

PATENT SPECIFICATION

(11) 1 364 735

1 364 735

- (21) Application No. 48500/71 (22) Filed 19 Oct. 1971
 (31) Convention Application No. 81 756 (32) Filed 19 Oct. 1970 in
 (33) United States of America (US)
 (44) Complete Specification published 29 Aug. 1974
 (51) International Classification B23K 27/00
 (52) Index at acceptance
 B3V 4A2
 H1K 357 54Y 563 591 59Y 602 607 60Y
 (72) Inventors PAUL HERMAN SCHMIDT
 EDWARD GUERRANT SPENCER



(54) A METHOD OF SELECTIVELY REMOVING MATERIAL BY ION BOMBARDMENT

- (71) We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195, Broadway, New York City, New York State, United States of America, a Corporation organized and existing under the laws of the State of New York, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—
- This invention relates to a method of selectively removing material.
- The etching of patterns on solid surfaces has become of primary importance in the field of miniaturized electromagnetic signal processing devices. In the field of integrated circuitry it is necessary to accurately etch patterns in deposited films of both insulating and metallic materials. This is done primarily through the use of photolithographically produced masks and chemical etchants. As the desired circuit element packing density becomes higher and higher, the inherent problems of this technology become apparent. Chemical etchants tend to undercut the photolithographic masks producing dimensional uncertainties and irregular edges. When the lateral dimensions of the patterns being produced become as small as the film thickness, these problems become the dominant limitation on further miniaturization. In addition to these mechanical considerations, chemical etchants bring with them the problems of chemical compatibility with the various materials present and of the removal of reaction products.
- Some of the chemical problems can be avoided by a process variously known as sputter-etching and back sputtering. In this process the device to be etched is placed in a chamber containing a gas such as argon under low pressure. A plasma is produced in the chamber and positive ions from the plasma are caused to strike the device surface, physically removing the desired material. If the device is a conductor, the plasma is produced by, first, imposing several thousand volts between the device and an anode electrode. An electron gun is then used to ionize some of the gas atoms and initiate a plasma discharge. If the sample is an insulator, the plasma is produced by a large RF field produced in the chamber. This process, while chemically clean, produces heating of the device being etched. This heating is accentuated by the fact that the incident ions have a broad energy spectrum. The low energy ions heat the device without removing material. In addition, the ions in the plasma are scattered many times before striking the surface and thus strike the surface at a large variety of angles, thereby limiting the fidelity of the etched patterns.
- It is therefore an object of the invention to provide an improved method of selectively removing material from a surface of a body.
- According to the invention there is provided a method for selectively removing material from a surface of a body, the method comprising forming a mask on the surface and removing material from exposed parts of the surface by means of bombardment, with a substantially parallel beam of ions, the ions having energies greater than 1000 electron volts.
- It has been demonstrated by using embodiments of the invention that high quality thin film patterns on an extremely small scale can be produced through the use of a substantially parallel (i.e. within ± 5 degrees) energetically controlled beam of ions, in conjunction with conventional masking techniques. Patterns including stripes less than 1 micron wide have been reliably and reproducibly made. This small

[Price 25p]

scale, for instance, allows the fabrication of memory and logic devices using single wall magnetic domain techniques with a bit density of 10^7 bits per square inch.

5 In one embodiment of the invention an energetically controlled beam of ions, parallel to within ± 5 degrees, is produced by an ion gun within which the ions are accelerated by a large DC voltage. The
10 magnitude of this voltage can be adjusted for the desired material removal rate in view of the particular material being removed. The emerging ion beam is essentially free of low energy ions which tend to
15 heat the device without removing material. The lowest energy ions possess energies roughly equal to the acceleration voltage while multiply ionized ions will possess multiples of this energy.

20 The ion beam is made incident on the device being etched within a vacuum chamber. Pressure in the chamber is kept sufficiently low (less than 10^{-2} Torr) such that scattering of the ions is minimal and
25 the ions strike the surface at the predetermined angle. The device may be situated on a stage capable of rotation, translation and angular adjustment relative to the position of the ion beam. This process is
30 essentially independent of the composition of the device being etched although the accelerating voltage and the angle of incidence can be adjusted for the desired removal rate and definition. The process will
35 etch conductors, insulators, or composite bodies consisting of conducting or insulating thin films deposited on conducting or insulating substrates. The required patterns can be defined by photolithographic masking
40 techniques or by removable masks.

Embodiments of the invention will now be described with reference to the accompanying drawing in which the single figure is a cross sectional view of a device undergoing ion bombardment while mounted on
45 a stage capable of rotation.

The figure shows a device undergoing ion bombardment to remove material. The ion beam 11 is incident on the film 16 and mask
50 15 at the preselected angle 10, material being removed from part of the film 16 where masking material is not provided.

The device is mounted on a stage 13 which is capable of translation and rotation
55 about an axis 14 perpendicular to the device surface at the position of incidence of the ion beam. The device 12 is shown, by way of example, as a metallic film 16 on a ceramic substrate 17. However, the inventive etching process can be applied to a
60 unitary rigid body of any composition or a composite rigid body of any combination of compositions. The substrate 17 can be a temporary backing plate for a removable
65 film device 16.

The speed of material removal by the ions of the ion beam varies with a number of factors. Since the material is removed primarily by momentum transfer from the ions to the atoms of the surface and not
70 by the heating of the surface above the vaporization temperature, the accelerating voltage of the ion gun must be sufficient that each ion is able to overcome the binding energy of the atoms being struck. As
75 the accelerating voltage is increased, the average number of surface atoms dislodged per incident ion (referred to hereafter as the dislodging coefficient) increases. Inordinately high acceleration potentials can produce
80 crystalline subsurface damage which will degrade the performance of some classes of devices. The particular voltages which would be considered too low or too high of course depend upon the particular
85 materials being etched. In view of the above, voltages less than 1000 volts or greater than 75,000 volts are usually not useful. Greatest expediency and control
90 over the material removal rate usually results from the use of acceleration voltages between 2500 and 15,000 volts.

The angle of incidence (denoted by 10 in the figure) also affects the dislodging coefficient. Angles between 10 degrees and
95 45 degrees usually result in larger dislodging coefficients and less subsurface damage than angles closer to 90 degrees. However, 90 degree incidence usually results in better edge definition.

Another factor influencing the dislodging coefficient is the ion species used. Since the dislodging process is primarily a momentum transfer process, more massive ions will
100 generally possess larger dislodging coefficients than less massive ions of the same energy. Species which are gaseous at room temperature are most convenient to use although species which are not gaseous may
105 be used for special purposes. If such a non-gaseous species were used, heating means would be required to produce a vapour of the species. Of the gaseous species, the noble gases He, Ne, Ar, Kr and Xe are most
110 generally advantageous since they do not react chemically with the device being etched and can easily be removed from the system after collision. Of these, argon is most widely used. However, it is definitely possible to use the reactive gases
115 in this process. Oxygen has been tried to advantage.

The most widely used masking process in the microminiature device art is the photolithographic process. In this process
120 the surface to be etched is covered by a polymer layer. Portions of the layer are caused to crosslink by exposure to light and the uncrosslinked portions are subsequently washed away during the developing step.
125 130

An additional step, which is sometimes performed when photolithography is used in conjunction with chemical etchants but is more advantageous in conjunction with the instant ion beam process, is a prebaking step. In this prebaking step the polymer layer is heated in order to harden it by, perhaps, driving off any water remaining after the development step. In selecting the thickness of the photolithographic polymer to be used, it must be remembered that during ion bombardment the mask material is removed at roughly the same rate as the exposed surface material. The skilled practitioner will choose a polymer thickness such that the polymer does not disappear before the surface is etched to the desired depth.

The skilled practitioner will recognize that the processing of some classes of devices will require the use of removable masks such as metal foil masks. This may be necessary if, for instance, the surface is not compatible with the photolithographic chemicals. The use of removable masks will result in a completely dry process with a minimum of device handling.

The disclosed process can be applied to any material which is not degraded by the required degree of vacuum within the bombardment chamber. The process can be used for etching depressions in crystalline or amorphous insulators, semiconductors, or metals, or holes in thin bodies of these materials. Patterns of such depressions in insulators or semiconductors are required, for instance, for subsequent metal depositions needed for "buried conductor" device techniques. It is envisaged that the technique will be most widely used for cutting patterns in thin deposited layers. Such patterns on semiconducting substrates are widely used in monolithic microminiature circuitry. Patterns of semiconductors and magnetic metals on insulating substrates are employed, for instance, in magnetic bubble memory and signal processing devices. Tantalum thin films on glass and ceramic substrates are used in integrated circuitry.

For the magnetic bubble device use, patterns of permalloy on glass substrates have been produced as overlays for magnetic bubble shift registers. One such shift register pattern has a 7.5 micron periodicity and is composed principally of stripes 0.8 microns wide produced from a film 0.6 microns thick. A 1000 bit shift register has been produced whose overall dimension is 0.010 inches square. The bit density of this shift register is 10^7 bits per square inch.

This has been accomplished using photolithography including a prebaking. The ion bombardment took place at an angle of 30 degrees and an accelerating potential of 7,000 volts.

WHAT WE CLAIM IS:—

1. A method for selectively removing material from a surface of a body, the method comprising forming a mask on the surface and removing material from exposed parts of the surface by means of bombardment with a substantially parallel beam of ions, the ions having energies greater than 1000 electron volts.

2. A method according to claim 1 wherein the ions strike the surface at an angle lying between 10° and 45° from the surface.

3. A method according to claim 1 or 2, wherein the ions are argon, helium, neon, krypton or xenon.

4. A method according to any one of claims 1 or 2, wherein the ions are oxygen ions.

5. A method according to any one preceding claim, wherein the method is used in the manufacture of miniaturised electronic or electromagnetic devices.

6. A method according to any one preceding claim, wherein the body comprises a substrate having a surface layer, and wherein material is removed from the surface layer.

7. A method according to claim 6, wherein the surface layer is a metal and the substrate is an insulator.

8. A method according to any preceding claim, wherein the mask is formed on the surface by a photolithographic process.

9. A method according to any one of claims 1 to 7, wherein the mask used for masking the surface of the body is formed before being placed on said surface.

10. A method according to any one of claims 6 to 9, wherein the body is rotatable relative to the beam of ions.

11. A method for selectively removing material from the surface of a body, the method being substantially as herein described with reference to the accompanying drawing.

12. A body having had material removed from a surface thereof by a method according to any of the preceding claims.

K. G. JOHNSTON,
Chartered Patent Agent,
5, Mornington Road,
Woodford Green,
Essex.
Agent for the Applicants.

An additional step, which is sometimes performed when photolithography is used in conjunction with chemical etchants but is more advantageous in conjunction with the instant ion beam process, is a prebaking step. In this prebaking step the polymer layer is heated in order to harden it by, perhaps, driving off any water remaining after the development step. In selecting the thickness of the photolithographic polymer to be used, it must be remembered that during ion bombardment the mask material is removed at roughly the same rate as the exposed surface material. The skilled practitioner will choose a polymer thickness such that the polymer does not disappear before the surface is etched to the desired depth.

The skilled practitioner will recognize that the processing of some classes of devices will require the use of removable masks such as metal foil masks. This may be necessary if, for instance, the surface is not compatible with the photolithographic chemicals. The use of removable masks will result in a completely dry process with a minimum of device handling.

The disclosed process can be applied to any material which is not degraded by the required degree of vacuum within the bombardment chamber. The process can be used for etching depressions in crystalline or amorphous insulators, semiconductors, or metals, or holes in thin bodies of these materials. Patterns of such depressions in insulators or semiconductors are required, for instance, for subsequent metal depositions needed for "buried conductor" device techniques. It is envisaged that the technique will be most widely used for cutting patterns in thin deposited layers. Such patterns on semiconducting substrates are widely used in monolithic microminiature circuitry. Patterns of semiconductors and magnetic metals on insulating substrates are employed, for instance, in magnetic bubble memory and signal processing devices. Tantalum thin films on glass and ceramic substrates are used in integrated circuitry.

For the magnetic bubble device use, patterns of permalloy on glass substrates have been produced as overlays for magnetic bubble shift registers. One such shift register pattern has a 7.5 micron periodicity and is composed principally of stripes 0.8 microns wide produced from a film 0.6 microns thick. A 1000 bit shift register has been produced whose overall dimension is 0.010 inches square. The bit density of this shift register is 10^7 bits per square inch.

This has been accomplished using photolithography including a prebaking. The ion bombardment took place at an angle of 30 degrees and an accelerating potential of 7,000 volts.

WHAT WE CLAIM IS:—

1. A method for selectively removing material from a surface of a body, the method comprising forming a mask on the surface and removing material from exposed parts of the surface by means of bombardment with a substantially parallel beam of ions, the ions having energies greater than 1000 electron volts.

2. A method according to claim 1 wherein the ions strike the surface at an angle lying between 10° and 45° from the surface.

3. A method according to claim 1 or 2, wherein the ions are argon, helium, neon, krypton or xenon.

4. A method according to any one of claims 1 or 2, wherein the ions are oxygen ions.

5. A method according to any one preceding claim, wherein the method is used in the manufacture of miniaturised electronic or electromagnetic devices.

6. A method according to any one preceding claim, wherein the body comprises a substrate having a surface layer, and wherein material is removed from the surface layer.

7. A method according to claim 6, wherein the surface layer is a metal and the substrate is an insulator.

8. A method according to any preceding claim, wherein the mask is formed on the surface by a photolithographic process.

9. A method according to any one of claims 1 to 7, wherein the mask used for masking the surface of the body is formed before being placed on said surface.

10. A method according to any one of claims 6 to 9, wherein the body is rotatable relative to the beam of ions.

11. A method for selectively removing material from the surface of a body, the method being substantially as herein described with reference to the accompanying drawing.

12. A body having had material removed from a surface thereof by a method according to any of the preceding claims.

K. G. JOHNSTON,
Chartered Patent Agent,
5, Mornington Road,
Woodford Green,
Essex.

Agent for the Applicants.

