

## 3. Focused Ion Beam Fabrication

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### Focused Ion Beam Program

A focused ion beam system, capable of mass separation and accurate writing on a wafer, has been purchased from Ion Beam Technologies, Inc. as part of the Microsystems Program. The system is specified to focus a beam of ions down to a diameter of  $0.1 \mu\text{m}$  at a current density of  $1 \text{ A/cm}^2$  and at accelerating voltages up to 150 kV. The species available are Ga, Au, Pt, B, As, Si and Be, i.e., the major dopants of Si and GaAs are included. The beam can be positioned over a 12 cm diameter wafer with  $\pm 0.15 \mu\text{m}$  precision.

The Microsystems Technology Laboratories' site for the system is ready, and it is expected to be moved to M.I.T. in 1986. One of the more exotic uses of this system is planned to be the custom, maskless, resistless doping of Si and GaAs which will permit novel structures to be fabricated.

In addition, we will purchase a simple focused ion beam system without mass separation which can focus a beam of Ga ions to diameters below  $0.05 \mu\text{m}$ . The diameter of the beam is easily variable. This system is intended mainly for ion assisted deposition and ultra fine feature definition.

### 3.1 Focused Ion Beam Microsurgery of Integrated Circuits

*Charles Stark Draper Laboratory (Contract DL-H-225270)*

*Hughes Research Laboratories*

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Focused ion beams can be used to restructure or repair integrated circuits. The beam can simply be used to mill away part of a conductor to create an open circuit. To join two conductors

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is more difficult. We have developed a method of connecting two intersecting conductors separated by a layer of oxide. Two concentric vias are milled down through the structure. Redeposition of metal on the sidewall of the larger via due to the milling of the smaller via creates a short circuit. By this method connections of  $0.4 \Omega$  resistance measuring  $3 \mu\text{m} \times 3 \mu\text{m}$  can be made in 200 sec., or 4 to  $5 \Omega$  connections measuring  $0.5 \mu\text{m} \times 0.5 \mu\text{m}$  can be made in 7 sec. Conductors of  $10 \mu\text{m} \times 0.6 \mu\text{m}$  cross section can be cut in about 200 sec. For a focused ion beam optimized for this application the milling times can be reduced by a factor of 100. The focused ion beam, used in the scanning microscope mode, can display the circuit to be altered and can, in addition, also provide voltage contrast for circuit diagnostics.

### **3.2 Ion Beam Assisted Deposition**

*Charles Stark Draper Laboratory (Contract DL-H-225270)*

*International Business Machines, Inc. (Contract 456614)*

*Nippon Telegraph and Telephone, Inc.*

*U.S. Navy – Office of Naval Research (Contract N00014-84-K-0073)*

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If gas molecules are adsorbed on a surface, then incident ions can cause their break up. In this way deposition of material can take place, for example, tungsten from  $\text{WF}_6$ . The adsorbed layer is produced by a local gas ambient on the surface. We use a miniature capillary gas feed, while workers at Osaka University have reported deposition of a mixture of Al, C and O from  $\text{Al}(\text{CH}_3)_3$  and W from  $\text{WF}_6$  using a different gas feed. In either case a local pressure of about 30 mtorr is created without degrading the pressure in the ion column, which is in the range of  $10^{-6}$  torr. We have assembled apparatus loaned to us by Ion Beam Technologies for the purpose of achieving patterned deposition using focused ion beams. In addition, we are also completing assembly of apparatus for performing ion assisted deposition using a conventional ion implanter. A thermoelectrically cooled stage is included to permit deposition measurements as a function of temperature. Preliminary experiments have been carried out using an ion milling machine with a flood beam of 750 V Ar ions. A deposit was obtained at the mouth of the capillary tube which was Auger analyzed to be 90% tungsten, 5% carbon, and 5% oxygen. Cooling the sample increased the deposition rate but also increased the oxygen content. The deposition of metal in a submicron pattern can be used for photo and x-ray lithography mask repair and for the local rewiring and repair of integrated circuits.

### 3.3 Fabrication of Graded Channel FET's in GaAs and Si

*U.S. Department of Defense (Contract MDA903-85-C-0215)*

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Focused ion beams can implant semiconductors in a submicron resolution pattern without the use of masks or resist. This project is to exploit this capability to make field effect transistors (FET's) in both GaAs and Si with the doping in the channel varying as a function of position from source to drain. Thus a higher doping near the source will reduce the source resistance while lower doping near the drain will lead to a higher gate-to-drain breakdown voltage. This is expected to improve device performance. Computer programs have been developed to predict the distribution of focused ion beam implanted dopants and to predict device performance fabricated with such implants.

### 3.4 Measurement of Beam Profile

*Hitachi Central Research Laboratory*

*John Melngailis*

The focused ion beam profile at the sample is expected to be Gaussian. There is, however, some preliminary indication that the decay of the beam tails is slower than the expected exponential. We have prepared samples of PMMA with 0.3  $\mu\text{m}$  period gratings exposed by x-ray lithography but not developed. By exposing lines of various doses perpendicular to these gratings and developing the PMMA, a structure is produced in which the remaining PMMA thickness can be measured as a function of position. This can be related to ion dose.

#### Publications

- Melngailis, J., C.R. Musil, E.H. Stevens, M. Utlaut, E.M. Kellog, R.T. Post, M.W. Geis, and R.W. Mountain, "The Focused Ion Beam as an Integrated Circuit Restructuring Tool," *J. Vac. Sci. Technol.* B4, Jan./Feb. 1986, to be published.
- Melngailis, J., "Focused Ion Beam Technology," *IEEE Electrotechnol. Rev.* 1985, to be published.
- Musil, C.R., J.L. Bartelt, and J. Melngailis, "Focused Ion Beam Microsurgery for Electronics," *IEEE Electron Device Lett.* EDL7, 285 (1986).

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<sup>6</sup>Harris Semiconductor

