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SEPARATION OF CF_4 AND C_2F_6 FROM
A PERFLUOROCOMPOUND MIXTURE ✓

FIELD OF THE INVENTION

The present invention generally relates to a gas separation process. The invention particularly relates to a process for separating CF_4 and C_2F_6 from a
5 perfluorocompound gas mixture by a hybrid system involving membrane and adsorption separation techniques.

BACKGROUND OF THE INVENTION

Various fluorinated hydrocarbon gases including tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6) are
10 used in the semiconductor industry to etch silica materials for use in integrated circuits. A major use of C_2F_6 , for example, is as a plasma etchant in semiconductor device fabrication. Gases of high purity are critical for this application. It has been found that even small amounts of
15 impurities in the etchant gas can increase the defect rate in the production of these integrated circuits. Thus, there has been a continuous effort in the art to provide a relatively simple and economical process for producing etchant gases having minimal amounts of impurities.

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One source of such etchant gases, of course, is the exhaust or vent gas from a semiconductor plasma etching process. The exhaust gas often contains unreacted CF_4 and/or C_2F_6 , and other perfluorocompounds (PFCs) such as SF_6 , NF_3 , and CHF_3 , as well as N_2 . The exhaust gas is usually recovered from the plasma etching process and concentrated from a few parts per million to above 90% by volume in a PFC recovery stage. This concentrated exhaust gas is sometimes referred to as a PFC mixture or a PFC soup. The PFC mixture normally contains about 90% by volume of CF_4 and/or C_2F_6 , and about 10% by volume of N_2 , SF_6 , NF_3 , and CHF_3 .

One way of purifying the PFC mixture to obtain substantially pure CF_4 and/or C_2F_6 is by cryogenic distillation. However, there are some drawbacks to such a process. Cryogenic distillation often requires special equipment and has high utility costs. In addition, the PFC mixture is difficult to separate by cryogenic distillation due to the physical properties of the gaseous components themselves; e.g., CF_4 and NF_3 , and C_2F_6 and CHF_3 form an azeotropic mixture with each other.

It is also known in the art to use activated carbon or zeolites to remove chlorotrifluoromethane (CClF_3) and/or

fluoroform (CHF_3) from C_2F_6 . See, e.g., U.S. Patent No. 5,523,499. However, this adsorption process is not said to be able to remove N_2 , SF_6 , and/or NF_3 from a gas mixture such as PFC soup.

5 Thus, it is an object of the present invention to address this need in the art by providing a process that can separate CF_4 and/or C_2F_6 from a PFC mixture.

 This and other objects of the invention will become apparent in light of the following specification, and the
10 appended drawing and claims.

SUMMARY OF THE INVENTION

 The present invention relates to a process for separating at least one of CF_4 and C_2F_6 from a gas. The process comprises the steps of:

15 (a) contacting a gas mixture comprising (i) at least one of CF_4 and C_2F_6 , (ii) at least one of NF_3 , CHF_3 , and N_2 , and (iii) SF_6 with a membrane at conditions effective to obtain a retentate stream rich in SF_6 and at least one of CF_4 and C_2F_6 , and a permeate stream rich in at least one of
20 NF_3 , CHF_3 , and N_2 ; and

(b) contacting the retentate stream with an adsorbent at conditions effective to adsorb SF_6 and produce a product stream rich in at least one of CF_4 and C_2F_6 .

In a preferred embodiment, the present invention
5 relates to a process for separating both CF_4 and C_2F_6 from a gas. The process comprises the steps of:

(a) contacting a gas mixture comprising CF_4 , C_2F_6 , NF_3 , CHF_3 , N_2 , and SF_6 with a membrane at conditions effective to obtain a retentate stream rich in SF_6 , CF_4 , and C_2F_6 , and a
10 permeate stream rich in NF_3 , CHF_3 , and N_2 ; and

(b) contacting the retentate stream with an adsorbent at conditions effective to adsorb SF_6 and produce a product stream rich in CF_4 and C_2F_6 .

BRIEF DESCRIPTION OF THE DRAWING

15 Figure 1 is a schematic diagram of a process according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides a process for separating at least one of CF_4 and C_2F_6 from a gas mixture.
20 The gas mixture preferably comprises (i) at least one of CF_4 and C_2F_6 , (ii) at least one of NF_3 , CHF_3 , and N_2 , and (iii)

SF₆. More preferably, the gas mixture is an exhaust or vent gas from semiconductor fabrication process which comprises CF₄, C₂F₆, NF₃, CHF₃, N₂, and SF₆. The exhaust gas preferably has undergone an initial recovery or concentration step.

5 The gas mixture to be separated preferably comprises from about 10 to about 95% by volume of at least one of CF₄ and C₂F₆. The balance of the gas mixture preferably comprises SF₆ and at least one of NF₃, CHF₃, and N₂.

 The process according to the present invention
10 comprises the steps of contacting the gas mixture with a membrane at conditions effective to obtain a retentate stream rich in SF₆ and at least one of CF₄ and C₂F₆, and a permeate stream rich in at least one of NF₃, CHF₃, and N₂; and contacting the retentate stream with an adsorbent at
15 conditions effective to adsorb SF₆ and produce a product stream rich in at least one of CF₄ and C₂F₆.

 As used herein, the term "rich" means that the concentration of a particular component in that stream is greater than the concentration of the same component in the
20 feed stream to that process step. Likewise, the term "depleted" means that the concentration of a particular component in that stream is less than the concentration of the same component in the feed stream to that process step.

Any membrane can be used in the process of the present invention so long as the membrane can selectively retain SF_6 and at least one of CF_4 and C_2F_6 while passing the other components in the gas mixture through. The membrane should
5 also be substantially non-reactive with the gaseous components to be separated.

Membranes suitable for use in the present invention include glassy membranes such as polymer membranes made preferably from polyimides; polyamides; polyamide-imides;
10 polyesters polycarbonates; polysulfones; polyethersulfone; polyetherketone; alkyl substituted aromatic polyesters; blends of polyethersulfone, aromatic polyimides, aromatic polyamides, polyamides-imides, fluorinated aromatic polyimide, polyamide, and polyamide-imides; glassy
15 polymeric membranes such as those disclosed in USSN 08/247,125 filed May 20, 1994, the content of which is hereby incorporated by reference; cellulose acetates; and blends thereof, copolymers thereof, substituted polymers (e.g. alkyl, aryl) thereof and the like.

20 Other membranes suitable for use in the present invention include asymmetric membranes. Asymmetric membranes are prepared by the precipitation of polymer solutions in solvent-miscible nonsolvents. Such membranes

are typified by a dense separating layer supported on an anisotropic substrate of a graded porosity and are generally prepared in one step. Examples of such membranes and their methods of manufacture are disclosed in U.S.

5 Patent Nos. 4,113,628; 4,378,324; 4,460,526; 4,474,662; 4,485,056; 4,512,893; 5,085,676; and 4,717,394; all incorporated herein by reference. The '394 and '676 patents disclose preparation of asymmetric separation membranes from selected polyimides. Particularly preferred
10 membranes are polyimide asymmetric gas separation membranes as disclosed in the '676 patent.

Yet other membranes suitable for use in the present invention include composite gas separation membranes. These membranes typically have a dense separating layer on
15 a preformed microporous substrate. The separating layer and the substrate are usually different in composition. Composite gas separation membranes have evolved to a structure of an ultrathin, dense separating layer supported on an anisotropic, microporous substrate. These composite
20 membrane structures can be prepared by laminating a preformed ultrathin dense separating layer on top of a preformed anisotropic support membrane. Examples of such membranes and their methods of manufacture are disclosed in

U.S. Patent Nos: 4,664,669; 4,689,267; 4,741,829;
2,947,687; 2,953,502; 3,616,607; 4,714,481; 4,602,922;
2,970,106; 2,960,462; 4,713,292; 4,086,310; 4,132,824;
4,192,824; 4,155,793; and 4,156,597; all incorporated
5 herein by reference.

Alternatively, composite gas separation membranes may
be prepared by multistep fabrication processes, wherein
first an anisotropic, porous substrate is formed, followed
by contacting the substrate with a membrane-forming
10 solution. Examples of such methods are described in U.S.
Patent Nos. 4,826,599; 3,648,845; and 3,508,994; all
incorporated herein by reference.

U.S. Patent No. 4,756,932 describes how composite
hollow-fiber membranes may also be prepared by co-extrusion
15 of multiple polymer solution layers, followed by
precipitation in a solvent-miscible nonsolvent.

The membrane used in the present invention can be
post-treated with, or coated by, or co-extruded with, a
fluorinated or perfluorinated polymer layer in order to
20 increase its ability to withstand harmful constituents in
the gas mixture from which PFCs are to be separate, at low
levels or temporary contact with such components.

The temperature of the gas mixture and/or the membrane during the contacting step can vary from about -10°C to about 100°C . Preferably, the temperature is between about 10°C and 80°C . More preferably, the temperature ranges from ambient, i.e., from about 20°C to 25°C , to about 60°C .

It is preferred, according to the present invention, to have a pressure drop across the membrane of less than about 2,000 psig. More preferably, the pressure drop ranges from about 3 to about 200 psig. Even more preferably, the pressure drop is about 20 to about 60 psig.

The requisite pressure drop across the membrane can be provided in one of two ways. First, the feed gas stream can be compressed. Preferred compressors are sealed and oil-free, such as the compressors sold under the tradename POWEREX, available from the Powerex Harrison Company of Ohio. Second and more preferably, the pressure drop across the membrane can be established by lowering the pressure on the permeate side of the membrane. To create the lower pressure on the permeate side, a vacuum pump or any other suction device can be used.

The flowrate of the gas mixture across the membrane can vary from about 0 to about $10^5 \text{ Nm}^3/\text{h}$ per square meter of membrane available for separation. Preferably, the

flowrate is from about 10^{-4} to about $10 \text{ Nm}^3/\text{h-m}^2$. More preferably, the flowrate is from about 0.01 to about 0.5 $\text{Nm}^3/\text{h-m}^2$.

The membrane separation step preferably yields a
5 retentate stream comprising from about 60 to about 99% of
at least one of CF_4 and C_2F_6 , and from about 0.5 to about 4%
of SF_6 . The retentate stream may also contain trace amounts
of NF_3 and CHF_3 . This trace amount of impurities may be
removed in a subsequent adsorption unit. The membrane
10 separation step also preferably produces a permeate stream
comprising from about 10 to about 60% by volume of at least
one of NF_3 , CHF_3 , and N_2 .

The adsorption step in the process of the present
invention can be carried out by either pressure swing
15 adsorption (PSA) or thermal swing adsorption (TSA). Both
adsorption techniques are well known in the art. This step
can be carried out with the adsorbent in a packed bed,
moving bed, or fluidized bed.

The adsorption step may be conducted at a pressure
20 ranging from 50 to 1.5 bar, and preferably from 20 to 3
bar. From an economic standpoint, the adsorption pressure
is mostly dictated by the membrane retentate stream
pressure. The temperature for carrying out this step can

vary from 30° to 100°C. The flowrate per unit adsorbent (i.e., space velocity) can vary from 20 min⁻¹ to 0.1 min⁻¹, and preferably from 10 min⁻¹ to 1 min⁻¹.

Any adsorbent can be used in the process according to
5 the present invention so long as the adsorbent can selectively adsorb SF₆ from a gas stream comprising CF₄ and C₂F₆. Suitable adsorbents include zeolites, activated carbons, carbon molecular sieves, and polymeric adsorbent resins.

10 Preferably, the zeolite used in the present invention has a silica to alumina molar ratio of 1:1 to 100:1, and more preferably, of 1:1 to 50:1. Even more preferably, the zeolite is an X-type zeolite. Prior to use, the zeolite should be ion-exchanged with Ca, Na, Li, Li/Zn, Be, Mg, or
15 Fe. Exemplary ion-exchanged, X-type zeolites include NaX zeolite, CaX zeolite, and LiX zeolite.

Various commercially available activated carbons may be used in the present invention including BPL, F-300, F-400, and PCB from Calgon, BAC from Union Carbide, and RB2
20 from Norit. PCB activated carbon sold by Calgon is preferred.

Similarly, various commercially available polymeric adsorbent resins may be used in the present invention. An

exemplary polymeric adsorbent resin that is suitable for use in the present invention is DOWREX, which is sold by Dow Chemical Company.

The amount of adsorbent used, of course, varies
5 depending on the amount of impurities to be separated and the desired purity of the product gas. Such a determination is within the scope of one skilled in the art.

Following use, the adsorbent is usually regenerated by
10 desorption of the adsorbed impurities such as SF_6 . Various methods are known in the art for desorbing impurities adsorbed onto the adsorbent. Generally, desorption can be effected by changing any thermodynamic variable which is effective in removing the adsorbed components. For
15 example, desorption may be carried out using a thermal swing cycle, a pressure swing cycle, or a vacuum cycle; all of which are known in the art. Alternatively, the adsorbed components may be removed by using a stripping gas or liquid. The stripping material may be one of the process
20 feed materials or another material such as N_2 , He, Ar, or steam.

The conditions for carrying out the regeneration step and the amounts of stripping material, if employed, can be readily determined by one of ordinary skill in the art.

The recovery of CF_4 and/or C_2F_6 from the gas mixture
5 can be further increased either by increasing the number of separation stages or by incorporating one or more feedback (recycle) loops. Such modifications are within the scope of the present invention.

Furthermore, the process according to the present
10 invention can be employed in combination with a cryogenic distillation column to produce high purity CF_4 and/or C_2F_6 . It can also be installed on-site of a semiconductor fabrication facility with a typical PFC recovery unit. This would reduce the shipping volume for off-site
15 purification.

Figure 1 is a flow diagram of a preferred process of the present invention. A feed gas stream 1 comprising CF_4 , C_2F_6 , NF_3 , CHF_3 , N_2 , and SF_6 is introduced into a membrane separation unit 10. The feed gas stream 1 is contacted
20 with a membrane at conditions effective to obtain a retentate stream 2 rich in SF_6 , CF_4 , and C_2F_6 , and a permeate stream 3 rich in NF_3 , CHF_3 , and N_2 . The retentate stream 2 is then passed to an adsorption unit 20 in which SF_6 and any

remaining NF_3 and CHF_3 are adsorbed. The adsorption unit 20 produces a product stream 4 rich in CF_4 and C_2F_6 .

While the invention has been described with preferred embodiments, it is to be understood that variations and
5 modifications may be resorted to as will be apparent to those skilled in the art. Such variations and modifications are to be considered within the purview and the scope of the claims appended hereto.



WHAT IS CLAIMED IS:

1. A process for separating at least one of CF_4 and C_2F_6 from a gas, said process comprising the steps of:

(a) contacting a gas mixture comprising (i) at least one of CF_4 and C_2F_6 , (ii) at least one of NF_3 , CHF_3 , and N_2 , and (iii) SF_6 with a membrane at conditions effective to obtain a retentate stream rich in SF_6 and at least one of CF_4 and C_2F_6 , and a permeate stream rich in at least one of NF_3 , CHF_3 , and N_2 ; and

(b) contacting said retentate stream with an adsorbent at conditions effective to adsorb SF_6 and produce a product stream rich in at least one of CF_4 and C_2F_6 .

2. The process according to Claim 1, wherein said gas mixture comprises both CF_4 and C_2F_6 , and said retentate stream and said product stream are rich in both CF_4 and C_2F_6 .

3. The process according to Claim 1, wherein said gas mixture comprises NF_3 , CHF_3 , and N_2 , and said permeate stream is rich in NF_3 , CHF_3 , and N_2 .



4. The process according to Claim 1, wherein said conditions in step (a) comprise a temperature between about 10 and about 80°C, a pressure drop between about 3 and about 200 psig, and a flowrate rate between about 10^{-4} and about $10 \text{ Nm}^3/\text{h-m}^2$.

5. The process according to Claim 1, wherein said adsorbent is a zeolite, activated carbon, or polymeric adsorbent resin.

6. The process according to Claim 1, wherein said membrane is selected from the group consisting of polyimides, polyamides, polyamide-imides, polyesters, polycarbonates, polysulfones, polyethersulfone, polyetherketone, alkyl substituted aromatic polyesters, and blends of polyethersulfone, aromatic polyimides, aromatic polyamides, polyamides-imides, fluorinated aromatic polyimide, polyamide, and polyamide-imides.

7. A process for separating CF_4 and C_2F_6 from a gas, said process comprising the steps of:

(a) contacting a gas mixture comprising CF_4 , C_2F_6 , NF_3 , CHF_3 , N_2 , and SF_6 with a membrane at conditions effective to



obtain a retentate stream rich in SF_6 , CF_4 , and C_2F_6 , and a permeate stream rich in NF_3 , CHF_3 , and N_2 ; and

(b) contacting said retentate stream with an adsorbent at conditions effective to adsorb SF_6 and produce a product stream rich in CF_4 and C_2F_6 .

8. The process according to Claim 7, wherein said conditions of step (a) comprise a temperature between about 10 and about 80°C , a pressure drop between about 3 and about 200 psig, and a flowrate rate between about 10^{-4} and about $10 \text{ Nm}^3/\text{h-m}^2$.

9. The process according to Claim 7, wherein said adsorbent is a zeolite, activated carbon, or polymeric adsorbent resin.

10. The process according to Claim 7, wherein said membrane is selected from the group consisting of polyimides, polyamides, polyamide-imides, polyesters, polycarbonates, polysulfones, polyethersulfone, polyetherketone, alkyl substituted aromatic polyesters, and blends of polyethersulfone, aromatic polyimides, aromatic



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polyamides, polyamides-imides, fluorinated aromatic
polyimide, polyamide, and polyamide-imides.