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(54) FORMATION OF EXTREMELY NARROW METALLIC LINES

(71) We, INTERNATIONAL BUSINESS MACHINES CORPORATION, a Corporation organized and existing under the laws of the State of New York in the United States of America, of Armonk, New York 10504, 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 methods for forming extremely narrow metallic lines on a substrate.

Techniques have previously been described for forming narrow lines, composed of polysilican, using doping and etching techniques. A publication in the *New Scientist* 25 September 1975 on page 707 discusses a technique wherein polysilicon is masked and doped with boron by diffusion. The masking layer is removed followed by removal of the undoped region of polysilicon by selective etching to leave the fine boron doped line.

Application of the present invention enables extremely narrow metallic lines to be formed which are more highly conductive than polysilicon lines of the same dimensions.

A method of forming extremely narrow metallic lines according to the invention, comprises the successive steps of: covering selected portions of a thin metal film on a surface of a substrate, with masking material to delineate a desired pattern, removing the unmasked portions of the thin metal film, selectively ion implanting the edges of the remaining masked portions of the thin metal film to a predetermined depth, removing the masking material from the remaining portions of the thin metal film, and removing by selective etching the unimplanted portions of the thin metal film to provide a pattern of extremely narrow metallic lines on the substrate.

How the invention can be carried into effect will now be described with reference to the accompanying drawings, in which:—

FIGS. 1A, 1B, 1C, 1D and 1E illustrate separate steps of a preferred method for forming ultra-narrow metallic lines.

In forming lines for integrated circuit packages, it is very important that the lines be as thin as possible for optimum packing density. In typical methods of forming lines such as photolithography, electron beam lithography and x-ray lithography, the thickness of the masks employed create a practical limit on minimum line thickness. This is because the vertical dimension of the mask aperture through which the beam is directed is much larger than the horizontal dimension of the line being formed on the substrate beneath the mask. Metallic lines are preferable to semiconductor lines such as poly-silicon, because of their much higher conductivity, and even circuits formed from semiconductor material usually use metal for interconnection lines.

Referring to FIG. 1A, a suitable substrate 10 composed, for example of a non-metal, such as silicon or saphire, has a metal film 12 disposed thereon. Tungsten may be used for film 12, however metals such as molybdenum and other transition metals whose transition temperature increases due to ion implantation may also be employed. In FIG. 1A a photoresist pattern 14 or other suitable masking layer is disposed on the metal film 12 and exposed to radiation in a conventional manner. Then, as illustrated in FIG. 1B, the exposed portion of the metal layer 12 is etched away leaving portion 12-1.

In the next step (FIG. 1C), the exposed edge of the metal 12-1, as well as the photoresist 14 and substrate 10 are ion-implanted by directing an ion beam at an angle with respect to substrate 10. The depth of the implant is directly determined by a desired line width W, which can be of the order of 300 Angstroms for a 40 kev N^+ ion implant into tungsten. The photoresist layer 14 is then removed by conventional techniques leaving the metal layer 12-1 including the narrow implanted region of width W remaining on substrate 10.

The implanted region of metal layer 12-1 has a greater etch resistance than the unimplanted region of metal layer and therefore selective or preferential etching may be carried out. Thus, in FIG. 1E, the result of the etching step is illustrated wherein the unimplanted metal layer has been etched away leaving an ultra-narrow metal line 12-2 of width W which remains because of its greater etch-resistance.

The fact that ion implantation of certain impurities enhances the superconductivity of selected transition metals is also known, and is described in chapter 69 of the publication by O. Meyer entitled *Ion Implantation in Superconductors in New Uses of Ion Accelerators*, Ed. by J. F. Ziegler, Plenum Press, New York 1975.

The ultra-narrow metal line 12-2 illustrated in FIG. 1E is also suitable for superconductive applications because ion implantation into certain metals greatly enhances super-conductivity, for example N^+ or S^+ implantation into tungsten can raise the transition temperature from 0.02 degrees K to approximately 5 degrees K depending on the dose. Some superconductive applications for the ultra-narrow lines fabricated by the disclosed method include very low capacitance Josephson tunnel junctions for detection and mixing at submillimeter wavelengths. Such junctions may be made by depositing one ultra-narrow line across another, with a tunnel barrier in between. Also, loops, probes and flux transformers for superconducting magnetometers can be fabricated by the present method. Probes, in particular, can be made very small, permitting extremely fine-scaled variations in the magnetic field to be mapped. For example, a 3000 Angstrom line produced in photoresist with a 500 Angstrom implantation on each side of the line would leave a region only 2000 Angstroms wide enclosed by the superconducting loop.

In summary what has been described is a method for fabricating extremely narrow metal lines, particularly metal lines which are superconductive. The method basically includes the steps of delineating a pattern on a thin metal film on a substrate by masking techniques, ion implanting the edge of the metal film to a desired depth, removing the mask portion from the metal film and etching away the unimplanted portion of the metal film to leave an extremely narrow line having a width equal to the implanted depth.

One skilled in the art will appreciate that a number of suitable metals and suitable ions can be employed in the method depending on the end use of the fabricated lines.

WHAT WE CLAIM IS:—

1. A method of forming exteremely narrow metallic lines comprising the successive steps of: covering selected portions of a thin metal film on a surface of a substrate, with masking material to delineate a desired pattern, removing the unmasked portions of the thin metal film, selectively ion implanting the edges of the remaining masked portions of the thin metal film to a predetermined depth, removing the masking material from the remaining portions of the thin metal film, and removing by selective etching the unimplanted portions of the thin metal film to provide a pattern of extremely narrow metallic lines on the substrate.

2. A method as claimed in claim 1, in which the metal film consists of a transition metal, the transistion temperature of which increases when the metal is ion implanted.

3. A method as claimed in claim 1 or claim 2, in which the metal film consists of tungsten.

4. A method as claimed in claim 3, in which the ions implanted are N^+ or S^+ ions.

5. A method as claimed in any preceding claim, in which the depth of the ion implantation is approximately 500 Angstroms and the resulting extremely narrow metallic lines are approximately 500 Angstroms wide.

6. A method of forming extremely narrow metallic lines substantially as described with reference to the accompanying drawings.

7. A substrate having extremely narrow metallic lines formed thereon by a method as claimed in any preceding claim.

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FIG. 1A

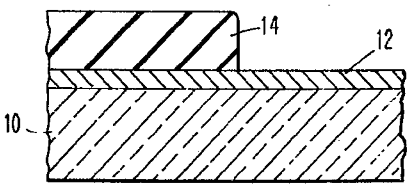


FIG. 1B

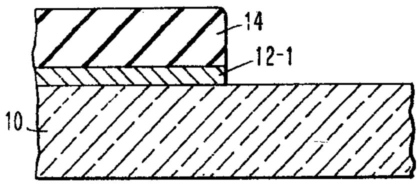
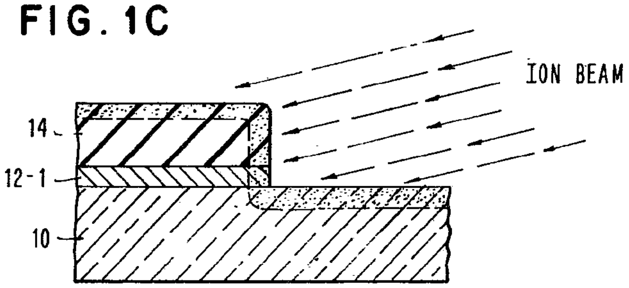


FIG. 1C



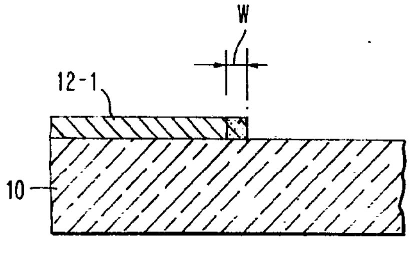


FIG. 1D

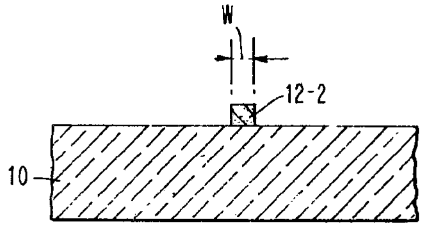


FIG. 1E