

[54] PROCESS AND MATERIAL FOR MANUFACTURING SEMICONDUCTOR DEVICES

[75] Inventor: Adir Jacob, Framingham, Mass.

[73] Assignee: LFE Corporation, Clinton, Mass.

[21] Appl. No.: 194,539

[22] Filed: Jun. 12, 1978

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: 3,867,216
Issued: Feb. 18, 1975
Appl. No.: 416,422
Filed: Nov. 16, 1973

U.S. Applications:

[63] Continuation-in-part of Ser. No. 252,863, May 12, 1972, Pat. No. 3,795,557.

[51] Int. Cl.4 B44C 1/22; B29C 37/00; C03C 15/00; C03C 25/06

[52] U.S. Cl. 156/668; 252/79.1; 134/1; 204/192.36

[58] Field of Search 204/192 E, 192 EC, 298, 204/164, 168, 169, 170, 192.36; 156/643, 646, 659, 668, 659.1; 252/79.1; 134/1, 21; 96/36.2, 38.4; 430/313, 329

[56] References Cited

U.S. PATENT DOCUMENTS

Table with 4 columns: Patent No., Date, Inventor, and Reference. Includes entries for Gillery et al., Irving et al., Smith, LaCombe, and Irving et al.

OTHER PUBLICATIONS

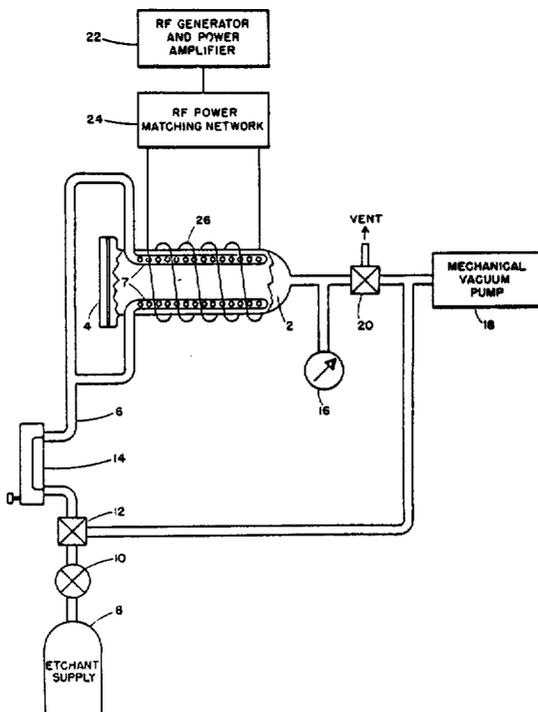
The Merck Index of Chemicals & Drugs, Seventh Edition, Published by Merck & Co., Inc. in 1960, p. 112.

Primary Examiner—William A. Powell
Attorney, Agent, or Firm—Lahive & Cockfield

[57] ABSTRACT

A process step and material for use in the manufacture of semiconductor devices. To facilitate the removal of organic photoresist material from a substrate, the material is exposed to a low pressure rf generated "cold" plasma (under 32° C.) produced from a homogeneous gaseous binary mixture of oxygen and a halocarbon, where the halocarbon is preferably a gas having one carbon atom per molecule and fully fluorine-substituted, and wherein the mixture contains at least 25% of oxygen by volume.

4 Claims, 1 Drawing Sheet



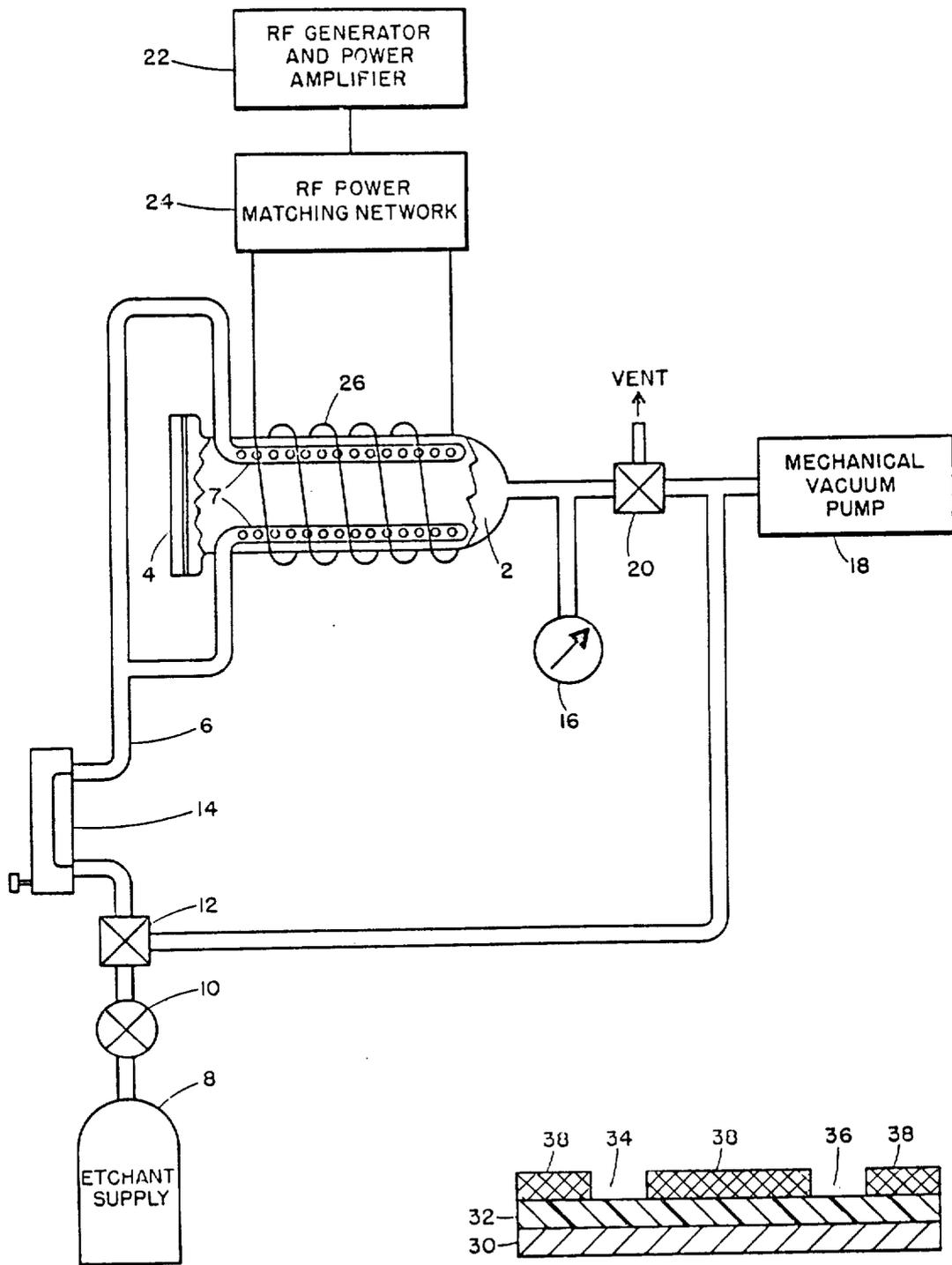


FIGURE 1

FIGURE 2

PROCESS AND MATERIAL FOR MANUFACTURING SEMICONDUCTOR DEVICES

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This is a continuation-in-part application of copending U.S. Pat. application Ser. No. 252,863 filed May 12, 1972, now U.S. Pat. No. 3,795,557 entitled Process And Material For Manufacturing Semiconductor Devices.

FIELD OF THE INVENTION

This invention relates in general to a process and material useful in analytical procedures, and more particularly to a process and material useful in the manufacture of semiconductor devices, enabling the stripping of organic material and the etching of various metals (molybdenum, tungsten, tantalum, etc.) and common passivation or diffusion barrier materials (e.g., SiO, SiO₂, Si₃N₄) during the processing of such devices.

BACKGROUND OF THE INVENTION

In the conventional technique for the manufacture of semiconductor devices, a slice of semiconductor material (p or n-type) accepts a relatively thin layer, typically 5,000 to 10,000Å, of an insulating film grown or deposited on one or both of its surfaces. A layer of photoresist material is then spun on to the insulating layer of one side, and is subsequently exposed to UV light through a mask having openings corresponding to those areas on the semiconductor slice where it is desired to generate semiconductor junctions. After exposure of the photoresist material through the mask, the mask is removed and the layer of photoresist is developed and processed by means of a suitable solvent, exposing select areas of the underlying insulating layer. A wet acid-based dip is then used to etch the insulating layer from the surface of the semiconductor slice in the exposed areas, the remaining photoresist material serving as an etch-mask for the surface covered by it. Following the wet etching process, a water rinse and a drying step are implemented. The remainder of the photoresist material is subsequently removed, followed by an acid dip required for the removal of inorganic residues. The photoresist material can also be removed by a plasma process utilizing the halocarbon-oxygen gaseous mixtures disclosed by the present inventor in his U.S. Pat. application, Ser. No. 322,134, filed Jan. 9, 1973, now U.S. Pat. No. 3,806,365, which is a continuation of U.S. Pat. application Ser. No. 173,537, now abandoned. Following a further drying step, diffusion of dopant material into the exposed areas of the semiconductor slice (where there is no insulating layer) is commenced to produce a predetermined junction.

Among the problems and drawbacks associated with the etching step used in this particular technique are:

1. Physical degradation of a photoresist etch mask.
2. Finite chemical degradation of a metallic etch mask.
3. Impairment of line-line resolution due to (1) and/or (2).
4. Enhanced undercutting effects creating undesirable slopes of the etched channel.

5. Severe chemical degradation (corrosion) of underlying metalization layers; e.g., aluminum in multileveled structures.

6. Slow and technically elaborate etching of silicon monoxide and silicon nitride.

7. Required post-etch water rinse and drying steps invariably reducing production yields.

8. Short shelf-life of etching solution due to inevitable contamination.

9. Generally very hazardous to personnel and undesirably polluting.

Accordingly, the general object of the present invention is to provide an improved process and new material that overcome the aforementioned problems and provide uniform etching reactions at a rapid rate and to provide an efficient stripping process for photoresist material.

SUMMARY OF THE INVENTION

In accordance with the present invention, there is provided a gas discharge flow apparatus adapted to form a gaseous plasma within a reaction chamber. It has been discovered that if the generated plasma comprises reactive species resulting from the decomposition and excitation of a gaseous binary mixture of oxygen and a halocarbon that includes fluorine as a major substituent, passivation layers or diffusion barriers (e.g., SiO, SiO₂, Si₃N₄) can be etched in excess of 3,000Å/min without degradation of an organic photoresist etch mask. Polycrystalline and single crystals of silicon, and a variety of metals (e.g., molybdenum, tantalum, tungsten, etc.) can be etched in excess of 2,000Å/min under similar conditions. While the above etch rates are commensurate with the preservation of an organic photoresist etch mask in this chemically hostile environment, appreciably higher etch rates can be achieved with the utilization of metallic etch masks (e.g., aluminum, gold, etc.). Metallic etch masks are normally attacked by aqueous acidic etch solutions currently in use; however, they are chemically inert to the etching plasma disclosed herein. These higher etch rates are achieved with a higher percentage of oxygen in the gaseous plasma. With this high percentage, obviously, organic photoresist stripping may also be achieved since the degradation of organic photoresist material at these high oxygen concentrations indicates the desirability of utilizing metallic etch masks.

DESCRIPTION OF THE DRAWING

In the drawing:

FIG. 1 is an illustration in diagrammatic form of a gas discharge flow system useful in the process of this invention; and

FIG. 2 is an illustration in cross-sectional view of a typical semiconductor slice at an intermediate stage of the manufacturing process.

DESCRIPTION OF PREFERRED EMBODIMENT

FIG. 1 depicts diagrammatically an apparatus performing the process described in the invention. The apparatus includes a reactor chamber 2, typically made of quartz, having a cover 4 and a gas inlet manifold 6. The side of the reactor 2 has been partially broken away in the drawing so as to better illustrate the gas diffusion tubes 7 which are disposed therein and are externally connected to manifold 6. Such a reactor is disclosed in U.S. Pat. No. 3,619,402, issued on Nov. 9, 1971, and assigned to LFE Corporation.

A pressurized supply 8 of a binary gaseous mixture comprised of oxygen and a halocarbon gas described below is connected through a pressure regulating valve 10, a three-way solenoid valve 12, and a flowmeter 14 to manifold 6. A vacuum gauge 16 provides an indication of total reaction pressure in reactor 2. At any time, and prior to introduction of the gas mixture to manifold 6, the corresponding flow lines are constantly evacuated through the three-way solenoid valve 12 leading to the mechanical vacuum pump 18, this being the case also under conditions where air at atmospheric pressure prevails in reactor 2 through the utilization of the three-way isolation valve 20. A source of radio frequency power 22 provides exciting energy through a matching network 24 to coil 26 which surrounds reaction chamber 2. Preferably, inductor 26 consists of a multiturn coil having two coil sections whose respective coil turns are wound in opposite directions, as disclosed in U.S. Pat. No. 3,705,091, issued Dec. 5, 1972, and assigned to LFE Corporation. Although the binary gaseous mixture is preferably premixed and supplied to the reactor from a single container 8, it will be apparent that the oxygen and halocarbon gases may, if desired, be supplied from separate sources via separate flow lines and mixed within either manifold 6 or reactor 2. In operation, the gaseous mixture is admitted to reaction chamber 2 where the inductively coupled radio frequency energy creates a cold plasma. Such a reaction system is commercially available from the Process Control Division of LFE Corporation, under the trade designation PDE-301 or PDE-504. Typically the rf power employed is between 175 and 225 watts continuous radiation at 13.5 MHz.

The general process is one in which as many as 25 semi conductor wafers at an appropriate stage of the manufacturing process are placed in reactor 2 and exposed to the plasma generated by the admission of an appropriate gaseous mixture of oxygen and a halocarbon gas. For the appropriate reactions to take place, the reaction chamber is evacuated to a residual pressure of 20 to 50 microns mercury prior to the admission of the gaseous etchant. The process provides rapid and uniform etching of dielectrics (up to 5000A/min) across a typical production batch of semiconductor slices with negligible loss of an organic etch mask.

In FIG. 2 there is shown in cross-sectional view a portion of a typical semiconductor device at a suitable processing stage for the utilization of this invention. The semiconductor device consists of a semiconductor material 30, such as silicon (or GaAs, GaAsP, InSb) having a relatively thin (200 to 10,000A) layer of a dielectric material 32 (e.g., SiO, SiO₂, Si₃N₄) either deposited or thermally grown on to it. This dielectric layer 32 (sometimes p or n-type doped) is to be etched at the openings 34 and 36 in the overlying photoresist mask 38. These openings or windows in the etch mask 38 represent fractional areas of less than 1 percent to 80 percent of the total area of the semiconductor slice, and correspond to positions on the semiconductor slice where it is desired to form a semiconductor junction by a subsequent diffusion of suitable dopants.

If the semiconductor device, as depicted in FIG. 2, is exposed to the prescribed plasma formed from a gaseous mixture of oxygen a halocarbon gas or vapor, the photoresist material will stay intact while the exposed dielectric film 32 will be etched down to the semiconductor layer 30 in openings 34 and 36. It has been found that an effective halocarbon should be selected from the

group of organohalides having no more than two carbon atoms per molecule and in which the carbon atoms are attached to a predominance of fluorine atoms. If a liquid halocarbon is considered, it should have a boiling point between 20° and 120° C. associated with a vapor pressure of at least 50 torr at 25° C. The preferred gaseous mixture is produced from a mixture containing 8.5 percent by volume of oxygen and 91.5 percent tetrafluoromethane gas. This optimum combination can be supplied from a prepared pressurized mixture maintained in a commercially available metal cylinder. Careful and close control of this dry etching process will permit the manufacture of semiconductor devices with high line-line resolution. It also provides a significant reduction in the undercutting of the etch mask, coupled with the option to control the slope of the etched channel. It further provides an efficient and simultaneous means for etching various dielectrics with an insignificant chemical or physical deterioration of overexposed underlying substrates such as aluminum, gallium arsenide, indium antimonide, garnets, etc. Satisfactory results were achieved with mixtures of up to 25 percent by volume of oxygen. In general, for the mixture combinations in the aforementioned group, an increase in the number of carbon atoms per molecule tends to slow down the etching process, while an increase in the mole fraction of oxygen (up to 0.5) tends to result in an excessive etch rate of the dielectric layer 32 with associated degradation of the photoresist mask and the line-line resolution. It is apparent that degradation of the photoresist mask implies that at these higher oxygen fractions, the gaseous plasma may be utilized for efficient organic photoresist stripping rather than as an efficient dielectric or metal etching medium. Increasing the mole fraction of the halocarbon beyond 0.5 tends to appreciably reduce the average etch rate.

The successful operation of this process is believed to include competitive homogeneous and heterogeneous reactions in the plasma such that atomic oxygen, generated by the decomposition of molecular oxygen, reacts with solid silicon dioxide layers to form a reduced silicon oxide entity, e.g., silicon monoxide. This lower oxide silicon is further converted by the fluorocarbon-based plasma to either volatile silicon tetrafluoride, SiF₄, or to volatile silicon oxyfluoride; Si₂OF₆, that is removed with the main gas stream to the vacuum pump. This reaction path, via the lower oxide of silicon, gives rise to thermochemically preferable reaction products as opposed to products that will ensue from the direct attack of either fluorine atoms or fluorinated hydrocarbon radicals on a silicon dioxide solid film. As a result, the presence of molecular oxygen in the etchant mixture enhances the etching (volatilization) of commonly encountered silicon dioxide films, since this reaction is coupled with a correspondingly higher probability of occurrence. By the same token, it is also believed that etching of silicon nitride layers proceeds via a similar lower oxide of silicon. In this case, the overall reaction is more exothermic, leading to a correspondingly enhanced etching of silicon nitride over silicon dioxide- a much desired result currently unobtainable within the semiconductor industry. It is this very feature of the plasma etch process that enables the direct photoresist masking of silicon nitride layers prior to etching, as opposed to indirect masking of such films by silicon dioxide and photoresist films in a multistep procedure currently employed with wet chemical etchants.

It has been found that the mixtures and operating parameters set forth below produce acceptable results in the described process. These parameters are intended to optimize the etch rate of dielectric films at negligible loss or degradation of any commercially available organic photoresist etch masks. Higher gaseous flow rates, rf power levels, etc., will enable correspondingly higher etch rates which may be used in conjunction with inorganic (e.g., metal) etch masks whose degradation is substantially avoided with this etching process. Again it is apparent that the parameters which result in the degradation of organic photoresist masks may be directly employed as a method and means for stripping organic photoresist masks.

and wherein oxygen constitutes at least 25% by volume of said binary mixture.
 2. A process in accordance with claim 1 wherein said halocarbon and said oxygen are supplied to a reactor from a common premixed source.
 3. A process in accordance with claim 1 wherein said halocarbon is trifluoromethane.
 4. A process in accordance with claim 1 wherein said halocarbon is tetrafluoromethane.
 5. A composition of matter useful for stripping organic photoresist material from a substrate in a plasma environment, said composition comprising a binary gaseous mixture of oxygen and a halocarbon having no more than two carbon atoms per molecule, wherein at

Etchant	Etchant Flowrate (micromoles sec ⁻¹)	Total Pressure (microns Hg)	RF Power (watts)	Material Etched	% Area Etched	No. Wafers	Etch Rate (Å min ⁻¹)
CF ₄ -1% O ₂	42.6	695	200	Th.* SiO ₂	40	1	390
CF ₄ -8.5% O ₂	9	220	150	"	5	1	620
CF ₄ -8.5% O ₂	52	780	200	"	40	25	300
CF ₄ -3.5% O ₂	55	350	250	"	20	1	1000
CF ₄ -8.5% O ₂	22	450	150	Dep.* SiO ₂ on Al	5	1	2600
CF ₄ -8.5% O ₂	45	690	200	Molybdenum	70	1	1500
CF ₄ -8.5% O ₂	15	340	250	Dep. Si ₃ N ₄	5	20	670
CF ₄ -8.5% O ₂	55	850	200	Tungsten	70	1	1000
CF ₄ -8.5% O ₂	55	850	200	Selenium	70	1	1500
CF ₄ -8.5% O ₂	15	340	200	Dep. Si ₃ N ₄	5	1	1300
CF ₄ -15.5% O ₂	55	770	200	Th. SiO ₂	40	1	840
CF ₄ -23.5% O ₂	28	465	125	"	40	1	300
CF ₄ -29% O ₂	100	1343	300	"	100	1	5100
CF ₄ -50% O ₂	110	1415	150	"	100	1	1890
CF ₄ -69% O ₂	17	275	300	"	100	1	1000
CHF ₃ -41% O ₂	50	1365	300	Th. SiO ₂	100	1	2000
CHF ₃ -55% O ₂	38	1005	125	"	100	1	1200
CHF ₃ -80.5% O ₂	133	3496	400	"	100	1	2800
CHF ₃ -93.7% O ₂	115	2996	300	"	100	1	500
C ₂ F ₆ -50% O ₂	108	1435	300	"	40	1	500
CF ₂ ClCCl ₂ H-75% O ₂	53	710	300	"	40	1	1000

*Th. Thermally Oxidized
 Dep. Vapor Deposited

I claim:

1. A process for removing organic photoresist material from a substrate in a plasma environment, comprising the step of:
 exposing the material to a gaseous plasma formed from a binary mixture of oxygen and a halocarbon having no more than two carbon atoms per molecule, wherein at least one carbon atom in said molecule is linked to a predominance of fluorine atoms,

40 least one carbon atom in said molecule is linked to a predominance of fluorine atoms and wherein said oxygen comprises at least 25% by volume of said binary gaseous mixture.]
 [6. A composition of matter in accordance with claim 5 wherein said halocarbon is trifluoromethane.]
 [7. A composition of matter in accordance with claim 5 wherein said halocarbon is tetrafluoromethane.]

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