

3.0 Focused Ion Beam Fabrication

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3.1 Focused Ion Beam Program

John Melngailis

A focused ion beam system capable of mass separation and accurate submicron beam writing on a wafer has been purchased from Ion Beam Systems Inc. as part of the Microsystems Technology Program. So far the system has demonstrated 150kV operation. It has exposed dots in PMMA of 0.1 μm diameter and operated with the following ion species: Ga, Au, Si, Pd, B, As. The system will be delivered to M.I.T. in March 1987 and is scheduled to be in operation in May 1987. We had access to the machine and have carried out precision patterned doping of GaAs and Si.

In addition we have purchased a 50kV non-mass separated column which has a beam diameter of 0.05 μm . This system is intended for ion milling and ion induced deposition and etching. A DOD/University Instrumentation Grant has been received for the construction of an ultrahigh vacuum chamber to be used with this column. In the meantime the system will be used with an ordinary vacuum chamber.

3.2 Fabrication of Graded Channel FETs in GaAs and Si

DARPA/Naval Electronic Systems Command (Contract MDA-903-85-C-0215)

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The goals of this program are to use the focused ion beam system to fabricate field effect transistors in GaAs and in Si with graded doping profiles and to model the behavior of these novel device structures. Graded doping profiles, where the implanted density varies linearly from source to drain, have been successfully implanted in GaAs. These implants were aligned to existing features, and, in addition, alignment marks were ion milled into the surface to align the gate electrodes with the ion implants. Preliminary results show an increase in transconductance in the graded devices as well as flatter I_D vs. V_D curves in the saturation region. Computer simulation of these structures are being carried out. In silicon, we have used a Pd/B/As liquid metal ion source to implant test structures. A mask has been designed for transistors which will have the channel region implanted by focused ion beams. In silicon, device models have been developed which include graded doping and the dependence of the mobility on the distance from the surface.

3.3 Ion Induced Deposition

Charles Stark Draper Laboratory (Contract DL-H-261827)
U.S. Navy - Office of Naval Research (Contract N00014-84-K-0073)
Nippon Telephone and Telegraph

Gordon M. Shedd, Andrew D. Dubner, Henri Lezec, Carl V. Thompson, John Melngailis

A focused ion beam can be used to induce material deposition with submicron resolution if a local gas ambient is produced at the point of ion impact. The local gas ambient is produced by aiming a miniature gas nozzle at the surface in close proximity. We have used WF_6 and deposited tungsten. However, because the deposition was carried out in a background vacuum of 10^{-6} to 10^{-7} torr, the film contains from 5 to 30% oxygen. We are building an ultrahigh vacuum chamber to eliminate the oxygen. In the meantime by choosing a less reactive material we have deposited gold from a gas of dimethyl gold hexafluoro acetylacetonate. The ions used were either 15kV Ga^+ from a $0.5 \mu m$ diameter focused beam, unfocused 70 keV Si^+ ions from an implanter, or 0.75 keV Ar^+ from an ion miller. Deposition occurred in all cases with yields of between 5 to 16 atoms deposited/incident ion. Except for the expected Ga other contaminants such as C or O are at levels below 5%. The resistivity of the film was measured to vary between 20 and $500 \mu\Omega cm$ (bulk gold is $2.5 \mu\Omega cm$) depending on the deposition conditions. This is comparable to or better than polysilicon which is used as an IC interconnect material. With the focused ion beam lines of $0.5 \mu m$ width (equal to the beam diameter) were deposited. Thus this is a promising technique for integrated circuit rewiring, repair, or prototyping, and for repair of x-ray lithography masks.

3.4 Focused Ion Beam Microsurgery for Electronics

Charles Stark Draper Laboratory (Contract DL-H-261827)

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The modification of selected areas of an integrated circuit to alter its electrical function has many potential applications. The simplest such application is the breaking or making of electrical connections, which can lead to circuit diagnostics and debugging, to customization, and to defect avoidance. At present lasers are used in large integrated circuit memories to cut conductors and excise faulty circuit elements and wire in redundant spares. However, lasers typically blast away the conductors leaving craters 5-10 μm in diameter. The focused ion beam can perform such cutting in a much more controlled fashion with submicron resolution.

We have demonstrated the cutting of conductors and also developed methods for electrically connecting two overlapping conductors initially separated by oxide. The cost of the increased resolution is the time taken to cut conductors. This can extend to minutes if a fine beam is simply scanned over an area to mill an opening in the conductor. To make connections we have developed a method which consists of milling two concentric square sided pits through a conductor-insulator-conductor sandwich. Deliberate redeposition on vertical sidewalls makes an electrical connection. The pits ranged in size from $3 \times 3 \mu\text{m}$ to $0.5 \times 0.5 \mu\text{m}$. For the smallest pits a 4 to 8 Ω connection can be made in 7 seconds. In addition, in many cases the breaking or making of connections can be verified by using the focused ion beam in the scanning ion microscope mode. Depending on the electrical connections parts of a circuit will charge up to different voltages limiting the secondary electron emission and showing up on the screen with different contrast. As circuit dimensions shrink and their complexity grows focused ion beam circuit restructuring, because of the increased control and precision, will become an increasingly useful technique.

3.5 Measurement of Beam Profile

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John Melngailis and W.B. Thompson⁷

The focused ion beam profile is expected to be Gaussian. We have measured the profile over five orders of magnitude in intensity and found that from about two orders of magnitude below the peak, the profile has shoulders which make the beam broader. We also plan to investigate the relation between resolution in the imaging mode and beam diameter, and the relation between beam diameter and the resolution of the dopant pattern implanted.

Publications

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