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(71) Applicant: **CORNING INCORPORATED**
Houghton Park
Corning New York 14831(US)

(72) Inventor: **Hagerty, Robert James**
Corning Incorporated,
Patent Dept.,
SP FR 02-12
Corning, NY 14831(US)
Inventor: **Jones, Clinton Raymond**
Corning Incorporated,
Patent Dept.,
SP FR 02-12
Corning, NY 14831(US)

(74) Representative: **Boon, Graham Anthony et al**
Elkington and Fife
Prospect House
8 Pembroke Road
Sevenoaks, Kent TN13 1XR (GB)

(54) Method of finely polishing planar optical elements.

(57) The present invention relates to a method of finely polishing an optically transparent surface with a polishing liquid containing abrasive particles. The polishing mixture, while subjected to ultrasonic agitation, is contacted with an optically transparent surface under conditions effective to polish finely that surface. The abrasive particles typically have a size of up to 1 micron. This process is particularly useful in smoothing the optically transparent surfaces which define cavities or sidewalls for planar optical elements in optical waveguides.

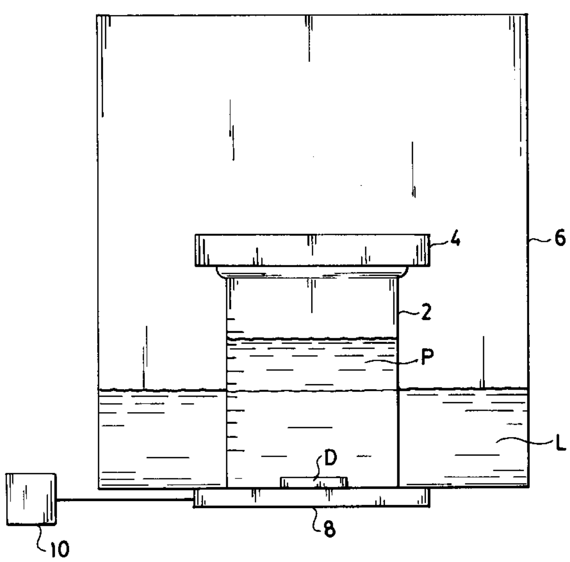

FIG. 1

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FIELD OF THE INVENTION

The present invention relates to a method of finely polishing planar optical elements used in conjunction with optical waveguides.

BACKGROUND OF THE INVENTION

Remote information is commonly transmitted by passing light waves through an optical waveguide, for example, an optical fiber. One type of optical waveguide device of current interest is a planar optical waveguide component. Such optical waveguide devices include a guide or core layer sandwiched between two cladding layers of media with lower indices of refraction than that of the guide layer. Increasingly, such optical waveguide devices include an integral planar optical element in the optical path of the waveguide. Such elements include lenses, gratings, and microprisms.

Where manufacturing integral optical elements, a technique of reactive ionic etching is sometimes used, see e.g. U.S. Patent No. 4,865,453 and U.S. Patent No. 4,740,951.

One problem encountered with reactive ionic etching is the formation of rough cavity surfaces. As a result, the integral optical elements formed in such cavities tend to have rough surfaces. Due to the small and isolated nature of such cavities, it is difficult to eliminate such roughness. These defects cause light scattering or loss which reduces the performance of the planar optical element. Such performance is generally expressed in terms of excess loss -- i.e. the amount of light loss above the loss in each optical channel due to optical circuitry splitting.

In M.M. Minot, et al., "A New Guided-Wave Lens Structure," Journal of Lightwave Technology, vol. 8, no. 12 (1990) a cavity is formed in the host waveguide by reactive ionic etching. The walls of the resulting cavities are then made smoother by a wet chemical polishing etch. A lens-shaped waveguide is then formed in the cavity by evaporative deposition of SiO_2 in the bottom of the cavity as a cladding layer. Glass, which acts as a guiding layer, is then diode sputter deposited in the cavity.

This technique is not commercially useful, because long treatment periods must be utilized. The present invention is directed to overcoming the surface roughness problem encountered in integral optical elements in a more efficient and cost effective fashion.

SUMMARY OF THE INVENTION

The present invention is directed to a method of finely polishing an optically transparent surface with a polishing liquid containing abrasive particles. The polishing liquid, while subjected to agitation, is contacted with an optically transparent surface under conditions effective to polish finely the optically transparent surface. Such agitation is desirably ultrasonic with the abrasive particles preferably having a size of up to 1 micron. The process is particularly useful where the optically transparent surface defines a cavity configured to define a planar optical element.

The procedure of the present invention substantially reduces the roughness of optically transparent cavity surfaces. When a planar optical element is subsequently formed in the cavity, the smoothness of the cavity surfaces causes the conforming surfaces of the planar optical element to be smooth. This substantially reduces the excess loss in the waveguide.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an ultrasonic polishing apparatus in accordance with the present invention.

FIG. 2 is a photograph taken with a scanning electron microscope of a cavity in an optical waveguide which has not been subjected to ultrasonic polishing.

FIG. 3 is a photograph taken with a scanning electron microscope of a cavity in an optical waveguide which has been subjected to one hour of ultrasonic polishing in accordance with the present invention.

FIG. 4 is a photograph taken with a scanning electron microscope of a cavity in an optical waveguide which has been subjected to 2 hours of ultrasonic polishing in accordance with the present invention.

FIG. 5 is a photograph taken with a scanning electron microscope of a cavity in an optical waveguide which has been subjected to ultrasonic polishing for 4 hours in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION AND DRAWINGS

The present invention relates to a method of finely polishing an optically transparent surface with a polishing mixture containing abrasive particles. The polishing mixture, while subjected to ultrasonic agitation, is contacted with an optically transparent surface under conditions effective to polish finely the optically transparent surface. This contact preferably involves immersing the surface in the polishing mixture.

FIG. 1 is a schematic view of an apparatus for ultrasonic polishing in accordance with the present invention. In this device, generator 10, which produces electrical output pulses, comprises a device for rapidly switching high-voltage DC on and off to produce pulses. Several known devices can accomplish such switching, and they include blocking oscillators, multivibrators, flip-flops, tunnel diodes, and others.

Pulses from generator 10 are supplied to transducer 8 which moves mechanically in response to the pulses. Several generally known devices can be made pulse-responsive to serve as transducer 8, and these include crystals, piezo-electrics, electrostrictive, magnetostrictive devices, and others.

Generator 10 is designed to operate in the ultrasonic frequency range of 20-45 kilohertz at an agitation power level of 150 to 200 watts. Transducer 8 is caused to operate under these conditions as a result of its being coupled to generator 10. In turn, transducer 8 is attached to the base or a side of tank 6 to vibrate liquid L under these conditions. Transducer 8, generator 10, and tank 6 are preferably together embodied in a conventional ultrasonic cleaning unit. One example of such a unit is the Branson D-150 Ultrasonic cleaner manufactured by Branson Equipment Co., Shelton, CT.

Planar optical device D is placed in container 2 for fine polishing in accordance with the present invention. A weighted cover 4 is then placed over container 2 to keep it in contact with the bottom of tank 6. Also held within container 2 is polishing mixture P which is subjected to ultrasonic conditions as the high intensity positive displacements produced in liquid L are transmitted through the wall of container 2. In turn, such displacements of polishing mixture P impinge planar optical device D. During operation of the apparatus of FIG. 1, the level of liquid L should be maintained at a height sufficient to ensure transmission of such positive displacements. Generally, a depth of 2.0 to 2.6 centimeters, preferably 2.54 centimeters, of liquid in tank 6 is sufficient.

Instead of utilizing the arrangement of FIG. 1, the ultrasonic polishing process of the present invention can employ a workholder or clamp to immerse planar optical device D in polishing mixture P of container 2. This technique is disclosed in U.S. Patent Nos. 2,796,702 and 3,564,775 to Bodine, Jr. which are hereby incorporated by reference.

In another alternative embodiment of the present invention, the process can be carried out without utilizing container 2 and cover 4. Polishing mixture P and planar optical device D can be placed directly in tank 6 for fine polishing.

Polishing mixture P is prepared from a mixture of a liquid and abrasive particles. The polishing mixture has a volumetric ratio of liquid to abrasive particles of 1:0.4 to 1:2.5, preferably 1:1.

Polishing can be carried out at any temperature which is not detrimental to the optically transparent surface being polished. Temperatures of not more than 20 to 50 °C should be used with room temperature being preferred. If need be, ice can be added to liquid L to ensure that it is not overheated by transducer 8.

Generally, the longer polishing is carried out, the smoother the optically transparent surfaces become. Polishing times of about 1 to 4 hours are usually satisfactory.

The abrasive particles preferably have a size of up to 1 micron, more preferably .1 to .3 microns. These particles are made from aluminum oxide, glass, diamond dust, carborundum, tungsten carbide, silicon carbide, boron carbide, and mixtures thereof. Preferably, aluminum oxide powder with a .3 micron particle size is utilized.

The liquid component of polishing mixture P can be any liquid suitable for slurrying the above abrasive particles. Such liquids include tap water and deionized water.

The fine polishing method of the present invention is useful in treating optically transparent surfaces which define a cavity or sidewall in an optical waveguide. Such cavities or sidewalls are formed by subjecting optical waveguides to reactive ionic etching and have a configuration corresponding to that of a planar optical element. After the cavity or sidewall is formed, it is finely polished in accordance with the present invention. A planar optical element is then formed in the polished cavity in accordance with the procedure of U.S. Patent Nos. 4,868,453 to Gidon, et al. and 4,740,951 to Lizet, et al. and M.M. Minot, "A New Guided-Wave Lens Structure," Journal of Lightwave Technology, vol. 8, no. 12 (1990), all of which are discussed above. Suitable planar optical element configurations are those of a geodesic component, a Luneberg lens, a Fresnel lens, a grating lens, a TIPE lens, and other similar microcomponent devices.

Several techniques are known for producing such planar optical elements in planar integrated optical devices. The following references disclose suitable procedures: U.S. Patent No. 4,712,856 to Nicia for geodesic components; Suhara, et al., "Graded-Index Fresnel Lenses for Integrated Optics," Applied Optics, vol. 21, no. 11, pp. 1966-71 (1982) for Fresnel lenses; Columbini, "Design of Thin-film Luneberg-type Lenses for Maximum Focal Length Control," Applied Optics, vol. 20, no. 20, pp. 3589-93 (1981) for Luneberg lenses; and Hatakoshi et al., "Waveguide Grating Lenses for Optical Couplers," Applied Optics, vol. 23, no. 11, pp. 1749-53 (1984) for grating lenses. Another technique has been developed where planar optical waveguides and components therein are fabricated using polymers, e.g., Fan, et al., EPO Patent Publication No. 0,446,672.

Geodesic lenses are characterized by a surface indentation in the top of the planar optical waveguide. Geodesic lenses require tight control during the manufacture of this surface indentation in order to keep scattering losses at transition points to a minimum.

Luneberg lenses, which are a subclass of geodesic lenses, require the use of a lens material which has a higher index of refraction than the planar optical waveguide substrate with which it is used.

Fresnel lenses, which are similar to zone plates in bulk optics, rely on phase shifting and/or absorption to obtain the desired focusing effect. This phase shifting is achieved through a series of half-period zones which are applied to a planar optical waveguide. For a more detailed discussion of the use of Fresnel lenses in planar optical waveguides, see Ashley et al., "Fresnel Lens in a Thin-film Waveguide", Applied Physics Letters, vol. 33, pages 490-92 (1978).

Other techniques for producing planar optical elements in optical waveguides are disclosed in U.S. Patent Application Serial No. 840,749 to Bhagavatula, which is hereby incorporated by reference.

Optically transparent surfaces treated in accordance with the present invention generally have a surface roughness which is substantially smoother than that encountered after reactive ionic etching. When surfaces of an optical waveguide cavity are finely polished in this fashion before formation of a planar optical element in the cavity, the waveguide has substantially less excess loss than waveguides which have not been polished in this fashion. Thus, optical waveguides treated in accordance with the present invention exhibit substantially better performance than those not subjected to polishing.

EXAMPLES

Example 1

An optical waveguide with a cavity formed by reactive ionic etching was subjected to a buffered oxide etch with a modified HF buffered solution for 30 seconds at an etch rate of 400 Angstroms per minute. After completion of the buffered oxide etch treatment, a photograph of the optical waveguide was taken with a scanning electron microscope. See Figure 2. This photograph shows that the cavity surfaces have significant roughness.

Example 2

An optical waveguide with a cavity like that of Example 1 was subjected to a buffered oxide etch according to the procedures set forth in Example 1.

The waveguide was then placed in a 30 milliliter beaker to which has been added a polishing mixture formulated from 10 milliliters of 0.3 micron alumina powder and 10 milliliters of water. The beaker was then placed in the tank of a Branson D-150 ultrasonic cleaner and a weighted plastic cover was put on top of the beaker to ensure that it remained in good contact with the base of the ultrasonic cleaner. The ultrasonic cleaner tank was then filled to a height of 2.54 centimeters of water so that ultrasonic vibrations were transmitted to the beaker contents. The ultrasonic cleaner was then turned on and operated for a period of 1 hour.

After completion of the ultrasonic treatment, the optical waveguide was removed and a photograph of it was taken with a scanning electron microscope. This photograph is FIG. 3. A comparison of FIGS. 2 and 3 show that the fine polishing procedure of the present invention produces a substantially smoother cavity.

Example 3

The test procedure of Example 2 was repeated except that the ultrasonic polishing stage was carried out for 2 hours. After completion of ultrasonic polishing, the optical waveguide was removed from the polishing mixture and a photograph of it was taken with a scanning electron microscope. This photograph is FIG. 4. A comparison of FIG. 4 with FIGS. 2 and 3 shows that increasing the ultrasonic polishing time enhances the smoothness of the cavity walls.

Example 4

The process of Example 2 was repeated except that the ultrasonic polishing time was 4 hours. After completion of ultrasonic polishing, the optical waveguide was removed from the polishing mixture and a photograph of it was taken with a scanning electron microscope. This photograph is FIG. 5. A comparison of FIG. 5 with FIGS. 2, 3, and 4 indicates that the 4 hour polishing time achieved increased smoothness of the cavity walls.

Example 5

1x8 coupler/splitter devices were made according to the design and process set forth in copending U.S. Patent Application Serial No. 07/840,749, which is incorporated herein by reference. One such device was measured after processing according to Example 1 for optical performance. The mean ratio between the input power and the output power for the 8 outputs was approximately 12 dB (theoretical ratio is 9 dB for 1x8 splitting).

Another such device was additionally treated according to the polishing process of Example 4. The mean excess loss was about 11 dB, an improvement of 33% from the excess loss without the inventive polishing treatment.

Claims

1. A method of finely polishing an optically transparent surface which defines a cavity or wall in an optical element contained in a small, planar optical device, said method comprising:

providing a polishing mixture in the form of a liquid slurry containing small abrasive particles and

contacting the polishing mixture, while subjected to agitation, with an optically transparent surface which defines a cavity or wall in an optical waveguide contained in a small, planar optical device under conditions effective to polish finely the optically transparent surface.

2. A method according to claim 1, wherein said contacting involves immersing the optically transparent surface in the polishing mixture.

3. A method according to claim 2, wherein the polishing mixture is in a container, wherein the container is maintained in a liquid bath which is subjected to ultrasonic agitation.

4. A method according to claim 1, wherein the agitation is carried out under ultrasonically at a frequency of 20 to 45 kilohertz, or a power level of 150 to 200 watts, or both.

5. A method according to claim 1, wherein the abrasive particles are made from aluminum oxide, glass, diamond dust, carborundum, tungsten carbide, silicon carbide, boron carbide, and mixtures thereof.

6. A method according to claim 1, wherein the polishing mixture has a volumetric ratio of liquid to abrasive particles of 1:0.4 to 1:2.5.

7. A method according to claim 1, wherein the optically transparent surface is configured to define a planar optical element, a geodesic component, a Luneberg lens, a Fresnel lens, a grating lens, a TIPE lens, or other similar microcomponent devices.

8. A method according to claim 9, wherein the optically transparent surface defines a cavity or sidewall in an optical waveguide.

9. A method according to claim 1, wherein the abrasive particles have a size of up to 1 micron, preferrably a size range of .1 to .3 microns.

10. A method of finely polishing an optically transparent surface which defines a cavity or wall in an optical waveguide contained in a small planar optical device, said method comprising:

providing a polishing mixture, while subjected to ultrasonic agitation, with an optically transparent surface which defines a cavity or wall in an optical waveguide contained in a small planar optical device under conditions effective to polish finely the optically transparent surface.

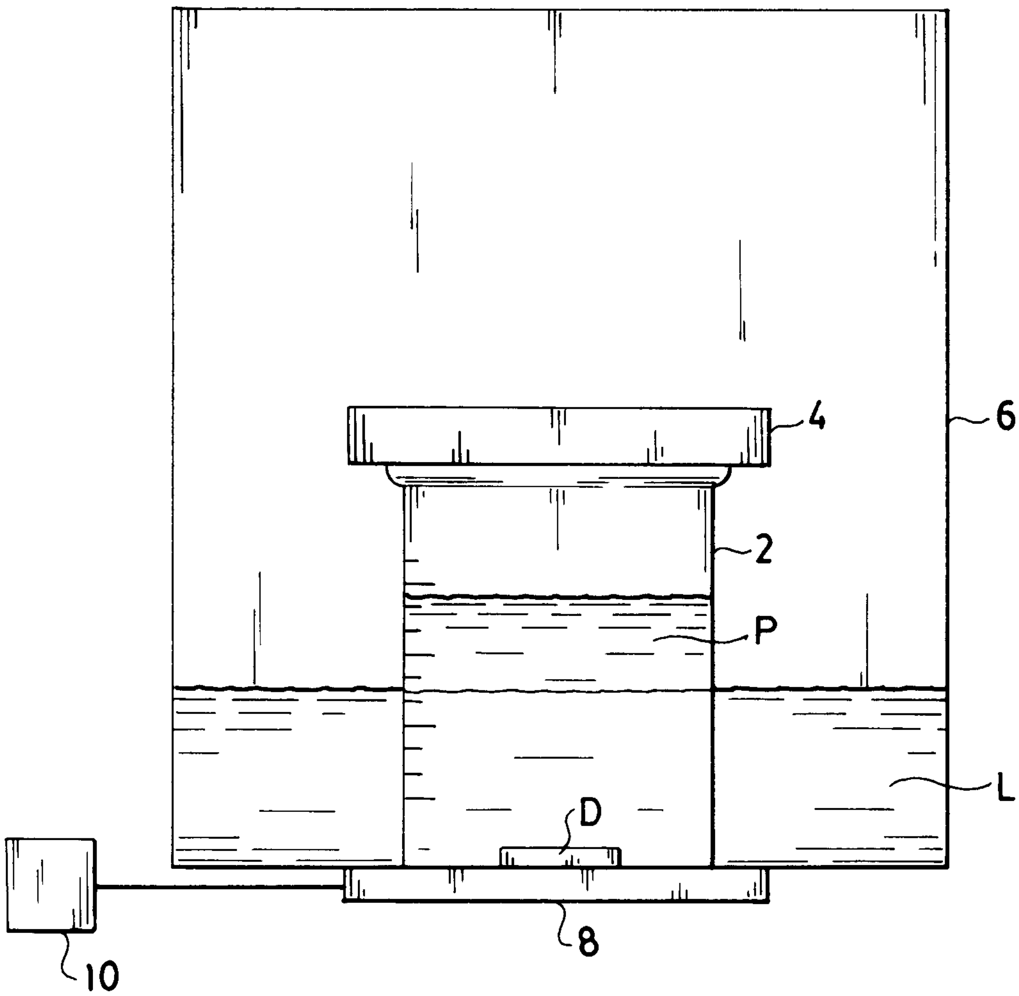

FIG. 1

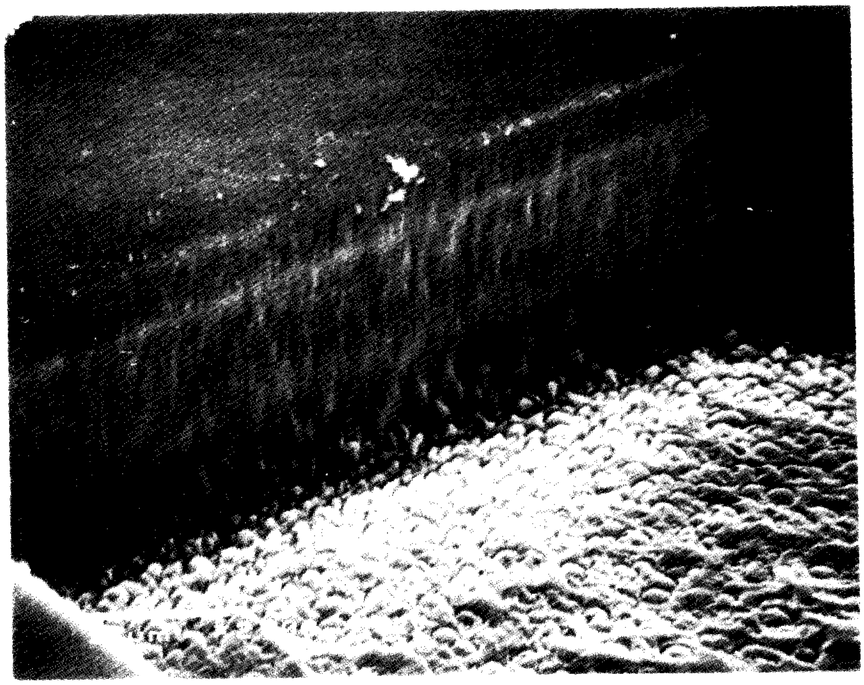

FIG. 2

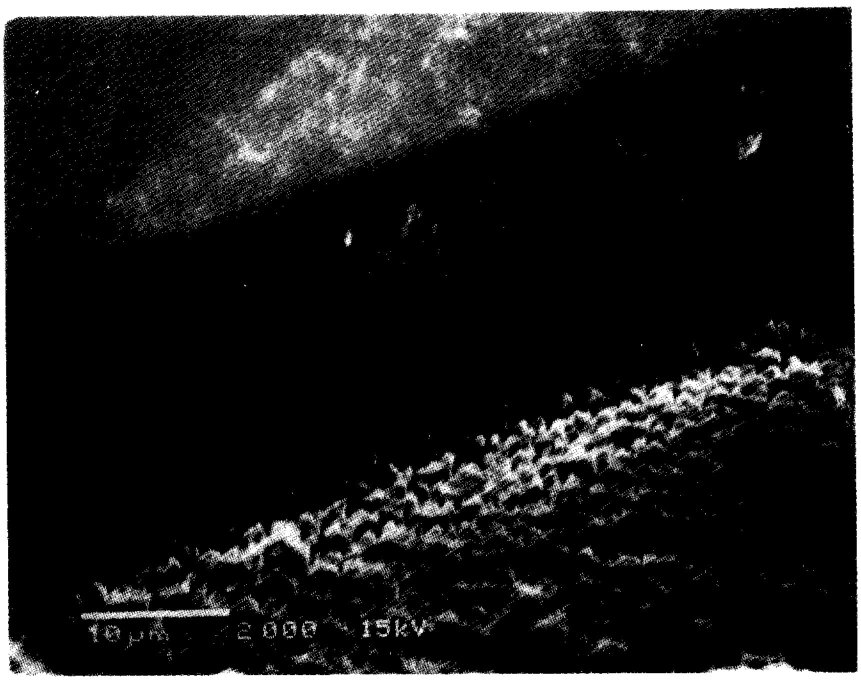

FIG. 3

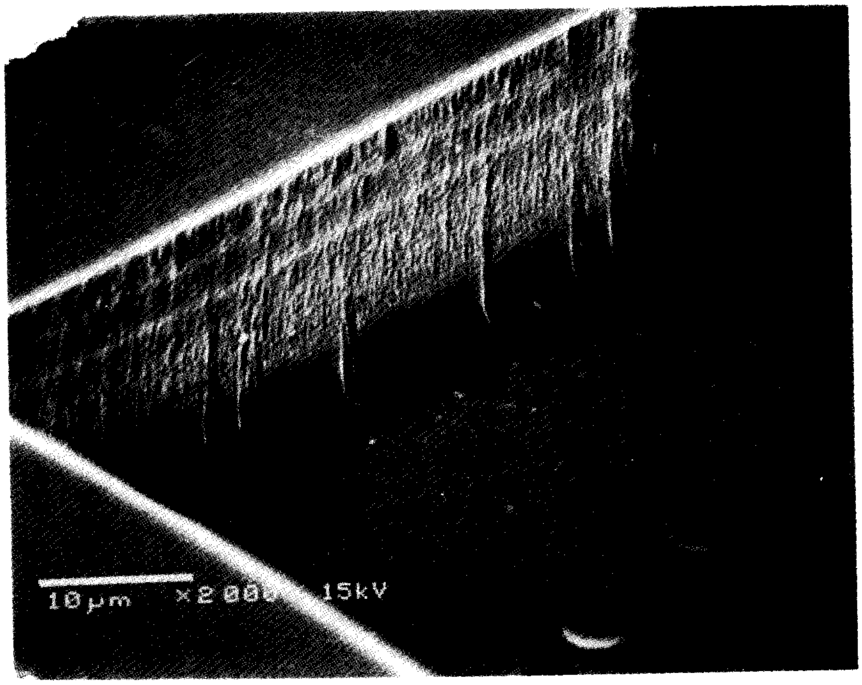

FIG. 4

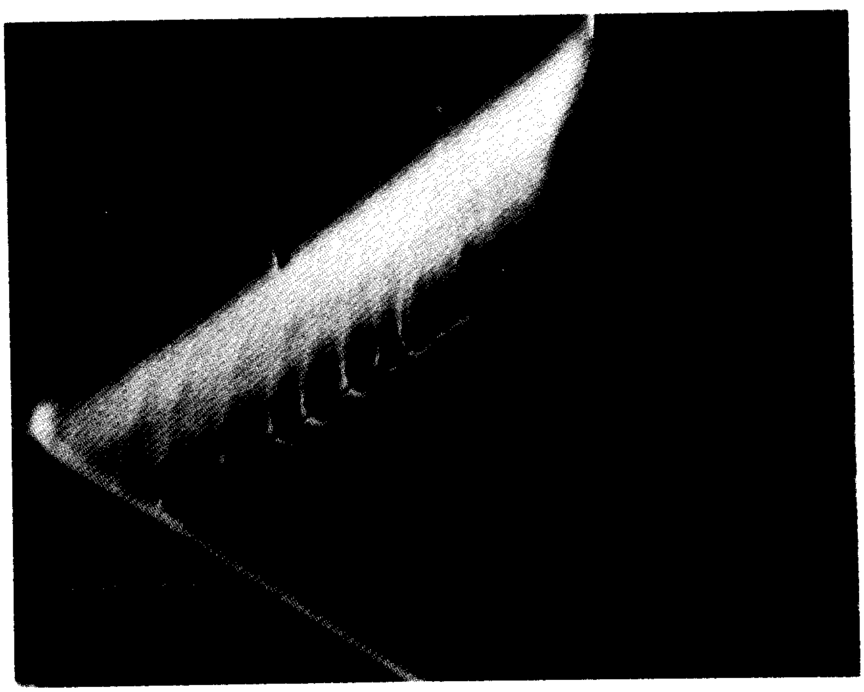

FIG.5

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EUROPEAN SEARCH REPORT

Application Number
EP 94 10 0543

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 April 1994	Eschbach, D

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EUROPEAN SEARCH REPORT

Application Number
EP 94 10 0543

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
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TECHNICAL FIELDS SEARCHED (Int.Cl.5)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 April 1994	Eschbach, D

CATEGORY OF CITED DOCUMENTS

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