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(54) Polishing system and method for soft metal surfaces using CO₂ snow

(57) A system (10) and method for polishing metal surfaces (20), such as gold mirror surfaces, and the like, using CO₂ snow (18) is disclosed. The system and method produces sub-Angstrom surface roughness of the polished metal surface. The system includes an enclosure (12) for holding a component (32) having a metal surface (20) that is to be polished. A CO₂ jet spray system (11) is provided for producing solid CO₂ gas snow (18). An operator-controllable robotic arm (30) is used to position the component (32) within the enclosure (12) and position the CO₂ jet spray system (11) relative to the surface (20) to polish it. The CO₂ jet spray

system (10) polishes the metal surface (20) using mechanical action derived from the solid CO₂ gas snow (18) produced by controlled expansion of liquid CO₂. The method comprises disposing the component having the metal surface that is to be polished into an enclosure. Solid CO₂ gas snow is generated within the enclosure using the CO₂ jet spray system. The CO₂ jet spray system is moved to move the solid CO₂ gas snow (18) relative to the surface of the component to polish the metal surface.

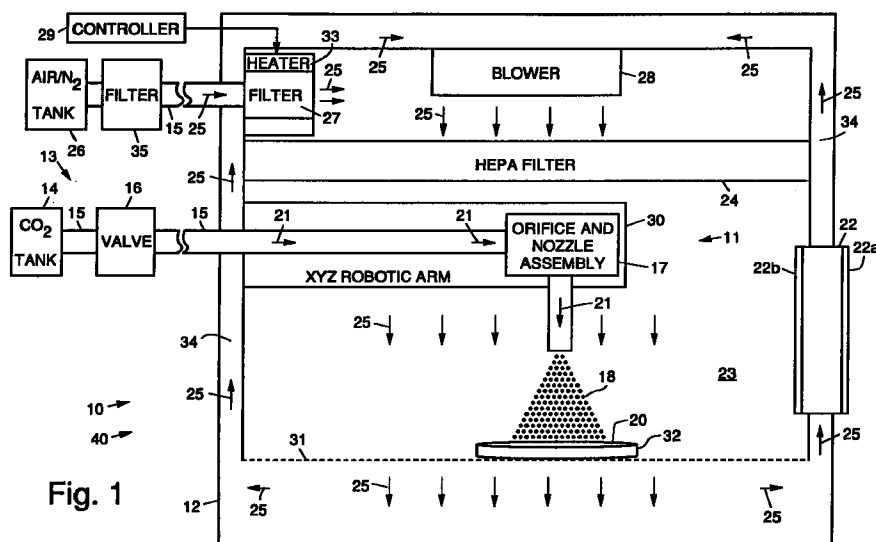


Fig. 1

Description

BACKGROUND

The present invention relates generally to systems and methods for polishing soft metal surfaces, and more particularly, a system and method for polishing soft metal surfaces, such as gold mirrors, and the like, using CO₂ snow that achieves sub-Angstrom surface roughness.

Heretofore, no system or method has been available to polish soft metal surfaces, such as gold mirror surfaces, for example, to provide sub-Angstrom surface roughness. Presently available technology uses wet polishing to prepare a substrate to Angstrom roughness or better, then gold is applied using thin film deposition processes. The resulting gold surface is very soft and cannot be mechanically or chemically polished to the same smoothness as the underlying substrate.

Also, there is no presently available system that employs a gas/solid jet spray polishing system using CO₂ snow within an ultra-clean processing environment enclosure to provide a polishing system for use with soft metal surfaces. These two separate technologies have not heretofore been combined to provide a system for polishing of soft metal surfaces. Conventional systems actually contribute to the production of dirt contamination and condensation of the metal surface that is polished because of the nature of the conventional polishing processes that are used. Consequently, the conventional polishing systems would not be employed in an ultra-clean processing environment.

Accordingly, it is an objective of the present invention to provide for a system and method for polishing soft metal surfaces to sub-Angstrom surface roughness. It is a further objective of the present invention to provide for a system and method for polishing soft metal surfaces using CO₂ snow.

SUMMARY OF THE INVENTION

To meet the above and other objectives, the present invention provides for a system and method that may be used to polish metal surfaces, such as gold mirror surfaces, and the like, using CO₂ snow. The system and method produces sub-Angstrom surface roughness of the polished metal surface.

In general, the system comprises an enclosure for holding a component having a metal surface that is to be polished. A CO₂ jet spray system is provided for producing solid CO₂ gas snow. An operator-controllable robotic arm is disposed within the enclosure for positioning the component whose metal surface is to be polished and for moving and positioning the CO₂ jet spray system relative to the surface of the component to polish it. The CO₂ jet spray system polishes the metal surface using mechanical action derived from the solid CO₂ gas snow produced by controlled expansion of liquid CO₂.

The present invention employs a gas/solid jet spray device disposed within the enclosure, such as is provided by an ultra-clean process enclosure. The enclosure houses precision process tools for inspecting, testing, and polishing soft metal coatings, including gold mirror coatings, and the like. The jet spray polishing system includes a CO₂ gas delivery system and orifice and nozzle combinations that are used to optimally expel CO₂ snow. The jet spray orifice and nozzle combinations are designed to polish metal surfaces with mechanical action derived from solid gas snow produced by controlled expansion of liquid CO₂.

The polishing is performed in the ultra-clean enclosure. Environmental dust and condensation causes damage to soft metal surfaces, and particularly to gold surfaces. The ultra-clean enclosure includes a large sealed chamber or processing space, a pre-filter, a high capacity blower, a high flow rate, high efficiency particulate air (HEPA) filter, a ducting system, and a dry gas purge system to reduce humidity. A dry, clean environment is provided within the ultra-clean enclosure, which is necessary to eliminate condensation that interferes with the polishing process.

The solid/gas jet spray polishing system was specifically designed to be used as a final step required to produce ultra-low scattering gold mirrors employed in optical systems manufactured by the assignee of the present invention. However, the present system and method may also be used to prepare other soft metal surfaces used in metrology and other fields where Angstrom quality surfaces are required.

The present method comprises disposing a component having a metal surface that is to be polished into an enclosure. Solid CO₂ gas snow is generated within the enclosure using a CO₂ jet spray system. The CO₂ jet spray system is moved to move the solid CO₂ gas snow relative to the surface of the component to polish the metal surface. The solid CO₂ gas snow polishes the metal surface using mechanical action produced by controlled expansion of liquid CO₂.

The polishing system and method of the present invention can polish a delicate surface, such as gold, without scratching or mechanical contact that is encountered with using an abrasive agent. The present system and method is clean and produces no waste residue in the form of liquid slurries or chemical residues. The jet spray produced by the polishing system is environmentally friendly and the snow that is produced sublimates away and is vented to the atmosphere. The present jet spray polishing system and method is believed to be the only currently-available technology capable of polishing a gold or other soft metal surface without damaging the surface. However, the present system and method for polishing gold and other soft metal surfaces is relatively slower than chemical or mechanical polishing methods.

BRIEF DESCRIPTION OF THE DRAWINGS

The various features and advantages of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

Fig. 1 illustrates a gas/solid jet spray polishing system and method in accordance with the present invention;

Fig. 2 is a graph showing the measured surface roughness of a gold surface prior to use of the system and method of Fig. 1;

Fig. 3 is a graph showing the measured surface roughness of a gold surface after use of the system and method of Fig. 1; and

Fig. 4 is a flow diagram illustrating one embodiment of the present method.

DETAILED DESCRIPTION

Referring to the drawing figures, Fig. 1 is illustrative of a gas/solid jet spray polishing system 10 and method 40 in accordance with the present invention that is used to polish a metal surface 20 to sub-Angstrom surface roughness. The gas/solid jet spray polishing system 10 is comprised of a jet spray system 11, that may comprise an ECO-SNOW™ jet spray device manufactured by the assignee of the present invention, for example, that is disposed within an ultra-clean processing enclosure 12. The jet spray system 11 includes a gas delivery system 13 comprising a tank 14 for storing liquid CO₂ 21 and tubing 15, a valve assembly 16 or assemblies, and a nozzle and orifice assembly 17 that includes different nozzle and orifice combinations that are used to produce solid CO₂ gas snow 18. The jet spray nozzle and orifice combinations that form the nozzle and orifice assembly 17 are designed to polish the metal surface 20 with mechanical action derived from the solid gas snow 18 produced by controlled expansion of the liquid CO₂ 21 through the selected nozzle and orifice combination that is used. Typical orifice assemblies 17 are disclosed in US Patent Application Serial No. 08/356,606 filed December 15, 1995, entitled CO₂ Jet Spray Nozzles with Multiple Orifices, and US Patent Application Serial No. 08/356,607 filed December 14, 1995, entitled CO₂ Jet Spray Nozzles Having a Fixed Orifice, both of which are assigned to the assignee of the present invention.

The ultra-lean processing enclosure 12 is comprised of a loadlock pass-through 22 having a front entry door 22a and a rear exit door 22b that permits entry into a laminar flow, inner processing space 23 of the enclosure 12. A high efficiency particulate air (HEPA) filter 24 is provided to filter nitrogen gas 25 or dry air 25 supplied from a nitrogen or dry air tank 26. A stainless steel mesh surface 31 or floor 31 is provided

within the ultra-clean processing enclosure 12 through which the filtered nitrogen gas 25 or dry air 25 passes to permit recirculation thereof. The nitrogen gas 25 or dry air 25 is pre-filtered by means of an inlet filter 35 and a second filter 27 or pre-filter 27, and the prefiltered nitrogen gas 25 or dry air 25 is recirculated through the inner processing space 23 using a high scfm capacity recirculation blower 28. A heater 33 surrounds the second filter 27 which is controlled by a temperature controller 29. The HEPA filter 24, blower 28, stainless steel mesh surface 31, and inner processing space 23 form a nitrogen gas 25 or dry air 25 purging system. An operator-controllable XYZ robotic arm 30 is disposed within the inner processing space 23 that is used to move and position the nozzle and orifice assembly 17 and to move and position a component 32 that is to be polished into position.

The ultra-clean processing enclosure 12 also includes temperature controls (not shown) that are part of the temperature controller 29. The ultra-lean processing enclosure 12 encloses precision process inspection and testing tools (not shown), in addition to the present jet spray system 11. The inspection, testing and jet spray system 11 provides a complete system 10 for polishing soft metal surfaces 20 and coatings, including gold mirror surfaces and coatings, and the like.

In operation, an operator of the system 10 loads the component 32 having a metal surface 20 or coating that to be polished through the loadlock pass-through 22 and into the inner processing space 23. Initial entry into the loadlock pass-through 22 may be gained by opening the front access door 22a. When the component 32 has been placed into the pass-through, the rear door 22b is opened, and the robotic arm 30 is manipulated by the operator to pick up the component 32. The robotic arm 30 is used to transport the component 32 into the inner processing space 23 for cleaning, testing and polishing.

The temperature of the inner processing space 23 is held above ambient and is regulated by feedback controls (not shown) on the heater 33 that surrounds the second filter 27. Nitrogen gas 25 or air 25 coming into the inner processing space 23 is filtered three times, by the inlet filter 35, by the second filter 27, and by the high flow HEPA filter 24. The nitrogen gas 25 or air 25 is pulled through the high capacity blower 28 and pushed through the HEPA filter 24 into the inner processing space 23. Gas flowing during the polishing process is collected by a return duct 34 and is recirculated through the inner processing space 23.

The high velocity spray of solid gas particles that forms the solid gas snow 18 is directed over the surface 20 of the component 32 that is to be polished. The contact of the solid gas particles with the surface 20 removes protruding surface features one atom at a time. This removal leaves a very fine, sub-Angstrom, polished surface 20.

Atomic force microscopy confirms polishing of a gold mirror surface 20 with a CO₂ gas, solid jet spray. Fig. 2 is a graph showing the measured surface rough-

ness of a gold surface 20 prior to use of the system 10 and method 40 of the present invention, while Fig. 3 is a graph showing the measured surface roughness of the gold surface 20 after use of the present system 10 and method 40.

A WYCO surface profiler was used to measure the surface roughness of the polished component 32 which supports the atomic force microscopy data of the component 32 that was polished and tested. The gold surface 20 had an root-mean-square (RMS) roughness of 9.83Å prior to polishing, and after polishing with solid CO₂ as snow 18, the RMS roughness was 6.13Å. The peak-to-valley went from 4.48Å before polishing to 2.65Å after polishing, further indicating the effectiveness of the sub-Angstrom polishing of the surface 20 of the component 32 using the CO₂ gas/solid jet spray system 10.

The polishing process using the present system 10 and method 40 is performed in the ultra-clean enclosure 12. Environmental dust and condensation causes damage to metal surfaces 20, and particularly to gold surfaces. The second filter 27, high capacity blower 28, HEPA filter 24, ducting 34, and dry gas purge system reduces humidity. The dry, clean environment provided within the ultra-lean enclosure 12 eliminates condensation that interferes with the polishing process.

The solid/gas jet spray polishing system 10 was specifically designed to be used as the final step required to produce ultra-low scattering gold mirrors employed in optical systems manufactured by the assignee of the present invention. However, the present system 10 and method 40 may also have use in preparing other metal or soft metal surfaces 20 for metrology and other fields where Angstrom quality surfaces 20 are required.

The polishing system 10 and method 40 of the present invention is capable of polishing a delicate surface 20, such as gold, without scratching or mechanical contact using an abrasive agent. The process is clean with no waste residue in the form of liquid slurries or chemical residues. The gas/solid jet spray 18 is environmentally friendly and the snow that is produced sublimates away and may be vented to the atmosphere. The present solid/gas jet spray polishing system 10 and method 40 is believed to be the only available technology capable of polishing a gold surface 20 without damaging the surface 20. While the present system 10 and method 40 polishes gold and other soft metal surfaces 20 to sub-Angstrom surface roughness, it is relatively slow compared to conventional chemical or mechanical polishing methods.

For the purposes of completeness, the present polishing method 40 will be described with reference to Fig. 4. Fig. 4 is a flow diagram illustrating one embodiment of the present method. In its most general form, the present method 40 comprises the steps of disposing 41 a component having a metal surface that is to be polished into an enclosure 12. Solid CO₂ gas snow 18 is generated 42 within the enclosure 12 using a CO₂ jet

spray system 11. The CO₂ jet spray system 11 is moved 43 to move the solid CO₂ gas snow 18 relative to the surface 20 of the component 32 to polish the metal surface 20. The solid CO₂ gas snow 18 polishes the metal surface 20 using mechanical action produced by controlled expansion of liquid CO₂ 21.

Thus, a system and method for polishing soft metal surfaces using CO₂ snow that achieves sub-Angstrom surface roughness has been disclosed. It is to be understood that the described embodiments are merely illustrative of some of the many specific embodiments which represent applications of the principles of the present invention. Clearly, numerous and other arrangements can be readily devised by those skilled in the art without departing from the scope of the invention.

Claims

1. A system for polishing a metal surface, characterized by

an enclosure (12) for holding a component having a metal surface (20) that is to be polished; a CO₂ jet spray system (11) for producing solid CO₂ gas snow (18); and an operator-controllable robotic arm (30) disposed within the enclosure (12) for positioning the component (32) whose metal surface is to be polished and for moving and positioning the CO₂ jet spray system (11) relative to the surface (20) of the component (32) to polishing it; and wherein the CO₂ jet spray system (11) polishes the metal surface (20) using mechanical action derived from solid CO₂ gas snow (18) produced by controlled expansion of liquid CO₂ (21).

2. The system of claim 1, characterized in that the enclosure (12) comprises a processing space (23) and means for transferring said component that is to be polished into the processing space (23);

said CO₂ jet spray system (11) is coupled to the enclosure (12) and comprises a tank (14) comprising liquid CO₂, a nozzle and orifice assembly (17) that includes a nozzle and orifice for producing solid CO₂ gas snow (18), and tubing (15) coupled between the tank (14) and the nozzle and orifice assembly (17) for transferring the liquid CO₂ to the nozzle and orifice assembly (17); and said operator-controllable robotic arm (30) is disposed within the processing space (23) for positioning the component (32) that is to be polished and for moving and positioning the nozzle and orifice assembly (17) relative to the surface (20) of the component (32) for polishing thereof.

3. The system of any of the preceding claims, characterized in that the CO₂ jet spray system (11) further comprises a valve assembly (16). surface (20) of the component (32).
4. The system of any of the preceding claims, characterized in that the enclosure (12) comprises an ultraclean processing enclosure (12). 5
5. The system of any of the preceding claims, characterized in that the enclosure (12) comprises a load-lock pass-through (22) having a front entry door (22a) and a rear exit door (22b) that permits loading of the component into the inner processing space (23) of the enclosure (12). 10
6. The system of any of the preceding claims, characterized in that the enclosure (12) comprises a temperature controller (29) coupled to a heater (33) for controlling the temperature of the processing space (23). 15 20
7. The system of any of the preceding claims, characterized in that the means for recirculating gas through the processing space (23) comprises 25
 - a blower (28);
 - a high efficiency particulate air filter (24) for filtering the gas (25); and
 - a stainless steel mesh surface (31) through which filtered gas (25) passes to permit recirculation thereof. 30
8. A method of polishing a metal surface characterized by the steps of: 35
 - disposing (41) a component having a metal surface (20) that is to be polished into an enclosure (12);
 - generating (42) solid CO₂ gas snow (18) within the enclosure (12) using a CO₂ jet spray system (11); and 40
 - moving (43) the CO₂ jet spray system (11) to move the solid CO₂ gas snow (18) relative to the surface (20) of the component (32) to polish the metal surface (20); 45
 - and wherein the solid CO₂ gas snow (18) polishes the metal surface (20) using mechanical action produced by controlled expansion of liquid CO₂ (21). 50
9. The method of claim 8, characterized by the step of recirculating gas through the enclosure (12) to purge the enclosure.
10. The method of claim 8 or 9, characterized by the step of moving the CO₂ jet spray system (11) comprises using an operator-controllable robotic arm (30) disposed within the processing space (23) to move the solid CO₂ gas snow (18) relative to the 55

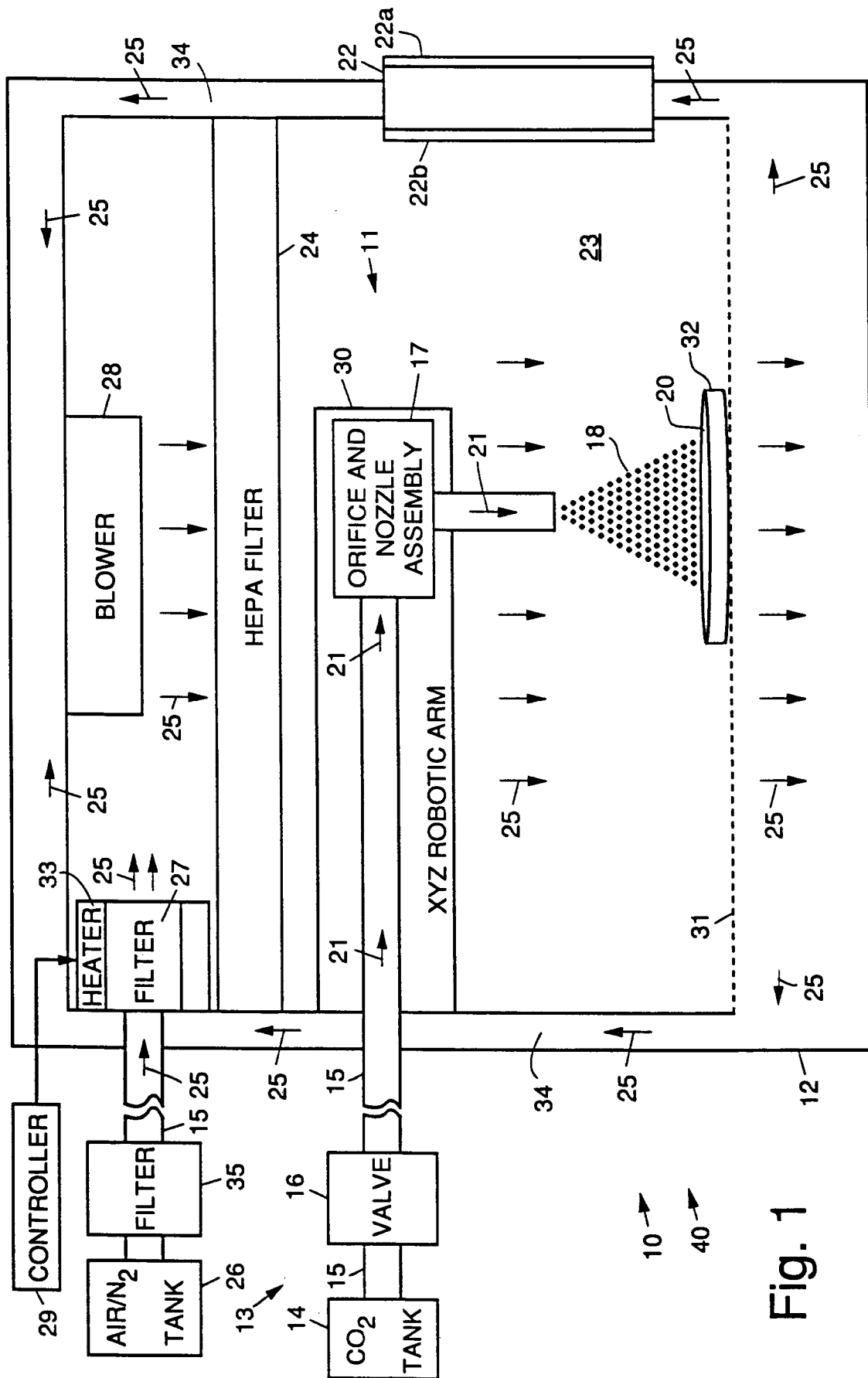


Fig. 1

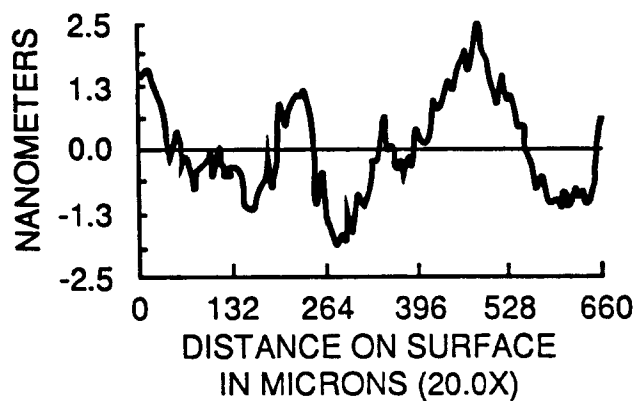


Fig. 2

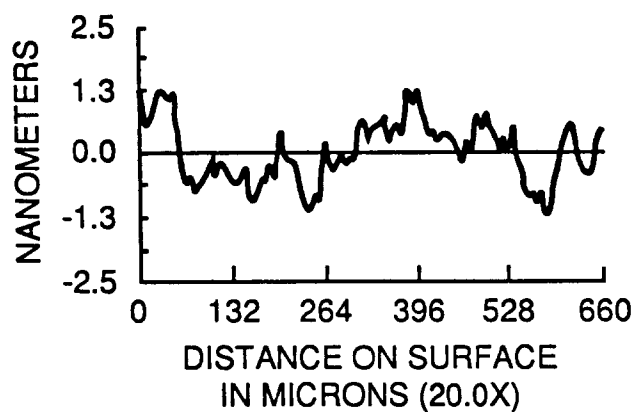
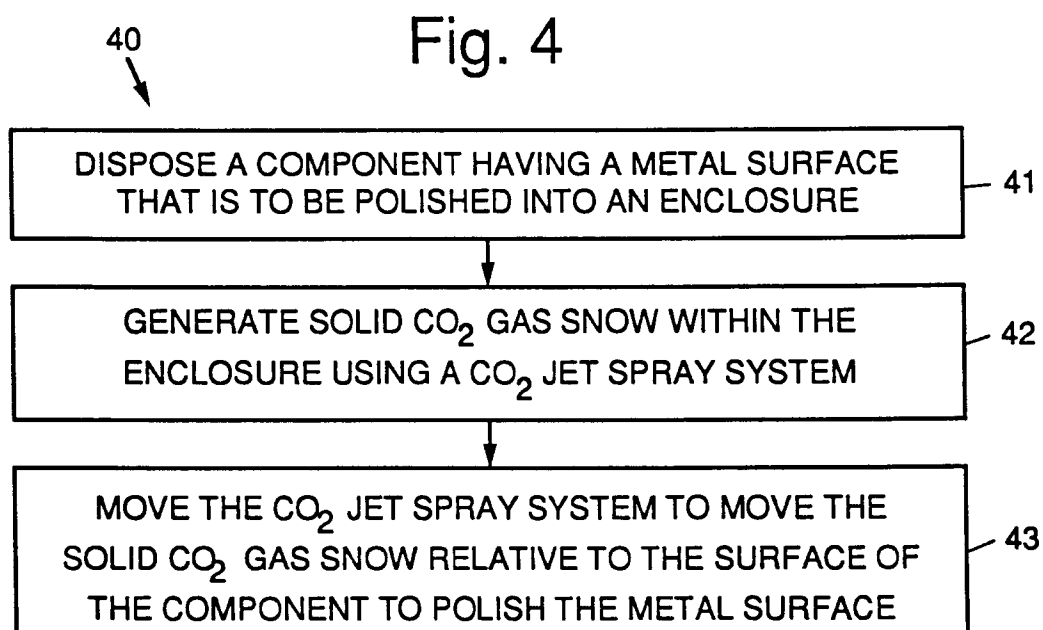


Fig. 3





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 11 5274

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.6)
Y	US-A-3 702 519 (EDWIN EUGENE RILE ET AL.) * abstract; figure 1 * ---	1-3,5,8,10	B24C1/00
Y	US-A-5 364 472 (GARRET J. HEYNS ET AL.) * abstract; figure 1 * ---	1-3,5,8,10	
A	EP-A-0 535 680 (HUGHES AIRCRAFT COMPANY) * abstract; figure 1 * ---	4,6,7,9	
A	EP-A-0 288 263 (THE BOC GROUP, INC.) * abstract; figure 1 * ---	1-10	
A	US-A-4 475 794 (MARTIN L. BAKER ET AL.) * abstract; figure 1 * -----	1,3,8	
A		1,8	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			B24C
Place of search		Date of completion of the search	Examiner
BERLIN		16 December 1996	Cuny, J-M
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document			

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