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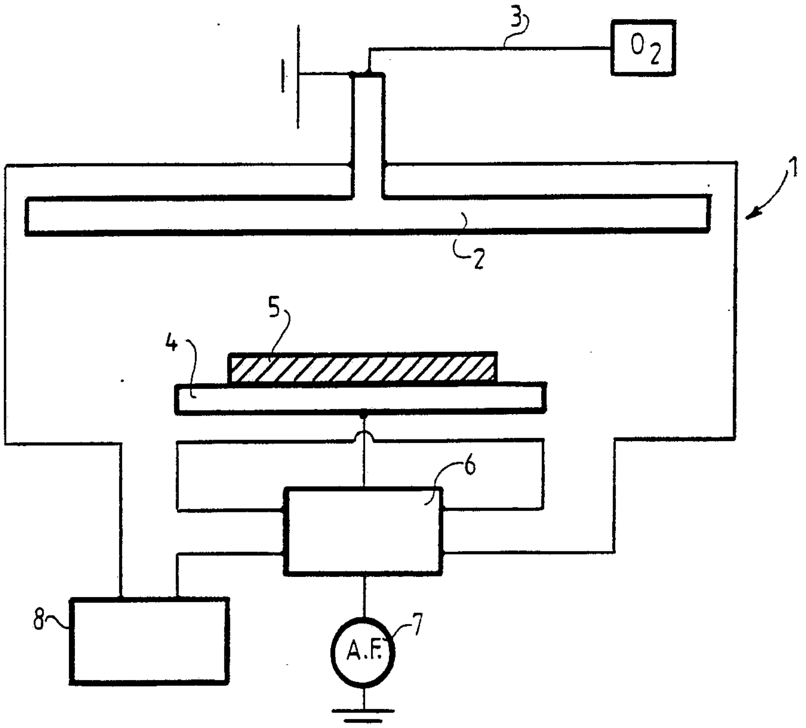
(54) Title: A METHOD AND APPARATUS FOR DRY PROCESSING OR ETCHING A SUBSTRATE



(57) Abstract

The patterning of substrates necessarily involves selective etching of some material. The present invention provides a method for dry processing or etching a substrate, in which the substrate is brought into a processing area; a vacuum is applied over the processing area; and an audio frequency signal is applied at electrodes of the processing area, such as to create a plasma at the processing area, having a power density substantially above 0.01 Watt/cm^3. Further an apparatus for carrying out this method comprises a self-DC-bias on the electrode.

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A method and apparatus for dry processing or etching a substrate

This invention relates to a method of plasma processing, more particularly to the dry processing of polymers and other materials and the dry development of photoresist for use, e.g. in the microelectronics industry.

Many different plasma systems are known: reactive ion etching; high pressure plasma etching; magnetron ion etching; microwave etching; and electron-cyclotron resonance.

The patterning of substrates necessarily involves selective etching of some material. This is typically done using a masking layer (such as photoresist) which has been previously patterned (e.g. using conventional photolithography and wet development) and which will be used to mask the substrate during the subsequent etch. Also, as more and more polymers are used in manufacturing, the need for fast and clean processing of those materials becomes important. In many cases, and this is specially true in the microelectronics industry, the dimensional control becomes more and more stringent due to the decreasing minimum linewidths. Also, the defect densities need to be reduced to increase the yield of the processes. To achieve this, it is often decided to replace the wet chemical processing steps by dry processes. In general, the etching of a material by use of plasma is carried out in a specially configured chamber at reduced pressure. An etchant gas (or gaseous liquid) is introduced in the reaction vessel. The gas as such mostly is not reactive and will have no effect on the substrate to be etched. To make the gas reactive, it is ionized by powering electrodes located in the reaction vessel. The ionization is often done using microwaves (GHz) or radio-frequencies (RF)(MHz).

From US-A-4.253907 it is known to use etching at audio-frequencies; this known etching method has no practical use as a power density of lower than 0.01 Watt/cm^3 is used.

The present invention has for its object to provide a method for dry processing or etching, that is fast and shows a high degree of anisotropy; an apparatus designed for this method can be kept simple.

Therefor the present invention provides a method for dry processing or etching a substrate, in which:
the substrate is brought into a processing area;
a vacuum is applied over the processing area;
a audio frequency signal is applied at electrodes of the processing area, such as to create a plasma at the processing area, having a power density substansally above 0.01 Watt/cm^3.

Further an apparatus for carrying out this method comprises a self-DC-bias on the electrode.

The matching network of the power system of the apparatus according to the prevent invention is designed such as to obtain a self-DC-bias on the cathode. The matching unit together with the plasma, will provide an equivalent load which matches the generators output impedance, resulting in an optimal power transfer to the plasma. The self-DC-bias will sustain the plasma at those low frequencies so that a stable working regime can be obtained. In a specific embodiment, the volume power densities can be much higher (typically ranging from 0.03 to 1 Watt/cm^3), resulting in a highly ionized plasma. The combination of the audio-frequencies and the self-DC-bias of the plasma results in a high density plasma, well suited for advanced processes of different types of materials such as polymers, oxides, nitrides, polycrystalline materials, etc. Indeed, as the ions can follow the audio frequency alternating electrical field (with radio-frequency plasmas (13.56 MHz), the ions cannot follow the alternating field due to their low mobility), they will be forced to strike the substrate perpendicularly, having an energy which is approximately proportional to the DC-self-bias (if no collisions occur in the dark sheath). This means that the ions will also have a sputtering effect, enhancing the anisotropy by promoting the directional sputter assisted etch component. In a practical system, the DC-self-bias voltages range from several volts to several hundreds of volts while the ionization - being defined as the number of ionized particles per cm^3 - ranges from 5.10^{11} to 10^{12} at a pressure of eg. 100 mTorr. The ionization degree - defined as the ratio of the number of ionized particles to the total number of particles at that specific pressure - can thus be as high as 10^{-3}. These figures are typically a decade higher than for other existing plasma processes.

Experiments carried out on a prototype using the above mentioned combination of audio frequency and matching network have shown that this plasma can be favorably applied to the etching of polymeric materials, including organometallics, with high etchrate. A clean, very fast and anisotropic etch can be performed showing a high power efficiency, resulting in a good definition of the patterned structures. A specific application of this process is its use for dry development of resists and the patterning of multilayer-structures in the micron and sub-micron region.

Preliminary experiments have shown that plasmas created with the above method can be successfully used for treatments of large areas, such as printed circuit boards, displays and plates of glass (up to several square meters). The impedance of the audio frequency plasma (strongly resistive as opposed to capacitive for high frequency etching) and the flexibility of our proposed matching network makes this possible and easy to implement.

Further details, advantages and features of the present invention will be clearified in the following description, in which references are made to the drawing, in which show:

Fig. 1 a diagramatic view of an apparatus for carrying out a method according to the present invention and

fig. 2 a more detailed view of the matching of the apparatus of fig. 1.

As mentioned above, due to the further decrease of the minimal dimensions, the wet processing of photoresist can be replaced by dry processing for accurate linewidth control and reproducibility. This of course is also true for other materials. To obtain a high enough etchrate, and thus a high enough throughput, a highly ionized plasma should be used so as to have as much reactive species as possible contributing to the etching process. A possible way to achieve this is to use audio frequencies to generate the plasma which will attack the substrate thereby forming volatile products which will be pumped away by the vacuum system. The pressure in such a system typically ranges from 1 mTorr up to several mTorr. In our application the optimal pressure range seems to start at 20 mTorr and goes up to 500 mTorr. The pressure will impact on the anisotropy of the process.

From the prior art it is clear that high etchrates using state of the art etching processes requires high power densities - even if magnetic confinement is used -, possibly resulting in damage to the structures to be etched. The use of audio frequencies enables one to achieve high etchrates and good anisotropy with low power densities and medium pressures.

An embodiment of an apparatus 1 for carrying out the method according to the present invention (fig. 1) comprises a top electrode 2, in the present example used as connection to the gas-inlet 3 (shower-head) for supplying gas - in this embodiment oxygen (O_2)- into the apparatus or reaction vessel 1 through a not shown mass flow meter. A substrate 5 is placed on a bottom electrode 4 (the cathode) which can be heated or cooled depending on the process. An audio frequency alternating signal from a source 7 (fig. 1) or generator 9 (fig. 2) is applied on the cathode through a matching network 6 (fig. 1,2) containing a transformer 13 and a capacitor 11.

Typically the plasma 12 (fig. 2) between the electrodes in the apparatus 1, is fed with a voltage of eg 1200 - 1400 Volt (peak - peak-value). The matching at audio frequencies is very simple; a simple transformer substantially matches the impedances between generator and plasma. The capacitor has a typical value of 1 μF and provides the DC-bias at the cathode (eg 1000 - 2000 Volt), because of differences in mobility in ions and electrons in the plasma.

The gas is ionized and a negative bias voltage develops on the cathode as a result of the charging of the capacitor. The DC-bias attracts positive ions out of the bulk of the plasma accelerating them to the substrate. Those reactive species strike the plasma perpendicularly and with enough energy to promote the directional sputter assisted etching component.

In the prototype, dry development of photoresist (see EP-A-85.870.142.8) has extensively been studied. Etchrates higher than 1 μm/min for power densities of 0.3 to 1 Watt/cm^2 and pressures ranging from 50 to 300 mTorr. A limited amount of physical sputtering - as introduced by the present invention - is beneficial in removing residues upon development.

In the case of etching other polymers such as polyimides, PVDF, kapton etc., the same increase in etchrate compared to state of the art technologies is seen.

Also, in the case of etching silicon oxide, etchrates of 7000 A/min have been observed for power densities of 0.5 Watt/cm^2.

Although detailed etching experiments on other materials have not yet been done, it is expected that these other materials will also exhibit increased etchrates and good anisotropy.

As a conclusion, it is clear that the use of the audio-frequencies combined with the matching network consisting of a transformer and a blocking capacitor result in a high rate etch with good anisotropy without having to build a more complex system such as Magnetron confinement or Electron-Cyclotron systems.

CLAIMS

1. A method for dry processing or etching a substrate, in which the substrate is brought into a processing area; a vacuum is applied over the processing area; and a audio frequency signal is applied at electrodes of the processing area, such as to create a plasma at the processing area, having a power density substantially above 0.01 Watt/cm^3.

2. A method of claim 1, in which the power density is between 0.3-1 Watt/cm^3 and the vacuum pressure ranges from 50 to 300 mTorr.

3. A method according to claim 1, in which the audio frequency signal is modulated such as to influence the degree of anisotropy of the etching.

4. A method according to claim 1, 2 or 3 pattering polymeric materials - such as to polyimides, organo-metallics, PVDF, teflon and epoxy resins - (plain layers, multi-layers, ...).

5. The use of the method as under (1) for silicon trench etching, polysilicon etching, silicon nitride and silicon dioxide etching for application to the fabrication of integrated circuits.

6. An apparatus for carrying the method of the claims 1 - 5 in which a matching network between an electrode and a audio frequency signal source comprises a self-DC-bias on the electrode.

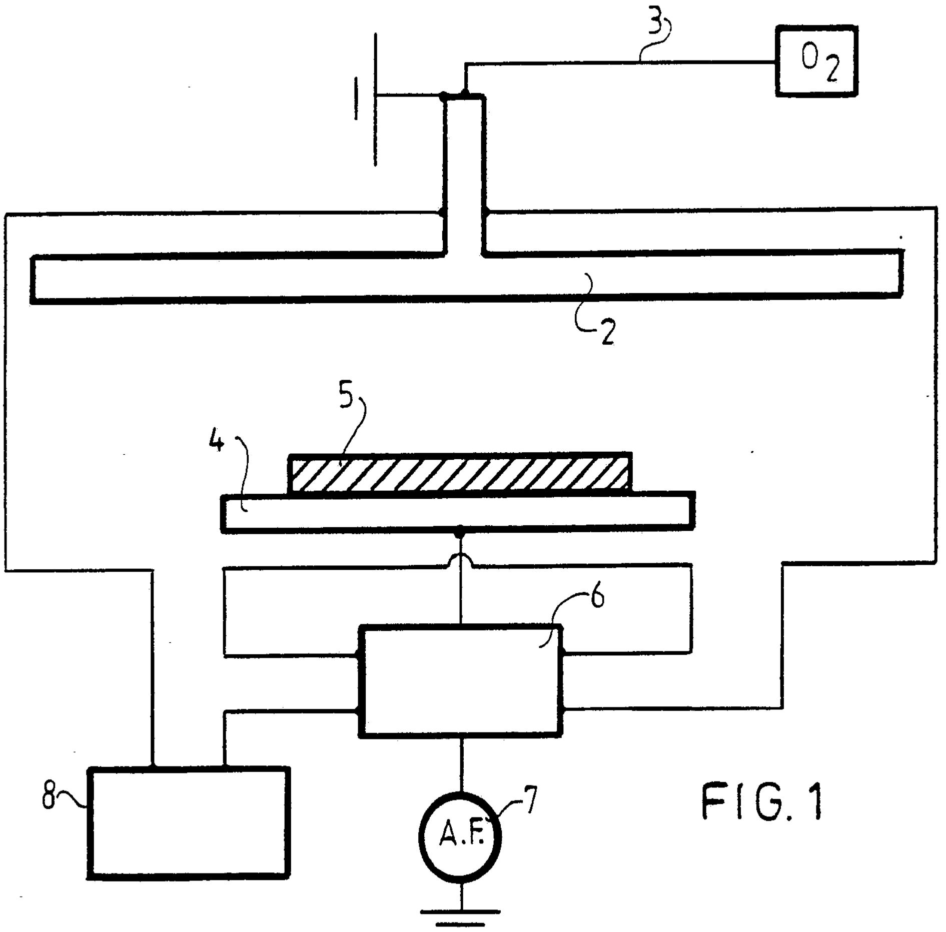

FIG. 1

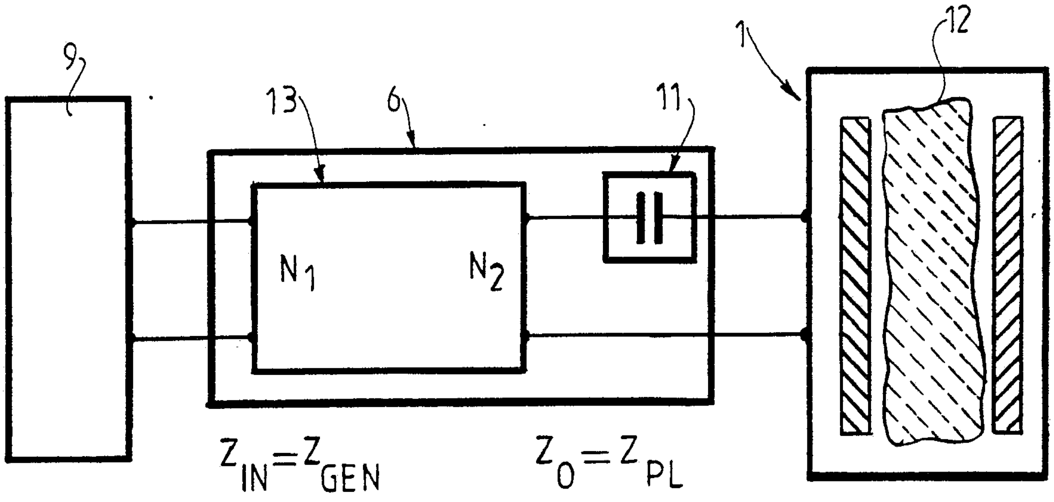

FIG. 2

INTERNATIONAL SEARCH REPORT

International Application No PCT/EP 88/00719

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: H 01 L 21/31

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	H 01 L

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US, A, 4253907 (P.D. PARRY et al.) 3 March 1981 see claims 1,2,8-14,20-25,29-32; figures 8-12 cited in the application	1-3
A		5
	--	
Y	Journal of Vacuum Science & Technology B, volume 4, no. 5, second series, September/October 1986, American Vacuum Society, (New York, US), K.M. Eisele: "Etching of SiO_2 in a narrowly confined plasma of high power density", pages 1227-1232 see page 1232, "Summary"	1-3
A		5
	--	
Y	Journal of Applied Physics, volume 57, no. 5, 1 March 1985, American Institute of Physics, (Woodbury, New York, US), ./.	1-3

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search 20th November 1988	Date of Mailing of this International Search Report 15 DEC 1988
International Searching Authority EUROPEAN PATENT OFFICE	Signature of Authorized Officer P.C.G. VAN DER PUTTEN

International Application No. PCT/EP 88/00719

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

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	T.E. Wicker et al.: "Plasma etching in a multipolar discharge", pages 1638-1647 see page 1642, table I; figures 12; pages 1646-1647, "Conclusions" --	5,6
A	EP, A, 0140294 (HITACHI) 8 May 1985 see claims 1-8 --	1,3,5
A	Solid State Technology, volume 24, no. 10, October 1981, (Port Washington, New York, US), R.H. Bruce: "Anisotropy control in dry etching", pages 64-68 see figure 7; page 66, column 1, paragraph 4 - page 68, column 1, paragraph 1 --	1-3,6
A	EP, A, 0195477 (PHILIPS) 24 September 1986 see claims 1,3,4 --	1,5
A	US, A, 4615764 (S.M. BOBBIO et al.) 7 October 1986 see figures 1,2 --	1,2,5
A	Journal of Electrochemical Society, volume 130, no. 11, November 1983, G. Turban et al.: "Dry etching of polyimide in O_2-CF_4 and O_2-SF_6 plasmas", pages 2231-2236 see figure 2; page 2231, "Experimental setup and method" --	1,2,4
A	US, A, 4407850 (R.H. BRUCE et al.) 4 October 1983 see claim 1 --------	1-4

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. EP 8800719

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 08/12/88
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4253907	03-03-81	None	
EP-A- 0140294	08-05-85	JP-A- 60086831 JP-A- 61013625	16-05-85 21-01-86
EP-A- 0195477	24-09-86	JP-A- 61214524 NL-A- 8500771 US-A- 4698126 CA-A- 1243133	24-09-86 16-10-86 06-10-87 11-10-88
US-A- 4615764	07-10-86	None	
US-A- 4407850	04-10-83	None	

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82