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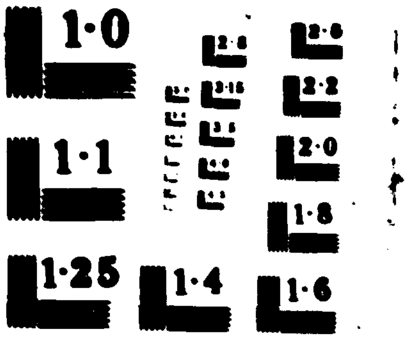
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Focused Ion Beam Fabrication of Graded Channel FET's in GaAs and Si

Semiannual Technical Report

1 July 1986 - 31 December 1986

by John Melngailis

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"Focused Ion Beam Fabrication of Graded Channel Field Effect Transistors in GaAs and Si"

Background

The aim of this program is to fabricate field effect transistors in Si and GaAs in which the doping in the channel is varied as a function of distance from source to drain. The focused ion beam machine is a unique tool which is capable of producing such graded implants. In achieving this goal alignment procedures of the focused ion beam to existing features on the wafer have to be developed, and the focused ion beam implants must be characterized and compared to conventional implants. In addition, models of the behavior of the graded channel devices must be developed.

Personnel working on the program:

Jarvis B. Jacob, Grad. student, Elect. Eng. & Comp. Science
Henri Lezec, Grad. student, Elect. Eng. & Comp. Science
Christian Musil, Grad. student, Physics
Khalid Ismail, Grad. student, Elect. Eng. & Comp. Science
Len Mahoney, Lincoln Laboratory
Dimitri Antoniadis, Associate Professor of E.E.&C.S., Coprincipal Investigator
John Melngailis, Principal Research Scientist, R.L.E., Principal Investigator

Progress During the Third Half Year Period

During this period our work has concentrated on refining the techniques for producing focused ion beam implants aligned to existing features, fabricating and testing GaAs FET's with focused ion beam implanted channels, performing test implants in Si, and modeling the behavior of devices with graded doses in the channel.

1. Implantation Technology Development

We have worked in collaboration with the manufacturer of our focused ion beam machine, IBS, on developing and refining techniques of implanting dopants in areas aligned to existing features and on measuring the minimum beam diameter achieved. The main vehicle for the refining of the techniques was the implantation into GaAs FET's of ions of Si^+ and Si^{++} emitted from an AuSi source. The first implantations relied heavily on the precision laser controlled table and were done essentially using "manual" alignment. Existing features were first located in crosshairs in the middle of the field of view, and their exact position measured with the laser interferometer. Then the location of the feature to be implanted was calculated in this laser table coordinate system. The stage was then moved to this location and the feature was implanted. Since some of the features were bigger than a single field, the implants had to be stitched together. This again was done manually. Based partly on this experience software was written by IBS to do this tedious procedure automatically.

In addition the final octopole of the column has been realigned, and the performance of the ion column has been improved. Beam diameter of near 0.1 μm has been achieved. This is shown in Fig. 1. The ion beam was blanked and stepped from point to point on PMMA. After development the dots are seen to be of less than 0.1 μm diameter, Fig. 1. The machine has had a history now of many weeks of trouble free operation. It has been dismantled and will be moved to M.I.T. on March 13, 1987.

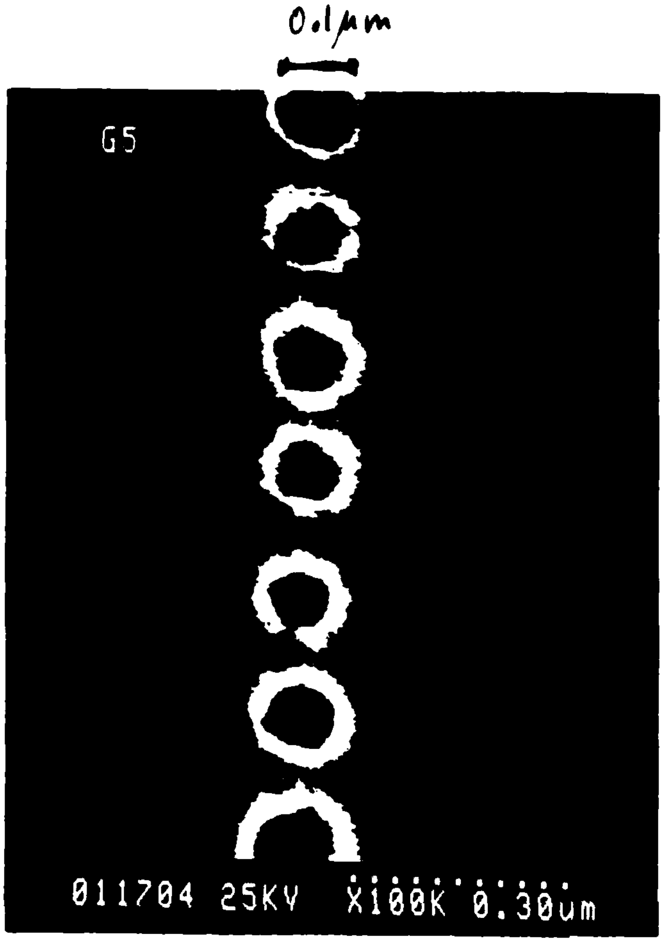


Fig. 1. Focused ion beam exposed. PMMA Si^{++} ions at 130 kV (or 260 keV) were used. The PMMA was 0.5 μm thick and was developed in MIBK. The scale marker (row of dots lower right) is 0.3 μm. Thus the exposed dots are less than 0.1 μm diameter.

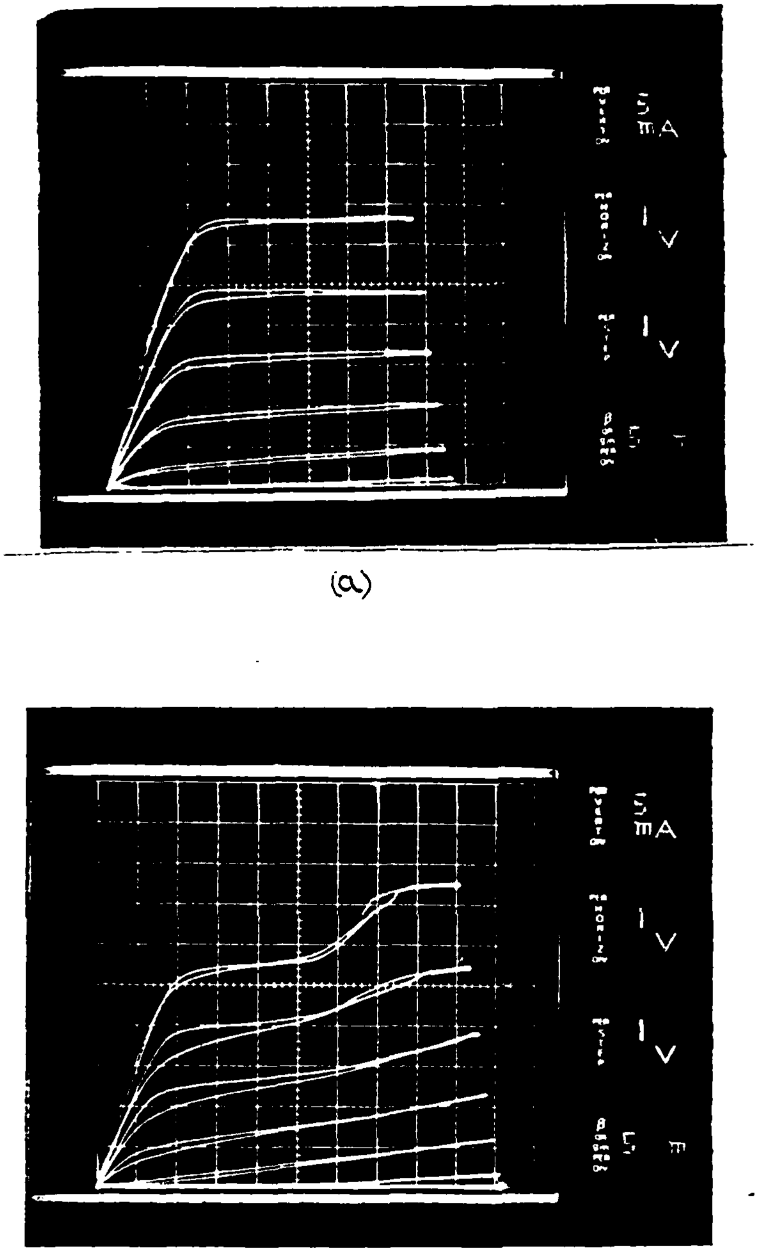
2. GaAs FET's:

The GaAs FET's with focused ion beam implanted channel regions have been tested. Both DC characteristics were measured, and high frequency performance was examined. About 30 devices were implanted with eight different doping gradients, as well as with uniform density implants for control purposes.

The DC characteristics of the graded channel MESFET's showed clear asymmetry, i.e. if source and drain are interchanged, the behavior is quite different as shown in Fig. 2. In the forward direction (drain region more highly doped) the devices showed very flat saturation characteristics while in the reverse direction the saturation region has a positive slope and a curved section. In general, graded devices operated in the forward direction had a transconductance about 20% higher than uniformly doped devices. These results are still quite preliminary. More tests will be carried out.

Five devices were installed in special mounts for high frequency testing, including a control device which had no gradient of doping. Four devices showed gain up to 18 GHz including the control device. One of the devices with a doping gradient showed gain only up to 7.5 GHz and is thought to be defective. One of the devices with a gradient was also tested backwards i.e. with ~~source~~ drain grounded. The gain dropped below unity at 13.5 GHz. Thus there is some indication that the doping gradient affects the maximum frequency of operation.

Based on this experience, plans have been made for future work both at 1 μm gate lengths and at gate lengths approaching 0.1 μm. In the latter case self aligned processing must be used; i.e. the graded channel implant



(a)

(b)

Fig. 2 Characteristics of laterally graded MESFET on GaAs. The background channel doping dose is 4.6 x 10^{12} Si ions/cm^2. The gradient corresponds to a 15% increase in doping accross the 1μm gate length from source to drain.

a) Source grounded, drain voltage positive.

b) Drain grounded, source positive.

Vertical scale 5 mH/cm, horizontal 1 V/cm, top trace corresponds to 0V. gate bias, next trace -1V etc. to -6V. gate bias when device is is turned off.

and the gate electrode placement must be defined in the same step. A bi-level PMMA resist scheme is used for this purpose. This procedure, as well as other planned experiments and methods of analysis are described in the Ph.D. thesis proposal of Henri Lezec (available upon request).

3. Implantation into Si

Test structures are ready for implantation of As and B into Si for the purpose of verifying self-annealing effects due to focused ion beam implantation reported in the literature. Limited implants were carried out with As ions from a Pd/B/As source. Those will be continued when sources become available.

In order to test the distribution of implanted species in the wafer, Ga^+ ions were implanted at 130 kV at a density of 10^{15} ions/cm^2. The distribution of the Ga will be measured by SIMS techniques combined with wafer thinning. Since, as mentioned above, some differences in focused-ion-beam implanted and conventionally implanted silicon has been observed, such differences need to be explored before devices are fabricated.

A mask set is being fabricated which will be used for focused ion beam implantation of graded profiles into the channels of MOS transistors. The mask pattern originally designed on the M.I.T. campus using the HPEDIT program was converted to Manplot format appropriate for fabricating the mask at Lincoln Laboratory.

4. Device modelling

A simple model has been developed for a MESFET with a channel doping that varies from source to drain under the gate. The device is described as a series of voltage controlled resistors. In each "resistor" the channel height is determined by the gate potential and the channel voltage in that segment. Values of the transconductance, gate capacitance, and cut-off frequency are deduced at the onset of saturation. The model provides a description of the fundamental causes of performance degradation, even though it neglects such effects as two dimensional current flow and velocity overshoot. It is useful for devices above 1 μm in gate length. This model predicts that the introduction of an appropriate doping gradient under the gate will lead to improvements in the magnitude of transconductance and cutoff frequency and in the linearity of their dependence on gate voltage. Further modeling and experimental verification will be carried out.

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