pp. 550-552 (1989). This paper does not describe a process for depositing diamond with enhanced crystal orientation in the (220) or (311) and (400) directions relative to the (111) directions, or with high electrical resistivity.

U.S. Patent 4,434,188, issued 28 February 1984 and a paper by K. Ito, et al. entitled, "Diamond Synthesis by the Microwave Plasma CVD Method Using a

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Mixture of Carbon Monoxide and Hydrogen Gas (I)", published in Chemistry Letters, pp. 589-592 (1988) describe the deposition of diamond films by microwave plasma CVD technique using mixtures of either hydrogen and hydrocarbon or hydrogen and carbon monoxide. These references do not disclose the deposition of diamond films with enhanced crystal orientation and high resistivity.

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A technical paper by B. Singh, et al. entitled, "Hollow Cathode Plasma Assisted Chemical Vapor Deposition of Diamond", published in Appl. Phys. Lett., Vol. 52(20), pp. 1658-1660 (1988) describes the deposition of diamond films by hot cathode plasma CVD using a mixture of hydrogen and hydrocarbon. European Patent Publication No. 0 320 657, published 21 June 1989, discloses deposition of diamond films using a combination of hot filament and microwave CVD techniques. These references do not disclose a process for depositing diamond films with enhanced crystal orientation or with high electrical resistivity.

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A. Sawabe, et al., describe deposition of diamond films by DC plasma CVD using a mixture of hydrogen and methane in a paper entitled, "Growth of Diamond Thin Films in a DC Discharge Plasma", published in Applied Surface Science, Vol. 33/34, pp. 539-545 (1988). This paper does not disclose a process for depositing diamond films with enhanced crystals orientation or with high electrical resistivity.

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Japanese Kokai Patent No. Sho 64(1989)-65092, published 10 March 1989, and Japanese Kokai Patent No. Sho 62(1987)-202897, published 7 September 1987, describe processes for depositing thin and adherent diamond films on substrates using a metal or metal carbide interlayer deposited on the substrates by PVD. Japanese Kokai Patent No. Sho 64(1989)-61397, published 8 March 1988, describes a process of depositing thin diamond films

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adherently on cutting tools by first embedding fine diamond particles on tool substrates. These patent applications neither describe a process for depositing diamond films with enhanced crystal orientation nor discuss the advantages of these films.

5 A number of technical papers by S. Matsumoto, et al. entitled, "Growth of Diamond Particles from Methane-Hydrogen Gas", published in J. Materials Service, Vol. 17, pp. 3106-3112 (1982), "Chemical Vapor Deposition of Diamond From Methane-Hydrogen Gas", published in Proc. 7th ICVM, Tokyo, Japan, pp. 386-391 (1982), and "Vapor Deposition of Diamond Particles from Methane," published in Japanese Journal of Applied Physics, Vol. 21, No. 4, pp. L183-L185 (1982), describe deposition of diamond films by a hot filament CVD technique. Technical papers by B. Singh, et al. entitled, "Growth of Polycrystalline Diamond Particles and Films by Hot-Filament Chemical Vapor Deposition", submitted for publication in J. Vac. Sci. Tech. (1988) and "Effects of Filament and Reactor Wall Materials in Low-Pressure Chemical Vapor Synthesis of Diamond", published in Appl. Phys. Lett., Vol. 52(6), pp. 451-452 (February, 1988) also describe deposition of diamond films by the hot filament CVD technique. None of the foregoing papers disclose a process for depositing diamond films with either enhanced crystal orientation or high electrical resistivity.

20 P. O. Joffreau, et al. disclose a hot filament CVD process for depositing diamond films on refractory metals in a paper entitled, "Low-Pressure Diamond Growth on Refractory Metals", published in R&HM, pp. 186-194 (December 1988). Another paper by T. D. Moustakas, entitled, "The Role of the Tungsten Filament in the Growth of Polycrystalline Diamond Films by Filament Assisted CVD of Hydrocarbons", published in Solid State Ionics, Vol. 32/33, pp. 861-868 (1989) describes an HFCVD process for depositing diamond films. These papers, once

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again, do not disclose a process for depositing diamond films with either enhanced crystal orientation or high electrical resistivity.

5 A technical paper by E. N. Farabaugh, et al. entitled, "Growth of Diamond Films by Hot Filament Chemical Vapor Deposition", published in SPIE, Vol. 969 Diamond Optics, pp. 24-31 (1988), discloses a process for depositing diamond films by HFCVD. These diamond films were deposited using a wide range of temperature,
10 analyzed by x-ray diffraction and shown to have no preferred crystal orientation. Therefore, this paper does not disclose a process for depositing diamond films with either enhanced crystal orientation or high electrical resistivity.

15 U.S. Patent Nos. 4,707,384 and 4,734,339 disclose an HFCVD process for depositing one or more polycrystalline diamond layers on a variety of substrates. These patents do not disclose a process for depositing diamond films with enhanced crystal
20 orientation or with high electrical resistivity.

Japanese Kokai Patent No. Sho 62(1987)-119, published 6 January 1987, discloses a HFCVD process for depositing diamond films on substrates with a variety of interlayers. Japanese Kokai Patent No. Sho
25 62(1987)-171993, published 28 July 1987, discloses a CVD process for depositing diamond films using a mixture of an organic compound and a reaction gas containing at least one species of boron, aluminum, gallium, indium, thallium, nitrogen, phosphorus, arsenic, antimony or
30 bismuth. Japanese Kokai Patent No. Sho 63(1988)-297299, published 5 December 1988, discloses a process for depositing diamond films using a mixture of hydrogen, hydrocarbon, chlorine and inert gas. Japanese Kokai Patent No. Sho 63(1988)-153815, published 27 June 1988,
35 discloses a HFCVD process for depositing diamond films using tungsten filament. None of the foregoing patent

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applications disclose processes for depositing diamond films with either enhanced crystal orientation or high electrical resistivity.

5 Japanese Kokai Patent No. Sho 63(1988)-166797, published 9 July 1988, discloses the use of filaments made of an alloy of Ta, Zr and/or Hf for enhancing filament life during HFCVD process. This application does not disclose the deposition of diamond films with enhanced crystal orientation or with high electrical
10 resistivity.

Japanese Kokai Patent No. Sho 63(1988)-159292, published 2 July 1988, discloses a DC current biased HFCVD process for depositing diamond films on a substrate with a large surface area or with a curved surface. It
15 does not disclose the formation of diamond films with enhanced crystal orientation or with high electrical resistivity.

R. G. Buckley, et al. disclose an HFCVD process for depositing diamond films in a paper entitled,
20 "Characterization of Filament-Assisted Chemical Vapor Depositing Diamond Films Using Raman Spectroscopy", published in J. Appl. Phys., 66 (8), 3595-3599 (1989). T. Kawato and K. Kondo disclose the effect of adding oxygen along with feed gas mixture upon diamond films deposited by HFCVD in a paper entitled, "Effect of Oxygen
25 on CVD Diamond Synthesis", published in Japanese Journal of Applied Physics, Part I, Vol. 2.(9), pp. 1429-1432 (1987). These papers do not disclose a method for depositing diamond films with either enhanced crystal
30 orientation or high electrical resistivity.

U.S. Patent No. 4,816,286 and a paper by Y. Hirose and Y. Terasawa entitled, "Synthesis of Diamond Thin Films by Thermal CVD Using Organic Compounds",
35 published in Japanese Journal of Applied Physics, Vol. 25(6), pp. L519-L521 (1986) disclose a CVD method for depositing diamond films using a mixture of hydrogen and

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an organic compound containing carbon, hydrogen, and at least one of oxygen and nitrogen. Japanese Kokai Patent No. Sho 64(1989)-24093, published 26 January 1989, discloses a CVD method of depositing diamond films using a mixture of an organic compound and water vapors. Japanese Kokai Patent No. Sho 63(1988)-307195, published 14 December 1988, discloses a CVD method of depositing diamond films using a mixture of an organic compound and a raw gas containing ammonia. These references do not describe a method of depositing diamond films with either enhanced crystal orientation or with high electrical resistivity.

U.S. Patent No. 4,859,490 and European Patent Publication Nos. 0 254 312 and 0 254 560 disclose HFCVD processes for depositing diamond films. These references teach that diamond films with high electrical resistivity can not be produced by HFCVD, and that high resistivity diamond films can only be produced by using a combination of hot-filament and plasma generated by either microwave or DC discharge during chemical vapor deposition. These patents teach away from using an HFCVD process to produce diamond films having enhanced crystal orientation and high electrical resistivity.

U.S. Patent No. 4,783,368 makes reference in column 2, lines 22-32, to the very poor electrical insulating properties, particularly dielectric breakdown, that are obtained when thin layers of polycrystalline diamond are deposited by CVD techniques. This reference goes on to describe and claim a method of producing an insulating layer comprising a diamond or diamond-like carbon material and an element from group IVA on a substrate by applying DC voltage and RF power to the substrate and a magnetic field parallel to the substrate's surface. Examples are given in which the transmission electron diffraction of the diamond-like carbon layers corresponded to (111) and (220) of natural

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diamond. This patent does not disclose a process for depositing diamond films with enhanced crystal orientation.

5 Japanese Kokai Patent No. Sho 63(1988)-307196, published 14 December 1988, discloses a plasma CVD process for depositing multilayered diamond films. The first layer deposited on the substrate is made of microcrystal diamond and the second layer deposited on the top of the first layer is formed with crystalline
10 facet with (110) or (200) orientation. The application discloses that if the methane concentration in the feed gas is smaller than about 1%, the deposited films have randomly oriented crystals. However, if the concentration of methane is higher than 1%, the films
15 show enhanced crystal orientation in the (220) direction. The deposited films are disclosed to have good thermal conductivity. This patent does not disclose a process for depositing diamond films either with enhanced crystal orientation in both the (220) or (311) direction and the
20 (400) direction, or with high electrical resistivity.

K. Kobashi, et al., disclose a microwave plasma CVD process for depositing diamond films with enhanced crystals orientation in (100) or (400) direction in papers entitled, "Synthesis of Diamonds by Use of
25 Microwave Plasma Chemical Vapor Deposition: Morphology and Growth of Diamond Films", published in Physical Review Bulletin of the American Physical Society, Vol. 38(6), pp. 4067-4084 (1988) and entitled "Summary Abstract: Morphology and Growth of Diamond Films",
30 published in J. Vac. Sci. Techn. Vol. A6(3), pp. 1816-1817 (1980). These papers disclose depositing films with (111) crystal orientation at methane concentration <0.4% and films containing diamond crystals oriented in (100) direction at methane concentration above 0.4%. The
35 films deposited at methane concentration ~1.6% have been shown to be structureless. W. Zhu, et al., disclose a

microwave plasma CVD process for depositing diamond films with enhanced crystals orientation in either (111) or (100) directions in a paper entitled, "Effects of Process Parameters on CVD Diamond Films", published in J. Mater. Res., Vol. 4(3), pp. 659-663 (1989). This paper discloses the disposition of diamond films with enhanced crystals orientation in (110) direction with less than 2% methane in hydrogen at temperatures between 910-950°C. A higher temperature (>1000°C) is claimed to favor the formation crystals oriented in (111) direction. An intermediate temperature (950-1000°C) has been shown to favor formation of crystals oriented in (111) and (100) directions with neither predominating. N. Setaka discloses a CVD method of depositing diamond films in a paper entitled, "Diamond Synthesis From Vapor Phase and its Growth Process", published in J. Mater. Res., Vol. 4, No. 3, pp. 664-670 (1989). The paper discloses that films deposited with 0.5% methane contained crystal oriented in (111) and (100) directions. It also discloses that as the methane concentration approaches 3%, a remarkable enhancement of crystal orientation in (220) direction relative to (111) is observed. Despite the fact that the authors of these papers have recognized enhanced crystal orientation in one plane relative to (111) plane, none of them disclose the formation of diamond films with enhanced crystal orientation in at least two planes relative to (111) plane nor a process for achieving diamond films having such crystal orientation as well as high electrical resistivity.

Although the polycrystalline diamond films deposited by the techniques described in the foregoing references have been shown to have good thermal conductivity, i.e., of not less than 50 W/mk, their use in the electronic industry has been limited due to poor electrical properties. Several attempts have been made by numerous researchers to produce polycrystalline

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diamond films with good electrical properties, but with limited success. For example, in two recent papers by K. V. Ravi and M. I. Landstrass one entitled "Silicon on Insulator Technology using CVD Diamond Films", published in PMAC, Electrochem Soc., 24-37 (1989) and the other entitled, "Resistivity of Chemical Vapor Deposited Diamond Films", published in Appl. Phys. Letter, Vol. 55(10), pp. 975-977(1989), it is disclosed that the poor electrical properties of DC plasma and microwave plasma deposited polycrystalline diamond films are due to the presence of dissolved hydrogen. The authors disclose that the dissolved hydrogen can be removed from the films by annealing, thereby improving the electrical properties. The authors neither present the electrical properties of hot-filament deposited polycrystalline diamond films nor describe the effect of annealing on the electrical properties of HFCVD films. Furthermore, the authors do not disclose the formation of diamond films with enhanced crystal orientation.

Contrary to the teaching of K. V. Ravi and M. I. Landstrass, the diamond films deposited by HFCVD contain only trace amounts of hydrogen (compared to films deposited by DC plasma or microwave plasma CVD) to begin with and the annealing process only results in marginal improvements in their electrical properties. However, it has been found in the present invention that the electrical properties (i.e. electrical resistance and breakdown voltage) of polycrystalline diamond films can be significantly improved over such polycrystalline diamond systems of the prior art by depositing diamond crystals with enhanced orientation.

Further, the polycrystalline diamond films deposited by the prior art techniques have a poor surface finish due to the presence of randomly oriented faceted crystals. Thus, the surface finish of polycrystalline diamond films can also be significantly enhanced by

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depositing diamond crystals with enhanced orientation on at least two planes.

SUMMARY OF THE INVENTION

5 The improved multi-layer composite structure of the present invention substantially reduces or eliminates the disadvantages and shortcomings associated with the prior art techniques. The invention discloses a coated substrate product comprised of a parent substrate and a polycrystalline diamond layer having enhanced crystal
10 orientation on at least two planes over industrial grade of diamond powder to provide (i) superior electrical isolation of one electronic device from another and from the base substrate, and (ii) excellent surface finish.

15 The invention also comprises a method for fabricating the substrate product. According to the method, the polycrystalline diamond layer is chemical vapor deposited on the substrate by the HFCVD technique with predetermined deposition parameters, such that the polycrystalline diamond film is deposited with an
20 enhanced crystal orientation and excellent electrical properties and surface finish. The intensity of (HKL) reflection in the (220) or (311) direction and the (400) direction relative to (111) of the film of the present invention are enhanced over that of industrial grade of
25 diamonds. The diamond films of this invention exhibit particularly high electrical resistivity and breakdown voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

30 Further features and advantages will become apparent from the following and more particular description of the preferred embodiment of the invention as illustrated in the accompanying drawings, in which:

35 FIGURE 1 is a simplified sectional view of a type of HFCVD reactor for use in carrying out the method of the present invention;

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FIGURES 2-10 are Laser Raman spectra graphs of polycrystalline diamond films deposited by HFCVD on molybdenum according to the present invention;

5 FIGURES 11-12 are Laser Raman spectra graphs of polycrystalline diamond films deposited by HFCVD on molybdenum according to the prior art techniques;

10 FIGURES 13-14 are scanning electron micrographs at 5000 times magnification of polycrystalline diamond films deposited by HFCVD on molybdenum by prior art techniques;

FIGURES 15-28 are scanning electron micrographs at 5000 times magnification of polycrystalline diamond films deposited by HFCVD on molybdenum according to the present invention;

15 FIGURES 29-30 are graphs of electrical resistivity versus polycrystalline diamond film crystal orientation in (220) and (400) directions, respectively, according to the present invention;

20 FIGURE 31 is a graph of electrical resistivity versus deposition temperature of polycrystalline diamond films deposited by HFCVD on molybdenum according to the present invention; and

25 FIGURE 32 is a scanning electron micrograph at 5000 times magnification of polycrystalline diamond film deposited by HFCVD on silicon according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The composition of the present invention is a multi-layer composite structure which comprises a parent substrate and a polycrystalline diamond layer. The substrate on which diamond film is deposited comprises a single crystal such as diamond, silicon carbide, silicon, sapphire, and similar materials; a polycrystalline material such as silicon; a metal such as tungsten, molybdenum, titanium, and tantalum, copper, and the like; a mixture of metals such as tungsten and molybdenum,

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tungsten and copper, molybdenum and copper, and the like; a ceramic material such as hot pressed, sintered or chemically vapor produced ceramics including silicon carbide, silicon nitride, polycrystalline diamond, cemented carbides, alumina, and the like or mixtures thereof. The substrate may contain various other layers and structures which constitute integrated circuitry. Such layers and structures may be formed before or after the application of a polycrystalline diamond layer.

Preferably the polycrystalline diamond layer is chemically vapor deposited on the substrate by means of a conventional deposition technique such that the diamond layer exhibits an enhanced crystal orientation in the (220) and the (400) directions. In particular the intensity of (HKL) reflection in the (220) and (400) directions are at least 47 and 12 percent, respectively relative to (111) intensity, which is normalized to 100, of the film of the present invention. The resulting structure thus enables the isolation of circuits and silicon devices from one another and from the base substrate via the high electrical insulating property and other superior electrical properties of the polycrystalline diamond layer and exhibits a superior surface finish by substantially reducing the faceted crystals.

The method of the present invention enables those skilled in the art to fabricate the substrate product of this invention. In the preferred embodiment of the invention, the polycrystalline diamond layer is chemically vapor deposited on a single crystal, a polycrystalline material, hard metal, metal alloy, mixture of metals, ceramic substrate or mixtures thereof, such that the polycrystalline diamond layer exhibits enhanced crystal orientation in either the (220) or the (311) direction and the (400) direction over that of industrial grade of diamonds. By the phrase "chemically

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vapor deposited," it is meant a layer of polycrystalline diamond resulting from the thermal decomposition of a mixture of hydrogen and carbon compounds, preferably hydrocarbons, into diamond generating carbon atoms preferentially from the gas phase activated in such a way as to avoid substantially the deposition of graphite carbon. The specific types of carbon compounds useful in this method include C₁-C₄ saturated hydrocarbons such as methane, ethane, propane, etc., C₁-C₄ unsaturated hydrocarbons such as acetylene, ethylene, propylene, etc., gases containing C and O such as carbon monoxide and carbon dioxide, aromatic compounds such as benzene, toluene, xylene, etc., and organic compounds containing C, H, and at least one of oxygen and/or nitrogen such as methanol, ethanol, propanol, dimethyl ether, diethyl ether, methylamine, ethylamine, acetone, and similar materials (a detailed list of organic compounds that can be used to deposit diamond layer with enhanced crystal orientation is provided in U.S. Patent No. 4,816,286, which patent is incorporated herein by reference). The organic compound can be in admixture with water as described in Japanese Kokai Patent No. Sho 64(1989)-24093, published 26 January 1989, which patent is incorporated herein by reference. The concentration of carbon compounds in the hydrogen gas can vary from about 0.1% to about 5%, preferably from about 0.2% to 3%, and more preferably from about 0.5% to 2%. The resulting diamond layer in such a deposition method is in the form of adherent individual crystallites or a layer-like agglomerates of crystallites substantially free from intercrystalline adhesion binders.

The polycrystalline diamond layer can be from 0.5 μ m to 250 μ m in thickness. Preferably, the thickness of the diamond layer is about 0.5 μ m to about 50 μ m in thickness. Still more preferably, it is about 3 μ m to 15 μ m.

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The polycrystalline diamond film of the present invention may be deposited in the preferred method by using an HFCVD reactor such as reactor 1 illustrated in FIGURE 1. The HFCVD technique involves activating a feed gaseous mixture containing a mixture of hydrocarbon and hydrogen by a heated filament and flowing the activated gaseous mixture over a heated substrate to deposit a polycrystalline diamond film. The feed gas mixture, containing from 0.1 to about 5% hydrocarbon in hydrogen, is thermally activated under sub-atmosphere pressure (\leq 100 torr) to produce hydrocarbon radicals and atomic hydrogen by using a heated filament made of W, Ta, Mo, Re or a mixture thereof. The filament is electrically heated to a temperature ranging from about 1800° to 2250°C. The substrate on which the films is to be deposited is heated to a temperature ranging from about 650° to 825°C. The control of substrate or deposition temperature at or below 825°C is critical for depositing polycrystalline diamond films with enhanced crystal orientation, excellent electrical properties, and excellent surface finish. The use of deposition temperatures above 825°C has been found to result in polycrystalline diamond crystals with random orientation. The use of deposition temperatures below 650°C, on the other hand, has been found to result in deposition of diamond films at extremely low and impractical rates.

After a suitable period of diamond deposition time, the flow of the reactive gaseous mixture is stopped and an inert gas, i.e. argon, helium and the like, is passed over said coated substrate while the filament remains electrically charged for a period of time to purge the activated gaseous mixture from the reactor and then the coated substrate is cooled by removing the charge from the filament while continuing to pass the inert gas over the substrate.

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Referring now to FIGURE 1, HFCVD reactor 1 for chemical vapor depositing a diamond film onto substrates 7 comprises a gas dispersion system 25, a filament network 26 and an apertured support plate 27. Gas dispersion system 25 and apertured support plate 27 are oriented within reactor 1 so that their surfaces are perpendicular to the axis of the gas flow through the reaction zone 28. Substrates 7 to be coated are supported by the apertured support plate 27 which rests on an apertured substrate heater 29. Substrate heater 29 is attached to adjustable rods 30, which are mounted to the reactor base 31. Substrate heater 29 is provided with lead 32 to which an electrical heating current is conducted from a suitable heat source 33. Substrate heater 29 is also provided with a thermocouple 38 to measure substrate temperature and a connecting electrical lead 39 through which the thermocouple output is transmitted to an external read-out or recorder/controller 40. To accurately record and control the temperature of the plurality of substrates 7 within the critical range of the method of the present invention the tip of the thermocouple 38 is placed immediately adjacent to the top surface of one of the substrates as shown in FIGURE 1.

The ends of reactor 1 are enclosed by removable bottom plate 31 and top plate 42 which isolate reactor 1 such that the interior can be evacuated without significant inward leakage from the surrounding ambient atmosphere. In order to regulate the gas pressure within reactor zone 28 and remove reaction product gases, bottom plate 31 is provided with an opening 43 therein through which an exhaust port tube 44 is suitably connected to a vacuum pump 45. A vacuum gauge 46 is connected in the line thereto for indicating the pressure within the reactor chamber. By properly operating the vacuum pump

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45, the gas pressure within the reactor chamber may be regulated as desired.

5 A gas inlet tube 47 is provided which extends through top plate 42. Gas inlet tube 47 is suitably connected to gas dispersion system 25 by means of a gas feed line 48. Gas inlet tube 47 is connected to a gas feed system (not shown) to introduce reactant gases into the reactor at desired flow rates.

10 Support plate 27 contains apertures 54 and heater 29 contains apertures 56 in heater 29 aligned with apertures 54 as shown in FIGURE 1 to provide a means of flowing the reactant gas through the support plate 27 to reduce the extent of radial (stagnation point) flow adjacent to the substrates 7 and improving coating
15 uniformity thereon. Support plate 27 and the substrate heater 29 assembly are provided with adjustable support rods 30 for varying the distance between substrates 7 and filament network 26, the support rods 30 consisting of threaded posts with lock nuts 60 removably secured
20 thereon.

With the noted reactor apparatus, reactant gas is introduced into the reactor chamber through gas inlet tube 47 and gas feed line 48. Gas feed line 47 is connected to gas dispersion system 25 which introduces
25 the reactant gas into reaction zone 28 of the reactor with substantially uniform axial gas velocity and temperature. Gas dispersion system 25 is supported within the reactor by a pair of adjustable rods 73, suitably connected to reactor cap 42; rods 73 consisting
30 of threaded post with suitable lock nuts 70 removably secured thereon.

Gas dispersion system 25 consists of a thin housing 74 with an apertured bottom surface 75 to
35 introduce and uniformly distribute the reactant gas over filament network 26.

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Filament network 26 is also supported in reaction zone 28 by one of the adjustable rods 73. Filament network 26 is provided with lead 76 to which the heating current is conducted from a suitable heat source 77. Filament network 26 extends transversely in reaction zone 28 of the reactor and is oriented such that the maximum cross-sectional area of filament network 26 is perpendicular to the axis of the gas flow in reaction zone 28.

Additional details of the type of reactor system used in the method of the present invention are found in the copending patent application, U.S. Serial No. 497,159, filed March 20, 1990 (Docket No. 723PUS04211); the detailed description of which is incorporated herein by reference.

A particular advantage of the structure and method of the present invention lies in the fact that the polycrystalline diamond layer is chemically vapor deposited on the substrate such that the polycrystalline diamond layer exhibits enhanced crystals orientation in the (220) or (311) direction and the (400) direction relative to (111) direction. Some of the diamond layers exhibit enhanced crystals orientation in the (311) direction in addition to the (220) and (400) directions. As a result, the polycrystalline diamond layer exhibits a particularly high electrical resistivity, i.e. greater than 10^6 ohm-cm., a high breakdown voltage, i.e. greater than 100 volts, and a superior surface finish, representing a significant improvement over the prior art.

The examples which follow illustrate the method of the invention and of the coated substrate products produced thereby. The examples are for illustrative purposes only and are not meant to limit the scope of the claims in any way.

EXAMPLES A-M AND CONTROLS N-O

A number of polycrystalline diamond deposition experiments, as set forth in Table 1, were carried out in a HFCVD reactor of the type illustrated in FIGURE 1. In these experiments, two 1.35 in. long x 0.387 in. wide x 0.062 in. thick molybdenum specimens were placed on a holder. The specimens were pre-etched with a slurry containing approximately 80 μ m diamond particles in ethyl alcohol for a predetermined time in an ultrasonic bath. The specimens were then heated to a temperature ranging from 670° to 850°C using a filament made of approximately 1 mm diameter tantalum wire, which was placed approximately 10 mm above the specimens. The filament was heated to a temperature ranging from 1850° to 2260°C using an AC power supply. The filament temperature was determined by using a dual wavelength pyrometer. The substrate temperature, however, was determined by placing a thermocouple next to the top surface of one of the specimens, as shown in Figure 1.

Reaction parameters set forth in Table 1 were used in these experiments. After deposition times of approximately 15 hours for all of the examples and controls, except for Example A in which the deposition time was approximately 19 hours, the flow of feed gas was switched from approximately 10 SCCM of 1% CH₄ in H₂ to approximately 50 SCCM of He. The filament power was turned off after approximately 1/2 hr. and the coated specimens were cooled under the flow of He gas.

The polycrystalline diamond (PCD) films deposited in these experiments were analyzed by Laser Raman Spectroscopy to determine their nature. The Laser Raman spectra of some of the PCD films of the present invention are shown in FIGURES 2 through 10 and the films of Controls N and O are shown in FIGURES 11 and 12. Each of the spectra showed a strong peak at approximately a 1332 cm⁻¹ which is a characteristic feature of crystalline

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diamond. The data also indicated the presence of a minor hump in a few films around 1580 cm^{-1} , indicating the presence of amorphous carbon in the film. (It must be borne in mind while interpreting the data that the Laser Raman response to amorphous carbon is about 50 times that of diamond.) The size of the hump at approximately 1580 cm^{-1} was, however, very small, suggesting that the quantity of the amorphous carbon present in these films was rather small. The Laser Raman Spectroscopy therefore confirmed these films to be comprised primarily of crystalline diamond.

The PCD films deposited on the specimens were sectioned and analyzed metallographically to determine their thickness. The specimens were found to have a molybdenum carbide interlayer of $2\mu\text{m}$ to $5\mu\text{m}$ thickness. Additionally, the specimens were found to be deposited with $4\mu\text{m}$ to $10\mu\text{m}$ thickness diamond coating, as shown in Table 1.

TABLE I

<u>Example</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>	<u>H</u>	<u>I</u>	<u>J</u>	<u>K</u>	<u>L</u>	<u>M</u>	<u>CONTROL</u> <u>N</u>	<u>CONTROL</u> <u>O</u>	<u>P</u>
<u>Experiment</u> <u>No.</u>	57-2	54-2	53-2	52-2	51-2	49-2	35-2	34-2	33-2	32-2	31-2	30-2	29-2	36-2	28-2	6-2
<u>Filament</u> <u>Temp., °C</u>	~1850	~2060	~2100	~2110	~2140	~2150	~2160	~2160	~2170	~2190	~2200	~2210	~2230	~2230	~2260	2200-2220
<u>Substrate</u> <u>Temp., °C</u>	670	690	700	710	720	740	760	770	780	790	800	810	820	830	850	808-820
<u>Flow Rate of</u> <u>1% CH4 in H₂</u> <u>SCCM</u>	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
<u>Total Pressure,</u> <u>Torr</u>	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
<u>Deposition</u> <u>Time, Hours</u>	~19	~15	~15	~15	~15	~15	~15	~15	~15	~15	~15	~15	~15	~15	~15	~15
<u>Thickness, μm</u>																
<u>Molybdenum</u> <u>carbide</u>	~2	~2	~2	~3	~2	~2	~3	~3	~4	~5	~5	~5	~4	~4	~5	~4
<u>Diamond</u>	~5	~4	~5	~4	~6	~7	~10	~10	~9	~10	~8	~10	~10	~10	~8	~9

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The PCD films were characterized by x-ray diffraction to determine the orientation of the crystals. The results of the x-ray diffraction are summarized in Table 2. The orientation of crystals in the industrial grade diamond is also shown in Table 2 for reference purposes. This value has been obtained from the powder diffraction card #PDF 6-675 and represents a random distribution of (HKL) intensities.

The orientation of crystals in Controls N and O in which the specimen temperature was 830° and 850°C, respectively was marginally enhanced in the (220) and (400) directions relative to the (111) direction. However, the (400) peak intensity for the controls was very close to that noted in industrial grade diamond powder (random orientation). The surface finish of these PCD control films was noted to be very poor, as shown by the scanning electron micrographs at 5000 times magnification in FIGURES 13 and 14.

The PCD films in Examples A to M, on the other hand, were found to be greatly enhanced in the (220) and (400) directions relative to the (111) direction, as shown in Table 2. The PCD films in Examples A to E and G were also greatly enhanced in the (311) direction compared to the (111) direction, as shown in Table 2. Furthermore, the PCD films produced in Examples A to M exhibited a smoother surface finish compared to the finish produced in Controls N and O, as shown in the scanning electron micrographs at 5000 times magnification (see FIGURES 15-27).

The electrical properties of the PCD films (measured through the thickness, i.e., in the direction perpendicular to the substrate surface) are summarized in Table 2. It is noted that the films of Controls N and O, which were marginally enhanced in the (220) and (400) directions relative to the (111) direction, showed low electrical resistivity and low breakdown voltage values.

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Contrary to these low resistivity and breakdown voltage values, the PCD films of Examples A-M of the present invention whose crystals were greatly enhanced in the (220) and (400) directions showed very high electrical resistivity and breakdown voltage values.

5

TABLE 2
Crystal Orientation and Electrical Properties

Example	A	B	C	D	E	F	G	H	I	J	K	L	M	CONTROL			Industrial Grade Diamond Powder ²
														N	O	P	
Intensity of (hkl) reflection relative to (111) ¹ (%)																	
(220) ³	99	151	167	263	123	108	115	67	65	62	59	55	50	45	38	185	25
(311)	20	23	27	32	26	17	28	15	14	11	12	12	11	11	7	19	16
(400) ⁴	41	30	40	50	31	24	25	17	15	14	14	13	12	11	8	39	8
Electrical Properties																	
Resistivity, ohm-cm	1.0x10 ¹³	1.3x10 ¹²	7.7x10 ⁹	1.9x10 ¹¹	2.0x10 ¹⁰	1.0x10 ¹¹	8.2x10 ¹¹	2.9x10 ¹¹	4.0x10 ¹¹	1.4x10 ¹¹	5.0x10 ¹⁰	1.0x10 ¹¹	1.4x10 ⁹	1.0x10 ⁵	1.0x10 ⁵	1.0x10 ⁵	
Breakdown voltage, volts	---	---	---	---	---	---	> 800	> 800	~ 800	~ 800	~ 800	~ 1000	~ 700	< 100	< 100	---	---

1 The relative intensity of crystals in (111) direction is normalized to 100.

2 PDF 6-675

3 (220) crystal orientation is parallel to (110) orientation, and therefore crystals are in the same family of planes.

4 (400) crystal orientation is parallel to (100) orientation, and therefore crystals are in the same family of planes.

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The PCD films deposited in Control O and in Examples H and L were analyzed for hydrogen content by using the Nitrogen Nuclear Reaction (NNR) analysis technique. The film in Control O was found to contain 0.2 atomic percent hydrogen. This amount is low and is believed not to cause a reduction in electrical properties of film produced in Control O. Contrary to this, the films produced in Examples H and L were found to contain 0.4 and 0.3 atomic percent hydrogen, respectively. Despite the fact that films produced in Examples H and L contained higher amounts of hydrogen than the Control O film, their electrical properties were far superior to Control O film. This information indicated that the hydrogen content of the film was not as important as claimed in papers by K. V. Ravi and M. I. Landstrauss referred to above under the Background of the Invention. Furthermore, the foregoing data leads to the conclusion that the improvements in the electrical properties had to be related to enhancements in crystal orientation in the (220) and (400) directions or (220), (311) and (400) directions.

The electrical resistivities of the PCD films were plotted against crystals enhancement of the films in the (220) and (400) directions, as shown in FIGURES 29 and 30, respectively. FIGURES 29 and 30 show an increase in film resistivity with an increase in crystal orientation of the films in the (220) and (400) directions. These figures also indicate that the relative intensity of crystals in the (220) and (400) directions has to be greater than or equal to approximately 47 and approximately 11.3, respectively, to deposit PCD film with high electrical resistivity and high breakdown voltage, i.e., greater than 1×10^6 Ohm - cm. and 100 volts, respectively.

The electrical resistivities of the PCD films produced in Examples A-M and Controls N and O were

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plotted against the deposition temperature, as shown in FIGURE 31. FIGURE 31 indicates that the deposition temperature has to be controlled below approximately 825°C to produce PCD films with enhanced crystal orientation, high electrical resistivity and high breakdown voltage. This is an unexpected and significant finding.

EXAMPLE P

Another PCD deposition experiment described in Table 1 was carried out in an HFCVD reactor of the type illustrated in FIGURE 1. Two molybdenum specimens similar to those described in Examples A to M and Controls N and O were placed on a holder and deposited with diamond using a filament temperature ranging from 2200° to 2220°C, a substrate temperature varying from 808° to 820°C, 30 torr total pressure, and 10 SCCM of 1% CH₄ in hydrogen for approximately 14 hours. The specimens were pre-etched with diamond slurry also using the foregoing procedure. Each of the coated specimens had an extremely smooth surface finish, as shown in FIGURE 28. Furthermore, the specimens had about 4μm thick interfilms of molybdenum carbide underneath the about 9μm thick film of diamond. The crystals in the PCD film were strongly oriented in the (220), (311), and (400) directions relative to the (111) direction, as shown in Table 2. Although the electrical properties of the film were not measured, they are expected to be excellent. This example therefore showed that highly oriented PCD films with excellent electrical properties and good surface finish can be deposited using low deposition temperatures.

EXAMPLE Q

Another PCD deposition experiment was carried out in an HFCVD reactor of the type illustrated in Figure 1. In this experiment, two 1.35 in long x 0.387 inch wide pieces of silicon wafer were placed on

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the holder. The pieces were etched with a diamond slurry containing $80\mu\text{m}$ diamond particles in ethyl alcohol for 1 hour prior to deposition. They were then heated to 750°C temperature using a filament made of ~ 1 mm diameter tantalum wire, which was placed ~ 10 mm above the specimens. The filament was heated to $\sim 1950^\circ\text{C}$ temperature using an AC power supply. A flow of ~ 10 SCCM of 1% methane in hydrogen was used to deposit diamond for 20 hours. After the deposition time, the flow of feed gas was switched from 10 SCCM of 1% CH_4 in H_2 to 50 SCCM of He. The filament power was turned off after $\sim 1/2$ hour and the coated pieces were cooled under the flow of the gas.

The silicon pieces were found to have a silicon carbide interlayer of $\leq 1\mu\text{m}$ in thickness. Additionally, the pieces were found to be deposited with uniform, adherent and $\sim 4\mu\text{m}$ thick diamond coating. The coating had a smooth surface finish as shown in Figure 32. X-ray diffraction analysis revealed enhanced crystals orientation in the (311) and (400) directions (see Table 3). Furthermore, the PCD film showed extremely high electrical resistivity, as shown in Table 3.

This example, therefore, showed that PCD film with enhanced crystals orientation in the (311) and (400) directions and excellent electrical properties can be deposited on silicon substrate.

TABLE 3

Crystal Orientation and Electrical Properties

5	<u>Example</u>	<u>Q</u>	<u>Industrial Grade Diamond Powder</u>
10	Intensity of (hkl) inflection <u>relative to (111)%</u>		
	(220)	22	25
	(311)	26	16
	(400)	13	8
15	Resistivity, ohm-cm	3.0×10^{10}	--

20 From the foregoing description, one of ordinary skill in the art can easily ascertain that the present invention provides a novel method for producing

diamond-on-substrate products comprised of a substrate which could be a single crystal, a polycrystalline

25 material, metal, metal alloy, a mixture of metals or ceramic material, and a polycrystalline diamond film with an enhanced crystal orientation in the (220) and (400)

directions relative to (111) direction. The invention makes it possible to fully utilize the electrical

30 properties of polycrystalline diamond to provide electrical isolation of one electronic device and circuit from another and from the base substrate.

GENERAL DISCUSSION

35 The poor electrical properties of Controls N and O could be related to random crystal orientation, the impurities present in the grain boundaries, and

structural imperfections such as large number of stacking faults and twins lying on the (111) plane of the film.

The improvement in the electrical properties of the films

40 in Examples A to M are related to the enhanced crystal orientation in the (220) and (400) directions or (220), (311) and (400) directions, relative to (111). It could also be related to the reduction in the impurities

present in the grain boundaries and lower degree of structural imperfections such as lower number of stacking faults and twins lying on the (111) plane of the film. Improved electrical properties could also be related to
5 reduction in the total number of inter-connected grain boundaries. In general, the PCD films with enhanced crystal orientation in the (220) and (400) directions or (220), (311) and (400) directions may have a greater degree of crystalline perfection, resulting in PCD films
10 with improved electrical properties compared to randomly oriented films.

Without the departing from the spirit and scope of this invention, one of ordinary skilled can make various changes and modification to the invention to
15 adapt it to various usages and conditions. As such, these changes and modifications are properly, equitably, and intended to be, within the full range of equivalence of the following claims.

WHAT IS CLAIMED IS:

1. A coated substrate product comprised of a parent substrate and a polycrystalline diamond layer; said parent substrate comprising a material selected from the group consisting of a single crystal, polycrystalline materials, metal, metal alloy, mixture of metals, ceramic materials and mixtures thereof; said polycrystalline diamond layer chemically vapor deposited on said parent substrate and having a smooth surface finish, an enhanced crystal orientation on at least two planes in comparison to industrial grade of diamond powder and a high electrical resistivity and breakdown voltage.

2. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer has an enhanced crystal orientation in the (220) and (400) directions relative to the (111) direction.

3. A coated substrate product according to Claim 2 wherein said polycrystalline diamond layer also has an enhanced crystal orientation in the (311) direction relative to the (111) direction.

4. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer has an enhanced crystal orientation in the (311) and (400) directions relative to the (111) direction.

5. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer is in the range of about $0.5\mu\text{m}$ to about $250\mu\text{m}$ in thickness.

6. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer is in the range of about $0.5\mu\text{m}$ to about $50\mu\text{m}$ in thickness.

7. A coated substrate product according to Claim 4 wherein said polycrystalline diamond layer is about $3\mu\text{m}$ to about $15\mu\text{m}$ in thickness.

8. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer has an electrical resistivity greater than 10^6 ohm-cm.

5 9. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer has a breakdown voltage greater than 100 volts.

10. A coated substrate product according to Claim 1 wherein said parent substrate is molybdenum.

10 11. A coated substrate product according to Claim 10 wherein molybdenum carbide is formed in situ between said parent substrate and said polycrystalline diamond layer.

12. A coated substrate product according to Claim 1 wherein said parent substrate is silicon.

15 13. A coated substrate product according to Claim 12 wherein silicon carbide is formed in situ between said parent substrate and said polycrystalline diamond layer.

20 14. A chemical vapor deposition method for fabricating a coated substrate product comprising: providing a parent substrate comprising a material selected from the group consisting of a single crystal, polycrystalline materials, metal, metal alloy, mixture of metals, ceramic materials; and mixtures thereof; and
25 chemical vapor depositing a polycrystalline diamond layer onto said parent substrate in the presence of a hot filament at conditions such that said diamond layer exhibits a smooth surface finish, an enhanced crystals orientation on at least two planes in comparison to
30 industrial grade of diamond powder and a high electrical resistivity and breakdown voltage.

35 15. The method of Claim 14 wherein said polycrystalline diamond layer is deposited onto said parent substrate at temperatures in the range of 650° to 825°C.

16. The method of Claim 14 wherein said polycrystalline diamond layer exhibits an enhanced crystal orientation in the (220) and (400) directions relative to the (111) direction.

5 17. The method of Claim 16 wherein said polycrystalline diamond layer also exhibits an enhanced crystal orientation in the (311) direction relative to the (111) direction.

10 18. The method of Claim 14 wherein said polycrystalline diamond layer exhibits an enhanced crystal orientation in the (311) and (400) directions relative to the (111) direction.

15 19. The method of Claim 14 wherein said polycrystalline diamond layer is in the range of about 0.5 μ m to about 50 μ m in thickness.

20. The method of Claim 14 wherein said polycrystalline diamond layer is about 3 μ m to about 15 μ m in thickness.

20 21. The method of Claim 14 wherein said polycrystalline diamond layer has a electrical resistivity greater than 10⁶ ohm-cm.

22. The method of Claim 14 wherein said polycrystalline diamond layer has a breakdown voltage greater than 100 Volts.

25 23. The method of Claim 14 wherein said parent substrate is molybdenum.

24. The method of Claim 23 wherein molybdenum carbide is formed in situ between said parent substrate and said polycrystalline diamond.

30 25. The method of Claim 14 wherein said parent substrate is silicon.

26. The method of Claim 25 wherein silicon carbide is formed in situ between said parent substrate and said polycrystalline diamond.

35 27. A chemical vapor deposition method for fabricating a coated substrate product comprising:

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placing a parent substrate comprising a material selected from the group consisting of a single crystal, polycrystalline materials, metal, metal alloy, mixture of metals, ceramic materials and mixtures thereof into a hot filament chemical vapor deposition reactor; heating said parent substrate to a temperature in the range of about 650° to 825°C by means of a filament electrically charged to a temperature in the range of about 1800 to 2250°C; passing a gaseous mixture of hydrocarbons and hydrogen into said reactor for a period of time to chemically vapor deposit a polycrystalline diamond layer onto the heated substrate; passing an inert gas over said coated substrate while said filament remains electrically charged for a period of time to purge said reactor of said gaseous mixture; cooling said substrate by removing the charge from said filament and continuing the passing of the inert gas over the substrate; and recovering a substrate coated with about 0.5 μ m to about 50 μ m of a smooth polycrystalline diamond layer exhibiting a high electrical resistivity and breakdown voltage which is selected from the group consisting of one exhibiting enhanced crystals orientation in the (220) and (400) directions, one exhibiting enhanced crystals orientation in the (311) and (400) directions and one exhibiting enhanced crystals orientation in the (220), (311) and (400) directions relative to the (111) direction in comparison to industrial grade of diamond powder.

28. The method of Claim 27 wherein said polycrystalline diamond layer is about 3 μ m to about 15 μ m in thickness.

29. The method of Claim 27 wherein said polycrystalline diamond layer has a electrical resistivity greater than 10⁶ ohm-cm.

30. The method of Claim 29 wherein said polycrystalline diamond layer has a breakdown voltage greater than 100 Volts.

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31. The method of Claim 27 wherein said parent substrate is molybdenum.

32. The method of Claim 31 wherein $2\mu\text{m}$ to $5\mu\text{m}$ of molybdenum carbide is formed in situ between said parent substrate and said polycrystalline diamond layer.

33. The method of Claim 27 wherein said parent substrate is silicon.

34. The method of Claim 31 wherein up to $2\mu\text{m}$ of silicon carbide is formed in situ between said parent substrate and said polycrystalline diamond layer.

AMENDED CLAIMS

[received by the International Bureau on 23 August 1991 (23.08.91);
original claims 1-34 replaced by amended claims 1-44 (7 pages)]

1. A coated substrate product comprised of a parent substrate and a polycrystalline diamond layer;

5 said parent substrate comprising a material selected from the group consisting of a single crystal, polycrystalline materials, metal, metal alloy, mixture of metals, ceramic materials and mixtures thereof;

10 said polycrystalline diamond layer chemically vapor deposited on said parent substrate and having a smooth surface finish, an enhanced crystal orientation on at least two planes in comparison to industrial grade of diamond powder including those in the (220) and (400) directions relative to the (111) direction and a high electrical resistivity and breakdown voltage and exhibiting an intensity of reflections in the (220) and (400) directions of at least 47 percent and 11.3 percent, respectively, relative to the (111) direction which is normalized to 100.

15 2. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer also has an enhanced crystal orientation in the (311) direction relative to the (111) direction.

3. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer is in the range of about $0.5\mu\text{m}$ to about $250\mu\text{m}$ in thickness.

20 4. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer is in the range of about $0.5\mu\text{m}$ to about $50\mu\text{m}$ in thickness.

5. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer is about $3\mu\text{m}$ to about $15\mu\text{m}$ in thickness.

25 6. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer has an electrical resistivity greater than 10^6 ohm-cm.

7. A coated substrate product according to Claim 1 wherein said polycrystalline diamond layer has a breakdown voltage greater than 100 volts.

8. A coated substrate product according to Claim 1 wherein said parent substrate is molybdenum.

5 9. A coated substrate product according to Claim 8 wherein molybdenum carbide is formed in situ between said parent substrate and said polycrystalline diamond layer.

10. A coated substrate product according to Claim 1 wherein said parent substrate is silicon.

10 11. A coated substrate product according to Claim 10 wherein silicon carbide is formed in situ between said parent substrate and said polycrystalline diamond layer.

12. A chemical vapor deposition method for fabricating a coated substrate product comprising:

15 providing a parent substrate comprising a material selected from the group consisting of a single crystal, polycrystalline materials, metal, metal alloy, mixture of metals, ceramic materials; and mixtures thereof; and

20 chemical vapor depositing a polycrystalline diamond layer onto said parent substrate in the presence of a hot filament at conditions such that said diamond layer exhibits a smooth surface finish, an enhanced crystals orientation on at least two planes in comparison to industrial grade of diamond powder including those in the (220) and (400) directions relative to the (111) direction and a high electrical resistivity and breakdown voltage and exhibiting an intensity of reflections in the (220) and (400) directions of at least 47 percent and 11.3 percent, respectively,
25 relative to the (111) direction which is normalized to 100.

13. The method of Claim 12 wherein said polycrystalline diamond layer is deposited onto said parent substrate at temperatures in the range of 650° to 825°C.

5 14. The method of Claim 12 wherein said polycrystalline diamond layer also exhibits an enhanced crystal orientation in the (311) direction relative to the (111) direction.

15. The method of Claim 12 wherein said polycrystalline diamond layer is in the range of about 0.5 μ m to about 50 μ m in thickness.

10 16. The method of Claim 12 wherein said polycrystalline diamond layer is about 3 μ m to about 15 μ m in thickness.

17. The method of Claim 12 wherein said polycrystalline diamond layer has a electrical resistivity greater than 10⁶ ohm-cm.

18. The method of Claim 12 wherein said polycrystalline diamond layer has a breakdown voltage greater than 100 volts.

15 19. The method of Claim 12 wherein said parent substrate is molybdenum.

20. The method of Claim 19 wherein molybdenum carbide is formed in situ between said parent substrate and said polycrystalline diamond.

21. The method of Claim 12 wherein said parent substrate is silicon.

20 22. The method of Claim 21 wherein silicon carbide is formed in situ between said parent substrate and said polycrystalline diamond.

23. A chemical vapor deposition method for fabricating a coated substrate product comprising:

25 placing a parent substrate comprising a material selected from the group consisting of a single crystal, polycrystalline materials, metal, metal alloy, mixture of

metals, ceramic materials and mixtures thereof into a hot filament chemical vapor deposition reactor;

heating said parent substrate to a temperature in the range of about 650° to 825°C by means of a filament electrically charged to a temperature in the range of about 1800° to 2250°C;

passing a gaseous mixture of hydrocarbons and hydrogen into said reactor for a period of time to chemically vapor deposit a polycrystalline diamond layer onto the heated substrate;

passing an inert gas over said coated substrate while said filament remains electrically charged for a period of time to purge said reactor of said gaseous mixture;

cooling said substrate by removing the charge from said filament and continuing the passing of the inert gas over the substrate; and

recovering a substrate coated with about 0.5 μ m to about 50 μ m of a smooth polycrystalline diamond layer exhibiting a high electrical resistivity and breakdown voltage which is selected from the group consisting of one exhibiting enhanced crystals orientation in the (220) and (400) directions, one exhibiting enhanced crystals orientation in the (311) and (400) directions and one exhibiting enhanced crystals orientation in the (220), (311) and (400) directions relative to the (111) direction in comparison to industrial grade of diamond powder.

24. The method of Claim 23 wherein said polycrystalline diamond layer is about 3 μ m to about 15 μ m in thickness.

25. The method of Claim 23 wherein said polycrystalline diamond layer has a electrical resistivity greater than 10⁶ ohm- cm.

26. The method of Claim 25 wherein said polycrystalline diamond layer has a breakdown voltage greater than 100 volts and exhibiting an intensity of

reflections in the (220) and (400) directions of at least 47% and 11.3 percent, respectively, relative to the (111) direction which is normalized to 100.

27. The method of Claim 23 wherein said parent substrate is molybdenum.

5 28. The method of Claim 27 wherein $2\mu\text{m}$ to $5\mu\text{m}$ of molybdenum carbide is formed in situ between said parent substrate and said polycrystalline diamond layer.

29. The method of Claim 23 wherein said parent substrate is silicon.

10 30. The method of Claim 27 wherein up to $2\mu\text{m}$ of silicon carbide is formed in situ between said parent substrate and said polycrystalline diamond layer.

31. A coated substrate product comprised of a parent substrate and a plurality of separately deposited polycrystalline diamond layers, each layer having a substantially uniform microstructure and having high electrical resistivity;

15 said parent substrate comprising a material selected from the group consisting of a single crystal, polycrystalline materials, metal, metal alloy, mixture of metals, ceramic materials and mixtures thereof;

20 said diamond layers comprising a first polycrystalline diamond layer chemically vapor deposited on said parent substrate during a first cycle of at least one set of two cycles, and having a smooth surface finish, at least a partially ordered crystal orientation on at least two planes in comparison to industrial grade diamond powder, including those in the (220) and (400) directions relative to the (111) direction, and a high electrical resistivity and breakdown voltage and exhibiting an intensity of reflections in the (220) and (400) directions of at least 47% and 11.3% respectively, relative to the (111) direction which is normalized to 100; and at least a
25 second polycrystalline diamond layer chemically vapor deposited on the coated

substrate during a second cycle in which the deposition process conditions are substantially different from those of the first cycle.

32. The product of Claim 30 wherein the total thickness of said polycrystalline diamond layers is at least about 11 μm .

5 33. The product of Claim 30 wherein the total thickness of said polycrystalline diamond layers is in the range of about 0.5 μm to about 250 μm .

34. The product of Claim 30 wherein the total thickness of said polycrystalline diamond layers is in the range of about 0.5 μm to about 50 μm .

10 35. The product of Claim 30 wherein said polycrystalline diamond layers have electrical resistivity greater than 10^6 ohm-cm.

36. The product of Claim 30 wherein said polycrystalline diamond layers have a breakdown voltage greater than 100 volts.

37. The product of Claim 36 wherein said parent substrate is molybdenum.

15 38. The product of Claim 37 wherein molybdenum carbide is formed *in situ* between said parent substrate and said first polycrystalline diamond layer and wherein the thickness of said molybdenum carbide is in the range of about 2 μm to about 5 μm .

39. The product of Claim 30 wherein said parent substrate is silicon.

20 40. The product of Claim 39 wherein silicon carbide is formed *in situ* between said parent substrate and said first polycrystalline diamond layer and wherein the thickness of said silicon carbide is in the range of $\leq 1\mu\text{m}$.

25 41. The product of Claim 30 wherein said polycrystalline diamond layer has at least a partially ordered crystal orientation in at least two planes in comparison to industrial grade diamond powder.

42. The product of Claim 41 wherein the polycrystalline diamond layer has at least a partially ordered crystal orientation in the (220) and (400) directions relative to the (111) direction and has a smooth surface finish, at least a partially ordered crystal orientation on at least two planes in comparison to industrial grade of diamond powder, including those in the (220) and (400) directions relative to the (111) direction, and a high electrical resistivity and breakdown voltage and exhibits an intensity of reflections in the (220) and (400) directions of at least 47% and 11.3 percent, respectively, relative to the (111) direction which is normalized to 100.

43. The product of Claim 42 wherein said second polycrystalline diamond layer includes at least a partially ordered crystal orientation in the (311) direction relative to the (111) direction.

44. The product of Claim 43 wherein said second polycrystalline diamond layer has at least a partial ordered crystal orientation in the (311) and (400) directions relative to the (111) direction.

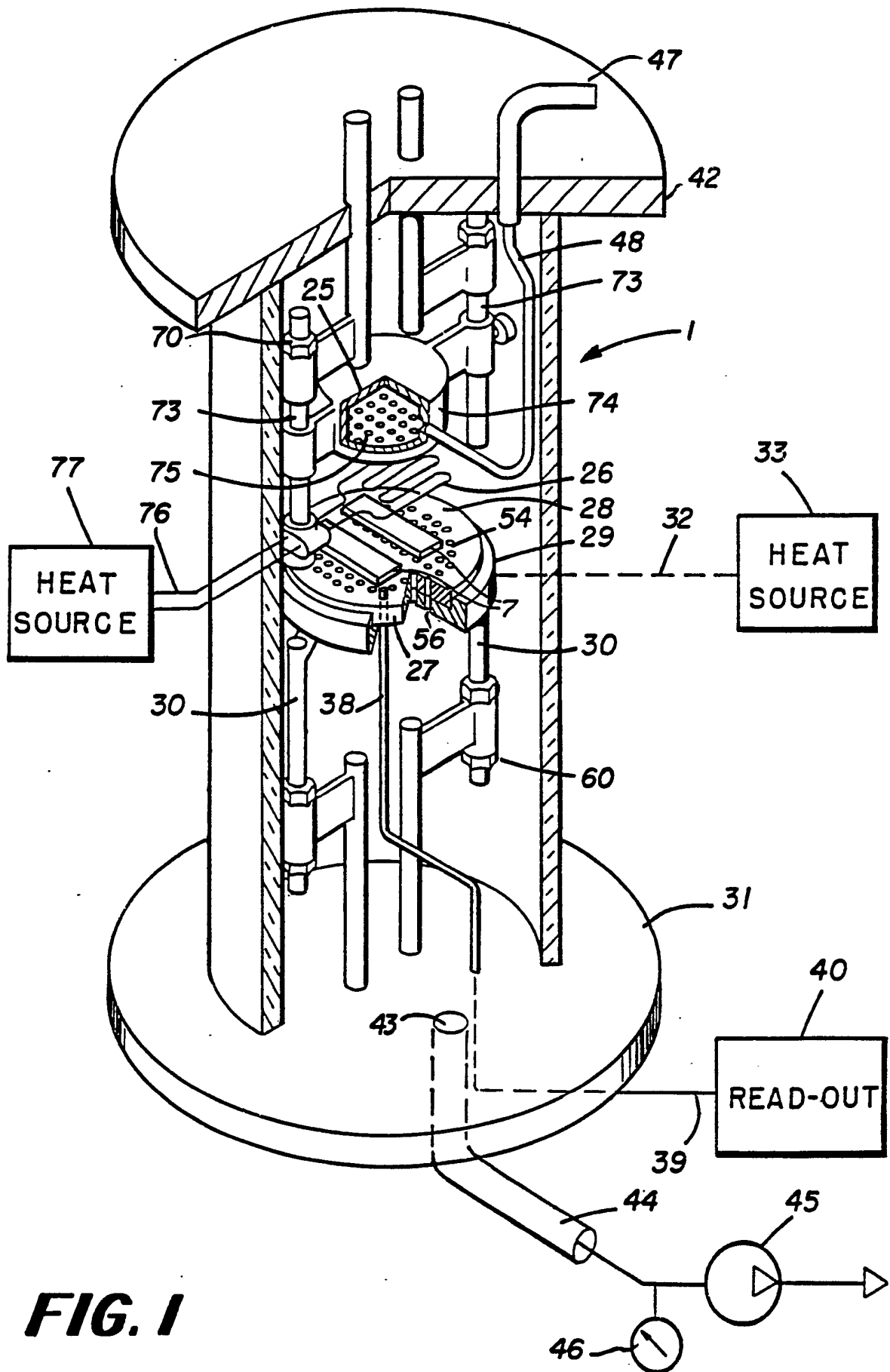
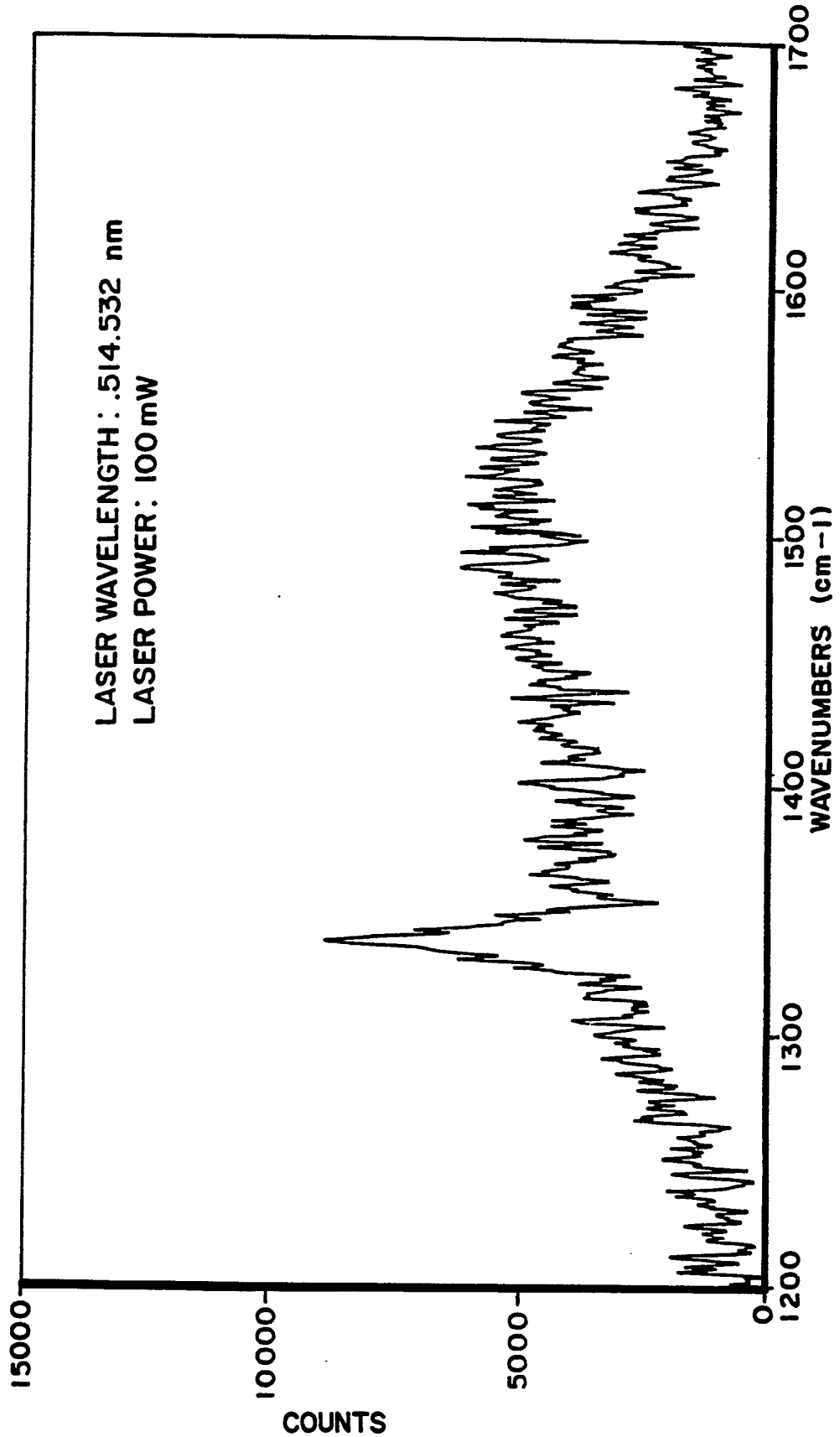


FIG. 1

SUBSTITUTE SHEET

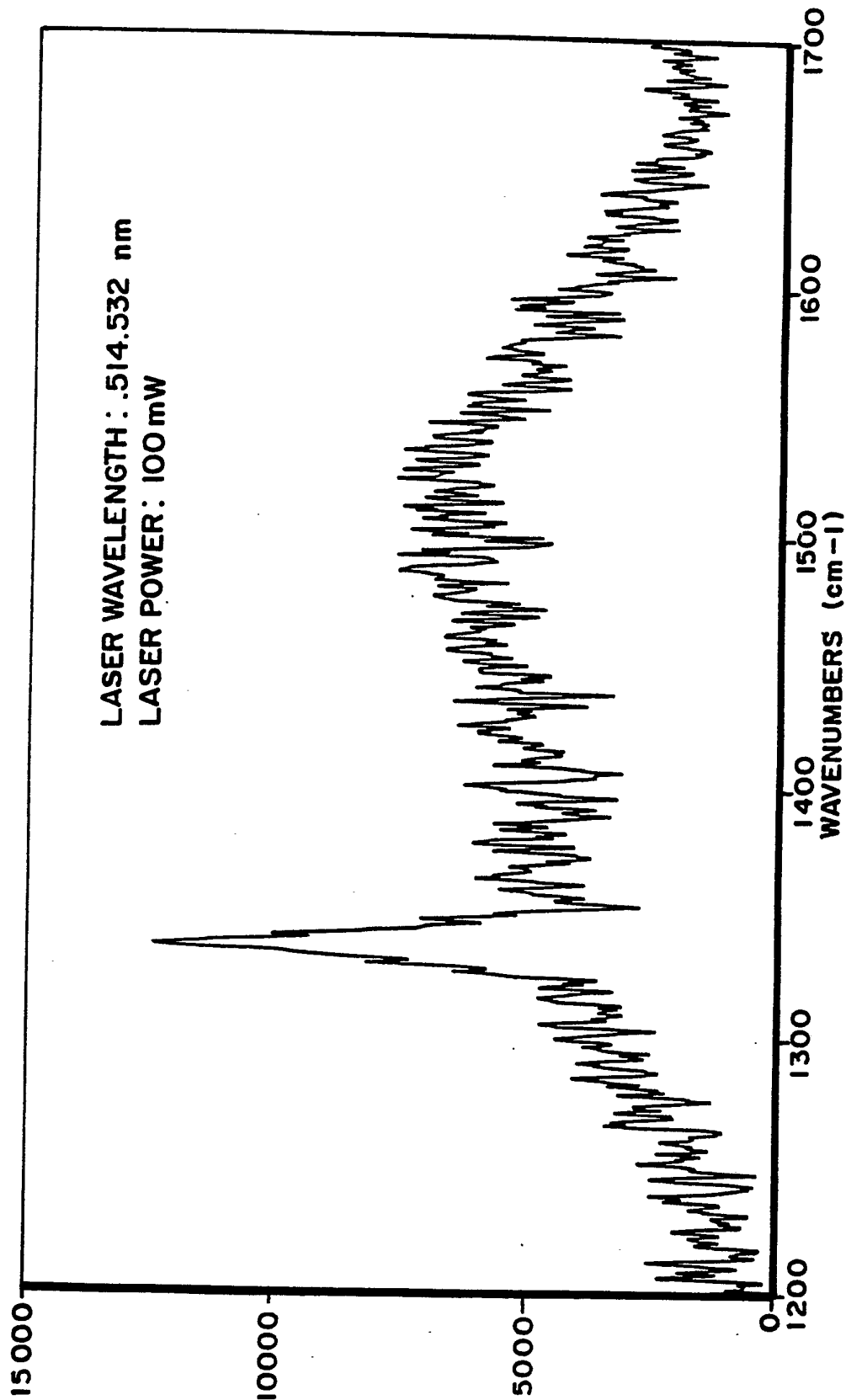
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FIG. 2
(EXAMPLE B)



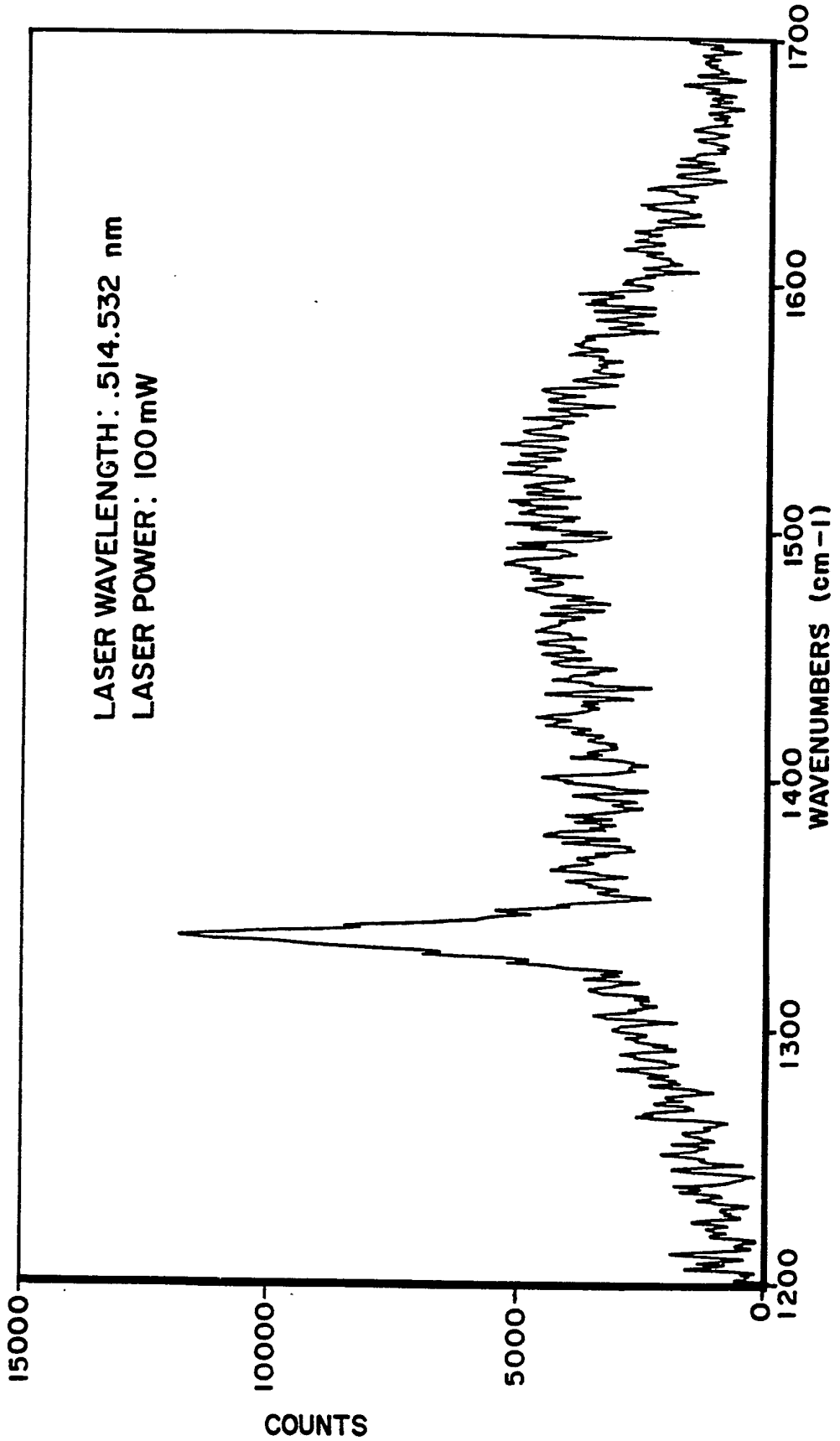
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FIG. 3
(EXAMPLE C)



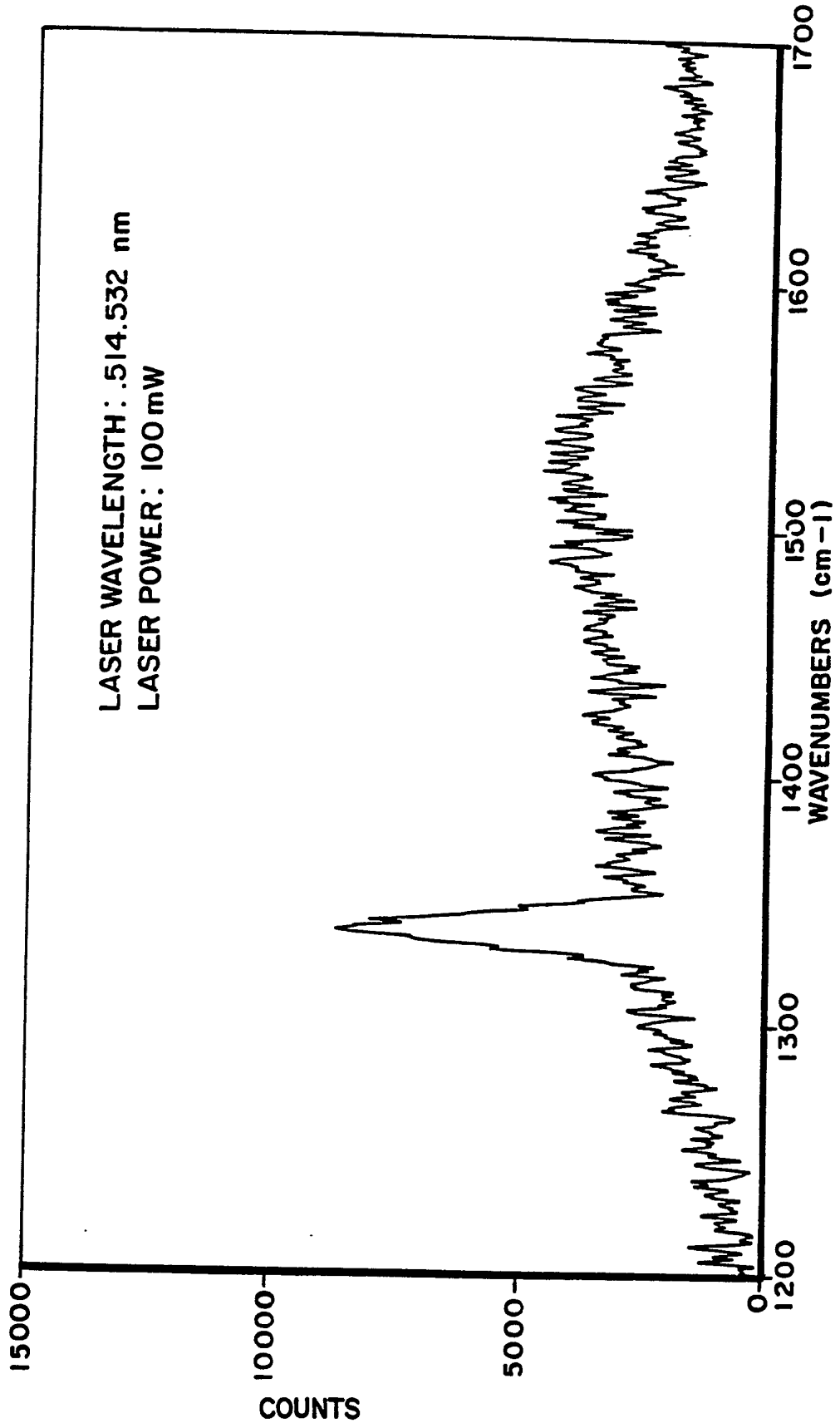
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FIG. 4
(EXAMPLE E)



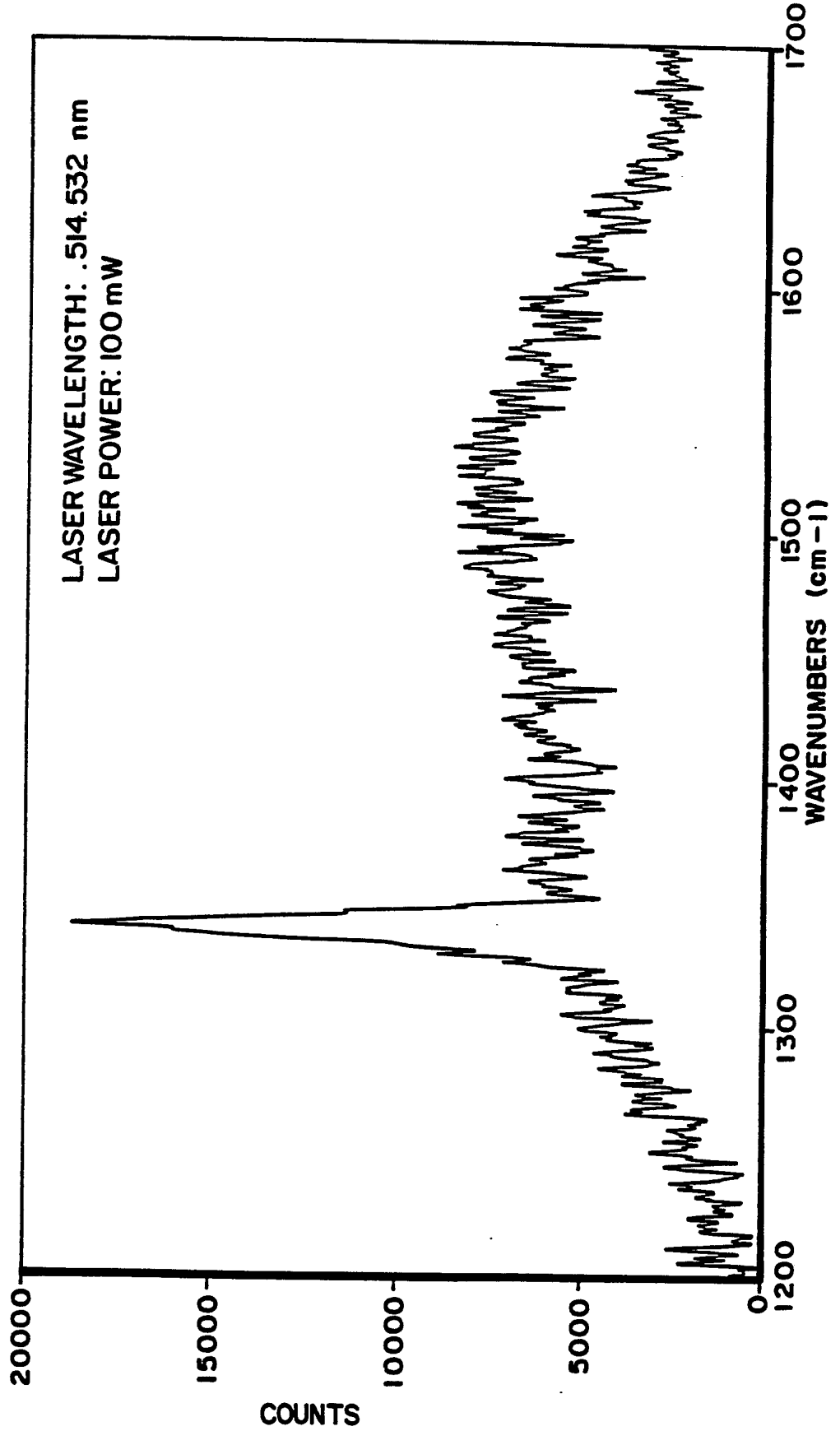
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FIG. 5
(EXAMPLE F)



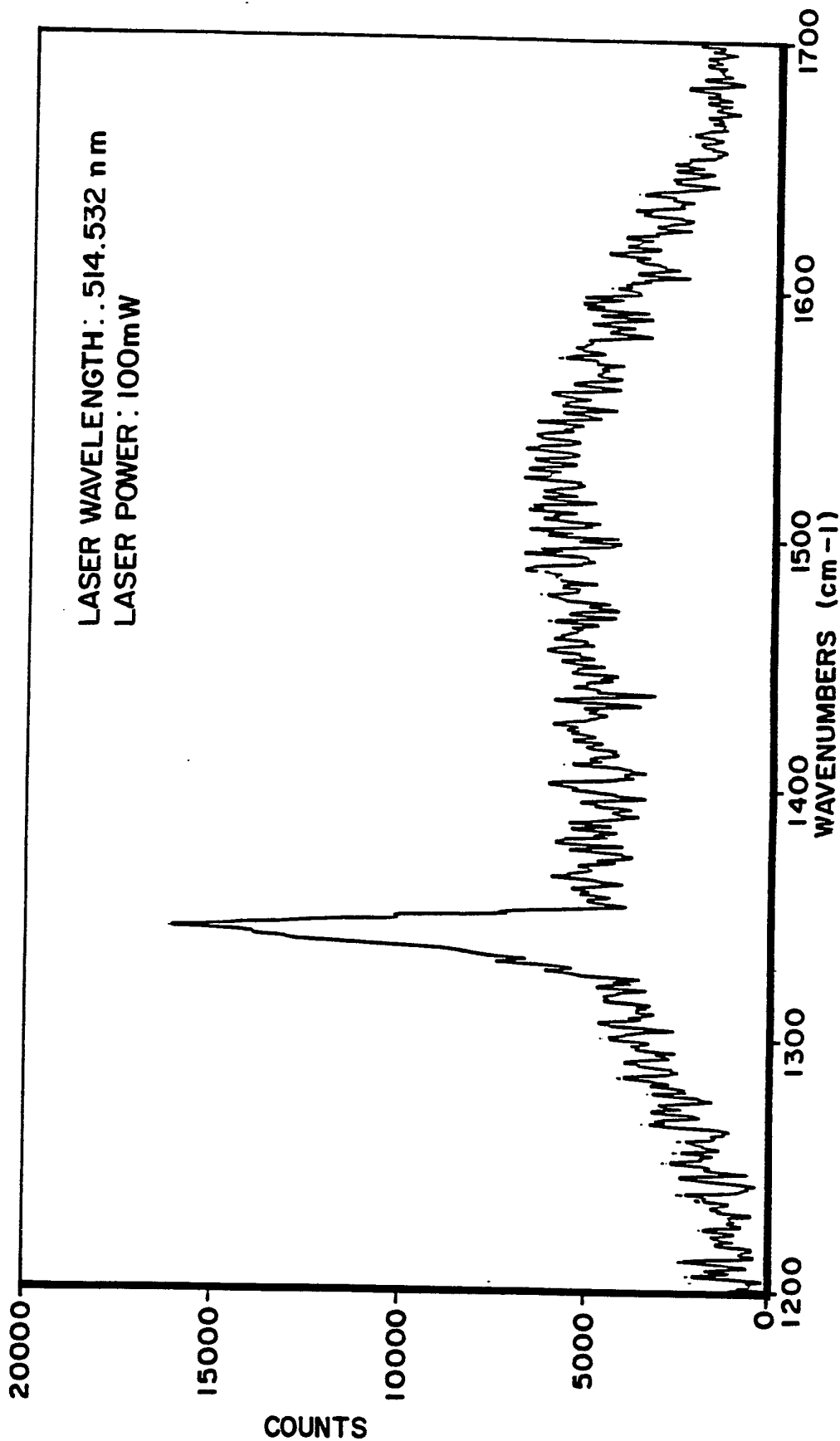
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FIG. 6
(EXAMPLE H)



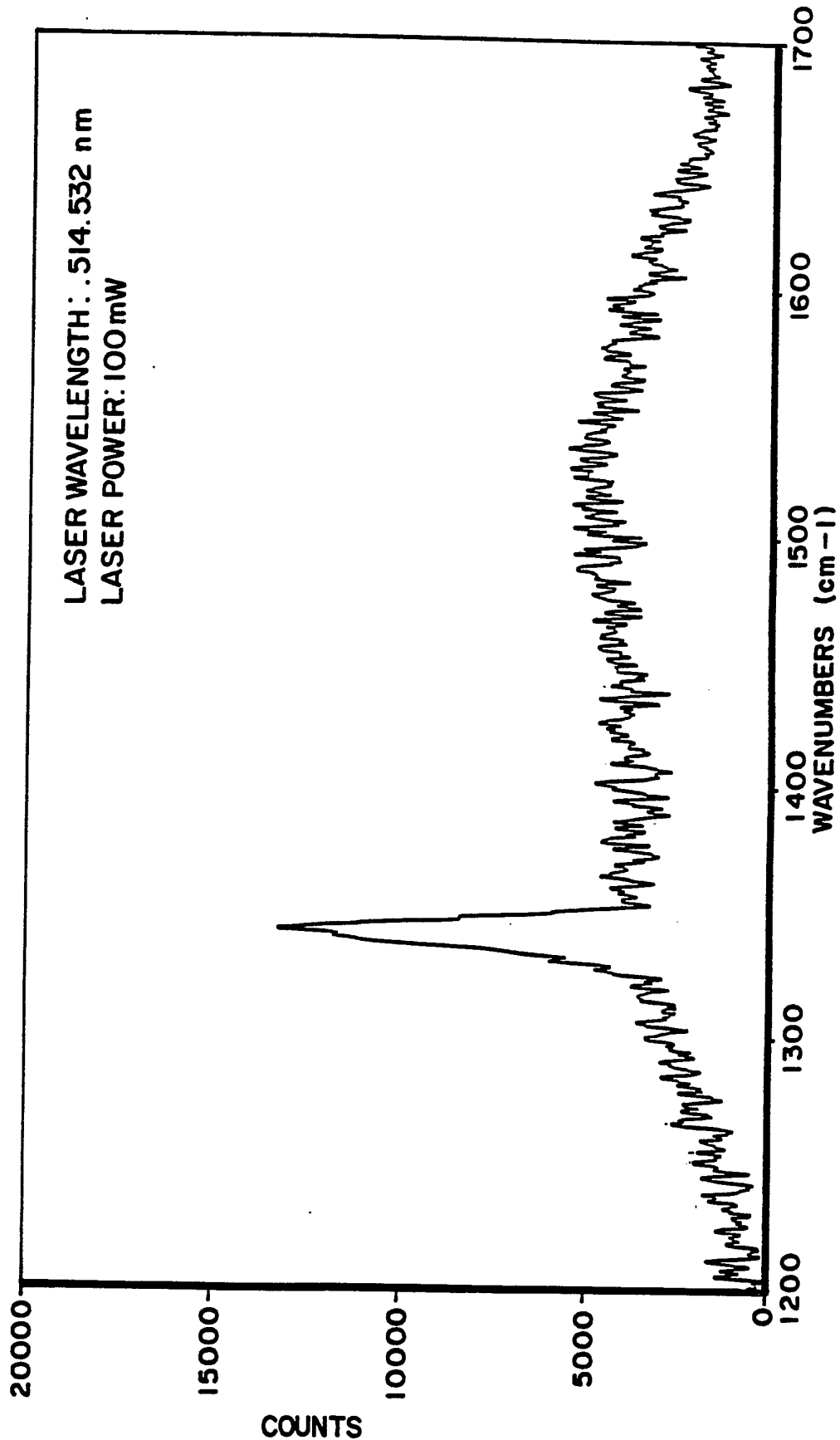
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FIG. 7
(EXAMPLE J)



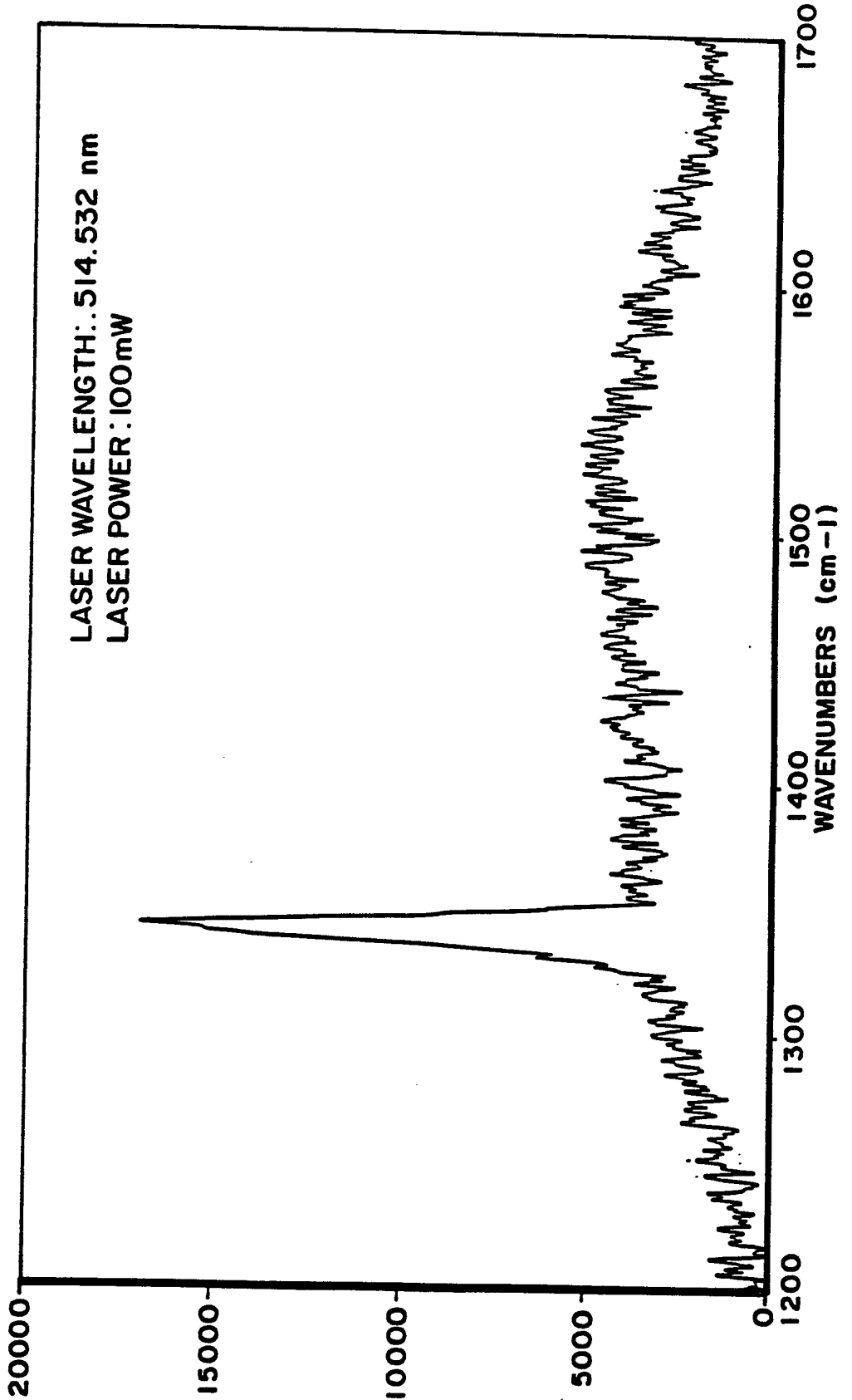
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FIG. 8
(EXAMPLE K)



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FIG. 9
(EXAMPLE L)



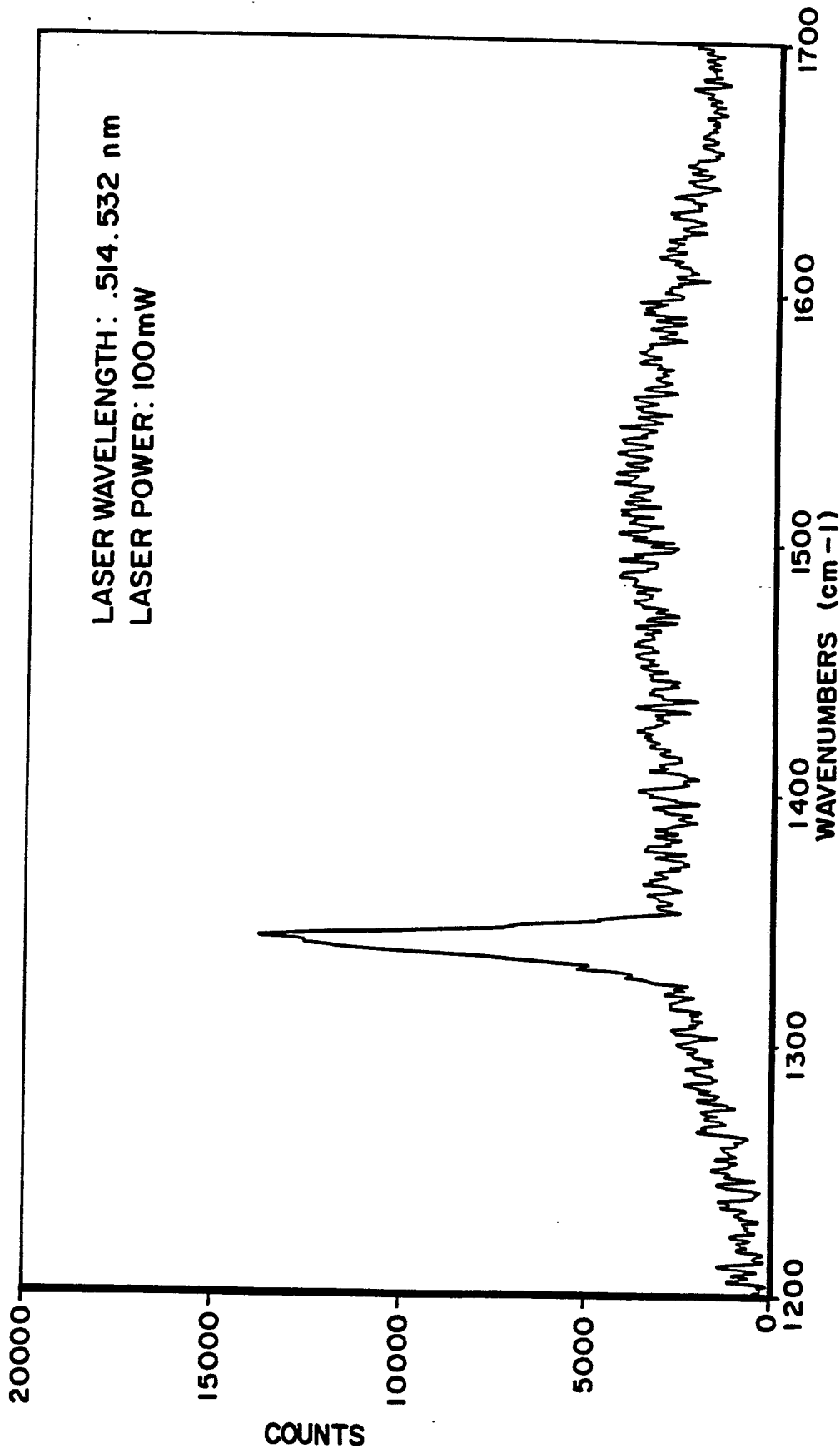
COUNTS

WAVENUMBERS (cm⁻¹)

SUBSTITUTE SHEET

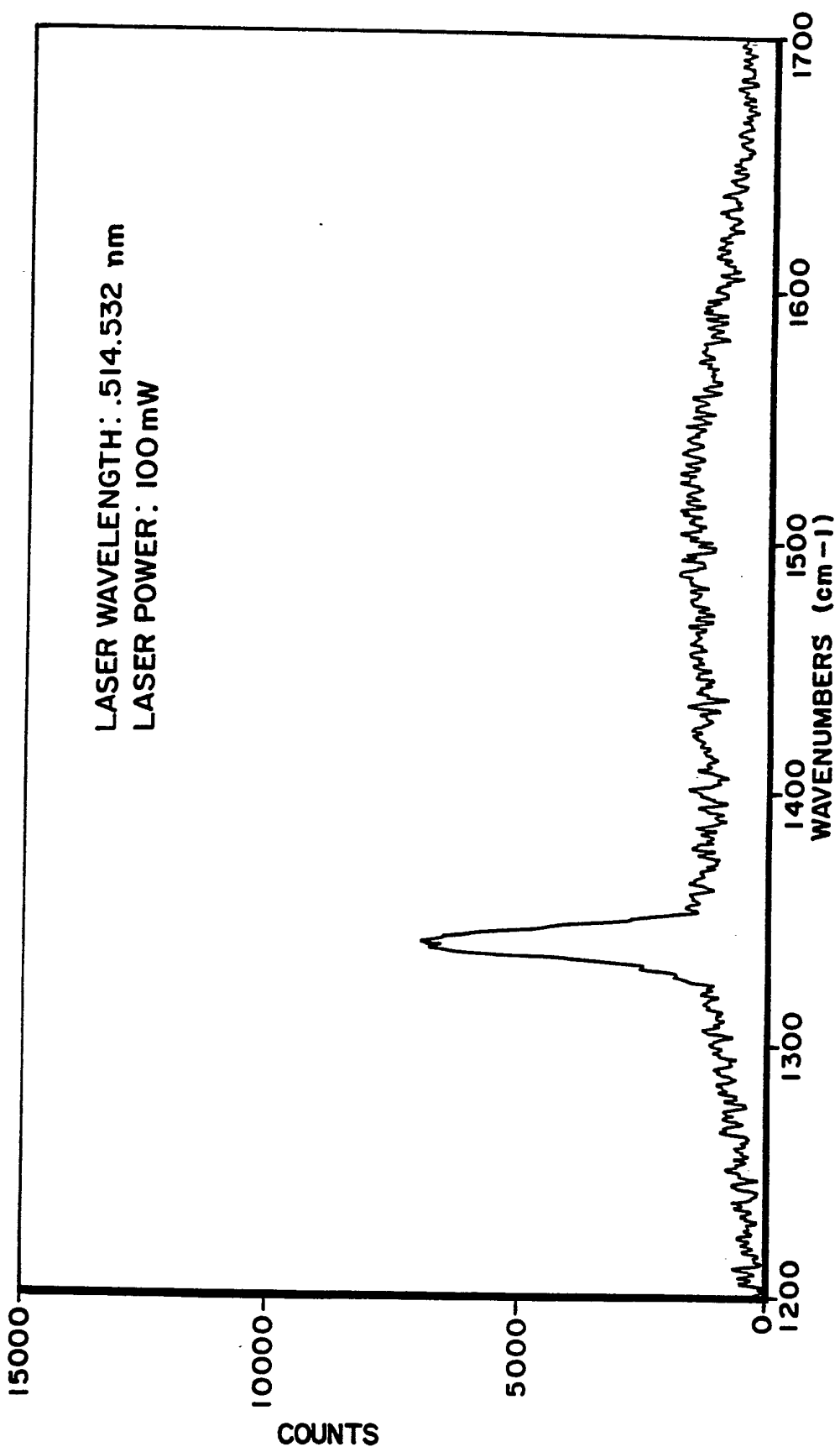
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FIG. 10
(EXAMPLE M)



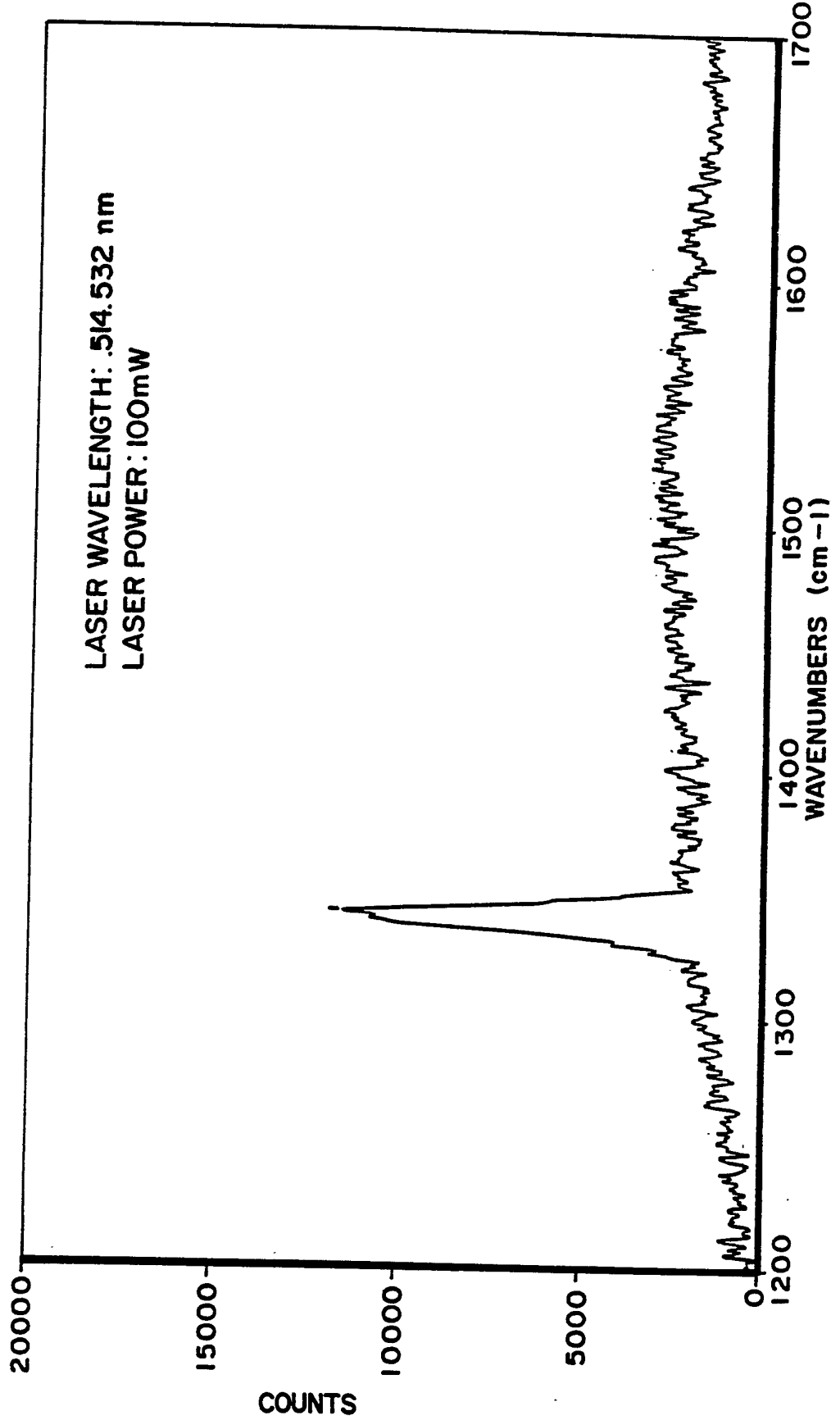
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FIG. 11
(EXAMPLE N)



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FIG. 12
(EXAMPLE 0)



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FIG. 13
(EXAMPLE N)



FIG. 14
(EXAMPLE O)

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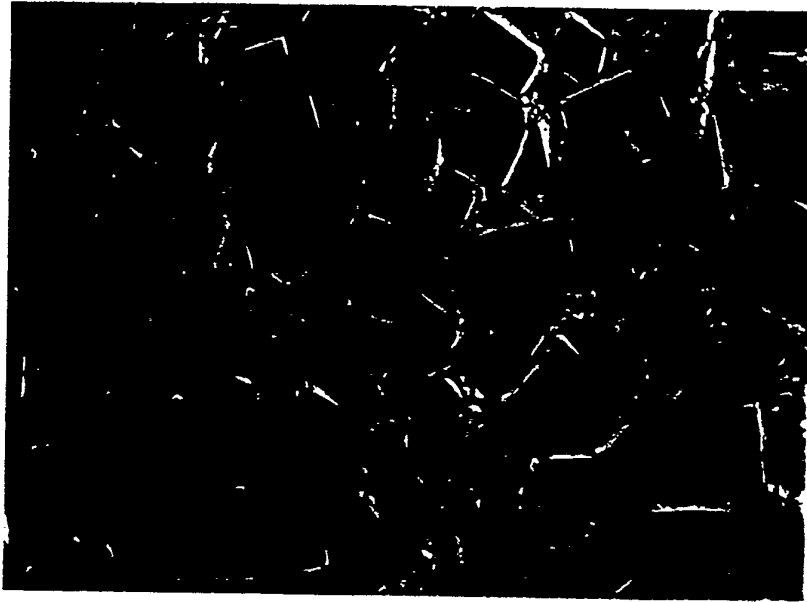


FIG. 15
(EXAMPLE A)

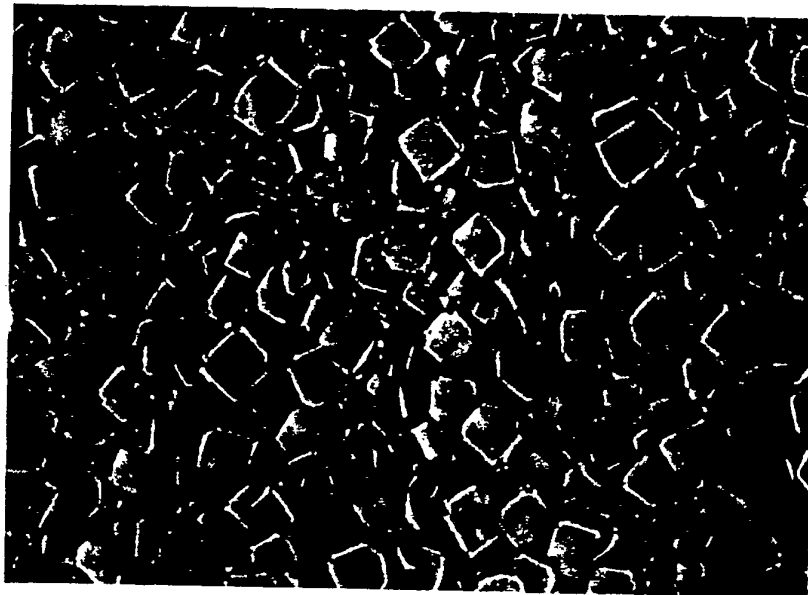


FIG. 16
(EXAMPLE B)

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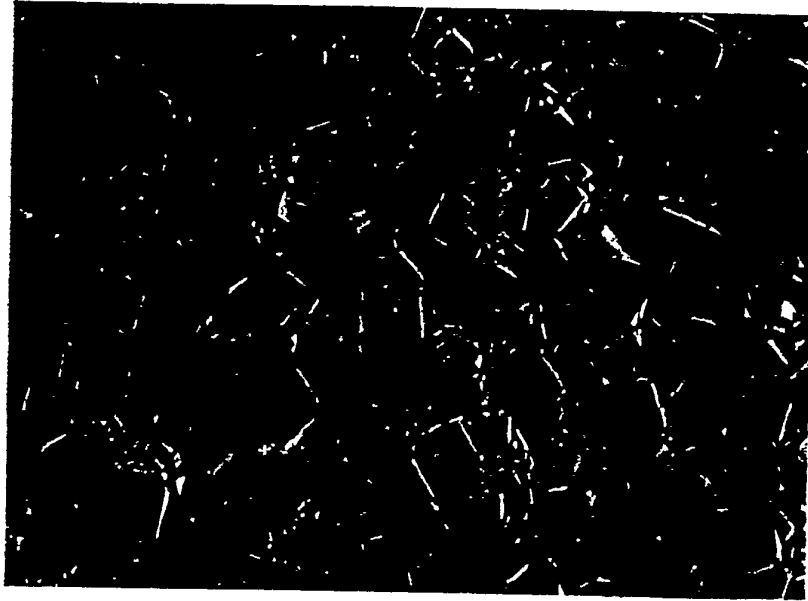


FIG. 17
(EXAMPLE C)

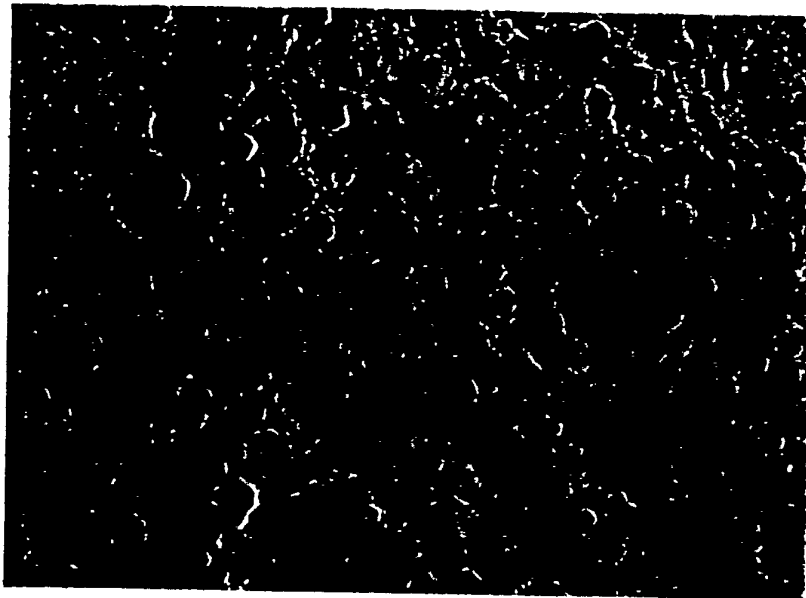


FIG. 18
(EXAMPLE D)

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FIG. 19
(EXAMPLE E)

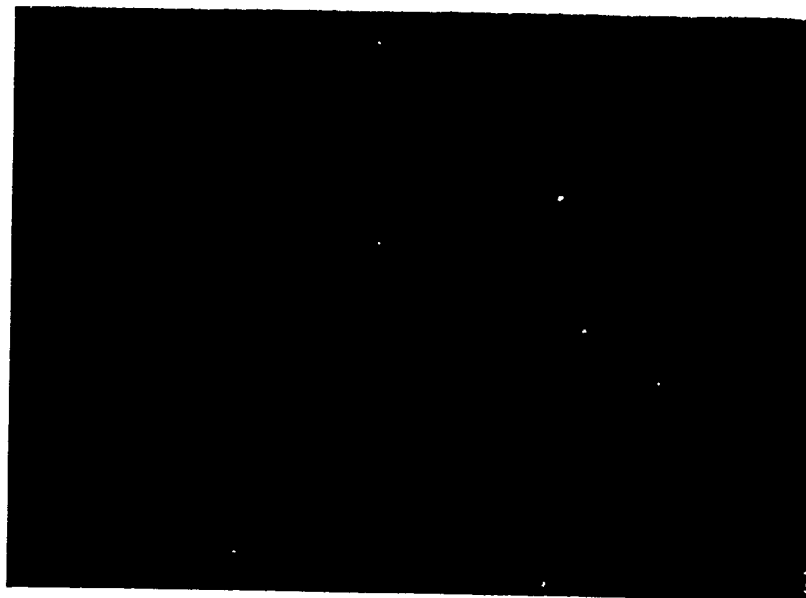


FIG. 20
(EXAMPLE F)

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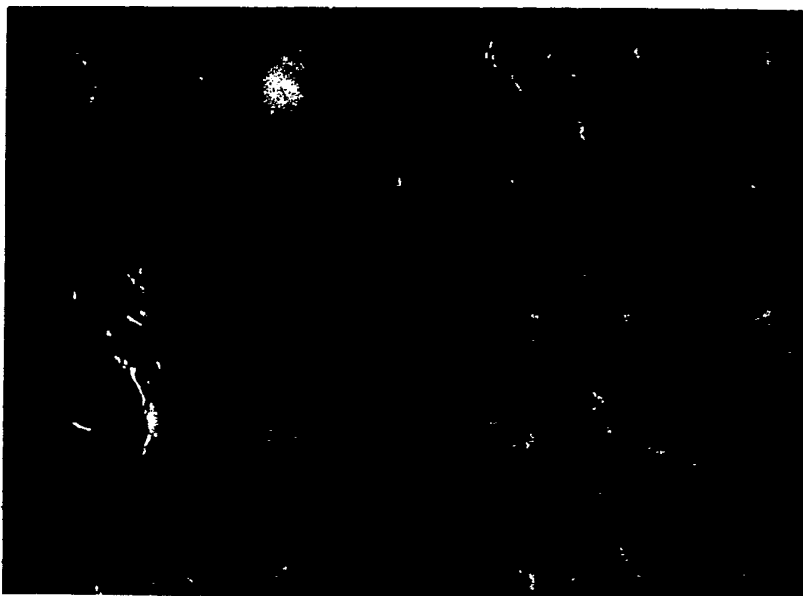


FIG. 21
(EXAMPLE G)

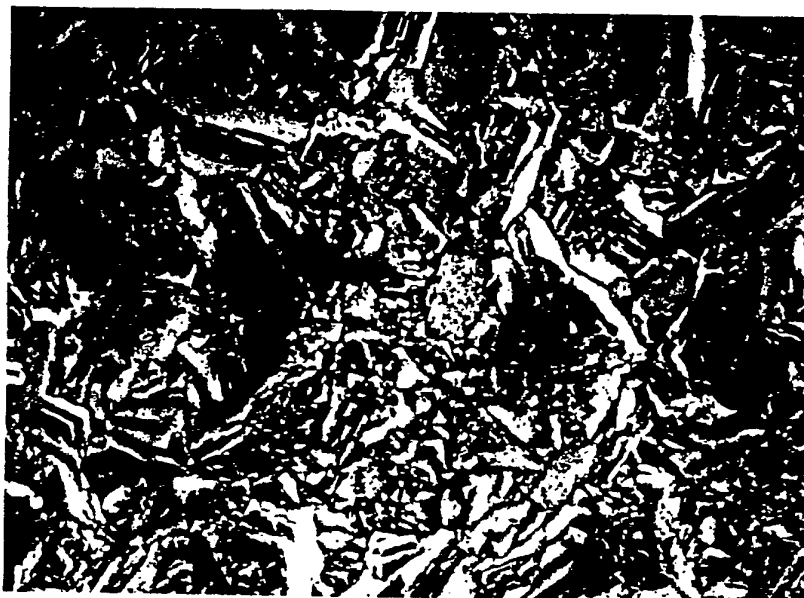


FIG. 22
(EXAMPLE H)

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FIG. 23
(EXAMPLE I)

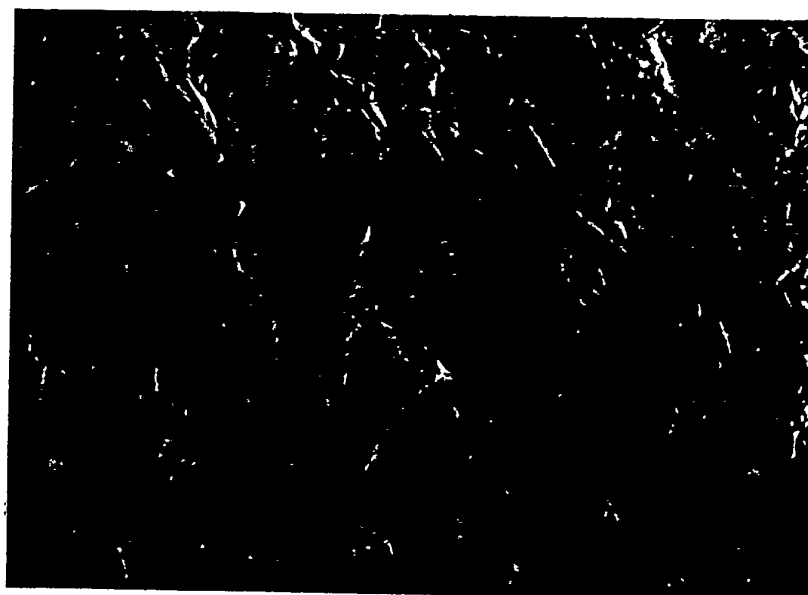


FIG. 24
(EXAMPLE J)

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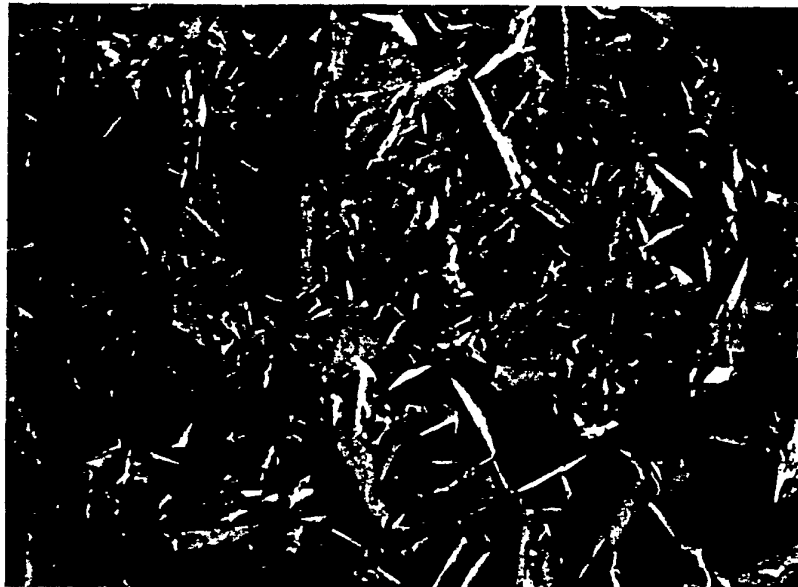


FIG. 25
(EXAMPLE K)

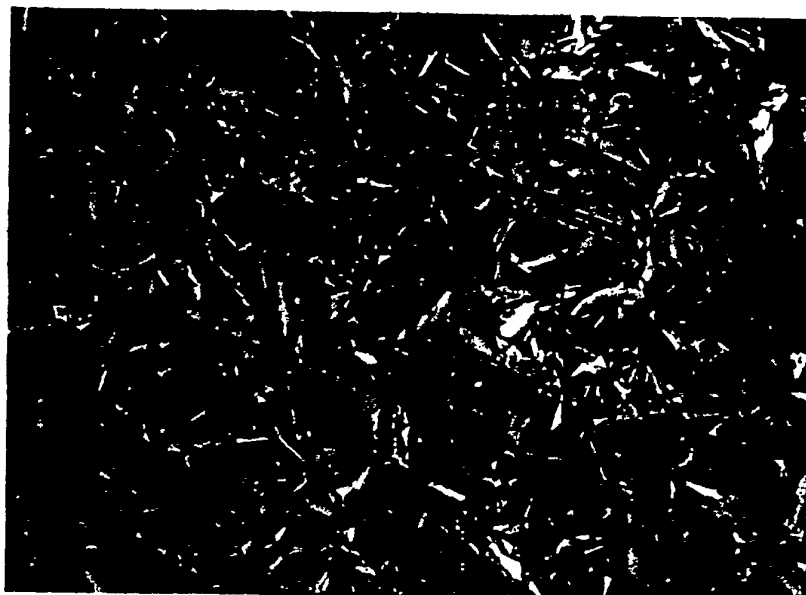


FIG. 26
(EXAMPLE L)

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FIG. 27
(EXAMPLE M)

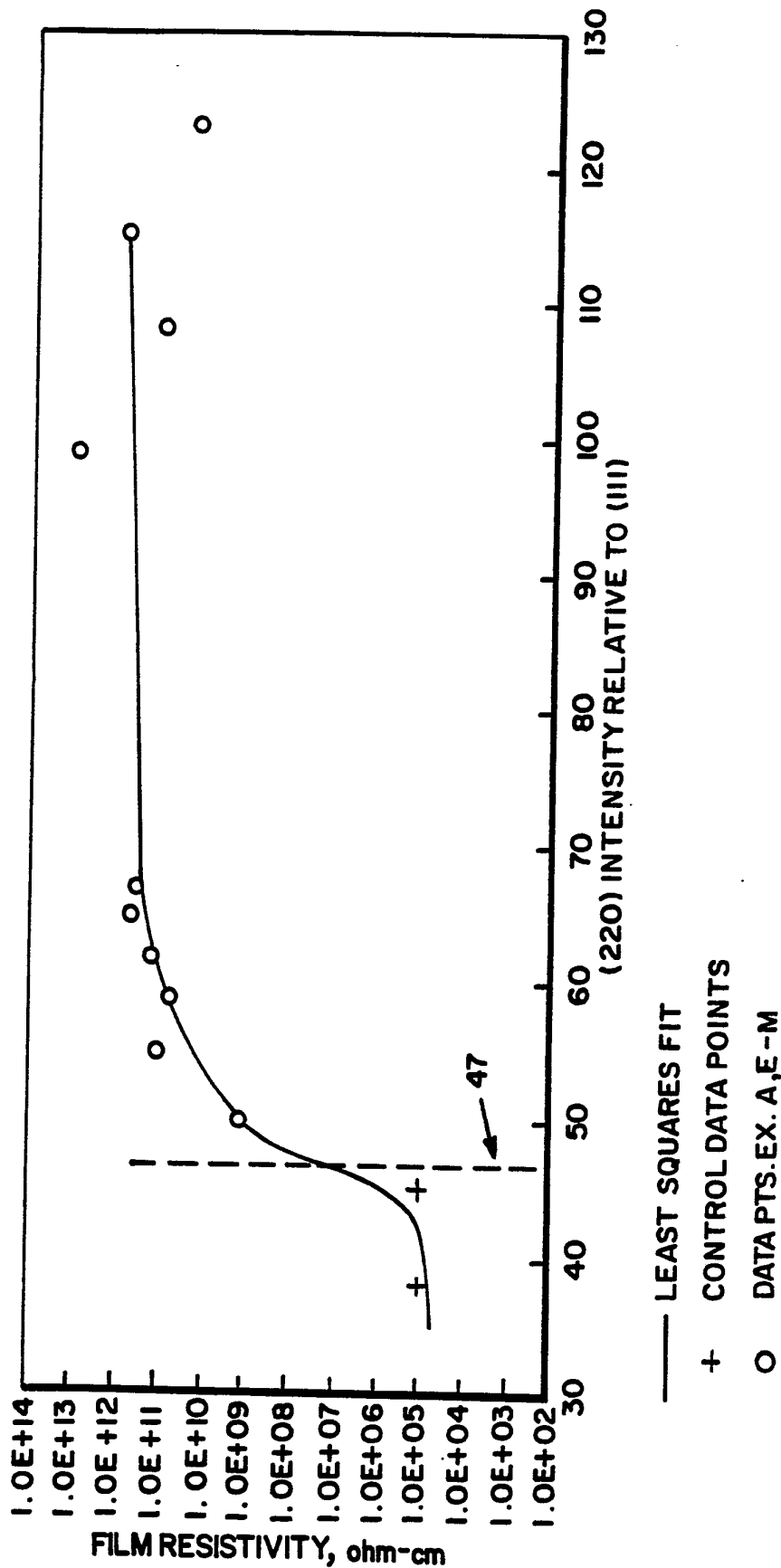


FIG. 28
(EXAMPLE P)

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FIG. 29

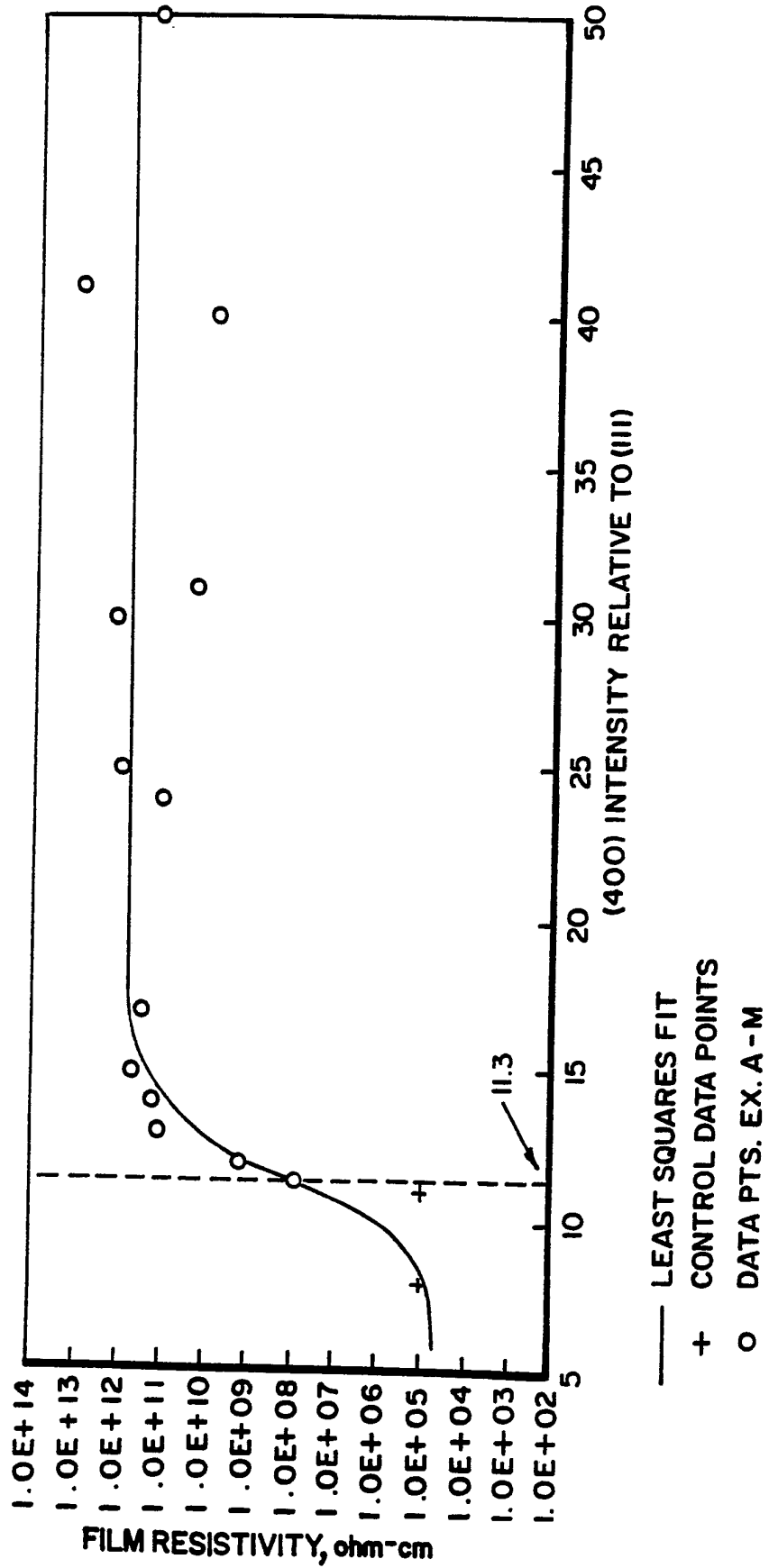
FILM RESISTIVITY VS. ORIENTATION
IN (220) DIRECTION



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FIG. 30

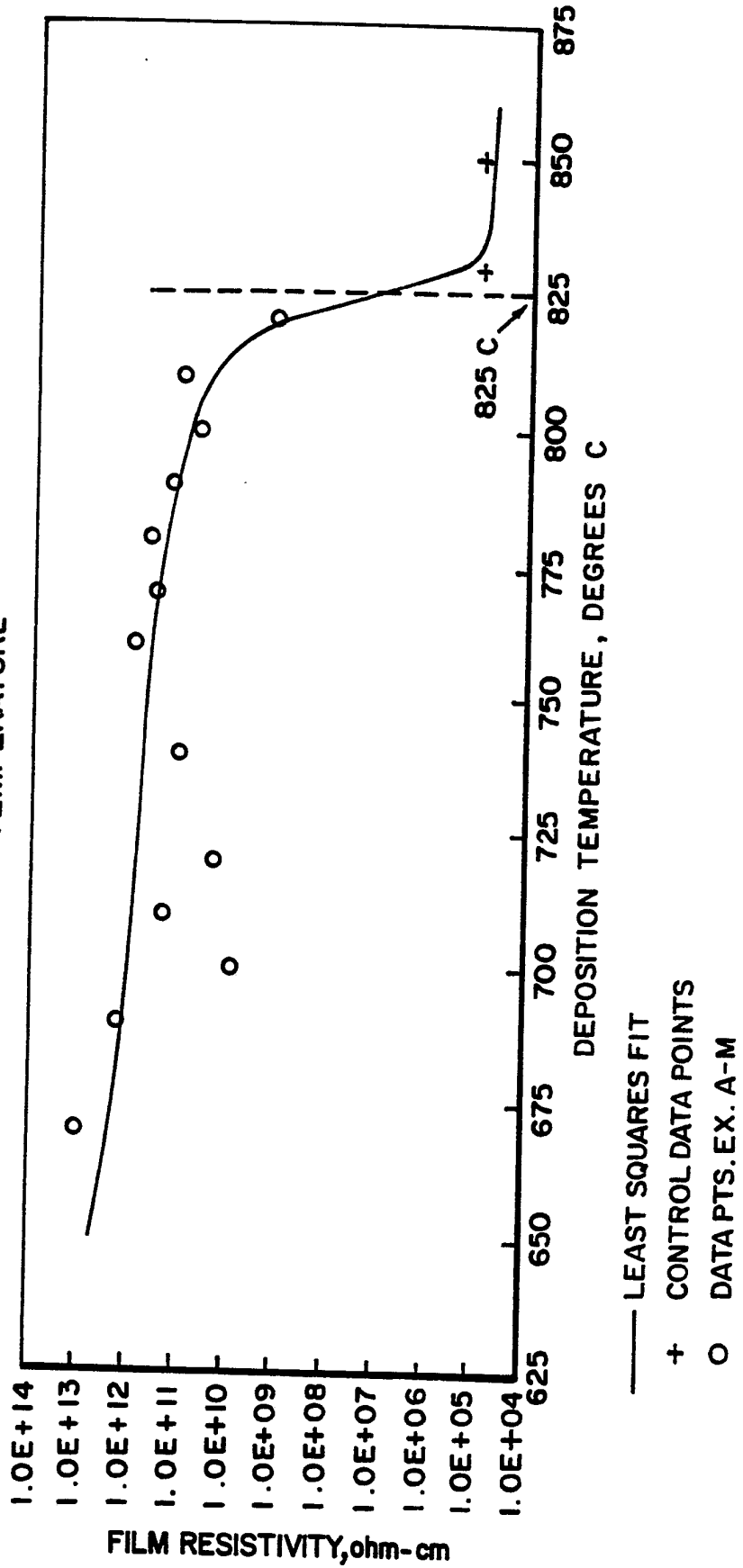
FILM RESISTIVITY VS. ORIENTATION
IN (400) DIRECTION



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FIG. 31

FILM RESISTIVITY VS. DEPOSITION TEMPERATURE



FILM RESISTIVITY, ohm-cm

DEPOSITION TEMPERATURE, DEGREES C

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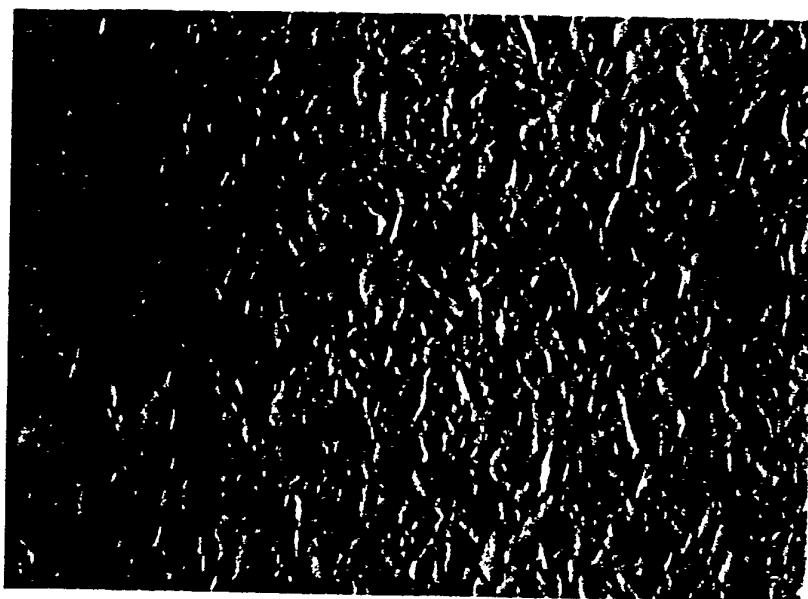


FIG. 32
(EXAMPLE Q)

INTERNATIONAL SEARCH REPORT

International Application No PCT/US91/01828

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ³		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC (5): B32B 9/00, 15/04; C23C 16/00, 16/26, 16/32		
U.S. CL: 428/336, 408, 446, 469, 472, 698; 427/255, 255.1, 255.2, 255.4		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁴		
Classification System	Classification Symbols	
U.S.	428/408, 336, 469, 472, 698, 446 427/255, 255.1, 255.2, 255.4	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁵		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴		
Category ⁶	Citation of Document, ¹⁵ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
Y	KOBASHI ET AL "Synthesis of diamonds by use of microwave plasma chemical-vapor deposition and growth of diamond films" <u>Physical Review</u> , Volume 38 Number 6 pages 4067-4084 (1988) see entire document.	1-4, 12
Y	US, A, 4,900,628 (IKEGAYA ET AL) 13 February 1990 see entire document.	1-13, 14-34
Y	ANGUS ET AL. "Low-Pressure, Metastable Growth of Diamond and 'Diamondlike' Phases" 1st <u>Science</u> Volume 241, 19 August 1988 pages 915-918.	14-22, 25, 27-34
Y	SINGH ET AL. "Hollow cathode plasma assisted chemical vapor deposition of diamond" <u>Appl. Phys. Lett</u> 52(20) 16 May 1988, see entire document.	1-10, 12, 14-22, 25, 27-34
A	JP, A, 61-163273 (FUJIMORI ET AL) 23 July 1986. English translation attached.	
A	JP, A, 61-163276 (KOBATA ET AL) 23 July 1986. English translation attached.	
<p>¹⁶ Special categories of cited documents: ¹⁵</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search ²	Date of Mailing of this International Search Report ²	
15 MAY 1991	25 JUN 1991	
International Searching Authority ¹	Signature of Authorized Officer ²⁰	
ISA/US	ARCHENE A. TURNER <i>Archene Turner</i>	

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, 1 ^a with indication, where appropriate, of the relevant passages 1 ⁷	Relevant to Claim No 1 ⁸
Y	HIROSE ET AL "Synthesis of Diamond Thin Films by Thermal CVD Using Organic Compounds" <u>Japanese Journal of Applied Physics</u> Volume 25 Number 6, June 1986. See Table II.	1-4, 12, 14-22, 25, 27-34
Y	ZHU ET AL "EFFECTS OF PROCESS PARAMETERS ON CVD DIAMOND FILMS" <u>J. Matter Res</u> Volume 4(3), 1989 pages 61-79, see entire document.	14-34
Y	US, A, 4,873,115 (MATSUMURA ET AL) 10 October 1989, see entire document.	1-4, 12, 14-22, 25, 27-34
Y	SETAKA "Diamond synthesis from vapor phase and its growth process" <u>J. Matter Res</u> , Volume 4, Number 3. May/June 1989 pages 664-670; see Fig. 7.	1-10, 12, 14-22, 25, 27-34
A	FARABAUGH ET AL "Growth of diamond films by hot filament chemical vapor deposition" <u>SPIE</u> , Volume 969 Diamond Optics (1988) pages 24-31.	
Y	JOFFREAU ET AL "Low-Pressure Diamond Growth on Refractory Metals" <u>R & HM</u> , December 1988, pages 186-194; see Table 2.	10-11, 23-24
Y	SAWABE ET AL "GROWTH OF DIAMOND THIN FILMS IN A DC DISCHARGE PLASMA" <u>Applied Surface Science</u> 33/34 (1988) pages 539-545; see Table 1.	1-10, 12
Y	ITO ET AL "Diamond Synthesis by the Microwave Plasma CVD Method Using a Mixture of Carbon Monoxide and Hydrogen Gas" <u>CHEMISTRY LETTERS</u> pages 589-592, 1988; see Fig. 4.	1-10, 12, 14-22, 25, 27-34
Y	US, A, 4,772,513 (SAKAMOTO ET AL) 20 September 1988, see column 2, lines 33-44.	1, 14, 27
Y	JP, A, 61-106494 (KYOCERA CORP) 24 May 1986. See Abstract.	12-13, 25-26
A	JP, A, 62-119 (KIKUCHI ET AL) 06 January 1987. English translation attached.	
A	EP, A, 0 161 829 (IMAI ET AL) 21 November 1985	
A	JP, A, 60-191097 (MITSUBISHI METAL KK) 28 September 1985	
A	FEDOSEEV ET AL "Synthesis of Diamond in its thermodynamic metastability Region" <u>Russian Chemical Reviews</u> , 53(5) 1984, pages 435-444.	
A	US, A, 4,434,188 (KAMO ET AL) 28 February 1984	

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No ¹⁸
A	MATSUMOTO ET AL "Growth of diamond particles from methane-hydrogen gas" <u>Journal of Materials Science</u> 17 (1982), pages 3106-3112.	
A	MATSUMOTO ET AL "Vapor Deposition of Diamond Particles from Methane" <u>Japanese Journal of Applied Physics</u> Volume 21, Number 4, April 1982.	