3.0 Focused Ion Beam Fabrication

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3.1 Focused Ion Beam Program

Research in focused ion beam applications is being carried out in two areas: maskless implantation patterning and ion induced deposition. In each area, the work is centered around a special machine. For implantation, we have a system capable of mass separation and submicron beam writing on the wafer, which was bought as part of the Microsystems Technology Program. It was delivered to MIT in March 1987, and was put into operation in June 1987. A number of implantations have been carried out as described below. The system can produce a beam of 0.1 μm diameter at 150 kV with several ion species which include the dopants of Si and GaAs.

We have also purchased a 50 kV column without mass separation, which will be used mainly with Ga^+ ions. It can produce a beam of 0.05 μm diameter, and is intended for ion induced deposition and ion milling. An ultrahigh vacuum chamber is being constructed to house this column. In the meantime, experiments have been carried out using a standard implanter.

3.1.1 Development of Focused Ion Beam Patterning

Microsystems Technology Laboratories
Defense Advanced Research Projects Agency/Naval Electronics Systems Command (Contract MDA 903-85-C-0215)

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To develop and test the patterning capability of the focused ion beam system, we have carried out exposure of PMMA, i.e., ion beam lithography. Features of 0.1 μm width were exposed using Be^{++} ions at 260 keV (accelerated by 130 kV) in 0.3μm thick PMMA. Gold features of 0.1μm thickness and 0.1μm width were then produced by electron-beam evaporation and lift-off. Field stitching was demonstrated by accurately calibrating the beam deflection against the laser interferometer controlled table motion. The pattern discontinuities observed in crossing the field boundaries were less than 0.1 μm. In addition, software for transferring patterns from the computer aided design facility, where they are drawn in standard workstations, directly to the focused ion beam computer was developed. These capabilities will make possible wider use of the machine in the future.

3.1.2 Fabrication of Devices by Direct Focused Ion Beam Implantation

Defense Advanced Research Projects Agency/Naval Electronics Systems Command (Contract MDA 903-85-C-0215)

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Focused ion beam implantation provides a new degree of freedom in device fabrication: the implantation dose can be varied as a function of position on the surface. Our goal is to exploit this capability in new devices or in improvements to existing devices. A novel device which we have conceived is a tunable Gunn diode. It is fabricated by implanting a gradient of doping between the two contacts. The distance that a Gunn domain can travel depends on D.C. bias, and the frequency can be tuned by tuning the bias. In one device the oscillation frequency was tuned from 6 to 23 GHz by tuning the bias from 37 to 27 volts. The operation of the device has also been simulated on the computer. We have, in addition, implanted GaAs MESFET's with a gradient of doping from source to drain. Compared to uniformly doped devices, these MESFET's showed a 15% increase in transconductance. The gate length was 1 μm. We plan to grade submicrometer gate lengths MESFET's, where the improvements are expected to be larger. Similarly, we plan to implant Si MOSFET's with doping gradients from source to drain.

3.1.3 Planar Vias Through Si_3N_4 Fabricated by Focused Ion Beam Implantation

U.S. Air Force (through Lincoln Laboratory)
Defense Advanced Research Projects Agency (through Lincoln Laboratory

John Melngailis, Terry O. Herndon, Mark I. Shepard, Henri Lezec

Previous work has demonstrated that silicon implanted into Si_3N_4 at doses above 10^{17} cm^{-2} can render the insulator conducting. This has been proposed as a means of

making planar via. We have used a focused ion beam to make such level to level interconnects in Si_3N_4, thus avoiding the need for resist or mask. Implants were carried out at a single energy, 160 keV, using Si++ ions, or at two energies, 80 keV and 160 keV, using Si+ and Si++ ions, respectively. Films of 0.25-μm-thick Si_3N_4 over Al metal were implanted. Then the upper layer was deposited, patterned, and the structure was sintered at 425°C for 30 minutes. The dose threshold for conduction was between 2 x 10^{17} and 5 x 10^{17} cm^{-2} and depended on whether the 160 keV or the two-energy implants were carried out. Interconnects formed in areas 1.6 x 1.6 μm had resistance as low as 0.15 Ω, while the minimum dimension implants, made with an unscanned beam in 6 to 12 s, had resistances of 1.5 to 5 Ω. For vias exposed with doses below threshold, permanent conduction could be induced by breakdown at voltages well below those needed to break down an unimplanted film. Even with the present state of technology, focused ion beam implantation appears to be a useful technique for making level-to-level interconnects through Si_3N_4 in limited, critical areas of devices.

3.1.4 Growth of Gold Films by Ion Induced Deposition

Charles Stark Draper Laboratory, Inc. (Contract DL-H-261827)
Hitachi Central Research Laboratory
Nippon Telegraph & Telephone
U.S. Army Research Office (Contract DAAL03-87-K-0126)

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A beam of ions incident on a surface can cause absorbed gas molecules to break up, resulting in material deposition. With a focused ion beam, we have demonstrated deposition of lines of 0.25 μm width, as well as lines of 0.5 μm width and 0.4 μm thickness. The gas used is dimethyl gold hexafluoro acetylacetonate ($C_7H_7F_6O_2Au$).

The resistivity of the films was 100 to 500 times higher than that of bulk gold. To study the deposition process, we have deposited films using a broad beam from an ion implanter. Various substrate temperatures were used, and the films were examined by transmission electron microscopy. Films grown at room temperature were discontinuous even up to the thickness of 0.25 μm, while films grown at higher substrate temperatures were continuous even at lower thicknesses. Deposition carried out on substrates at 100°C and 160°C using 70 keV Ar+ ions resulted in resistivities approaching the bulk value and a deposition yield of 60 to 75 atoms/ion. If such high quality films can also be deposited by the focused ion beam, this technique may be useful for integrated circuit restructuring and repair, and for repair of x-ray lithography masks.

Publications

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